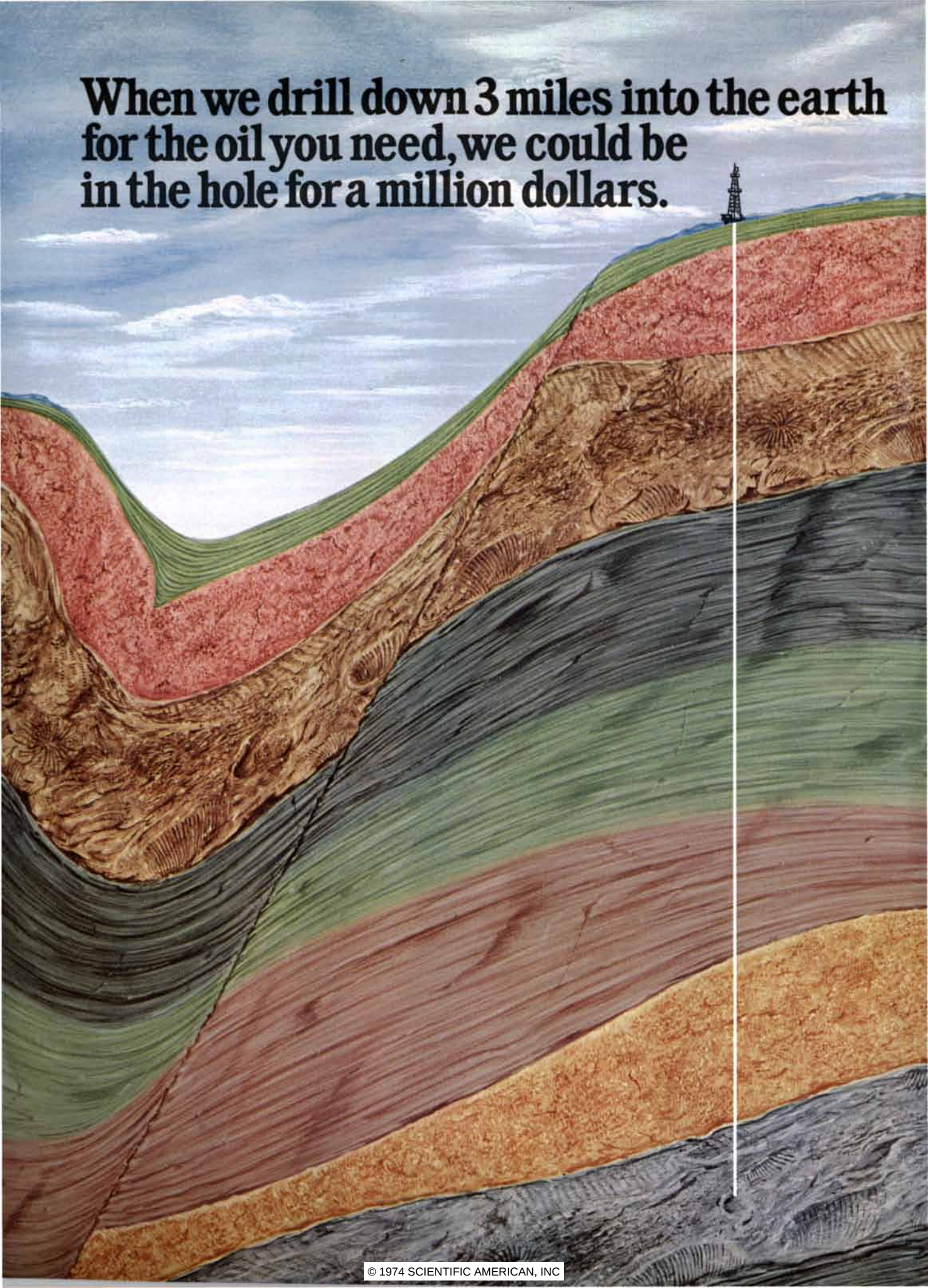
SCIENTIFIC AMERICAN

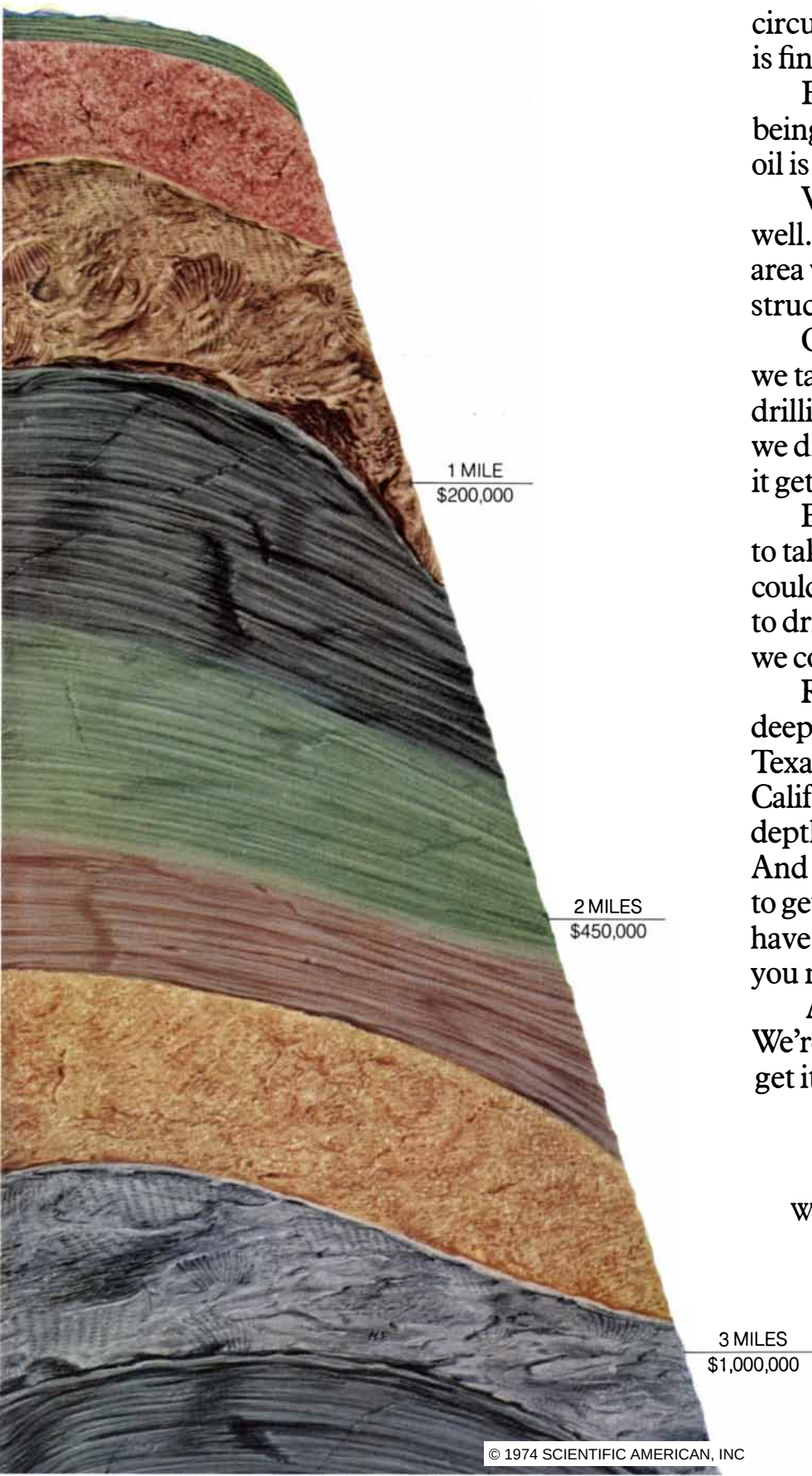
GIRAFFE PHYSIOLOGY

$1.00

November 1974

When we drill down 3 miles into the earth for the oil you need, we could be in the hole for a million dollars.





Even under normal circumstances, drilling for oil is financially risky.

Fairly risky if the well is being drilled in an area where oil is known to exist.

Very risky if it's a wildcat well. (That's a well in an area where oil has never been struck before.)

One of the biggest chances we take, of course, is deep drilling. Because the deeper we drill, the more expensive it gets.

But it's a chance we have to take. Even though it could cost a million dollars to drill down 3 miles, we could still come up dry.

Right now we're deep-drilling in places like Texas, Louisiana, and California. Sometimes to depths of 20,000 feet or more. And we'll keep on drilling to get the crude oil we must have to make the products you need.

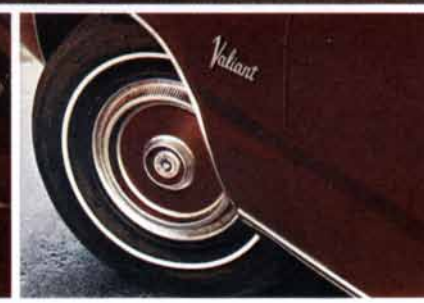
America needs energy. We're working to see that you get it

TEXACO

We're working to keep your trust.

The style of a European sedan. At the price of an American compact.

Valiant Brougham.



Valiant Brougham, from Plymouth, combines the look and feel of real European luxury with a most un-European price.

Disc brakes, power steering, automatic transmission, radio, crushed velour seats, cut-pile carpeting on floors and doors, and decidedly European touches like color-keyed wheel covers, map pockets and assist straps are all standard with Valiant Brougham.

Brougham also delivers the savings of an Electronic Ignition System (no points or condenser to replace), and with unleaded gas, the new longer-life spark plugs can go as much as 30,000 miles without replacement.

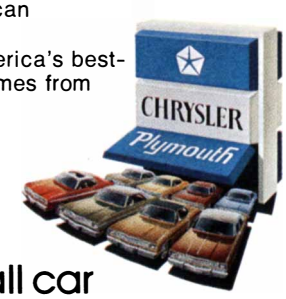
And now for "The Clincher." Valiant Brougham is covered under Chrysler's new 12-month unlimited mileage warranty.

For the first 12 months of use any Chrysler Motors Corporation dealer will fix, without charge for parts or labor, any part of our 1975 passenger cars we supply (except tires) which proves defective in normal use. Regardless of mileage.

The owner is responsible for maintenance services such as changing filters and wiper blades.

Valiant Brougham. Built in the style of a fine European sedan. At an American compact car price.

Little wonder, America's best-selling small car comes from Plymouth.



America's **No.1** selling small car comes from Plymouth.

Established 1845 **SCIENTIFIC AMERICAN** November 1974 Volume 231 Number 5

ARTICLES

DEPARTMENTS

PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK, N.Y. 10017. SECOND-CLASS POSTAGE PAID AT NEW YORK, N.Y., AND AT ADDITIONAL MAILING OFFICES. AUTHORIZED AS SECOND-CLASS MAIL BY THE POST OFFICE DEPARTMENT, OTTAWA, CANADA, AND FOR PAYMENT OF POSTAGE IN CASH. SUBSCRIPTION RATE: $12 PER YEAR, U.S., POSSESSIONS AND CANADA; $15 PER YEAR, ALL OTHER COUNTRIES. EUROPEAN SUBSCRIPTION COPIES MAILED C/O PUBLICATIONS DISTRIBUTION SERVICE, ST. KATELIJNEVEST 14, B2000 ANTWERP, BELGIË.

THE COVER

The painting on the cover shows the subject of an unusual experiment in its natural habitat, the East African plain. The animal is a reticulated giraffe, a representative of the most spectacular genus in the artiodactylan suborder of Ruminantia, a grouping that also includes cattle, sheep, goats and deer. The broad bandage on the giraffe's neck is at once holding in place and protecting from possible damage a telemetering instrument package that provided observers with a continuous record of the animal's arterial blood pressure and blood velocity as it roamed freely with its fellows (see "The Physiology of the Giraffe," by James V. Warren, page 96). When the instruments' power supply was exhausted, the experimenters recaptured the giraffe, removed the package and closed the incisions made to implant the necessary gauges; the animal was then returned to the wild.

THE ILLUSTRATIONS

Cover painting by Eric Mose

Page	Source	Page	Source
18–19	Charles B. Slackman	105	James V. Warren, Ohio State University College of Medicine
20–21	Ilil Arbel		
23	Philadelphia Museum of Art, photograph by A. J. Wyatt	107	Fergus W. Campbell, Physiological Laboratory, University of Cambridge
24–33	Alan D. Iselin	108	Ilil Arbel (*top*); John G. Robson and Fergus W. Campbell, Physiological Laboratory, University of Cambridge (*bottom*)
35–36	Ralph Morse		
37–44	Dan Todd		
50	Jerome Kuhl	109–111	Ilil Arbel
58	Alexander R. Lawton III, Medical Center, University of Alabama in Birmingham	113	Floyd Ratliff, Rockefeller University
		117	The Bettmann Archive, Inc.
60–70	George V. Kelvin		
78–95	Allen Beechel	118–120	Graphic Presentation Services, Inc.
97–98	Eric Mose and Laszlo Kubinyi	122–125	Ilil Arbel
100	Eric Mose	127–134	Jerome Kuhl

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

The most complete and most scholarly dictionary of the English language for only $15

Publisher's price $75

THE SUGGESTED TRIAL: You simply agree to buy four Club choices within a year at substantial savings on most books you choose

THE OXFORD ENGLISH DICTIONARY is generally regarded as the final arbiter of the meaning, origin, history and usage of words in the English language. Until now, it has been available only as a thirteen-volume set, priced at $350. Now, through the combination of an ingenious method of micrographic reproduction and a fine Bausch & Lomb optical lens, every single one of its 16,569 pages, fifty million words and close to two million illustrative quotations appears, in easily readable form, in the two volumes of *The Compact Edition.*

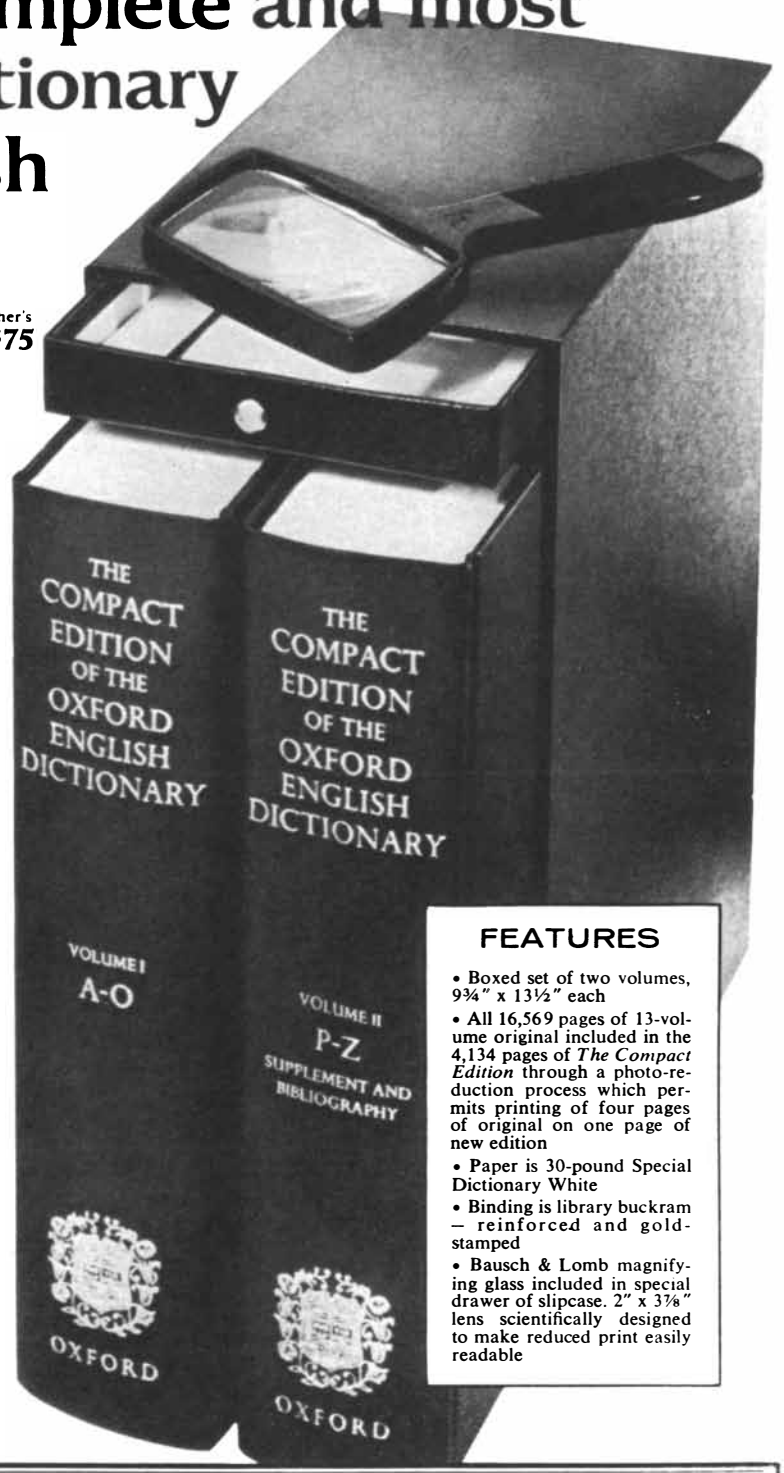
> The *New York Times* book critic Christopher Lehmann-Haupt has said of this edition: "It is something of a miracle. . . . *The Compact Edition* is easier to work with than the original with its 13 separate volumes. . . . Even at $75, the set is an extraordinary bargain."

Even more extraordinary, as a trial member of the Book-of-the-Month Club you may obtain *The Compact Edition of the Oxford English Dictionary* for only $15. And as long as you remain a member, you will receive the Book-of-the-Month Club *News,* a literary magazine announcing the coming Selection and describing other important books, most of which are available at substantial discounts – up to **40%** on more expensive volumes. All of these books **are identical to the publishers' editions in content, format, size and quality.**

If you continue after your trial membership, you will earn at least one Book-Dividend® Credit for every Selection or Alternate you buy. These Credits entitle you to obtain a wide variety of books, called Book-Dividends, at astonishing savings – *at least 70% of publishers' list prices.* Under this unique system, more than 100 Book-Dividends will be available to choose from every year, enabling you to acquire a well-rounded library at a small fraction of what you would otherwise have to pay.

FACTS ABOUT MEMBERSHIP

- You will receive the Book-of-the-Month Club *News,* a literary magazine published by the Club fifteen times a year. The *News* describes the coming Selection and scores of Alternates, and will be sent to you approximately every three and a half weeks.
- If you wish to purchase the Selection, do nothing and it will be shipped to you automatically.
- If you do not want the Selection – or you would like one of the Alternates, or no book at all – simply indicate your decision on the reply form always enclosed with the *News* and mail it so we receive it by the date specified.
- If, because of late mail delivery of the *News,* you should receive a Selection without having had 10 days to decide whether you want it, that Selection may be returned at Club expense.



FEATURES

- Boxed set of two volumes, 9¾" x 13½" each
- All 16,569 pages of 13-volume original included in the 4,134 pages of *The Compact Edition* through a photo-reduction process which permits printing of four pages of original on one page of new edition
- Paper is 30-pound Special Dictionary White
- Binding is library buckram – reinforced and gold-stamped
- Bausch & Lomb magnifying glass included in special drawer of slipcase. 2" x 3⅞" lens scientifically designed to make reduced print easily readable

BOOK-OF-THE-MONTH CLUB, INC. 4-A170-11
Camp Hill, Pennsylvania, 17012

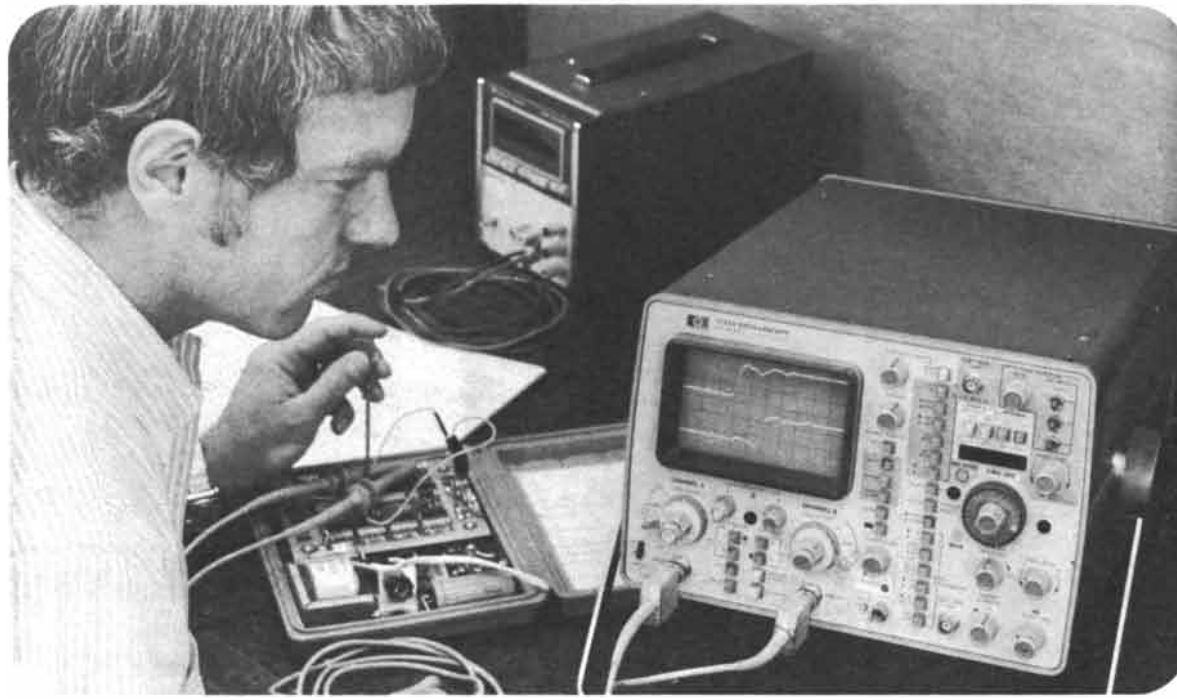
Please enroll me as a member of the Book-of-the-Month Club and send me *The Compact Edition of the Oxford English Dictionary,* billing me $15 (in Canada $17.50 – publisher's price $82.50). I agree to buy at least four Selections or Alternates during the first year I am a member, paying in most cases special members' prices. My membership is cancelable any time after I buy these four books. A shipping charge is added to all shipments.

MR. / MRS. / MISS .....
(Please print plainly)

Address 54

City .....

State ..... *Zip* .....



The first smart oscilloscope: an introduction to the "new measurement" technology.

Hewlett-Packard's "new measurement" technology radically changes the traditional relationship between man and machine. It does so by giving the machine some of the intelligence previously supplied by the human operator. It creates "smart" instruments that can monitor their own operations, detect and avoid procedural errors, perform all the necessary computations, and directly produce the desired final answer.

As a leading manufacturer of both measurement and computation instruments, we know that it's possible to make many kinds of "smart" instruments—right now—through a marriage of separate measurement and computation instruments. And we know that such a marriage results in unique advantages that far outweigh its cost.

The new HP 1722A oscilloscope is the most recent case in point. Its development started, typically, with a choice of candidates for the marriage. For *measurement*, we chose our 1720A scope, a 1.3 nanosecond rise time, 275 MHz bandwidth, dual-channel instrument; and for *computation*, the digital microprocessor originally developed for the HP-35 pocket-sized calculator.

It was clear from the outset that the proposed instrument could not realize the full potential of microprocessor control if the scope were limited to state-of-the-art *single* delayed sweep capability. So the marriage was put off while our designers developed the technology for *dual* delayed sweep. In the 1722, this new two-dot system operates under microprocessor control to keep track of any two events automatically, whether they originate on the same or different channels.

With its combined measurement and computation capabilities, the 1722 is clearly in a class by itself, the first of a new generation of "smart" oscilloscopes. It can make time interval measurements more accurately than has ever before been possible with an oscilloscope. The 1722 also avoids the numerous errors that can creep into conventional scope measurements: it never misreads control settings, never misses events, and its automatic lock-out systems prevent most wrong interpretations.

The 1722's built-in computation provides final answers—directly, digitally, and automatically—for frequency, instantaneous voltage, and relative amplitude measurements as well as for dc voltage and time interval.

Priced at $4500*, the 1722A is ideally suited for clock phasing measurements in large computer systems. It also easily qualifies for less demanding applications where its speed, convenience, and automation more than justify its moderately higher cost.

"New measurement" technique completely characterizes telephone circuits in two minutes.

Time was when human operators kept a day-to-day, even minute-to-minute appraisal of the transmission quality of the voice channels maintained by the nation's telephone companies. In those days a transmission test was simply a matter of saying "Can you hear me?"

With the advent and increasing use of voice-band circuits for data communication, the human ear no longer provides an adequate test. And with the increased use of direct distance dialing, operators rarely observe, much less report on, the condition of channels. Attempting to assure the day-to-day quality of these circuits by manual tests is an extremely expensive and nearly impossible task for the telephone companies, since there are thousands upon thousands of circuits in daily use and each manual analysis can take hours of several skilled craftsmen's time.

The new HP 5453A Transmission Parameter Analyzer substantially eases this problem. A computerized measurement system, the TPA provides comprehensive characterization of the two-way performance of a voice channel in less than two minutes. Operating without any of the complex analog devices usually associated with test systems, test personnel need only minimal training and experience.

Computer-generated test signals are transmitted over a channel; distortions that occur to signal frequency, phase, amplitude, and spectral content are measured, and from these the voice-band circuit quality is automatically calculated. Results are displayed by CRT terminal or hard-copy printer, and can be optionally stored on magnetic disc memory for later recall and analysis. They can be compared automatically with stored criteria to detect changes in transmission quality. The speed, simplicity, and data handling ability of the TPA make scheduled maintenance procedures technically and economically feasible, and result in improved data communications.

The TPA will not soon become obsolete. Since its ability to adapt to changing requirements is not tied to hardware, new tests and analyses can

be added simply by changing software. TPA is priced at $59,500*.

This system is a recent example of Hewlett-Packard's "new measurement," which combines computation with measurement. For users, the "new measurement" makes a profound difference. It gives *answers* you really need; not just intermediate data.

For more information on these products write to us. Hewlett-Packard, 1502 Page Mill Road, Palo Alto, California 94304.

*Domestic USA prices only 00435

Mail to: Hewlett-Packard, 1502 Page Mill Road, Palo Alto, CA 94304
Please send me information on:
( ) HP 1722A Oscilloscope
( ) HP 5453A Transmission Parameter Analyzer

Name _____ Title _____
Company _____
Address _____
City _____ State _____ Zip _____

HEWLETT hp PACKARD

Sales and service from 172 offices in 65 countries.
Palo Alto California 94304

LETTERS

Sirs:

Willard Bascom has argued convincingly for the persistent dream that the oceans are an appropriate place for the wastes of modern man ["The Disposal of Waste in the Ocean," by Willard Bascom; SCIENTIFIC AMERICAN, August]. But at this late stage in the development of the science of environment his arguments seem less than realistic. I set aside, as he has done, the extremely important question of whether we can continue to flush our fresh-water resources through cities to be fouled with waste nutrients and diverse toxins and dumped into salt-water bodies where neither the nutrients nor the fresh water can be recovered, and address only the question of pollution of coastal oceans. His principal assumption seems to be that the ocean is intrinsically variable and that thresholds for effects of human interference in the biotic processes of the ocean are therefore high. I would suggest that there is no basis in data for this assumption. On the contrary, there is substantial basis for belief that there are no thresholds for effects of changes in the chemistry of the oceans; all changes in the chemistry of the oceans are reflected in the biota. This is true for DDT and PCB's, as Bascom correctly asserts; it is also true for other toxins, for the nutrient elements and for physical and biotic changes as well as chemical changes. There may be very high thresholds for measurements of the biotic changes in nature. The existence of high thresholds for measurements of changes does not imply, as Bascom assumes, that the oceans have a high assimilative capacity for human interference; it says only that we measure effects crudely.

The belief of Bascom and others who articulate the same arguments is that man gains not only by having the freedom to dump these wastes conveniently but also by the enrichment of the coastal oceans. Although it may be true that the enrichment of certain waters with nitrogen and phosphorus enhances certain fisheries, the engineers have offered no evidence that sewage can be produced that contains only those elements or those elements in the appropriate proportions one to another to cause this type of enrichment without toxic hazards. Quite the contrary, there is great difficulty in building sewage systems that separate the industrial wastes of modern civilization from human fecal material. This means that the care and precision Bascom advocates in the design of sewage outfalls is well beyond reach.

The problems of sewage treatment and recovery of nutrients and water are far greater than Bascom indicates; so are the problems of management of the coastal oceans. The diverse accommodations worked out over millions of years among the organisms of the coastal oceans, accommodations that include the specialized functions of marshes, estuaries and other coastal ecosystems, can be destroyed much more easily than they can be restored. Losses of species are irreversible; so is the accumulation of toxins such as DDT in the oceans, as Bascom acknowledges. It is difficult to see how these changes can be avoided if the coastal oceans are to be used as Bascom advocates.

G. M. WOODWELL

Department of Biology
Brookhaven National Laboratory
Upton, N.Y.

Sirs:

Anyone who appreciates the complexities of biological responses is necessarily humbled, and the question of whether there are thresholds of toxicity is far from being answered. However, nearly all items called "pollutants" have long been present in the ocean, and many of them seem to be required by various animals. If they were damaging, presumably the evolutionary process would long ago have discarded individuals that required copper or vanadium (for example). But it did not. This suggests that there are *de facto* thresholds for many marine animals.

Our laboratory has looked intensively and been unable to find evidence of metal uptake into fish living above a bottom highly contaminated with many metals, although we measure metals in their various organs to parts per billion. Fish attracted to volcanic vents that spew out high concentrations of metals do not appear to be harmed.

Even halogenated hydrocarbons, until recently thought to be entirely man-made and toxic, occur in nature. William Fenical of the Scripps Institution of Oceanography has found several hundred species, many associated with red algae, some of which are the special food of certain bacteria. Very likely some species of bacteria break down man-made varieties, including DDT.

Now the question of controlling toxi-

cants from industrial wastes. In Los Angeles there is quite a successful campaign of "source control" in which individual dischargers are held responsible for toxicants in their discharges. Two much worse problems are: (1) The level of "pollutants," such as arsenic and copper, in municipal drinking water is higher than can be legally discharged into the ocean and (2) the high levels of some metals coming from purely domestic areas (chromium from stainless-steel cooking ware and chrome-plated bath fixtures) exceed legal discharge levels. In other words, before dilution in the sea the amounts of arsenic, copper and chromium in sewage must be five times lower than we are allowed to drink. After initial dilution the fish offshore are more than 500 times safer than the people of Los Angeles.

My basic thesis was that no single arbitrary solution makes sense everywhere. Careful thought based on scientific findings is needed.

WILLARD BASCOM

Southern California Coastal
Water Research Project
El Segundo, Calif.

Scientific American, November, 1974; Vol. 231, No. 5. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and secretary; George S. Conn, treasurer; Arlene Wright, assistant treasurer.

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

Advertising correspondence should be addressed to Harry T. Morris, Advertising Director, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Offprint correspondence and orders should be addressed to W. H. Freeman and Company, 660 Market Street, San Francisco, Calif. 94104. For each offprint ordered please enclose 30 cents.

Change of address (or other subscription correspondence) should be addressed to Circulation Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017. Please notify us four weeks in advance of change. If possible, kindly furnish an address imprint from a recent issue. Send both old and new addresses or complete and mail Post Office Form 3578.

☐ Please enter change of address.

☐ Please enter subscription.
U.S. and Canada:
☐ 1 year, $12 ☐ 2 years, $22 ☐ 3 years, $30
All other countries:
☐ 1 year, $15 ☐ 2 years, $27 ☐ 3 years, $37

NAME

NEW ADDRESS

OLD ADDRESS

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

NOVEMBER, 1924: "The geometry we study in the elementary schools is confined in the main to straight lines and planes. It is the geometry founded by the Greek genius Euclid. The rules of ordinary plane geometry do not apply, however, to figures drawn on a curved surface, and the geometry of such surfaces is therefore called 'non-Euclidean.' The notion of non-Euclidean geometries was extended by N. I. Lobatshevsky, B. Riemann and other geometers to three-dimensional space. They imagined possible geometries where the relations between figures in space might be different in the different geometries. The possibility that there are many kinds of space brings us to an interesting question: How much do we know about the so-called 'real' universe in which we live and into the depths of which we look whenever we see a star? In his general theory of relativity, Einstein was led to assume that the space of the real universe is, in fact, non-Euclidean. There can be an infinite number of varieties of space, however, each with its own special geometry. The discovery of the peculiarities of a particular variety of space may be, to dwellers within that space, an extremely difficult matter."

"Into the radio receiver of every Frenchman there is about to come the music of the spheres. The stately procession of those celestial light specks as they march by overhead will come to us audibly. This masterpiece of scientific poesy the Frenchman will put to work to set his clocks. Standard time is set already by the stars, but the method requires the intervention of a human watcher. An astronomer selects a star to watch, and when it crosses a fine wire in his telescope, he presses a signal button. Now two French scientists and radio experts, General Gustave-Auguste Ferrié and Monsieur R. Jouaust, have invented a method of determining the exact instant of coincidence between the star and the wire without the intervention of the fallible and inaccurate eye or brain or finger of a man. The method begins with a photoelectric cell, into which falls a ray of light from the star. The starlight is converted into electrical energy and then into a radio wave. As the star moves across the field of view of the telescope it crosses the wire, the light coming from it is cut off for an instant, and the audible note of the radio receiver changes."

"Instead of futilely berating a sentimental but callous world for denuding our forests of young trees to supply the great annual Christmas-tree market, the Northeastern Forest Experiment Station is trying out the possibility of growing trees purposely to supply that market. In a plantation of two-year-old Scotch pine that the station has just initiated for experimental purposes at Mount Toby, Mass., Norway spruce seedlings have been planted at the centers of the squares formed by the six-foot-by-six-foot spacing of the young pines. Here it will be possible to test the feasibility of raising Christmas-tree stock in mixture with a pine plantation and of making the Christmas tree an industry."

"It appears that the solution of the loud-speaker acoustic problem lies in the abandonment of the horn and the diaphragm and the adoption of a large parchment cone that serves as diaphragm and sound projector combined. To the apex of the parchment cone is anchored a rod leading to an armature actuated by the usual solenoids or electromagnets. Another novel loud-speaker, this one coming from England, possesses a number of separate vibrating diaphragms, each one tuned to a certain range of frequencies. It is said that by this device all notes are given equally good reproduction."

SCIENTIFIC AMERICAN

NOVEMBER, 1874: "A large proportion of the locomotives running on the 86,000 miles of railroads within the United States use wood for their fuel. Additional wood is employed by the railroads for ties; if we take 2,500 as the mean number of ties per mile of track, we find that 212 million pieces of timber, eight feet long and from six to eight inches thick, are required to supply this single item. A large amount of waste also occurs from hewing, and from leaving the upper parts of trees, some of which can be burned as firewood, the remainder being a complete loss. Besides ties and fuel, the railroads also demand timber for fencing, bridges, buildings and structures of various other kinds. The requirements of the railways in this direction are increasing even more rapidly than our supplies are being depleted."

"The large number of carrier pigeons used during the Franco-Prussian war for the transmission of dispatches has excited wide public interest in these curious birds and has led to their employment for a number of unusual purposes. It was recently proposed that they carry messages to shore during a transatlantic balloon voyage. In Paris many of the daily journals receive news of events transpiring in the Legislative Assembly, at Versailles, through the carrier pigeons, in preference to using the telegraph. The birds traverse the distance in from 15 to 20 minutes, and the intelligence thus reaches the newspaper offices much more quickly than would be the case were the dispatches obliged to wait their turn for transmission by the telegraph operators. When released, the birds fly upward and then circle. On foggy days they will not attempt to return to their cotes, nor during the night, except at times when there is a clear atmosphere and a full moon."

"Dr. Le Bow, of Paris, has communicated some recent work on hygiene in the hospitals. His statistics compare patients who had all suffered from the same lesion, amputation of the thigh. In a hospital containing 100 patients, 25 per cent died; in one containing 200, 31 per cent died; in one containing 300, 37 per cent died; in one containing 400, 40 per cent died; in the hospitals of Paris, there die 74 per cent. It thus appears that the most dangerous fields of battle are less murderous than for a wounded man to take refuge in one of the hospitals of Paris."

"A special report to Congress points up a curious economic paradox: within limits, the cost of production varies inversely as the wages paid. Taking the puddling of iron as a representative process, the report finds that the average price of labor per day for puddlers is from $1.80 to $1.88 in England, $1.38 in France and from $1.14 to $1.25 in Belgium. The average price of merchant bar iron is $32.50 in England, $35 in Belgium and $40 in France. The same contrast of cheap workmen and dear work was exhibited in the report of Mr. Redgrave on the condition of the textiles industry in England. Where labor is cheap the number of hands required to perform the work more than offsets the advantage in individual wages."

Presenting America's First Human CALCULATOR

Three major design breakthroughs and a one year insurance policy humanizes the answer to the four most common calculator errors.

The new Litronix memory calculator has no moving parts, shuts itself off, backspaces, and floats a decimal like no other pocket calculator. It weighs 6 ounces and measures only 3/4" x 3 1/8" x 6 1/2".

$49.95 NATIONAL INTRODUCTORY PRICE
RECHARGEABLE $59.95

You're human! You make mistakes. And finally a company has come up with a calculator that realizes this.

ERROR 1: Oops, I forgot to shut it off!

Ever forget to turn off your calculator? Chances are, even if you're careful, you've made that mistake. The Litronix 2220 actually turns itself off. After one minute of unattended use, a small integrated timing circuit causes the display to blink on for one second and shut off for three seconds, thus conserving power without affecting the data. Then after 15 minutes, it shuts off completely.

ERROR 2: Oops, I entered the wrong digit!

You're working a problem and you've entered 1.2356 when you wanted to enter 1.23 45. With most calculators you'd clear the entire last entry and start again. And you can do that with the Litronix. But the Litronix also has a backspace key which means you can backspace the number, digit by digit, and then enter the correct digits. In the example above, press the backspace key twice, eliminating the 5 and 6 so you end up with 1.23 on the display. Then add the 4 and 5 to make 1.2345.

ERROR 3: Oops, I read the decimal wrong!

Litronix has developed an eight-digit display whose decimal is in the center of a digit position, automatically separating the whole numbers from the decimals by the widest margin of any display. So there's no guesswork when it comes to spotting your decimal.

LITRONIX L.E.D. DISPLAY

CONVENTIONAL L.E.D. DISPLAY

The Litronix "digit-position" floating decimal provides a clear distinction between the whole number and the decimal on the display.

ERROR 4: Oops, I dropped it!

You're stepping out of your car, your briefcase flies open and out falls your calculator onto the solid cement walk. No problem with the Litronix. Just pick up the pieces, mail it to Litronix and they'll send you a brand new one anytime during the one year warranty period. It's the first pocket calculator actually insured against accidents.

BUT THERE'S SO MUCH MORE

We've told you how we've humanized the electronic calculator but there are many other exciting features:

Easy-to-use The Litronix features algebraic logic which means that you perform the functions exactly as you think.

Four key memory The memory system has four separate keys for data entry. You can now do calculations on your display, store the answers in a memory bank, and recall their total without erasing what was previously stored.

The keyboard on the Litronix was patterned after the expensive Hewlett Packard unit and has a four button, color-coded memory system. Instead of the conventional on/off switch the Litronix has on/off keys.

Fast percentage system You perform percentage problems exactly as you think. For example, to subtract 5% from $50, enter $50, press the minus key and then the five and percent key. An answer of $47.50 is on your display. In short, only four sets of entries were required to get your final answer.

Floating negative sign The Litronix not only has a full-floating decimal, but it has a full-floating negative sign. This means that when the display shows a negative number, the negative sign floats directly to the left of the first digit. There is also a key that permits you to change the sign of your answer from a positive to a negative number or back again.

More hidden features The separate "on-key" replaces the standard "on-switch" thus eliminating a calculator's only moving part (a major cause of calculator problems). The decimal point always remains in the two position unless the entry or answer is greater than six digits. This makes the Litronix especially useful when computing dollars and cents.

The Litronix has a true automatic constant on all five functions and can do reciprocals, raise numbers to whole powers, and show overflow conditions. You can do invoice extensions, compound interest problems, or many other business and scientific calculations.

Litronix is the world's largest display manufacturer, supplying over 40% of the world's calculator displays. Every component in the 2220 is manufactured by Litronix—from the integrated circuit to the unique keyboard. And this advanced technology means that you'll be getting the world's most advanced memory calculator.

AVAILABLE IN RECHARGEABLE OR DISPOSABLE BATTERY OPTIONS

The Litronix 2220's introductory price is only $49.95 complete with carrying case and three disposable AA cell batteries. The battery-saving features and the low-drain circuit will give many hours of carefree use. An optional AC adapter is only $4.95.

The Litronix 2220R (the exact same unit) is only $59.95 and comes complete with carrying case, rechargeable batteries, and AC adapter/charger. If you use your calculator daily in its portable mode, the rechargeable version is the better option. Both units are backed by a solid one year Litronix warranty and a prompt Litronix service-by-mail facility.

JS&A IS AMERICA'S LARGEST SOURCE OF ELECTRONIC CALCULATORS

If you own a Master Charge, BankAmericard, Diners Club or American Express credit card, simply call our toll-free number below or send us your check or money order including $2.50 for postage and handling (Illinois residents add 5% sales tax). Please specify the option you wish, and we'll rush your unit out by return mail. If you're not absolutely satisfied, you may return your Litronix within ten days for a prompt and courteous refund.

IT'S ONLY HUMAN

Finally, one of the very best calculators you can buy is also easy to operate and totally worry-free. What a refreshing change! Why not pick up your phone and order one at no obligation today.

JS&A NATIONAL SALES GROUP

DEPT. SAH-1 4200 DUNDEE ROAD
NORTHBROOK, ILLINOIS 60062

CREDIT CARD BUYERS CALL:

(800) 323-5880

In Illinois (312) 498-6900

THE AUTHORS

SISSELA BOK ("The Ethics of Giving Placebos") is a scholar and teacher whose teaching experience has encompassed philosophy and medical ethics; in the spring term of the current academic year she will conduct a seminar at the Radcliffe Institute on the rights of patients. She has studied at the University of Paris, George Washington University and Harvard University, where she obtained her Ph.D. (in philosophy) in 1970. She is a wife (of Derek Bok, the president of Harvard) and the mother of three children. She is the third member of her family to have published an article in SCIENTIFIC AMERICAN in three successive months: her father, Gunnar Myrdal, was the author of "The Transfer of Technology to Underdeveloped Countries" in the September issue and her mother, Alva Myrdal, was the author of "The International Control of Disarmament" in the October issue. An earlier version of Mrs. Bok's article was presented at the Aspen/Cornell Colloquium on Choice and Decision this past summer.

CLIFFORD M. WILL ("Gravitation Theory") is assistant professor of physics at Stanford University. Born in Canada, he was graduated from McMaster University in 1968 and then moved to the U.S., obtaining his Ph.D. (in physics) at the California Institute of Technology in 1971. Thereafter he spent a year as an instructor in physics at Cal Tech and two years as an Enrico Fermi Fellow at the Laboratory for Astrophysics and Space Research of the University of Chicago before going to Stanford in September. He writes that his present research interests, apart from the experimental foundations of gravitation theory, include the applications of general relativity theory to astrophysical and cosmological problems.

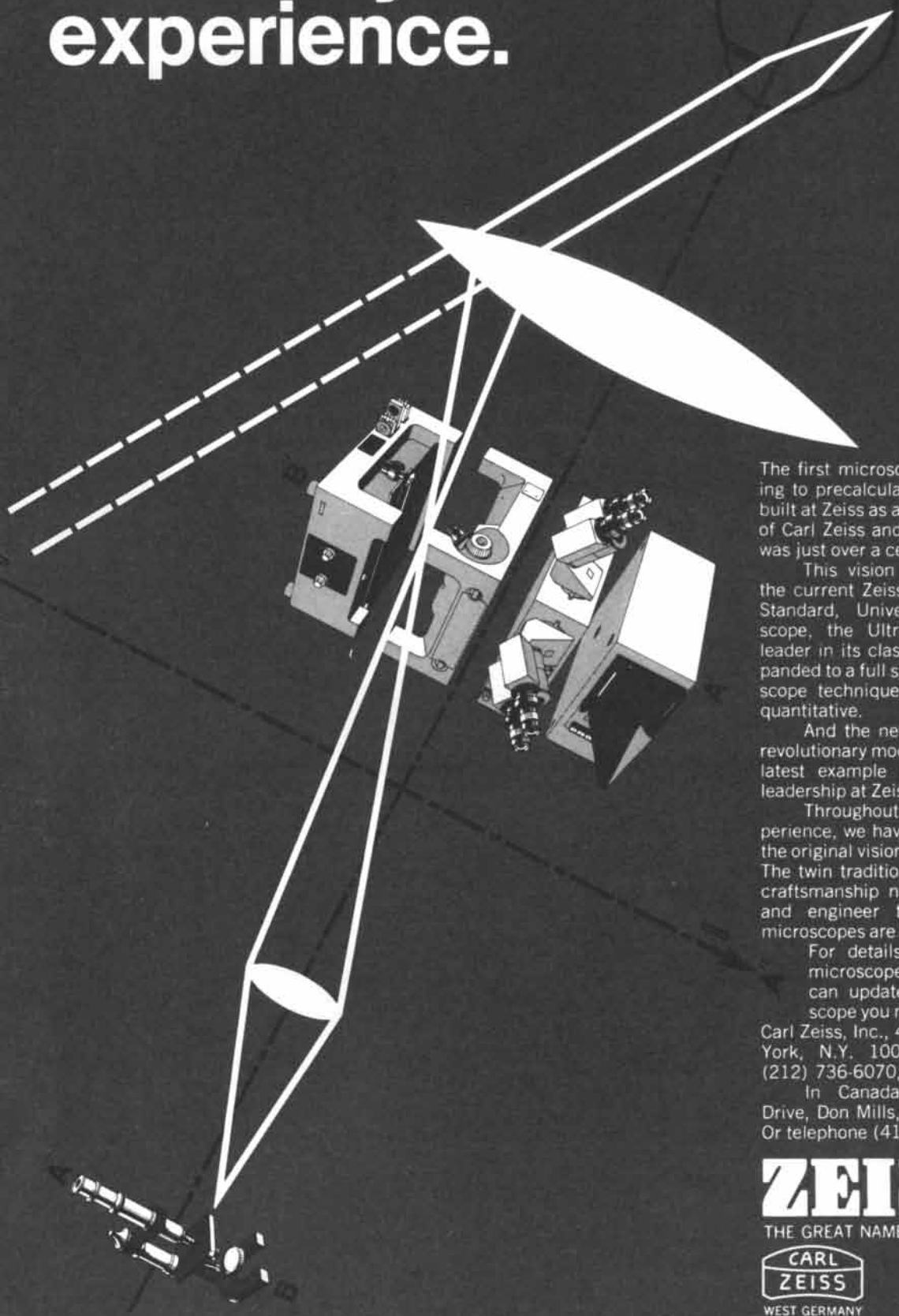
HANS GLAVITSCH ("Computer Control of Electric-Power Systems") is head of the automatic control group of the research center of Brown, Boveri & Company in Switzerland. Born in Austria, he was graduated from the Graz Technical University in 1958. He went to Stanford University for his master's degree, which he obtained in 1960. This year he received his doctorate in electrical engineering from the Technical University of Aachen. At Brown, Boveri, which he joined in 1961, he worked first on analytical studies in power systems and in engineering computing. In 1969 he became head of the engineering computing department, advancing to his present work in 1970. Among his outside interests is building and flying model gliders; he was Austrian champion in the gliders A2 category in 1955 and participated in the world championships in 1954 and 1955.

MAX D. COOPER and ALEXANDER R. LAWTON III ("The Development of the Immune System") are at the Medical Center of the University of Alabama in Birmingham, where they work in the cancer research and training program, Cooper as senior scientist and Lawton as scientist. Cooper was graduated from the University of Mississippi in 1954 and received his M.D. at the Tulane University Medical School in 1957. He holds an appointment as professor in the department of pediatrics in Alabama. For several years before going to Alabama in 1967 he taught pediatrics at the University of Minnesota. Lawton was graduated from Yale College in 1960 and from the Vanderbilt University Medical School in 1964. He was at the National Institute of Allergy and Infectious Disease for three years before going to Alabama in 1969.

BLAKE R. PATTERSON ("Musical Dynamics") is a research scientist at the Bell Laboratories, where he studies psychoacoustic effects. He writes: "As a high school senior in a Detroit suburb I played bassoon in six orchestras and two bands. I earned my bachelor's and master's degrees at the University of Michigan. Following work in Nigeria as a Peace Corps volunteer I developed an interest in plasma physics, completing work for my Ph.D. at the University of California at Berkeley in 1971. A postdoctoral fellowship at the Courant Institute of New York University supported much of my investigations into musical dynamics. I recently resigned from the New Jersey Symphony in favor of the Delbarton Baroque Ensemble and the Blake Wind Quintet. This summer I was principal bassoonist in the orchestra of the Festival of Two Worlds at Spoleto. Other favorite activities include hiking and vegetable gardening on seven acres shared with a beautiful lady."

JAMES V. WARREN ("The Physiology of the Giraffe") is professor of medicine and chairman of the department of medicine at the Ohio State University College of Medicine. Following his graduation from Ohio State in 1935 he

Visionary experience.



The first microscopes built according to precalculated formulae were built at Zeiss as a result of the vision of Carl Zeiss and Ernst Abbe—that was just over a century ago.

This vision is still implicit in the current Zeiss microscopes: the Standard, Universal, Photomicroscope, the Ultraphot. Each is a leader in its class, each can be expanded to a full system for all microscope techniques—qualitative and quantitative.

And the new Axiomat with its revolutionary modular concept is the latest example of the vision and leadership at Zeiss today.

Throughout our century of experience, we have remained true to the original vision of Zeiss and Abbe. The twin traditions of research and craftsmanship necessary to create and engineer the world's finest microscopes are found only at Zeiss.

For details on today's Zeiss microscopes, or on how you can update the Zeiss microscope you may now have, write Carl Zeiss, Inc., 444 Fifth Ave., New York, N.Y. 10018. Or telephone (212) 736-6070.

In Canada: 45 Valleybrook Drive, Don Mills, Ontario M3B 2S6. Or telephone (416) 449-4660.

ZEISS

THE GREAT NAME IN OPTICS

CARL ZEISS
WEST GERMANY

NATIONWIDE SERVICE: Boston, Chicago, Columbus, Houston, Los Angeles, New York, San Francisco, Washington, D. C.

went to Harvard Medical School, where he received his M.D. in 1939. After clinical training at Peter Bent Brigham Hospital in Boston he taught at Emory University, becoming professor of both medicine and physiology. At Emory he was a pioneer in the development of cardiac catheterization as a research tool, which he employed in his studies of the giraffe in Africa. He went to Ohio State in 1961 after service at Duke University and the University of Texas. Warren is a past president of the American Heart Association and is currently a fellow of the Explorers Club of New York.

FERGUS W. CAMPBELL and LAMBERTO MAFFEI ("Contrast and Spatial Frequency") work respectively at the University of Cambridge and the National Research Council of Italy; Campbell is reader in neurosensory physiology at the Physiological Laboratory in Cambridge and Maffei is an investigator with the National Research Council. Campbell has both the M.D. and the Ph.D. degrees from the University of Glasgow. He writes that he "intended to become a clinical ophthalmologist but became more and more interested in research and teaching." He avers that his interest in how cats see, which is reflected in much of the work described in his article, "was inspired by Martin Gardner's book, *The Annotated Alice*." Campbell's interests include "travel, photography, ham radio, hypnosis, reading newspapers and wondering about it all." Maffei obtained his medical degree at the University of Pisa in 1961. In addition to his work with the National Research Council he is acting professor of biophysics at the Superior Normal School of Pisa. He writes that he enjoys "swimming in the sea and riding a bicycle in the country."

JOANN VANEK ("Time Spent in Housework") is assistant professor of sociology at Queens College of the City University of New York. She was graduated from Saint Mary's College in 1963 and obtained her master's degree and her Ph.D. at the University of Michigan in 1964 and 1973 respectively. Before taking up her present work she was a lecturer in sociology at Michigan. She also served as a city planner in the Chicago Department of Development and Planning in 1966 and 1967. "A major diversion," she writes, "is food in New York City—restaurants, bars, groceries and chocolate shops." In forthcoming research she intends to study family spending patterns and time spent in leisure and work for all family members.

Is having your own $14.50 year's subscription to Business Week worth the cost?

Ask the man you work for...

Moving up in the executive world from a yearly salary in the teens to one in the 20's or 30's or more isn't just a matter of "getting the breaks." An important assist, as top executives know, is having your own personal source of the business news and information you need—in compact, easy-to-read form, fresh each week while it's still news.

That's why more than 725,000 executives in business and industry, have subscriptions of their own to Business Week—and they're paying $14.50 a year for it.

That breaks down to less than 29¢ a week, in return for which you can stay on top of . . .

ALL THIS VITAL DATA

Business news that's national and international, gathered by the world's largest business publisher, McGraw-Hill . . .

. . . News on marketing, finance, the economy, labor, new technology and design, government, the executive suite, the stock and commodities markets, transportation, corporations and conglomerates, business leaders . . .

. . . Plus a thumbnail Business Outlook each week, the unique Business Week Index, Personal Business information and counsel, and much more.

SAVE TIME, SAVE MONEY

As you can see, Business Week can save you the time you'd otherwise have to spend wading through a flood of bulky newspapers, specialized reports, and lightweight newsletters coming at you from every direction. And your value as an executive depends upon your getting the most accomplished in the limited hours available to you each week.

With Business Week, you can also save money on the cost of all those time-consuming newspapers, reports, and newsletters. What is more, having your own subscription to Business Week further entitles you to another immediate "dividend"...

FREE EXECUTIVE PORTFOLIO

Your own Executive Portfolio of "Special Reports on Major Business Problems," prepared by the Editors of Business Week. Twelve reports including three which won business journalism's highest awards for excellence. Your portfolio with your name stamped in gold on the cover—free when you subscribe to Business Week.

Right now, send for your free portfolio and a subscription to Business Week. Complete coupon, tear it out and drop it in the mail. Send no money —we'll bill you later.

Send no money now... Mail coupon for your subscription plus your free Executive Portfolio.

If coupon below is missing, please send us your name, title, company, address, whom to bill (you or company). Business Week, 1221 Avenue of the Americas, N.Y.C., N.Y. 10020.

Business Week

Michael Baron, Circulation Director
McGraw-Hill World Headquarters
1221 Avenue of the Americas
New York, New York 10020

PLEASE PRINT NAME AS IT SHOULD APPEAR IN GOLD. YOUR PORTFOLIO WILL BE SENT PROMPTLY ON RECEIPT OF ORDER.

Please send me my copy of the new *Executive Portfolio* of Special Reports on Major Business Problems as a bonus gift with my one year subscription to Business Week for $14.50 ☐ Payment Enclosed ☐ Bill Me ☐ Bill Company

NAME _____ TITLE _____

COMPANY _____ NO. EMPLOYEES IN COMPANY _____

COMPANY ADDRESS _____

CITY _____ STATE _____ ZIP _____

☐ Manufacturer ☐ Distributor OFFICE USE ONLY

PRODUCT OR BUSINESS _____

Check ☐ ONLY if you want publication mailed to Home Address as below:

STREET ADDRESS _____

CITY _____ STATE _____ ZIP _____

61080-4

For him it's another day, another heart attack.

Harvey is the very model of a heart patient.

A manikin full of the recognizable signs and symptoms of heart disease.

If you were a student doctor, you'd recognize something else about Harvey.

In some ways, he's even better than a live patient to study.

With a twist of a dial he can be programmed to reproduce any one of a number of common (and not so common) heart diseases.

Which lets a student doctor get experience relating one finding to another—on more kinds of heart disease than many doctors come across in a lifetime.

Doctors at the University of Miami Medical School developed this experimental manikin. The people at ITT designed its complex solid-state circuitry.

Now others are being built, with the same ITT circuitry, to help train tomorrow's doctors.

When you consider that heart disease is the nation's Number One killer, you can see one thing more about Harvey.

He has quite a future.

The best ideas are the ideas that help people. **ITT**

International Telephone and Telegraph Corporation, 320 Park Avenue, New York, N.Y. 10022.

Established 1845 SCIENTIFIC AMERICAN November 1974 Volume 231 Number 5

The Ethics of Giving Placebos

Ethical issues are raised when a treatment is prescribed that, unknown to the patient, cannot have any specific effect on his condition. The practice is often deceptive, the author finds, and should be restricted

by Sissela Bok

In 1971 a number of Mexican-American women applied to a family-planning clinic for contraceptives. Some of them were given oral contraceptives and others were given placebos, or dummy pills that looked like the real thing. Without knowing it the women were involved in an investigation of the side effects of various contraceptive pills. Those who were given placebos suffered from a predictable side effect: 10 of them became pregnant. Needless to say, the physician in charge did not assume financial responsibility for the babies. Nor did he indicate any concern about having bypassed the "informed consent" that is required in ethical experiments with human beings. He contented himself with the observation that if only the law had permitted it, he could have aborted the pregnant women!

The physician was not unusually thoughtless or hardhearted. The fact is that placebos are so widely prescribed for therapeutic reasons or administered to control groups in experiments, and are considered so harmless, that the fundamental issues they raise are seldom confronted. It appears to me, however, that physicians prescribing placebos cannot consider only the presumed benefit to an individual patient or to an experiment at a particular time. They must also take into account the potential risks, both to the patient or the experimental subject and to the medical profession. And the ethical dilemmas that are inherent in the various uses of placebos are central to such an estimate of possible benefits and risks.

The derivation of "placebo," from the Latin for "I shall please," gives the word a benevolent ring, somehow placing placebos beyond moral criticism and conjuring up images of hypochondriacs whose vague ailments are dispelled through adroit prescriptions of beneficent sugar pills. Physicians often give a humorous tinge to instructions for prescribing these substances, which helps to remove them from serious ethical concern. One authority wrote in a pharmacological journal that the placebo should be given a name previously unknown to the patient and preferably Latin and polysyllabic, and "it is wise if it be prescribed with some assurance and emphasis for psychotherapeutic effect. The older physicians each had his favorite placebic prescriptions—one chose tincture of Condurango, another the Fluid-extract of *Cimicifuga nigra*." After all, are not placebos far less dangerous than some genuine drugs? As another physician asked in a letter to *The Lancet:* "Whenever pain can be relieved with two milliliters of saline, why should we inject an opiate? Do anxieties or discomforts that are allayed with starch capsules require administration of a barbiturate, diazepam or propoxyphene?"

Before the 1960's placebos were commonly defined as just such pharmacologically inactive medications as salt water or starch, given primarily to satisfy patients that something is being done for them. It has only gradually become clear that any medical procedure has an implicit placebo effect and, whether it is active or inactive, can serve as a placebo whenever it has no specific effect on the condition for which it is prescribed. Nowadays fewer sugar pills are prescribed, but X rays, vitamin preparations, antibiotics and even surgery can function as placebos. Arthur K. Shapiro defines a placebo as "any therapy (or component of therapy) that is deliberately or knowingly used for its nonspecific, psychologic or psycho-physiologic effect, or that..., unknown to the patient or therapist, is without specific activity for the condition being treated."

Clearly the prescription of placebos is intentionally deceptive only when the physician himself knows they are without specific effect but keeps the patient in the dark. In considering the ethical issues attending deception with placebos I shall exclude the many procedures in which physicians have had—or still have—misplaced faith; that includes most of the treatments prescribed until this century and a great many still in use but of unproved or even disproved value.

Considering that in the past most therapies had little or no specific effect (yet sometimes succeeded thanks to faith on the part of healers and sufferers) and that we now have more effective remedies, it might be thought that the need to resort to placebos would have decreased.

Improved treatment and diagnosis, however, have raised the expectations of patients and health professionals alike and consequently the incidence of reliance on placebos has risen. This is true of placebos given both in experiments and for therapeutic effect.

Modern techniques of experimentation with humans have vastly expanded the role of placebos as controls. New drugs, for example, are compared with placebos in order to distinguish the effects of the drug from chance events or effects associated with the mere administration of the drug. They can be tested in "blind" studies, in which the subjects do not know whether they are receiving the experimental drug or the placebo, and in "double-blind" studies, in which neither the subjects nor the investigators know.

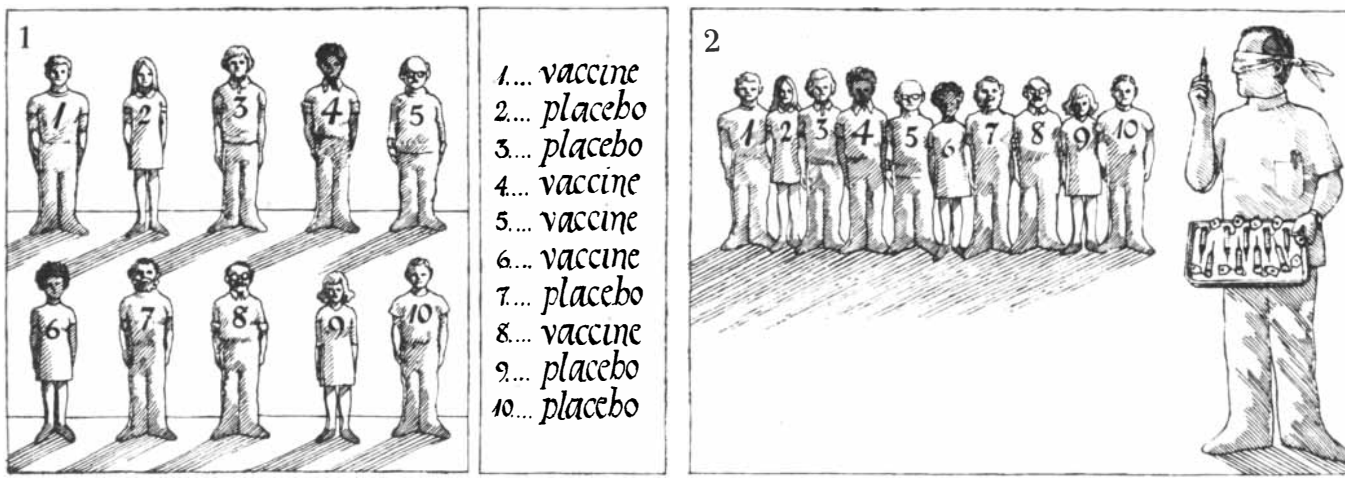
Experiments involving humans are now subjected to increasingly careful safeguards for the people at risk, but it will be a long time before the practice of deceiving experimental subjects with respect to placebos is eradicated. In all the studies of the placebo effect that I surveyed in a study initiated as a fellow of the Interfaculty Program in Medical Ethics at Harvard University, only one indicated that those subjected to the experiment were informed that they would receive placebos; indeed, there was frequent mention of intentional deception. For example, a study titled "An Analysis of the Placebo Effect in Hospitalized Hypertensive Patients" reports that "six patients ... were asked to accept hospitalization for approximately six weeks ... to have their hypertension evaluated and to undertake a treatment with a new blood pressure drug.... No medication was given for the first five to seven days in the hospital. Placebo was then started."

As for therapeutic administration, there is no doubt that studies conducted in recent decades show placebos can be effective. Henry K. Beecher studied the effects of placebos on patients suffering from conditions including postoperative pain, angina pectoris and the common cold. He estimated that placebos achieved satisfactory relief for about 35 percent of the patients surveyed. Alan Leslie points out, moreover, that "some people are temperamentally impatient and demand results before they normally would be forthcoming. Occasionally, during a period of diagnostic observation or testing, a placebo will provide a gentle sop to their impatience and keep them under control while the important business is being conducted."

A number of other reasons are advanced to explain the continued practice of prescribing placebos. Physicians are acutely aware of the uncertainties of their profession and of how hard it is to give meaningful and correct answers to patients. They also know that disclosing uncertainty or a pessimistic prognosis can diminish benefits that depend on faith and the placebo effect. They dislike being the bearers of uncertain or bad news as much as anyone else. Sitting down to discuss an illness with a patient truthfully and sensitively may take much-needed time away from other patients. Finally, the patient who demands unneeded medication or operations may threaten to go to a more cooperative doctor or to resort to self-medication; such patient pressure is one of the most potent forces perpetuating and increasing the resort to placebos.

There are no conclusive figures for the extent to which placebos are prescribed, but clearly their use is widespread. Thorough studies have estimated that as many as 35 to 45 percent of all prescriptions are for substances that are incapable of having an effect on the condition for which they are prescribed. Kenneth L. Melmon and Howard F. Morrelli, in their textbook *Clinical Pharmacology,* cite a study of treatment for the common cold as indicating that 31 percent of the patients received a prescription for a broad-spectrum or medium-spectrum antibiotic, 22 percent received penicillin and 6 percent received sulfonamides—"none of which could possibly have any beneficial specific pharmacological effect on the viral infection per se." They point out further that thousands of doses of vitamin B-12 are administered every year "at considerable expense to patients without pernicious anemia," the only condition for which the vitamin is specifically indicated.

In view of all of this it is remarkable that medical textbooks provide little analysis of placebo treatment. In a sample of 19 popular recent textbooks in medicine, pediatrics, surgery, anesthesia, obstetrics and gynecology only three even mention placebos, and none of them deal with either the medical or the ethical dilemmas placebos present. Four out of six textbooks on pharmacology consider placebos, but with the exception of the book by Melmon and Mor-



PLACEBOS are administered in clinical experiments to a control group that helps to establish the efficacy of the treatment being investigated. The drawings show how a typical double-blind test of a proposed vaccine might be conducted. Subjects are divided into two groups, a vaccine group and a control, or placebo, group. A list shows who gets which, but the subjects do not know (*1*). Nor does

relli they mention only the experimental role of placebos and are completely silent on ethical issues. Finally, four out of eight standard texts on psychiatry refer to placebos, again without ever mentioning ethical issues.

Yet little thought is required to see the dilemma placebos should pose for physicians. A placebo can provide a potent, although unreliable, weapon against suffering, but the very manner in which it can relieve suffering seems to depend on keeping the patient in the dark. The dilemma is an ethical one, reflecting contrary views about how human beings ought to deal with each other, an apparent conflict between helping patients and informing them about their condition.

This dilemma is pointed up by the concept of informed consent: the idea that the individual has the right to give prior consent to, and even to refuse, what is proposed to him in the way of medical care. The doctrine is recognized in proliferating "bills of rights" for patients. The one recommended by the American Hospital Association states, for example, that the patient has the right to complete, understandable information on his diagnosis, treatment and prognosis; the right to whatever information is needed so that he can give informed consent to any treatment; the right to refuse treatment to the extent permitted by law.

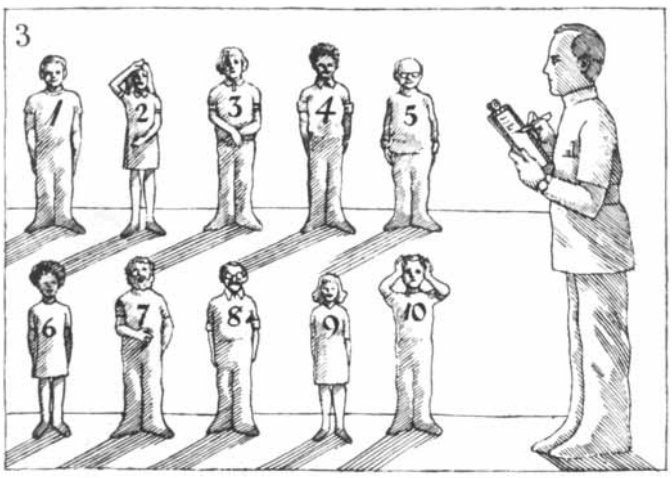
Few physicians appear to consider the implications of informed consent when they prescribe placebos, however. One reason is surely that the usefulness of a placebo may be destroyed if informed consent is sought, since its success is assumed to depend specifically on the patient's ignorance and suggestibility. Then too the substances employed as placebos have been considered so harmless, and at the same time so potentially beneficial, that it is easy to assume that the lack of consent cannot possibly matter. In any case health professionals in general have not considered the possibility that the prescription of a placebo is so intrinsically misleading as to make informed consent impossible.

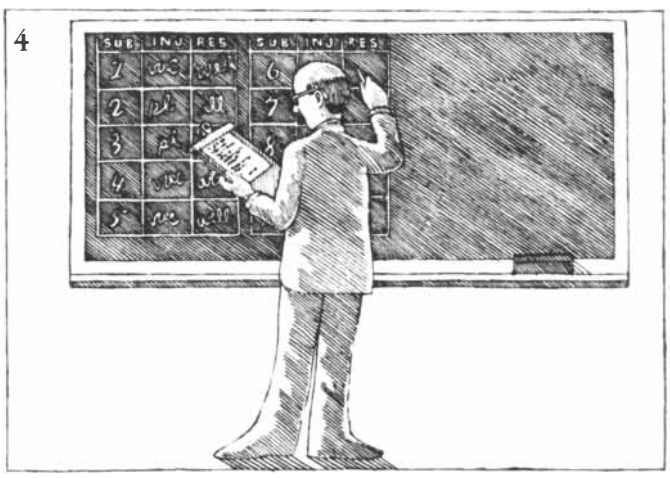
Some authorities have argued that there need not be any deception at all. Placebos can be described in such a way that no outright verbal lie is required. For example: "I believe these pills may help you." Lawrence J. Henderson went so far as to maintain that "it is meaningless to speak of telling the truth, the whole truth and nothing but the truth to a patient... because it is... a sheer impossibility.... Since telling the truth is impossible, there can be no sharp distinction between what is false and what is true."

Can one really think of prescribing placebos as not being deceptive at all as long as the words are sufficiently vague? In order to answer this question it is necessary to consider the nature of deception. When someone intentionally deceives another person, he causes that person to believe what is false. Such deception may be verbal, in which case it is a lie, or it may be nonverbal, conveyed by gestures, false visual cues or the myriad other means human beings have devised for misleading one another. What is common to all intentional deception is the intent to deceive and the providing of misleading information, whether that information is verbal or nonverbal.

The statement that a placebo may help a patient is not a lie or even, in itself, deceitful. Yet the circumstances in which a placebo is prescribed introduce an element of deception. The setting in a doctor's office or hospital room, the impressive terminology, the mystique of the all-powerful physician prescribing a cure—all of these tend to give the patient faith in the remedy; they convey the impression that the treatment prescribed will have the ingredients necessary to improve the patient's condition. The actions of the physician are therefore deceptive even if the words are so general as not to be lies. Verbal deception may be more direct, but all kinds of deception can be equally misleading.

The view that merely withholding information is not deceptive is particularly inappropriate in the case of placebo prescriptions because information that is material and important is withheld. The crucial fact that the physician may not know what the patient's problems are is not communicated. Information concerning the prognosis is vague and information about the specific way in which the treatment may affect the condition is not provided. Henderson's view fails to make the distinction between such relevant information, which it is usually feasible to provide, and infinite details of decreasing importance, which to be sure can never be provided with any completeness. It also fails to distinguish between two ways in which the information reaching the patient may be altered: it may be withheld or it may be





the person who gives the injection. He merely uses the syringe labeled for each subject; again, a list records whether the syringe held vaccine or placebo (*2*). The subjects are observed and a physician who does not know who got which injection records the clinical results (*3*). Only then are the various lists combined to yield the statistics that constitute the results of the experiment (*4*).

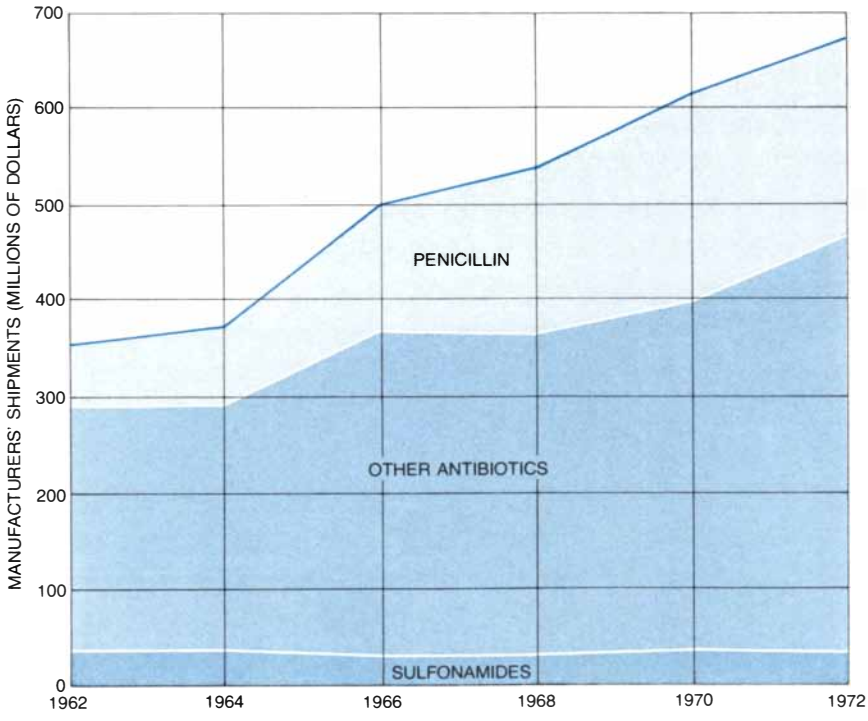
distorted. Often the two are mingled. Consider the intertwining of distortion, mystification and failure to inform in the following statement, made to unsuspecting recipients of placebos in an experiment performed in a psychiatric outpatient clinic: "You are to receive a test that all patients receive as part of their evaluation. The test medication is a nonspecific autonomous nervous system stimulant."

Even those who recognize that placebos are deceptive often dispel any misgivings with the thought that they involve no serious deception. Placebos are regarded as being analogous to the innocent white lies of everyday life, so trivial as to be quite outside the realm of ethical evaluation. Such liberties with language as telling someone that his necktie is beautiful or that a visit has been a pleasure, when neither statement reflects the speaker's honest opinion, are commonly accepted as being so trivial that to evaluate them morally would seem unduly fastidious and, from a utilitarian point of view, unjustified. Placebos are not trivial, however. Spending for them runs into millions of dollars. Patients incur greater risks of discomfort and harm than is commonly understood. Finally, any placebo uses that are in fact trivial and harmless in themselves may combine to form nontrivial practices, so that repeated reliance on placebos can do serious harm in the long run to the medical profession and the general public.

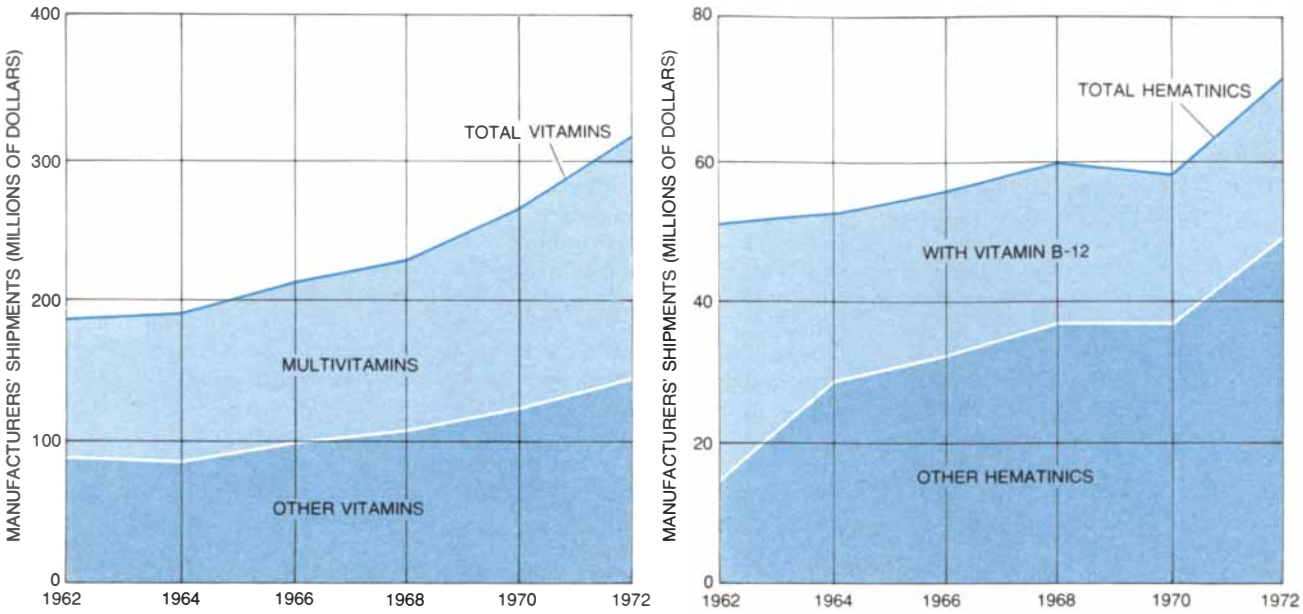
Consider first the cost to patients. A number of the procedures undertaken for their placebo effect are extremely costly in terms of available resources and of expense, discomfort and risk of harm to patients. Many temporarily successful new surgical procedures owe their success to the placebo effect alone. In such cases there is no intention to deceive the patient; physician and patient alike are deceived. On occasion, however, surgery is deliberately performed as a placebo measure. Children may undergo appendectomies or tonsillectomies that are known to be unnecessary simply to give the impression that powerful measures are being taken or because parents press for the operation. Hysterectomies and other operations may be performed on adults for analogous reasons. A great many diagnostic procedures that are known to be unnecessary are undertaken to give patients a sense that efforts are being made on their behalf. Some of these carry risks; many involve discomfort and the expenditure of time and money. The potential for damage by an active drug given as a placebo is similarly clear-cut. Calvin M. Kunin, T. Tupasi and W. Craig have described the ill effects—including death—suffered by hospital patients as a result of excessive prescription of antibiotics, more than half of which they found had been unneeded, inappropriately selected or given in incorrect dosages.

Even inactive placebos can have toxic effects in a substantial proportion of cases; nausea, dermatitis, hearing loss, headache, diarrhea and other symptoms have been cited. Stewart Wolf reported on a double-blind experiment to test the effects of the drug mephenesin and a placebo on disorders associated with anxiety and tension. Depending on the symptom studied, roughly 20 to 30 percent of the patients were better while taking the pills and 50 to 70 percent were unchanged, but 10 to 20 percent were worse—"whether the patient was taking mephenesin or placebo." A particularly serious possible side effect of even a harmless substance is dependency. In one case a psychotic patient was given placebo pills and told they were a "new major tranquilizer without any side effects." After four years she was taking 12 tablets a day and complaining of insomnia and anxiety. After the self-medication reached 25 pills a day and a crisis had occurred, the physician intervened, talked over the addictive problem (but not the deception) with the patient and succeeded in reducing the dose to two a day, a level that was still being maintained a year later. Other cases have been reported of patients' becoming addicted or habituated to these substances to the point of not being able to function without them, at times even requiring that they be stepped up to very high dosages.

Most obvious, of course, is the damage done when placebos are given in place of a well-established therapy that is clearly indicated for the patient's condition. The Mexican-American women I mentioned at the outset, for example, were actually harmed by being given placebo pills in the guise of contraceptive pills. In 1966 Beecher, in an article on the ethics of experiments with human subjects, documented a case in which 109 servicemen with streptococcal respiratory infections were given injections of a placebo instead of injections of penicillin, which was already known to prevent the development of rheumatic fever in such patients and which was



ANTIBIOTICS serve primarily as placebos when they are prescribed for minor virus diseases such as the common cold. Curves, based on Department of Commerce figures, show the value of manufacturers' shipments of systemic antibiotics and of sulfonamides, which are chemical anti-infective drugs. Among antibiotics, single penicillin preparations are shown separately. Antibiotic-sulfonamide combinations are included with other antibiotics.



RISING SALES of vitamins (*left*) and of hematinics, or drugs that improve the quality of the blood (*right*), reflect their frequent prescription or purchase across the counter as placebos rather than for their specific effects. The Department of Commerce figures used here include proprietary preparations (sold across the counter) as well as "ethical" ones (sold only on a physician's prescription).

being given to a larger group of patients. Two of the placebo subjects developed rheumatic fever and one developed an acute kidney infection, whereas such complications did not occur in the penicillin-treated group.

There have been a number of other experiments in which patients suffering from illnesses with known cures have been given placebos in order to study the course of the illness when it is untreated or to determine the precise effectiveness of the known therapy in another group of patients. Because of the very nature of their aims the investigators have failed to ask subjects for their informed consent. The subjects have tended to be those least able to object or defend themselves: members of minority groups, the poor, the institutionalized and the very young.

A final type of harm to patients given placebos stems not so much from the placebo itself as from the manipulation and deception that accompany its prescription. Inevitably some patients find out that they have been duped. They may then lose confidence in physicians and in bona fide medication, which they may need in the future. They may even resort on their own to more harmful drugs or other supposed cures. That is a danger associated with all deception: its discovery leads to a failure of trust when trust may be most needed. Alternatively, some people who do not discover the deception and are left believing that a placebic remedy works may continue to rely on it under the wrong circumstances. This is particularly true with respect to drugs, such as antibiotics, that are used sometimes for their specific action and sometimes as placebos. Many parents, for example, come to believe they must ask for the prescription of antibiotics every time their child has a fever.

The major costs associated with placebos may not be the costs to patients themselves that I have discussed up to this point. Rather they may be costs to new categories of patients in the future, to physicians who do not abuse placebo treatment and to society in general.

Deceptive practices, by their very nature, tend to escape the normal restraints of accountability and so can spread more easily. There are many instances in which an innocuous-seeming practice has grown to become a large-scale and more dangerous one; warnings against "the entering wedge" are often rhetorical devices but may sometimes be justified when there are great pressures to move along the undesirable path and when the safeguards against undesirable developments are insufficient. In this perspective there is reason for concern about placebos. The safeguards are few or nonexistent against a practice that is secretive by its very nature. And there are ever stronger pressures—from drug companies, patients eager for cures and busy physicians—for more medication, whether it is needed or not. Given such pressures the use of placebos can spread along a number of dimensions.

The clearest danger lies in the gradual shift from pharmacologically inert placebos to more active ones. It is not always easy to distinguish completely inert substances from somewhat active ones and these in turn from more active ones. It may be hard to distinguish between a quantity of an active substance so low that it has little or no effect and quantities that have some effect. It is not always clear to physicians whether patients require an inert placebo or possibly a more active one, and there can be the temptation to resort to an active one just in case it might also have a specific effect. It is also much easier to deceive a patient with a medication that is known to be "real" and to have power. One recent textbook in medicine goes so far as to advocate the use of small doses of effective compounds as placebos rather than inert substances—because it is important for both the doctor and the patient to believe in the treatment! The fact that the dangers and side effects of active agents are not always known or considered important by the physician is yet another factor contributing to the shift from innocuous placebos to active ones.

Meanwhile the number of patients receiving placebos increases as more and more people seek and receive medical care and as their desire for instant, push-button alleviation of symptoms is stimulated by drug advertising and by rising

expectations of what "science" can do. Reliance on placebic therapy in turn strengthens the belief that there really is a pill or some other kind of remedy for every ailment. As long ago as 1909 Richard C. Cabot wrote, in a perceptive paper on the subject of truth and deception in medicine: "The majority of placebos are given because we believe the patient... has learned to expect medicine for every symptom, and without it he simply won't get well. True, but who taught him to expect a medicine for every symptom? He was not born with that expectation.... It is we physicians who are responsible for perpetuating false ideas about disease and its cure.... With every placebo that we give we do our part in perpetuating error, and harmful error at that."

A particularly troubling aspect of the spread of placebos is that it now affects so many children. Parents increasingly demand pills, such as powerful stimulants, to modify their children's behavior with a minimum of effort on their part; there are some children who may need such medication but many receive it without proper diagnosis. As I have mentioned, parents demand antibiotics even when told they are unnecessary, and physicians may give in to the demands. In these cases the very meaning of "placebo" has shifted subtly from "I shall please the patient" to "I shall please the patient's parents."

Deception by placebo can also spread from therapy and diagnosis to experimental applications. Although placebos can be given nondeceptively in experimentation, someone who is accustomed to prescribing placebos therapeutically without consent may not take the precaution of obtaining such consent when he undertakes an experiment on human subjects. Yet therapeutic deception is at least thought to be for the patient's own good, whereas experimental deception may not benefit the subject and may actually harm him; even the paternalistic excuse that the investigator is deceiving the patient for his own good then becomes inapplicable.

Finally, acceptance of placebos can encourage other kinds of deception in medicine such as failure to reveal to a patient the risks connected with an operation, or lying to terminally ill patients. Medicine lends itself with particular ease to deception for benevolent reasons because physicians are so clearly more knowledgeable than their patients and the patients are so often in a weakened or even irrational state. As Melvin Levine has put it, "the medical profession has practiced as if the truth is, in fact, a kind of therapeutic instrument [that]... can be altered or given in small doses... [or] not used at all when deemed detrimental to the patients.... Many physicians have utilized truth distortion as a kind of anesthetic to promote comfort and ease treatment." Such practices are presumably for the good of patients. No matter how cogent and benevolent the reasons for resorting to deception may seem, when those reasons are considered in secret, without the consent of the doctored, they tend to be reinforced by less benevolent pressures, self-deception begins to blur nice distinctions and occasions for giving misleading information multiply.

Because of all these ways in which placebo usage can spread it is impossible to look at each incident of manipulation in isolation. There are no watertight compartments in medicine. When the costs and benefits of any therapeutic, diagnostic or experimental procedure are weighed, not only the individual consequences but also the cumulative ones must be taken into account. Reports of deceptive practices inevitably filter out, and the resulting suspicion is heightened by the anxiety that threats to health always create. And so even the health professionals who do not mislead their patients are injured by those who do and the entire institution of medicine is threatened by practices lacking in candor, however harmless the results may appear to be in some individual cases.

What should be the profession's attitude with regard to placebos? In the case of most experimental applications there are ways of avoiding deception without abandoning placebo controls. Subjects can be informed of the nature of the experiment and of the fact that placebos will be administered; if they then consent to the experiment, the use of placebos cannot be considered surreptitious. Although the subjects in a blind or double-blind experiment will not know exactly when they are receiving placebos or even whether they are receiving them, the initial consent to the experimental design, including placebos, removes the ethical problems having to do with deception. If, on the other hand, there are experiments of such a nature that asking subjects for their informed consent to the use of placebos would invalidate the results or cause too many subjects to decline, then the experiment ought not to be performed and the desired knowledge should be sought by means of a different research design.

As for the diagnostic and therapeutic use of placebos, we must start with the presumption that it is undesirable. By and large, given the principle of informed consent as well as concern for human integrity, no measures that affect someone's health should be undertaken without explanation and permission. Placebos are not so trivial as to be unworthy of ethical evaluation; they carry a definite possibility of harm and discomfort to patients as well as high collective costs; as a result placebo prescriptions present a more serious inroad on patient decision making than has been appreciated up to now. Surreptitious diagnostic and therapeutic administration of placebos should therefore be ruled out whenever possible.

The prohibition should not be absolute, however. In some cases the balance of benefit over cost is so overwhelming that reasonable people would choose to be deceived. There is no clear formula that will quickly reveal in each case whether the benefits will greatly outweigh the possible harm. Much of the problem can be avoided if care is taken to avoid placebos if possible and to observe the following principles in the remaining cases: (1) Placebos should be used only after a careful diagnosis; (2) no active placebos should be employed, merely inert ones; (3) no outright lie should be told and questions should be answered honestly; (4) placebos should never be given to patients who have asked not to receive them; (5) placebos should never be used when other treatment is clearly called for or all possible alternatives have not been weighed.

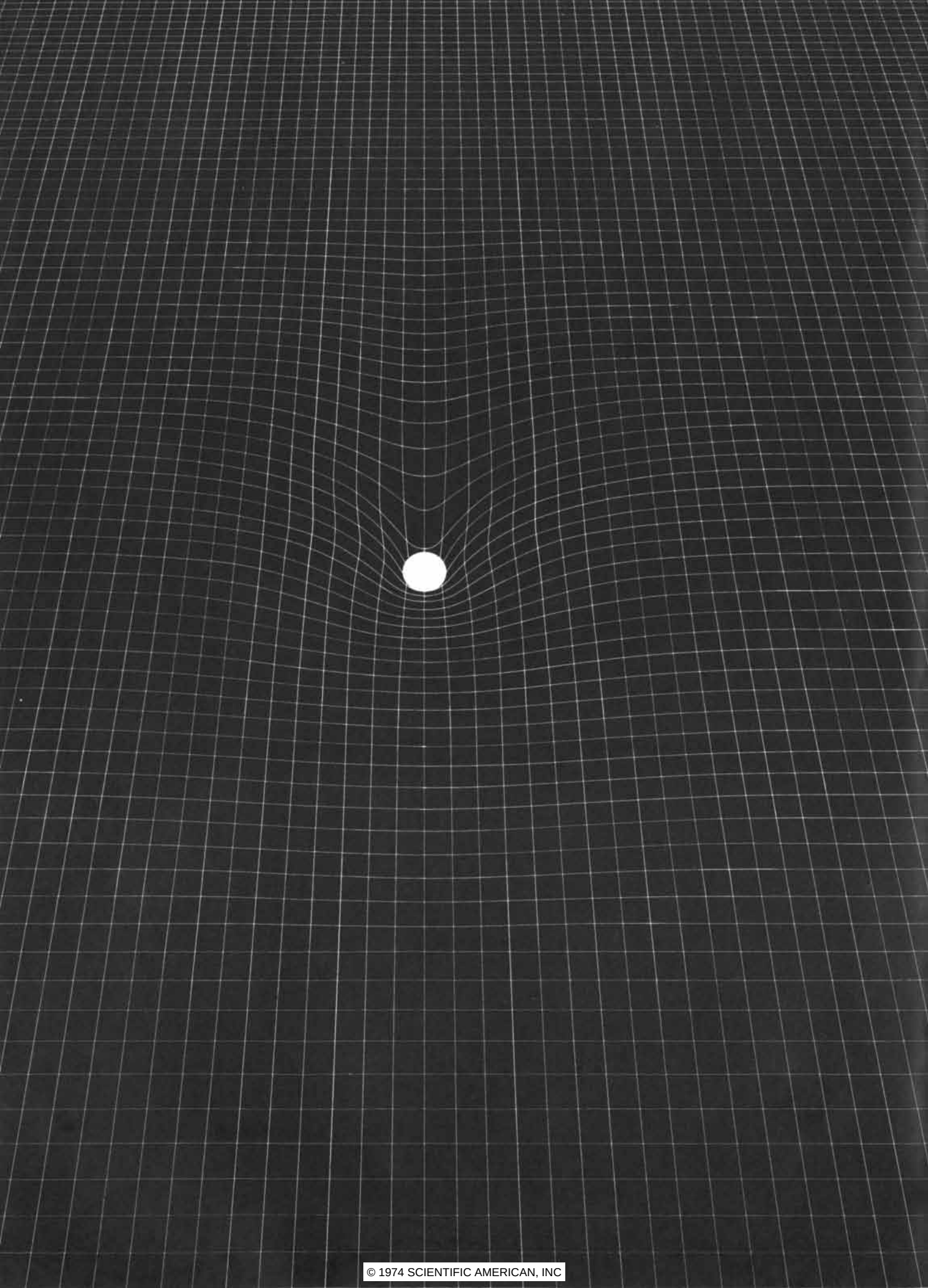
If placebo medicine is to be thus limited, the information provided to both medical personnel and patients will have to change radically. Placebos, so often resorted to and yet so rarely mentioned, will have to be discussed from scientific as well as ethical points of view during medical training. Textbooks will have to confront the medical and ethical dilemmas analytically and exhaustively. Similarly, much education must be provided for the public. There must be greater stress on the autonomy of the patient and on his right to consent to treatment or to refuse treatment after being informed of its nature. Understanding of the normal courses of illnesses should be stressed, including the fact that most minor conditions clear up by themselves rather quickly. The great pressure patients exert for more medication must be

countered by limitations on drug advertising and by information concerning the side effects and dangers of drugs.

I have tried to show that the benevolent deception exemplified by placebos is widespread, that it carries risks not usually taken into account, that it represents an inroad on informed consent, that it damages the institution of medicine and contributes to the erosion of confidence in medical personnel.

Honesty may not be the highest social value; at exceptional times, when survival is at stake, it may have to be set aside. To permit a widespread practice of deception, however, is to set the stage for abuses and growing mistrust. Augustine, considering the possibility of giving official sanction to white lies, pointed out that "little by little and bit by bit this will grow and by gradual accessions will slowly increase until it becomes such a mass of wicked lies that it will be utterly impossible to find any means of resisting such a plague grown to huge proportions through small additions."

"THE PUBLIC WANTS TO BE DECEIVED," read the two inscriptions, in Latin and in Dutch, at the base of this engraving. The print is in the Ars Medica collection of the Philadelphia Museum of Art. The engraving, depicting a street vender of medical materials and services and his eager customers, was made in the early 17th century by Jan van de Velde after a drawing by Willem Buytewech.



GRAVITATION THEORY

The general theory of relativity has many competing successors. For such theories to be viable they have to meet observational and theoretical criteria that are steadily becoming more rigorous

by Clifford M. Will

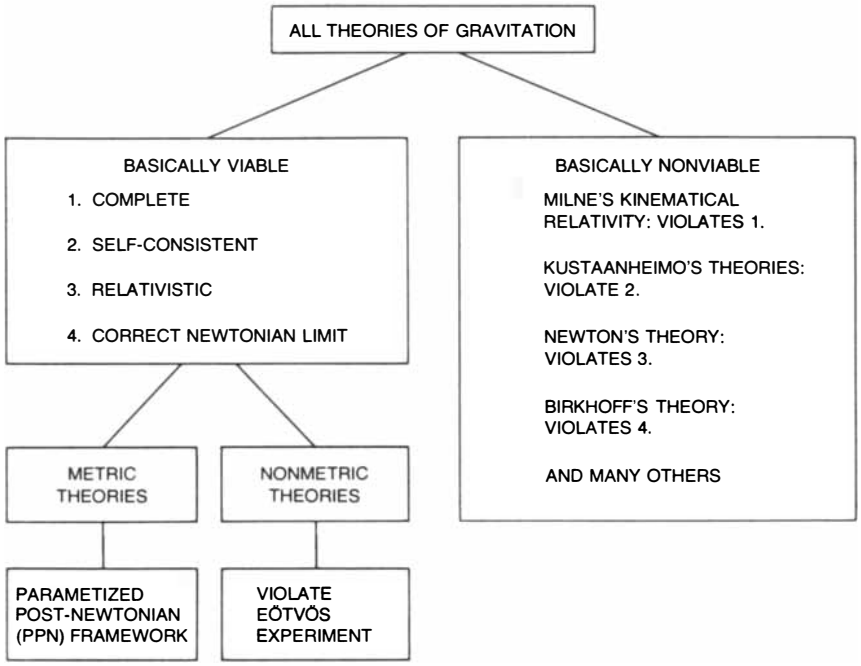
Throughout recorded history the speculations of civilized men on the nature of gravitation have ranged from the naïve to the sophisticated: from Aristotle's explanation that objects fall to the earth because that is their natural place to Newton's laws of gravity to Einstein's general theory of relativity. Today many physicists firmly believe that the general theory of relativity, which explains gravity as a curvature or warping of space and time, is the correct theory of gravitation. They praise its beauty, simplicity and agreement with observation and experiment. Other workers, however, are openly dubious of general relativity and suggest that alternative theories provide a better description of gravity. Some have devised theories of their own and expound on *their* beauty, elegance and agreement with observation and experiment. Somewhere between these two extremes there are a few individuals who have adopted a carefully guarded neutrality. Declining to favor one theory over another, they attempt to study all the theories as a class, hoping thereby to unlock some of the secrets of gravitation in an unbiased manner independent of any one particular theory. The results of their efforts could be called the theory of gravitation theories. Although this theory of theories has indeed led to some new insights into the nature of gravitation, it has proved to be most powerful as a tool for systematically determining which theories of gravitation are viable (that is, acceptable candidates for being the correct theory) and which theories are nonviable (that is, could never be the correct theory).

What makes a gravitation theory viable? As with all other kinds of theories the foremost criterion is agreement with observation and experiment. Naturally this criterion has changed over the years as observational techniques have improved and new experiments have been devised. In the 17th and 18th centuries it was enough for Newton's laws to account for the gross motions of the planets and the shape of the earth as they had been measured with the instruments of the day to establish that the Newtonian theory of gravity was the "correct" theory. By the middle of the 19th century the observational techniques had been refined enough to show that the perihelion (closest point to the sun) of the orbit of the planet Mercury advances 43 seconds of arc per century in a way not explained by Newton's theory. Einstein's general theory of relativity, put forward in 1916, accounted for it very well. Moreover, Einstein's theory further predicted that the light from distant stars should be deflected 1.75 seconds of arc as it passes through the gravitational field of the sun, a prediction that was verified to the highest degree of accuracy available with the instruments of the day. In the half-century since then the accelerating advance of technology has given rise to instruments both in the laboratory and in space that can measure the angular position of stars to a thousandth of a second of arc, determine the distance from the earth to the moon to within tens of centimeters and measure the distance to various planets and spacecraft within tens of meters. These high-precision tools have fostered a new generation of experiments that will further tighten the observational criteria for a theory's viability.

A theory must also be able to cope with newly discovered astronomical phenomena in which gravitation may play a vital role: quasars, pulsars, neutron stars, the cosmic background radiation, compact celestial X-ray sources and possibly even celestial gravitational radiation. For a gravitation theory to be useful in astrophysics it must incorporate mathematical machinery that meshes its laws with the nongravitational laws of physics: the laws of electromagnetism, quantum mechanics and elementary-particle theory. In addition the gravitation theory must be able to yield detailed models of the phenomena in question. The models need not be correct; at this stage it is more important that the theory have the capability to build models.

The capability to build models is part of a deeper theoretical criterion that can be briefly summed up: For a gravitation theory to be viable it must be complete and self-consistent. For a theory to be complete it must have the capability

CURVATURE OF SPACE is the explanation for gravitation according to the general theory of relativity and other theories of gravitation that are known as metric theories. Such curvature can be represented in what is called an embedding diagram. Here the three-dimensional space around the sun is compressed into a two-dimensional *x*-*y* plane. The plane is curved or warped into a third dimension by the sun's gravitational field. The curvature of space has the effect of making distances measured outward from the sun greater than they would be in the absence of the sun's gravitational field. Any distance from the sun can be expressed in terms of the coordinates *x* and *y* measured along the two perpendicular sets of grid lines. If Newton's theory of gravity were completely correct, the plane would be perfectly flat and the Euclidean formula for a distance *d* measured outward from the sun of $d = \sqrt{x^2 + y^2}$ would be valid. In curved space, however, the distance *d* may be greater than $\sqrt{x^2 + y^2}$. Embedding diagram shows this by "stretching" the *x*-*y* plane near the sun.



THEORIES OF GRAVITY must meet four fundamental criteria in order to qualify as being basically viable, that is, acceptable candidates for being the correct theory of gravitation. A theory must be complete, it must not have any internal inconsistencies, it must agree approximately with Newton's laws for such things as the gross motions of the planets, and it must agree with the special theory of relativity when gravity is in some sense "turned off." Four examples of theories that violate one of the criteria are given. Of those that are basically viable, some are metric theories, which explain gravity as a curvature of space, and some are nonmetric, which explain it on some other basis. The metric theories have more observational evidence to support them than the nonmetric theories. They can be divided into eight different classes (*see table on opposite page*). Many have been analyzed in terms of a "supermetric" theory known as the parametrized post-Newtonian (PPN) formalism.

to deduce the outcome of every experiment of interest from first principles, that is, from basic assumptions about the nature of the universe. For example, it is not enough for a theory simply to postulate that atomic clocks at two different distances from the source of a gravitational field run at two different rates (or, stated somewhat differently, to postulate that light is shifted toward redder, or longer, wavelengths as it "climbs" out of a gravitational field). The theory must mesh with and incorporate a complete set of electromagnetic laws and quantum-mechanical laws that can be used to calculate the detailed behavior of atomic clocks and light in gravitational fields. An example of an inadequate gravitation theory is the kinematical theory of relativity advanced by E. A. Milne in 1937, which lacks mathematical machinery capable of making a prediction about the gravitational red shift of light.

For a theory to be self-consistent its prediction for the outcome of every experiment must be unique. In other words, when one calculates the prediction by different methods, one must always arrive at the same result. Several theories of gravity suffer from internal inconsistencies. For example, the theories of Paul Kustaanheimo of Helsinki predict the correct gravitational red shift when light is regarded as a particle (a photon) but predict no red shift when light is regarded as a wave.

PARAMETER	WHAT PARAMETER MEASURES
γ	HOW MUCH IS SPACE CURVED BY MASS?
β	HOW MUCH NONLINEARITY IS THERE IN THE SUPERPOSITION OF TWO GRAVITATIONAL FIELDS?
α_1 α_2 α_3	DOES THE UNIVERSE HAVE A PREFERRED FRAME OF REFERENCE?
ζ_1 ζ_2 ζ_3 ζ_4	IS TOTAL MOMENTUM CONSERVED?
ζ_w	ARE THERE GALAXY-INDUCED EFFECTS?

TEN PARAMETERS or coefficients are used in the supermetric equations of PPN formalism. Many metric theories of gravity have been expressed in terms of these parameters and predict various values for each parameter. Thus measuring the value of the parameter tests predictions of each theory and yields information on which of the theories are viable.

In addition to being complete and self-consistent a basically viable gravitation theory must agree with two very fundamental bodies of experimental knowledge. First, when gravity is "turned off," that is, when the effects of gravity can in some sense be ignored, the theory's nongravitational laws should agree with the laws of the standard special theory of relativity. The validity of special relativity in the absence of gravity has been confirmed to a high degree of precision countless times in high-energy physics laboratories studying the behavior of subatomic particles traveling near the speed of light. If a gravitation theory is compatible with special relativity, it is called a relativistic gravitation theory.

At the other end of the theoretical spectrum, a gravitation theory should also agree with standard Newtonian theory. Its predictions should be compatible with the observed properties of matter and with the gross motions and structure of the sun and the planets. A theory with this property is said to have the correct Newtonian limit. One theory that does not have the correct Newtonian limit was proposed by G. D. Birkhoff in 1943; it demands that sound waves travel at the speed of light, in violent disagreement with fact.

To summarize, a basically viable gravitation theory is one that is complete, self-consistent and relativistic and has the correct Newtonian limit. On the basis of these four criteria it is possible to divide all gravitation theories into two classes: those that are basically viable and those that are basically nonviable. A great many theories are basi-

PPN PARAMETER	γ	β	α_1	α_2	α_3	ζ_1	ζ_2	ζ_3	ζ_4	ζ_W
GENERAL THEORY OF RELATIVITY (EINSTEIN)	1	1	0	0	0	0	0	0	0	0
SCALAR-TENSOR THEORIES (BRANS-DICKE)	$\frac{1+\omega}{2+\omega}$	1	0	0	0	0	0	0	0	0
VECTOR-TENSOR THEORIES (WILL-NORDTVEDT)	1	1	0	κ	0	0	0	0	0	0
TENSOR-TENSOR THEORIES (LEE-LIGHTMAN)	a	b	c	d	0	0	0	0	0	0
CONFORMALLY FLAT THEORIES (NORDSTROM)	-1	$\frac{1}{2}$	0	0	0	0	0	0	0	0
STRATIFIED THEORIES TYPE A (ROSEN)	λ	$\frac{1}{4}(3+\lambda)$	$-4(1+\lambda)$	0	0	0	0	0	0	0
STRATIFIED THEORIES TYPE B (NI)	a	b	c	d	0	0	0	0	0	0
QUASI-LINEAR THEORIES (WHITEHEAD)	1	1	0	0	0	-6	0	-1	-1	1

METRIC THEORIES OF GRAVITY that have been studied enough to have the values of their PPN parameters computed can be divided roughly into eight groups. Each group is given with one example of a theory in that group. The general theory of relativity stands alone, with the values of its parameters determined by convention. Two kinds of scalar-tensor theories are known; the Brans-Dicke theory is one kind. They have an adjustable coupling constant ω that can have any value between $-3/2$ and $+\infty$ (infinity). Two kinds of vector-tensor theories and one kind of tensor-tensor theory have been studied; they too have adjustable coupling constants: κ, *a*, *b*, *c* and *d*, with κ ranging between 0 and 2 and *a*, *b*, *c* and *d* being arbitrary. These theories incorporate additional scalar, vector and tensor fields into their descriptions of gravity. Six conformally flat theories are known; they all predict that the parameter γ measuring the curvature of space is -1. There are nine examples of theories in the class of stratified theories of Type *A*. In each one the values of α_1 and γ are related by the equation $\alpha_1 = -4(1+\gamma)$; since the value of γ is given by the arbitrary constant λ in the sample theory, then α_1 becomes $-4(1+\lambda)$. Stratified theories of Type *B* are generalizations of stratified theories of Type *A*; they form a class with two members. Quasi-linear theories have the property that ζ_W is 1; three such theories are known.

cally nonviable for at least one reason. I shall henceforth ignore such theories.

The basically viable theories of gravity can be further separated into two types: metric theories and nonmetric theories. In general terms a metric theory of gravity is one in which gravitation can be treated as being synonymous with the curvature of space and time. The precise definition of a metric theory, of course, requires rather technical mathematical language. That language can, however, be boiled down to the statement that in a gravitational field rigid measuring rods, rays of light, subatomic particles, indeed any physical system one cares to imagine, behave as though the events being monitored are taking place in non-Euclidean four-dimensional space-time rather than in the Euclidean space and time of our everyday experience.

Einstein's general theory of relativity is a metric theory, but it is not the only one. There are many others. Each metric theory differs from the rest in the way in which matter (the sun, planets, stars, men, protons and so forth) gives rise to the curvature of space and time. Nonmetric theories are by definition those that are not metric theories; they rely on some mechanism other than the curvature of space and time to account for gravity. There is compelling experimental evidence against nonmetric theories and in favor of metric theories. Before discussing that evidence, let me dwell a bit more on the nature of metric gravitation theories.

In the solar system gravity is a relatively weak force. This being the case, the predictions of any metric theory for the solar system can be analyzed using a weak-field limit of the theory. Such a limit is known as the post-Newtonian limit of the theory because it goes one step beyond the original approximate Newtonian limit. When one begins to examine the post-Newtonian limits of various metric theories, one observes a surprising thing: almost all metric gravitation theories have the same form for their post-Newtonian limit, that is, their equations describe weak fields in a very similar manner. This holds true even though their exact mathematical descriptions of the limits for strong fields may differ greatly. The only way any one metric theory differs from any other at the post-Newtonian limit is in the numerical value of a set of coefficients used in the equations. For example, a specific coefficient might have the value of 1 in one theory, zero in another, 3.7 in still another and so forth. Each theory possesses its own particular set of values for these coefficients.

Since all metric theories of gravity are

the same at the post-Newtonian limit except for the specific values of the coefficients, it is possible to assign the coefficients letter names with unspecified values and thus obtain a supermetric theory of gravity. Each metric theory's post-Newtonian limit is therefore only a special case of this supertheory. Every metric theory predicts the same kind of observable effects in the solar system; the size of each effect predicted, however, depends on the numerical values of the coefficients in that particular theory. Hence one result of having a supermetric theory is that experiments that measure the sizes of various effects can also be regarded as measuring the true values of the coefficients. And a set of high-precision experimental measurements of the values of the coefficients will enable us to pick out of the supermetric theory those theories of gravity that best agree with experiment.

The use of post-Newtonian coefficients or parameters to study metric theories of gravity and to analyze experimental tests pioneered by Kenneth Nordtvedt, Jr., of Montana State University is called the parametrized post-Newtonian (PPN) formalism. The coefficients are called PPN parameters. In the current version of the PPN formalism there are 10 PPN parameters, each of which describes or measures a particular physical property predicted by metric theories of gravity. I shall describe each one briefly.

As we have seen, curvature of spacetime is the fundamental characteristic of any metric theory of gravity. The degree to which space is curved by a unit amount of mass at rest is denoted by the parameter γ. For the sake of simplicity the value of γ in the general theory of relativity is set at 1.

In most metric theories gravitation is a nonlinear phenomenon, that is, the combined gravitational potential energy of two bodies is not simply the sum of the individual potentials. Instead the two potentials must be combined in a certain manner. The parameter β measures the magnitude of the nonlinear contributions. Its value in general relativity is also 1.

Some theories of gravity state that the universe has a single "preferred" frame of reference and that certain kinds of phenomena can be observed in systems that are moving with respect to that frame. The size and nature of such preferred-frame effects are described by the values of the three parameters α_1, α_2 and α_3. In the general theory of relativity all three parameters are zero, meaning that general relativity does not predict that the universe has a preferred frame of reference.

Some theories predict that the laws of the conservation of momentum will be violated under certain circumstances. The four PPN parameters ζ_1, ζ_2, ζ_3 and ζ_4 measure the extent to which these conservation laws are violated in isolated gravitational systems. In the general theory of relativity there are no such violations, so that all the parameters are zero.

The last PPN parameter, ζ_W, is associated with certain kinds of observable gravitational effect due to the presence of nearby matter, such as the matter of our galaxy. In general relativity the value of ζ_W is again zero, since no such galaxy-induced effects are predicted.

All the metric theories of gravity that have been studied closely enough to have had the values of their PPN parameters computed can be roughly classified into eight groups [*see illustration on preceding page*]. Many theories (general relativity is not one of them) are formulated with arbitrary constants whose values can be adjusted to best fit the results of experiments. One example is the theory put forward in 1961 by Carl H. Brans and Robert H. Dicke, which has a coupling constant, ω, the value of which ranges between $-3/2$ and $+\infty$ (infinity). As the value of ω gets closer to infinity, the Brans-Dicke theory becomes identical with the general theory of relativity. For a variety of reasons the Brans-Dicke theory is considered to be the strongest alternative to general relativity.

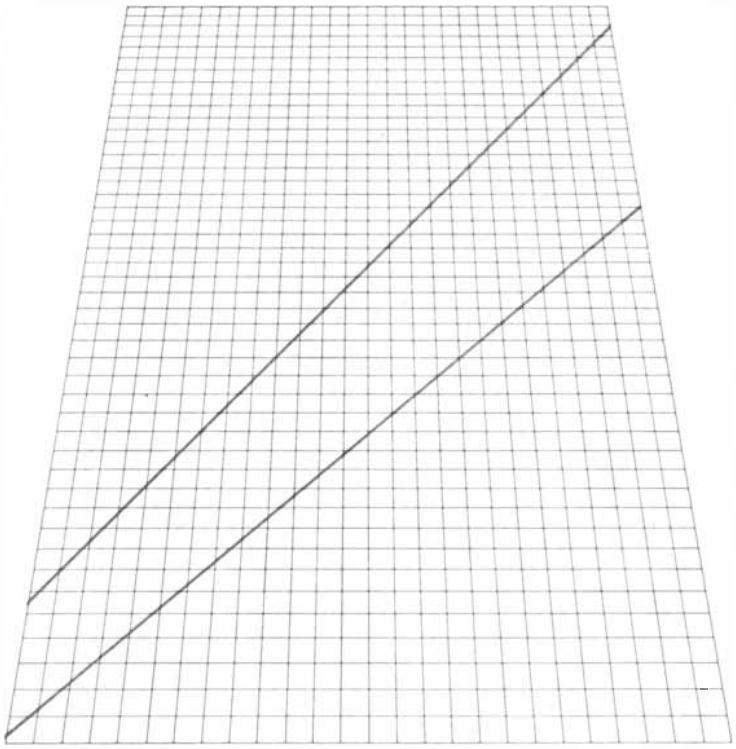
So far the discussion of nonmetric theories, metric theories and the PPN formalism has served only to classify theories of gravity according to various theoretical attributes. Since the foremost criterion of a theory's viability is its agreement with experiment, it is to experiment that we must now turn. There are two experiments in particular that are useful for testing the viability of nonmetric gravitation theories. One is the Eötvös experiment; the other is the measurement of the gravitational red shift.

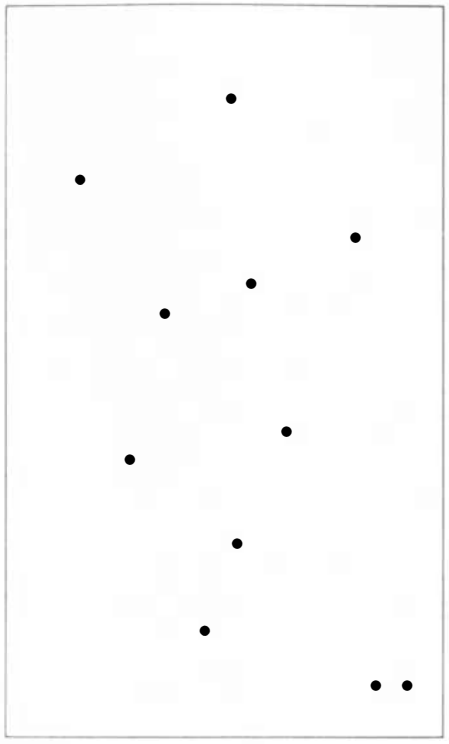
The Eötvös experiment measures whether or not objects that differ in composition fall at the same rate in a gravitational field. The experiment is named for Baron Roland von Eötvös of Hungary, who between 1889 and 1908 made a series of measurements accurate to five parts in 10^9 showing that gravity acts equally on all masses regardless of their composition [see "The Eötvös Experiment," by R. H. Dicke; SCIENTIFIC AMERICAN, December, 1961]. That equality has been confirmed to a precision of one part in 10^{11} by Dicke and his colleagues at Princeton University, and to a few parts in 10^{12} by Vladimir Braginsky and his co-workers in Moscow.

The theoretical interpretation of the Eötvös experiment has varied. Some theorists maintain it demonstrates that mass in any gravitational field behaves exactly like mass in an accelerating (noninertial) frame of reference. Others aver that the Eötvös experiment tests the weak equivalence principle, which states that the trajectories of small bodies free of electric charge are independent of their composition. These statements are more or less equivalent. The most powerful interpretation, however, is a conjecture advanced by the late Leonard Schiff of Stanford University. Schiff's conjecture states that any basically viable theory of gravity that agrees with the weak equivalence principle is necessarily a metric theory. Conversely, every nonmetric theory violates the weak equivalence principle. Therefore if Schiff's conjecture is correct, since the Eötvös experiment tests and confirms the weak equivalence principle, it also demonstrates that nonmetric theories of gravity are nonviable.

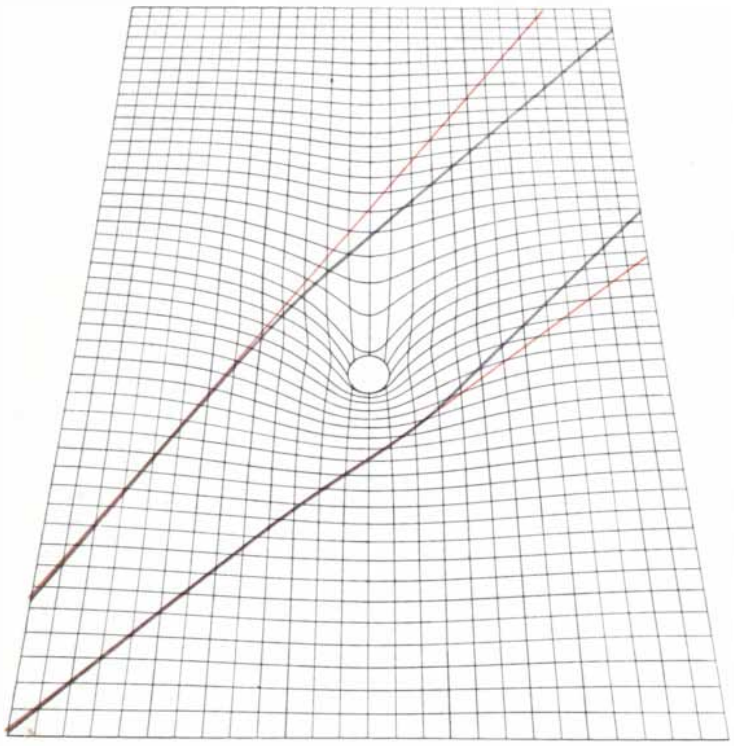
Alan P. Lightman and David L. Lee, then graduate students at the California Institute of Technology, proved that Schiff's conjecture was indeed correct, at least when it was applied to a subclass of gravitation theories that included all metric theories and many nonmetric theories. Moreover, Lightman and Lee showed that the confirmations of the Eötvös experiment conducted at Princeton and in Moscow were accurate enough to rule out many nonmetric theories of gravity previously thought to be viable.

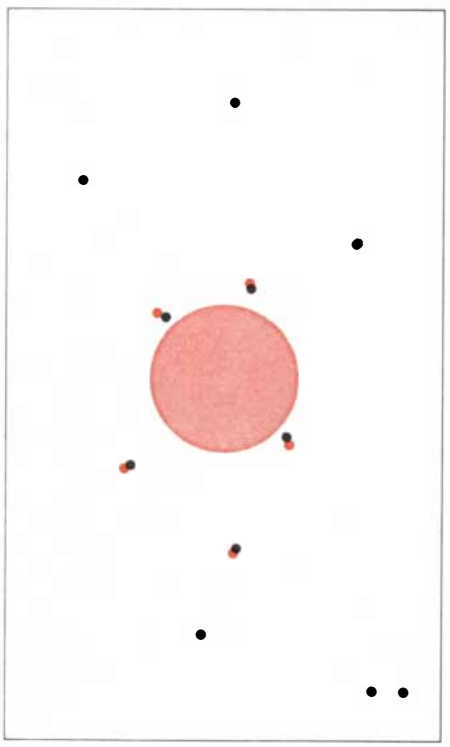
The measurement of the gravitational red shift is closely related to the Eötvös experiment in its theoretical meaning. Although Einstein considered the red shift to be one of the most important predictions of the general theory of relativity, it was not until 1965 that the shift was measured with genuine accuracy. Robert V. Pound of Harvard University and Joseph L. Snider of Oberlin College, using an improved version of an experimental apparatus set up five years earlier by Pound and G. A. Rebka, Jr., measured the gravitational red shift of photons climbing up the Harvard Tower through the earth's gravitational field. They found that to an accuracy of within 1 percent the amount of the shift agreed well with Einstein's prediction. Such accuracy was possible because they took advantage of the Mössbauer effect: the sharply defined frequency of





LIGHT TRAVELS IN STRAIGHT LINES in the absence of the gravitational field of a body such as the sun. In this case space can be represented by a flat *x-y* plane with the light from distant stars traveling across it unaltered in any way (*left*). A photograph that had been made of a certain field of stars could serve as a reference map for positions of the stars with respect to one another (*right*).





LIGHT IS BENT when it encounters the curved space of the gravitational field of a massive body such as the sun. A light ray moving on the *x-y* plane near the sun has farther to go to get across because it must cross a "stretched" region of space and must dip into the bowl of the embedding diagram (*left*). The path of the light ray is deflected in much the same way that a banked roadway acts to change the motion of an automobile without a turn of the steering wheel. A snapshot made of the same star field as the one in the illustration at the top of this page with the sun in the field of view would show that the apparent positions of the stars (*color*) had been displaced outward from the sun (*right*) from their real positions (*black*) as a result of the altered lines of sight to the stars along the deflected light rays. Moreover, each ray's dip into bowl of the embedding diagram delays it and causes it to arrive later than it would if the sun were not present. Time delay has been measured in radar-ranging experiments to planets and spacecraft.

a photon spontaneously emitted by an excited atomic nucleus locked into a crystal lattice [*see illustration below*].

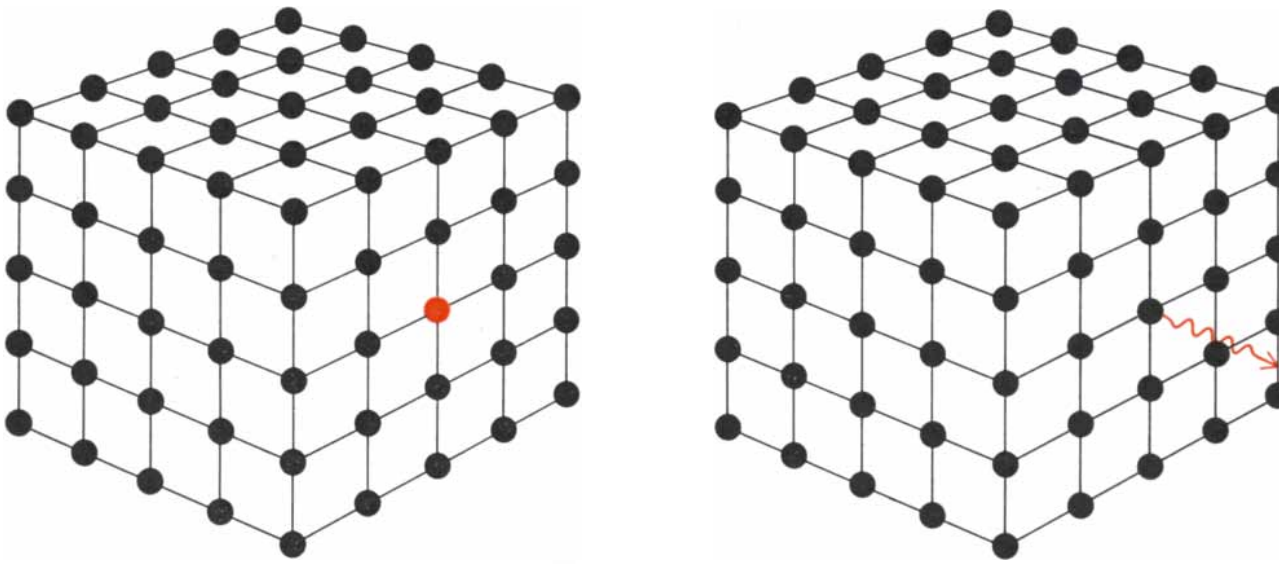
In the years since Einstein's prediction the interpretation of the gravitational red shift has changed. It is now known that the gravitational red shift is not a strong test of general relativity. Rather it is, like the Eötvös experiment, a test of all nonmetric theories of gravity. The reason is that every metric theory predicts the same gravitational red shift that general relativity does, whereas there is reason to believe every nonmetric theory predicts a different red shift. Unfortunately for experimenters the differences among the predictions may be so small that measurements of the red shift far more accurate than Pound and Snider's will be needed if all the nonmetric theories are to be tested with a precision comparable to that of the Eötvös experiment. One improved red-shift experiment is planned for late 1975 by workers at the Smithsonian Astrophysical Observatory. It will measure the red shift (actually a blue shift) of photons emitted by a hydrogen maser aboard a rocket probe at an altitude of 10,000 miles. Scientists hope for a test of the shift that will be accurate to .01 percent.

We have now seen that the experimental verification of the weak equivalence principle combined with Schiff's conjecture suggests that most if not all nonmetric theories of gravity are nonviable. How, then, does one determine the viability of the competing metric theories? For the most part they can be tested by specific gravitational experiments within the solar system. One of the best-known of these experiments is the bending of light in a gravitational field.

Einstein's general theory of relativity predicted that a ray of light from a distant star passing by the sun and just grazing its surface should be deflected from its original direction of travel by an angle of 1.75 seconds of arc. Such a phenomenon could be observed by photographing a field of stars close to the sun during a total eclipse (when the stars would be visible because the moon would have blotted out most of the sun's light) and then comparing the positions of the stars with the positions in a photograph of the same stars made at a time when the sun was not in the field of view. During the total eclipse of May 29, 1919, A. S. Eddington and his colleagues made such photographs of a field of stars close to the sun. The positions of the stars were shifted, demonstrating that light passing the sun was indeed deflected. It was a confirmation that helped to make Einstein famous. The observations had a margin of error of more than 30 percent, however, and later observations were not much better. The results for the angle through which the light was deflected ranged from about .5 to 1.5 times Einstein's predicted value of 1.75 seconds of arc, and the accuracy of the measurements was low.

Recently the new technique of long-baseline interferometry with radio telescopes has altered the situation. Two or more radio telescopes that may be as far apart as several thousand miles can be used in conjunction with one another to form an interferometer capable of resolving angles as small as .0003 second of arc. In addition, on October 8 of each year the sun comes very close to the line of sight between the earth and two strong celestial radio sources, the quasars 3C 273 and 3C 279; in fact, 3C 279 is eclipsed by the sun. Beginning in 1969 radio astronomers undertook to check Einstein's prediction by measuring how much the radio signals from the two quasars are bent with respect to each other.

Now, according to the PPN formalism the prediction of any metric theory of gravity for the bending of light depends on the parameter γ, that is, the prediction depends in part on the degree to which space is curved in the vicinity of the sun by virtue of the sun's gravitational field. To be more exact, the predicted amount by which a ray of light just grazing the surface of the sun is bent is 1.75 seconds of arc multiplied by the coefficient $\frac{1}{2}(1 + \gamma)$. In the general theory of relativity the coefficient has the value of 1. In the Brans-Dicke theory the coefficient has the value of .93 when the coupling constant ω is given a value of 5; therefore the Brans-Dicke theory predicts that a light ray will be bent only 1.62 seconds of arc. The results of the bending of the radio signals from the quasars can thus be expressed as experimental values for the coefficient $\frac{1}{2}(1 + \gamma)$. The observations of the past five years have yielded values of about 1, with margins of error of about 10 percent. It is hoped that an accuracy of a



MÖSSBAUER EFFECT allows the red shift of light in a gravitational field to be measured to high precision. An excited atomic nucleus locked into a crystal lattice (*left*) spontaneously emits a photon of a sharply defined frequency (*right*). Since the photon's frequency is so well defined, any deviations from it toward either end of the spectrum is detected and measured with great sensitivity.

few parts in 10,000 can be achieved within the next decade.

Another solar-system experiment that measures the value of the parameter γ is one that detects a brief delay in the total time required for a radar signal to make a round trip between the earth and a planet or a spacecraft when the signal passes very close to the sun. This time-delay effect was not considered by Einstein; it was predicted in 1964 by Irwin I. Shapiro of the Massachusetts Institute of Technology, who pointed out that it was a theoretical consequence of general relativity and other theories of gravity [see "Radar Observations of the Planets," by Irwin I. Shapiro; SCIENTIFIC AMERICAN, July, 1968]. For example, when Venus is on the far side of the sun from the earth the delay is .0002 second out of a total round-trip time of about 1,000 seconds. According to the PPN formalism, the delay predicted by any metric theory of gravity involves the same coefficient $\frac{1}{2}(1 + \gamma)$ as the bending of light. In the years following Shapiro's prediction there were a number of attempts to measure this effect with the planets Mercury and Venus as passive reflectors of the radar signals and with the spacecraft *Mariner 6, Mariner 7* and *Mariner 9,* which actively retransmitted the radar signals. Detailed analyses of the measured round-trip travel times again yielded a value close to 1 for the coefficient $\frac{1}{2}(1+ \gamma)$, with errors of about 5 percent. Analysis of the *Mariner* 9 data is still under way, but workers hope for a result with margins of error far less than 5 percent.

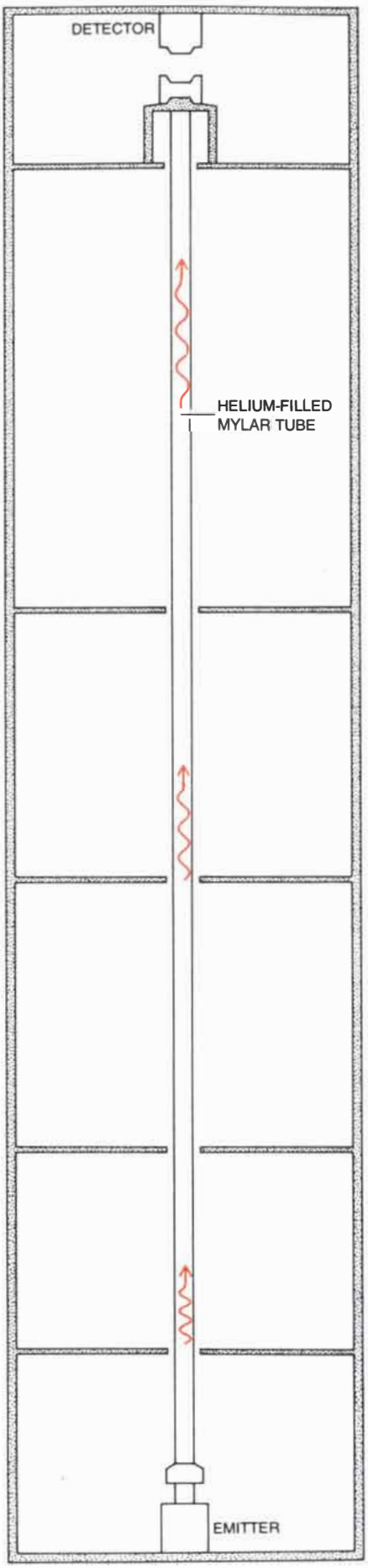
These measurements of the values of the parameter γ are by no means conclusive. Because of the large margins of error in individual measurements and because the measured values are scattered over a wide range, the most that can be said at the present time is that the value of the coefficient $\frac{1}{2}(1 + \gamma)$ is about 1 plus or minus 10 percent. Improved long-baseline interferometry, more precise radar ranging to the planets and future spacecraft missions should yield more accurate and more reliable measurements within the next five years.

On the basis of the present results, however, it is possible to suggest a few modest interpretations. First, we can conclude that every gravitation theory in which space-time is "conformally flat" (flat for light but curved for particles) is not viable because such theories predict that the parameter γ should have a value of -1, which is in violent disagreement with the measurements. Second, every theory that has adjustable parameters must restrict the values of those parameters to yield predictions for the coefficient $\frac{1}{2}(1 + \gamma)$ within 10 percent of 1. The Brans-Dicke theory, for example, can do that quite easily by restricting the coupling constant ω to values greater than 5 (the value preferred by Dicke). Further interpretation must await further measurements.

A third solar-system test harks back to the phenomenon that showed Newton's theory of gravity was nonviable: the advancing perihelion of Mercury. According to Newtonian theory, a planet travels around the sun in an elliptical orbit with the sun at one focus of the ellipse. The perihelion of Mercury is observed to shift slightly, at a rate of 5,600 seconds of arc per century, in the same direction in which Mercury goes around the sun. Nineteenth-century astronomers had discovered that most of the shift was due to the perturbing effect of the gravitational attraction of the other planets and to the slow precessional motion of the earth's axis of rotation. When these effects are taken into account, however, Mercury's perihelion still has a residual advance of 43 seconds of arc per century. (The perihelia of the other planets also shift, but they do so much less than Mercury's.) The fact that the general theory of relativity seems to account for that residual shift was one of the theory's triumphs.

In the past several years the theoretical interpretation of the perihelion shift has become more complex. According to the PPN formalism, the predicted amount of the shift of Mercury's perihelion depends on the parameters γ and β, that is, it depends on the curvature of space and on the nonlinearity of the gravitational field of the sun. (The exact form of the coefficient incorporating the two parameters is not important.)

For the general theory the predicted perihelion shift is precisely the 43 seconds of arc observed; for the Brans-Dicke theory with the value of the coupling constant ω of about 5 the predicted shift is only 39 seconds of arc. In 1967, however, Dicke and H. M. Goldenberg measured the visible shape of the sun



GRAVITATIONAL RED SHIFT was measured with the aid of the Mössbauer effect by Robert V. Pound of Harvard University and Joseph L. Snider of Oberlin College. They found that photons climbing 22.5 meters up the Harvard Tower against the force of gravity through a Mylar tube filled with helium gas were shifted toward the red end of the spectrum by an amount that agreed to within 1 percent of that amount predicted by Einstein's general theory of relativity.

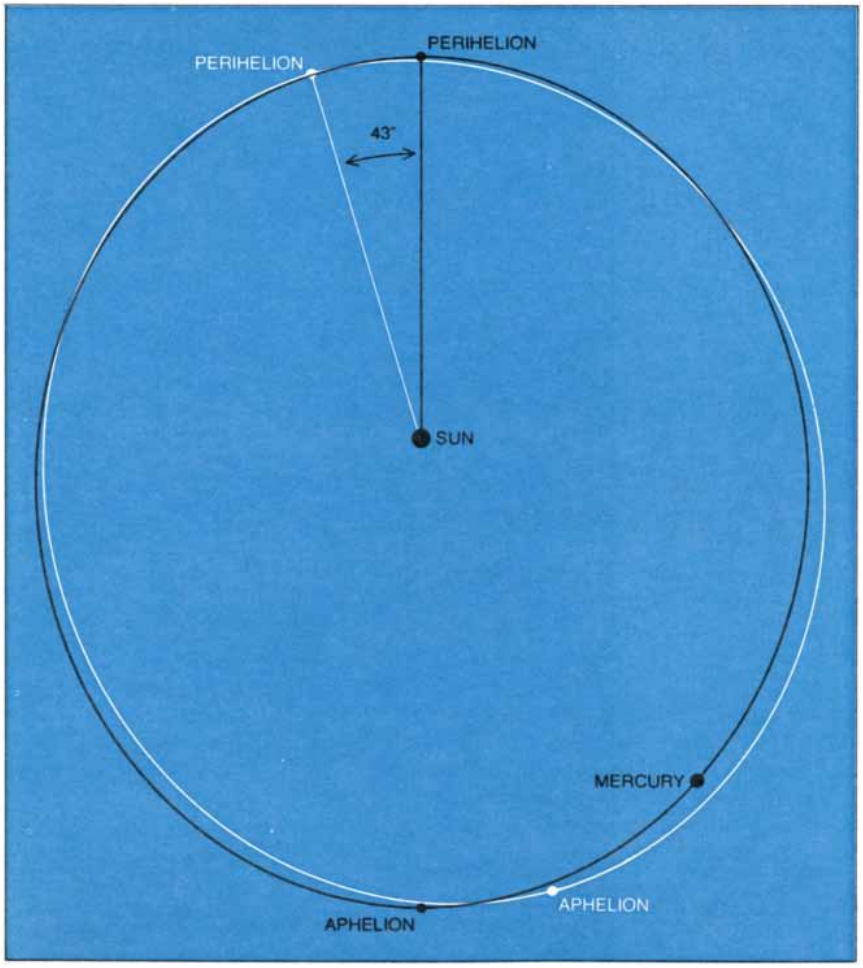
and found that it appears to be slightly oblate, or flattened at the poles. They suggested that the oblateness may cause an additional shift of Mercury's perihelion of four seconds of arc per century; the existence of such an oblateness would therefore favor the Brans-Dicke theory.

There is considerable debate about whether or not the optically measured shape of the sun demonstrates an oblateness large enough to produce a shift in Mercury's perihelion of four seconds of arc per century. Since the debate has not been settled it is difficult to deduce any reliable criterion of viability from the measurements of the shift of Mercury's perihelion. One promising way of resolving the issue is to use high-precision radar techniques to track the planets and spacecraft that are either in orbit around planets or landing on them. By determining the detailed structure of planetary orbits (as opposed to the gross or average motions of the planets) such radar-tracking experiments could obtain separate measurements of the effects of any oblateness of the sun and of the coefficient involving the parameters γ and β. Several experiments of this kind are now either in progress or in the planning stages.

There are other tests of gravitational theories that are not as well known as the ones I have been outlining. For example, there are a variety of tests of those theories maintaining that the universe has a preferred frame of reference. Such theories predict that, since the solar system moves with respect to the mean frame of reference of the universe as a result of its motion around the center of the galaxy and of the galaxy's own motion in space, there should be some observable gravitational effects from this movement. A few of these suggested effects are anomalous tides in the solid earth, anomalous variations in the rate of the earth's rotation and anomalous shifts in the perihelion points of Mercury and the other planets (above and beyond the shifts already mentioned). Geophysical data and measurements of perihelion shifts show no such effects within the present-day range of experimental accuracy, even taking into account the possibility of the sun's oblateness. Since the predicted anomalous effects depend on the values of the preferred-frame parameters α_1, α_2 and α_3, the data show that if their values are not zero, they must be very small. They must be so small, in fact, that every gravitation theory that falls into the class designated as stratified theories of Type A seriously violates experiment by predicting a sizable value for α_1. Other kinds of theories, such as one of the vector-tensor theories, must adjust their arbitrary constants so that they agree with the data. Since in the general theory of relativity and the Brans-Dicke theory all three parameters are zero, those theories do not predict any such anomalous effects.

Some theories of gravity predict that nearby collections of matter such as the matter in our galaxy should give rise to anomalous land tides on the earth and anomalous perihelion shifts in the orbits of various planets. These effects depend on the value of the parameter ζ_W. Again the observations have detected no such anomalies, indicating that if ζ_W is not zero, it must be very small. In serious violation of the experimental results are the quasi-linear theories of gravity, which predict a value of 1 for ζ_W. In virtually all other metric theories of gravity ζ_W is zero, and thus those theories agree with experiment.

A variety of new experimental tests of gravitation theories have been devised, and many of them will be carried out within the next decade. A group of workers at Stanford University are planning to measure the precession, or gradual change in direction, of the axes of an array of spinning gyroscopes made of a superconducting material and placed in orbit around the earth. The experiment will measure the precession arising from two different effects. The curvature of space around the earth created by the earth's gravitational field would cause the axes of the gyroscopes to precess by about seven seconds of arc per year. And the rotation of the earth is predicted to cause an additional precession, the Lense-Thirring preces-



ADVANCE OF MERCURY'S PERIHELION (the point of the planet's orbit closest to the sun) is 5,600 seconds of arc per century in the same direction in which the planet revolves. Most of the advance is due to the perturbing effects of the other planets in the solar system, but there is a residual amount of 43 seconds of arc per century. Einstein's general theory of relativity accounts for that residual amount very well; the Brans-Dicke theory predicts an advance of only 39 seconds of arc per century. The remaining advance of four seconds of arc per century is attributed to a predicted oblateness, or flattening at the poles, of the sun.

sion, of .05 second of arc per year. The planned accuracy of the measurements is .001 second of arc.

Another experiment that may measure or rule out a host of gravitational effects is the laser-ranging between the earth and the reflectors set up on the moon by the astronauts. The measurements establish the distance to the moon to an accuracy within 30 centimeters and will test whether or not the inertial mass and the gravitational mass of the earth are identical. The experiment will also investigate a variety of effects predicted by the remaining preferred-frame theories of gravity, and it will measure nonlinear effects generated by the superposition of the gravitational fields of the sun and the earth, which depend on the PPN parameter β and which are predicted even by the general theory of relativity.

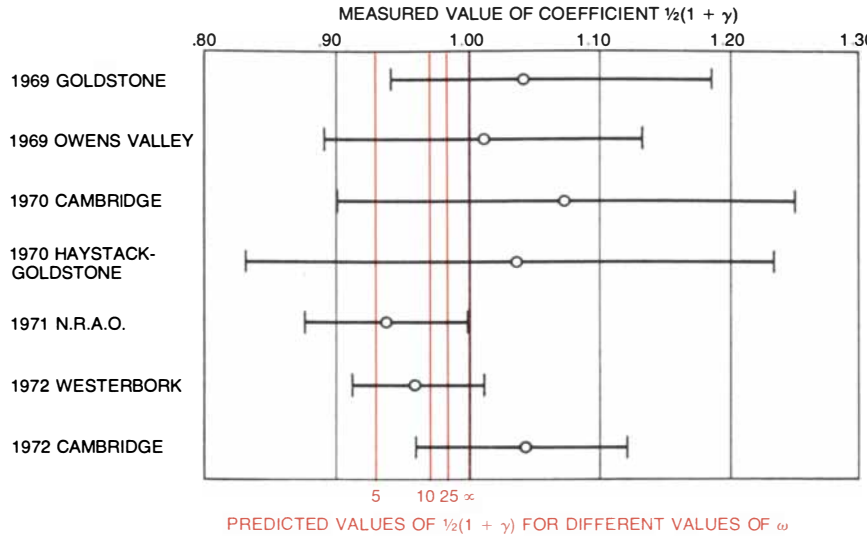
Studies of the motions of the planets both visually and by radar may determine whether or not the Newtonian gravitational constant G is changing with time. Such a variation, predicted by a number of theories (although not by the general theory of relativity), would be caused by the fact that the universe is expanding as it evolves. The variation cannot be analyzed within the PPN framework. Nonetheless, measuring any such variation with great precision could help in distinguishing among competing theories. The current precision of four parts in 10^{10} per year is not good enough, and improved measurements are planned.

In addition, as soon as reliable and sufficiently sensitive antennas for detecting gravitational waves have been developed, such characteristics of the waves as their speed of propagation and their polarization can be studied. Gravitational radiation also cannot be analyzed within the PPN framework. Yet several of the remaining viable metric theories of gravity (not including the general theory of relativity and the Brans-Dicke theory) predict that the speed of gravitational waves should differ slightly from the speed of light. Moreover, general relativity predicts that gravitational waves, like light waves, should have only two states of polarization, whereas the other theories predict additional possible states up to as many as six. Such studies of gravitational waves, although still far in the future, may provide crucial tests of gravitational theories.

What, then, can be concluded? Of all the basically viable theories of gravity, it is now believed only metric theories can agree with the Eötvös experiment. Of the eight known classes of metric theories, three are nonviable because they violate specific solar-system experiments. Of those remaining the general theory of relativity completely agrees with all experiments. The Brans-Dicke theory and other scalar-tensor theories are also viable as long as their coupling constant ω is confined to values larger than 5. Since they predict that the coefficient $\frac{1}{2}(1+\gamma)$ will be less than 1 for any finite value of ω, measurements of the deflection and delay of light offer the most promising test of their viability. Other tests that may play a key role in testing scalar-tensor theories are the measurement of perihelion shifts in the orbits of Mercury and the other planets, the resolution of the debate on the oblateness of the sun, and the laser-ranging measurements of the distance between the earth and the moon.

Most of the other viable theories of gravity have enough latitude in their adjustable constants so that they can be made to agree with any conceivable measured values of the PPN parameters. Therefore they can never be ruled nonviable by such measurements. It should be remarked, however, that almost every one of these theories was devised during the past four years by the very theorists who have helped to set up the supermetric theory of gravitation theories and the PPN formalism. They were devised not so much as serious competitors to the general theory of relativity as foils against which its predictions could be compared and contrasted and as guides to further experiments. For this reason the fact that these theories do exist underscores the importance of testing gravitation theories by experiments such as determining the variation of the gravitational constant and studying the speed and polarization of gravitational radiation, which cannot be analyzed within the PPN framework.

Understanding the universe and everything in it—quasars, black holes, neutron stars and all the rest—requires a gravitation theory that is complete, self-consistent and in agreement with a host of experiments that will become more precise and more numerous as time passes. Whether that theory is the general theory of relativity, the Brans-Dicke theory or a theory not yet formulated, finding it remains an exciting experimental and theoretical task for the coming decades.



MEASUREMENTS OF THE BENDING OF SIGNALS from two quasars as the sun passes close in front of them have yielded values for the coefficient $\frac{1}{2}(1+\gamma)$ that center about the value of 1, the prediction of the general theory of relativity. The color lines indicate the predictions of the Brans-Dicke theory for different values of the coupling constant ω. As ω gets closer to infinity, the Brans-Dicke theory becomes identical with general relativity. 1969 GOLDSTONE refers to the 210-foot and 85-foot radio telescopes of the Goldstone Deep Space Station of the National Aeronautics and Space Administration at Goldstone, Calif.; 1969 OWENS VALLEY refers to the 1,600-foot interferometer at Owens Valley Radio Observatory, Calif.; 1970 CAMBRIDGE refers to the One-Mile Telescope in Cambridge, England; 1970 HAYSTACK-GOLDSTONE refers to the 120-foot radio telescope of the Massachusetts Institute of Technology at Haystack Radio Observatory, Mass., and the 210-foot radio telescope at Goldstone Deep Space Station, used together as an interferometer; 1971 N.R.A.O. refers to the three-mile interferometer at the National Radio Astronomy Observatory at Green Bank, W.Va.; 1972 WESTERBORK refers to the Westerbork Synthesis Radio Telescope in the Netherlands; 1972 CAMBRIDGE refers to the five-kilometer interferometer at Cambridge in England.

Computer Control of Electric-Power Systems

After a cautious introduction, computers now play a critical role in ensuring the security and economy of the large networks that distribute electric power

by Hans Glavitsch

Nine years ago this month, on a mild, moonlit night, the northeastern part of the U.S. and the eastern part of Canada experienced a massive electric-power failure that left thousands of industrial plants and millions of homes without electricity for periods ranging from two to 16 hours. Until that time it had been thought that under normal operating conditions, in which weather was not a factor, existing control and emergency systems were adequate to limit a power failure to a small area and for a period usually measured in minutes. The blackout was traced to the tripping of a circuit breaker in Ontario during a momentary overload. As a result of the blackout the power pool of the region was subjected to a thoroughgoing systems analysis, leading to the installation of advanced monitoring and control systems in which computers have been assigned a prominent role.

To appreciate the quality of the service routinely provided by electric-power systems one can calculate that a single interruption of five minutes in the course of a year corresponds to an availability figure of 99.999 percent. Compared with availability figures for machines such as automobiles and household electrical appliances, the typical performance of an electric-power system is impressive. The achievement is made possible by the fact that electric power is supplied by an integrated system of generation, transmission and distribution built around carefully designed components, provided with redundant features and continuously monitored by both instruments and men.

The constancy of supply is complicated by the fact that electric energy cannot be stored economically on a large scale. Hence for each kilowatt of change in load a nearly instantaneous control action must take place at the power source. In accommodating such load changes electric utilities strive to apportion the load among the available generating units so that additional kilowatts are produced by the most efficient equipment (within the limits imposed by the necessity of maintaining the security of the system). Conversely, when the load drops, the least efficient units are throttled back or taken off the line. Thanks to such operating stratagems and, more basically, to the installation of ever larger and more economical generating units as the total demand has grown, the worldwide electric-power industry has generally managed to keep the cost of its product from rising as rapidly as the average cost of all goods and services.

In what follows I shall be concerned not with the planning and engineering of power systems but with their operation and in particular with the control devices necessary for their smooth and efficient performance. The device increasingly being called on for coordinating operations at different sites, for decision making, for data processing, for simulation, for graphic display and for instantaneous closed-loop control is of course the electronic digital computer. In exploiting the manifold capabilities of the computer the power industry has been understandably cautious. It had, after all, achieved a good performance record without the computer and, as computer users in many fields have discovered, there are numerous pitfalls in the path of those who adopt the machines precipitately.

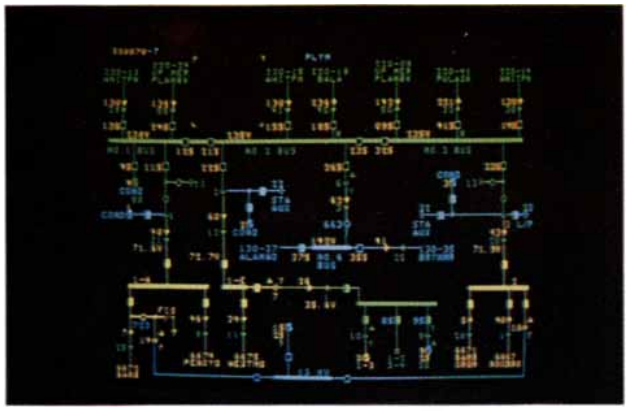
Today, however, a stage of development has been attained where computers are being integrated in various electric-power subsystems and at all levels of control. Since power systems themselves are organized in hierarchical fashion, the control system has taken the form of an information system that embraces the generation, distribution and transmission system.

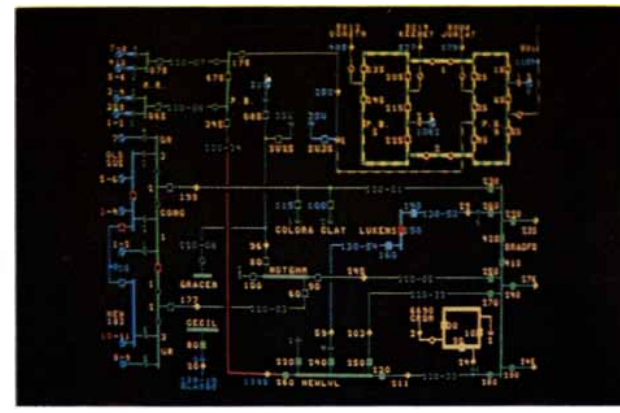
Before describing the control system in detail it may be helpful if I discuss a few of the principles that govern the behavior of a power system. Electric energy is commonly distributed in the form of alternating current, as opposed to direct current. Voltages and current vary sinusoidally at a frequency of 60 hertz (cycles per second) in the U.S. and Canada and 50 hertz in most other countries of the world. To minimize transmission losses it is desirable to transmit electricity at the highest practical voltage. Widely used voltages are 138 kilovolts (kV), 345 kV, 525 kV and recently even 765 kV. Since power (P) is the product of voltage (V) and current (I), it follows that for the transmission of a given amount of power the higher the voltage is, the lower the current is. The lower the current is, in turn, the lower the loss is due to electrical resistance in the transmission lines.

Consider what happens when alternating current is fed into a transmission line at A and delivered to a load just beyond point B [*see middle illustration on page 37*]. The line between A and B is characterized by a resistance and an inductance. The resistance is simply the

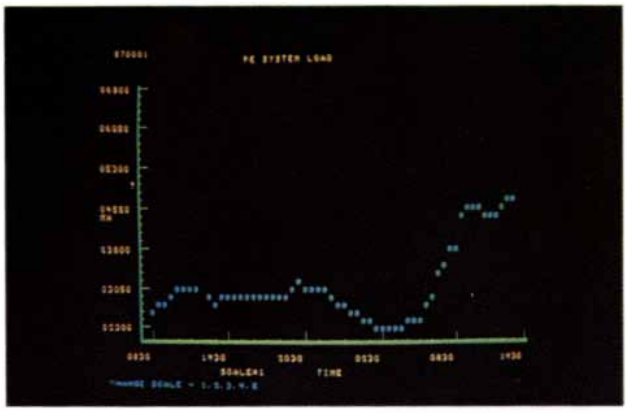
CONTROL CENTER for the Philadelphia Electric Power Company represents one of the most advanced applications of electronic computers in the electric-utility industry. Designed by North American Rockwell, the control center employs three Burroughs B-6700 computers in parallel. The system provides dispatchers with comprehensive, minute-by-minute information about an electric-power network that includes 11 fossil-fuel power stations, two hydroelectric stations and a large nuclear power plant, which together are capable of generating some 7,200 megawatts, making Philadelphia Electric Power the 15th-largest private electric utility in the U.S.

CATHODE-RAY-TUBE DISPLAYS include a 10-part "map" (*top*) of the entire Philadelphia Electric Power system. The screens at eye level can supply on request in graphic or tabular form more than 1,000 different displays, compiled and updated by the computers. Dispatchers communicate with computers and initiate changes in operating conditions by using alphanumeric keyboards.

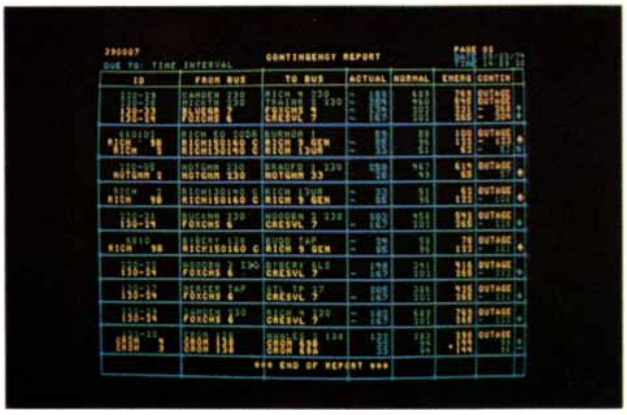


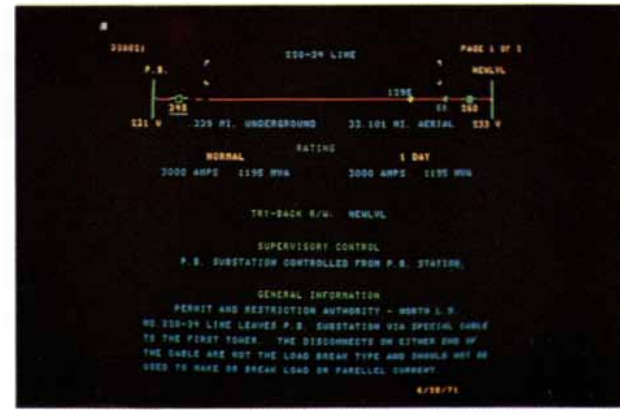


SYSTEM DIAGRAMS are color-coded to indicate voltage levels: alternating yellow and green lines for 500 kilovolts (kV), solid green lines for 220 kV, blue lines for 138 kV and yellow lines for 69 kV. (Colors repeat for lower voltages.) Red, as in the display at the right, indicates an overloaded line. The two large rectangles in the same display represent the 500-kV transmission station associated with the Peach Bottom (P.B.) nuclear power plant. Only one turbogenerator is in operation, producing 1,062 megawatts (MW).



SYSTEM LOAD AND OPERATING SUMMARY are depicted in these two displays. The system load (*left*) is plotted at half-hour intervals for the preceding 30 hours, in this case from 0830 hours on a Sunday to 1430 hours the following Monday. Note the steep rise in demand Monday morning compared with Sunday. The transmission and generation summary (*right*) provides such information as the amount of power purchased, the amount generated from different sources (fossil, nuclear and hydroelectric), the day's weather, water levels ("elevations") in two reservoirs at hydroelectric stations and amount of steam supplied to steam purchasers.





SPECIAL REPORTS appear on display screens at regular intervals or in response to a request or when a defined operating criterion is met. Thus the display at the left appears automatically every 15 minutes, during a switching operation, if a line flow changes by some prescribed value or if a line exceeds its rating by 25 percent. It shows, for example, that the bus, or line, from "Foxchs 6" (Foxchase) to "Cresvl 7" (Crescentville), which has a normal capacity of 202 MW, is actually carrying 167 MW. The last column shows what the line would be forced to carry if there were an outage on one of the lines named immediately above it. In each of five contingencies listed, the Foxchs 6-Cresvl 7 line would be forced to exceed its capacity. The display at right is a line-information report. The particular line from "P.B." (Peach Bottom) to "Newvl" (Newlinville) is in red because it is carrying a simulated overload (1,295 MW). Its normal rating is 1,195 megavolt amperes (MVA). The MVA rating includes any "reactive" power flow, here 58 megavars (megavolt-amperes reactive) from Newlinville to Peach Bottom, indicated by directional arrow over the number 58.

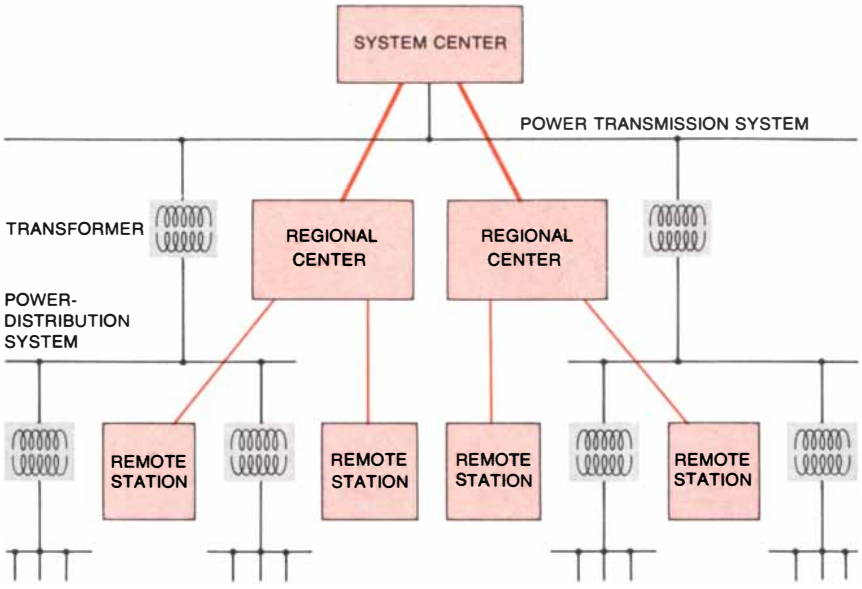
electrical resistance of the conductor; it dissipates a certain fraction of the input electric energy in the form of heat. The inductance (actually self-inductance) is a kind of electrical inertia that is noticeable only in a conductor carrying an alternating current. The continuously changing current produces a continuously varying magnetic field, which self-induces a voltage that is out of phase with the current. The self-induced voltage also creates a voltage drop whose magnitude is determined by the amount of current flowing in the line.

The voltage in the transmission line at point *A* has an amplitude *E* and a sinusoidal waveform corresponding, let us say, to 60 hertz [*see bottom illustration at right*]. If no load is present at terminal *B*, the voltage at *B* will be identical with the voltage at *A*. When a load in the form of a resistor is connected to terminal *B*, a current corresponding to the nature of the load will flow through the transmission line. Depending on the load, the voltage at terminal *B* will drop or even rise after the load is connected.

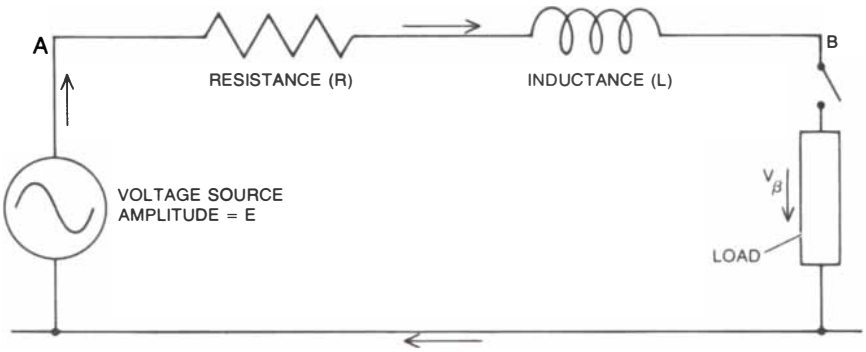
The electrical engineer visualizes the changes that take place in a power system before and after the connection of a load with the help of "phasor" diagrams that contain the essential parameters of the periodically varying quantities, such as the no-load voltage, the load voltage and the current. The essentials are the amplitude and the phase (angle), which can be converted into a real part and an imaginary part and displayed in what is called the complex plane [*see illustrations on next page*]. Since each of the variables changes continuously in an alternating-current circuit, it is convenient to convert the a.c. variables into their equivalent d.c. values as far as their power is concerned. To find the d.c. equivalent of an a.c. voltage, for example, one divides the peak a.c. voltage by the square root of two (or by 1.414); this yields the "root-mean-square" voltage. Thus an a.c. current with a peak value of 120 volts is equivalent to 85 volts d.c.

The components of a.c. power can be similarly divided into real and imaginary parts and depicted on a graph with one real axis and one imaginary axis [*see illustration on page 39*]. The projection on the real axis is the oscillating real power. The nonzero average value represents the power delivered at the point in the circuit under consideration. It is usually called the active power (*P*). The projection on the imaginary axis is a fictitious oscillating power. Its average value is called the reactive power (*Q*).

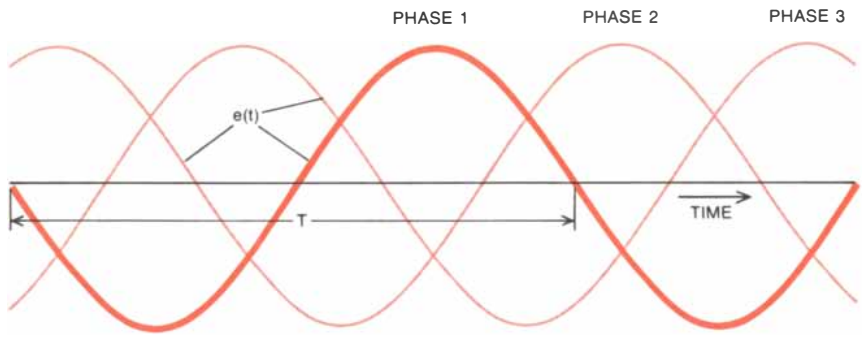
In an actual power system loads con-



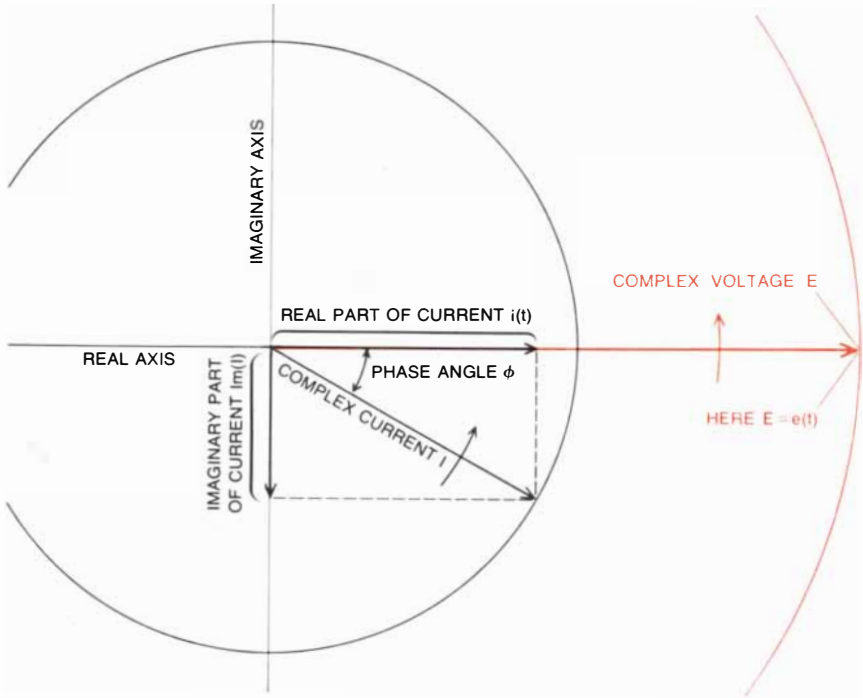
SUPERPOSITION OF INFORMATION SYSTEM (*color*) **on an electric-power system** (*black*) **exploits the hierarchical organization of the distribution of power itself. Electricity is generated at relatively few locations, and its "pressure" is raised to several hundred thousand volts for long-distance transmission. The voltage is reduced at regional centers for area distribution and further reduced at remote stations for local distribution. The levels of the power system are joined by transformers; levels of the information system, by data links.**



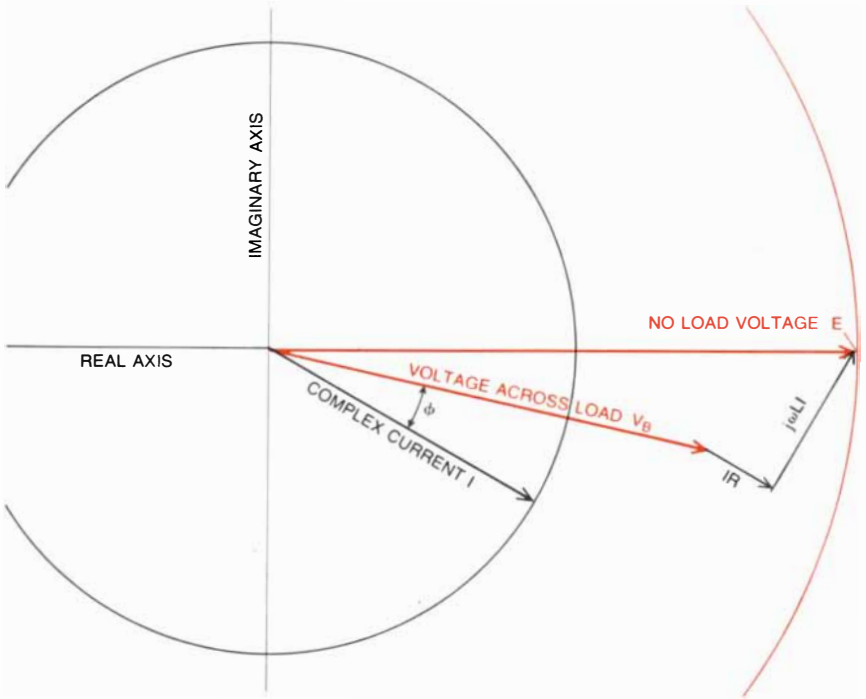
SINGLE LOOP in an alternating-current power system consists of a sinusoidal source voltage, a transmission line and a load. The line is characterized by a resistance, *R*, and an inductance, *L*. When the switch at *B* is closed, the load adds its own resistance and inductance. The load voltage, V_B, will ordinarily be less than the source voltage, *E*. In a steady state both the voltage and the current flowing through the closed loop will be sinusoidal.



VOLTAGE WAVEFORMS in an alternating-current power system vary sinusoidally with time. The three curves represent the voltages in the three conductors of a typical three-phase system: the peak voltages are offset by a third of a cycle. In U.S. systems, which operate at 60 hertz (cycles per second), the period *T* is 16.66 milliseconds. The instantaneous voltage on one conductor is designated *e*(*t*). Current has a similar sinusoidal waveform.



"PHASOR" DIAGRAMS are used to represent the complex voltage, *E*, and the complex current, *I*, at some instant of time in an alternating-current power system. The term "complex" signifies that a quantity has both a real part and an imaginary part. At the instant shown *E* lies entirely on the real axis, so that *E* equals $e(t)$, whereas *I*, which lags behind by phase angle ϕ, has a projection $i(t)$ on the real axis and a projection $Im(I)$ on the imaginary axis. The phase angle varies with the amount of inductance in the transmission system.



WHEN LOAD IS CONNECTED across the terminals of a power line, a current, *I*, starts to flow. The voltage available at the load terminals, V_B, is determined by the resistive voltage drop, *IR*, and the inductive voltage drop, $j\omega LI$, in the transmission line. These quantities are related by "Kirchhoff's law in the complex plane," diagrammed here. The resistive voltage drop, *IR*, is in phase with the current, whereas the inductive voltage drop, $j\omega LI$, leads the current by 90 degrees. The phase angle ϕ between the current and the voltage across the load is fixed by the nature of the load, that is, by its impedance. All the vectors are assumed to be rotating counterclockwise at the standard frequency of the power system.

sist of both active and reactive components. To use a homely example, when one switches on a kitchen toaster, which consists of a simple resistance heating element, the load added to the power system consists almost solely of active power, *P*. The change in reactive power, *Q*, is negligible. On the other hand, if one switches on a kitchen blender, which is operated by a small induction motor, the incremental load consists primarily of reactive power, *Q*, with only a small increase in *P* (due chiefly to the resistance in the motor winding). An induction motor produces a magnetic field in its armature that feeds oscillating power back into (or extracts power from) the power supply line; hence the term reactive. Therefore, although the two appliances could conceivably consume power at the same rate (they usually do not) and thus, if they were operated for equal lengths of time, add the same fraction of a cent to the electric bill, the generator at the power station would in principle "feel" the difference in the two kinds of load.

For the difference to have a measurable effect on the generator control system, of course, the two kinds of load would have to represent a significant fraction of the total power demand. Hypothetically this could be the case if one large industrial user switched off a battery of electric furnaces (active load) at the same instant that another company switched on a large number of big electric motors (reactive load). The active load will tend to slow down the turbogenerator and thus will demand a response from the machine's speed governor. The reactive load, on the other hand, alters the exchange of oscillating power between the magnetic field of the generator and the load itself. Since the magnetic field helps to determine the magnitude of the voltage produced by the generator, the reactive load affects the terminal voltage of the generator and calls for a suitable correction to maintain the desired voltage.

As far as the user is concerned, if the service voltage is maintained when he turns on a heavy load of either kind, he knows that the power system is providing the power he needs. The magnitude of the voltage at the terminals connected to the load is the square root of the squared sum of the two voltage components, one real, the other imaginary.

We are now ready to consider the apparatus that supplies the electric power. Electricity is produced by the rotating machines called alternators, or

generators, driven by steam or water turbines. An alternator consists of a rotor wound with coils that is normally driven at 3,000 revolutions per minute (in 50-hertz systems) or 3,600 r.p.m. (in 60-hertz systems). The rotor turns inside an armature that is also wound with coils [*see top illustration on page 41*]. The coils of the rotor, supplied with direct current from an outside source, create a strong magnetic field that induces an electromotive force, or voltage, in the coils of the armature.

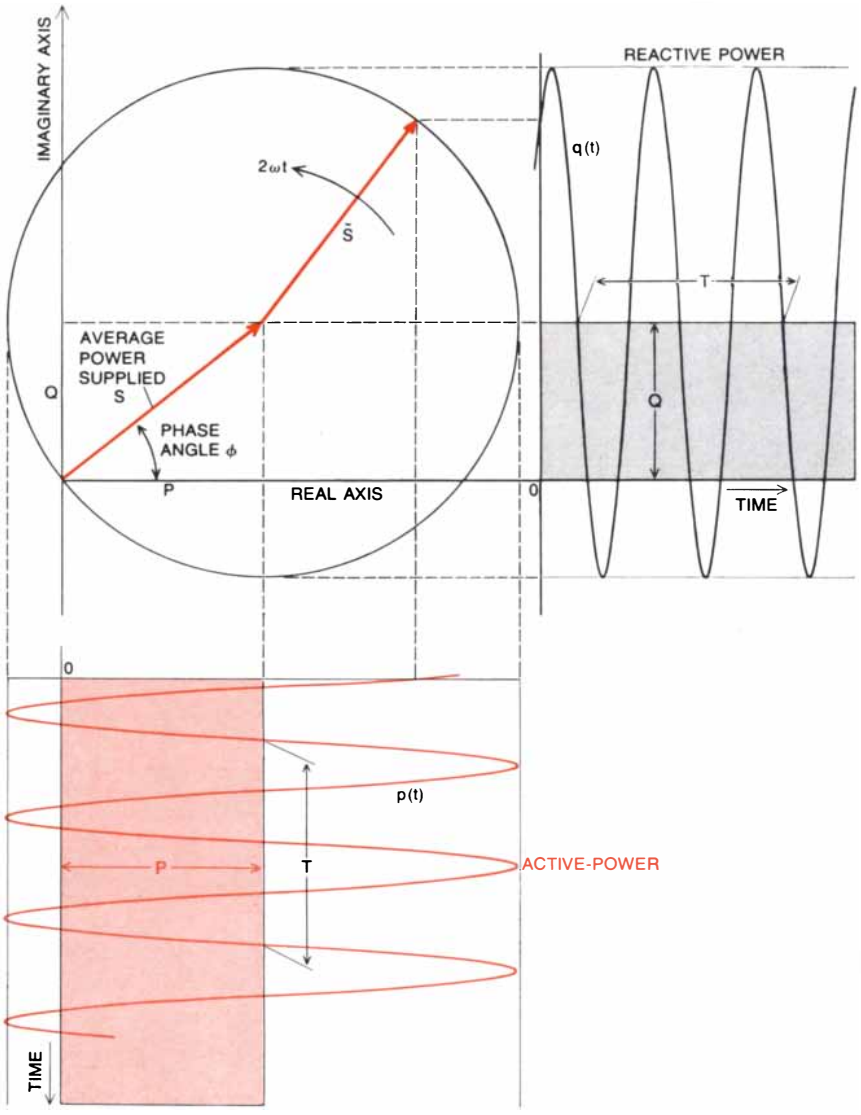
The armature winding consists of three separate sets of coils equally spaced around its 360-degree circumference. Each coil is connected to a separate conductor, with the result that the peak voltages on the three conductors are spaced a third of a cycle apart. Thus a 60-hertz alternator produces a peak voltage on one of the three conductors every 180th of a second.

The rotor is subjected to two torques: the input torque, provided by the prime mover (the steam or water turbine), and an opposing electrical torque, produced by currents in the armature winding. When the alternator is spinning without a load, the two torques are at a minimum. The effect of applying a load is to increase the currents in the armature winding, which increases the electrical torque. To keep the rotor from slowing down there must be a corresponding increase in the torque supplied by the prime mover. This balancing of torques, to maintain the rotor at a constant speed and hence to maintain the frequency of the power supply, is the first job of the generator control system.

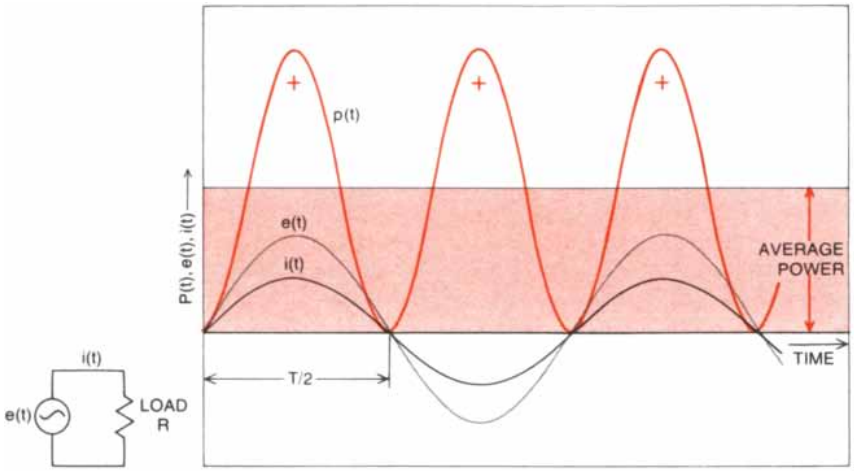
In an alternator driven by a steam turbine the input torque on the rotor of the alternator is regulated by the flow of steam into the turbine. The steam flow is modulated by a control valve actuated by a speed governor on the rotor [*see bottom illustration on page 41*]. Any load change in the power system that tends to alter the frequency will cause the speed governor to maintain the frequency. Even in the absence of a frequency deviation, however, the speed governor acts as a load controller to maintain the electrical output.

The other characteristic of a power system, in addition to frequency, that requires close control is voltage. Changes in load give rise to changes in voltages not only at the point of the load but also at the terminals of the generator. There voltage deviations are sensed by a voltage regulator, whose function is to change the amount of current flowing through the rotor coils. The change in the amount of current in turn changes the strength of the rotor's magnetic field and thus changes the voltage in the windings of the armature. The voltage regulator alters the rotor current by altering the output of an "exciter," which can be either a small rotating d.c. generator or a rectifier that converts alternating current into direct current.

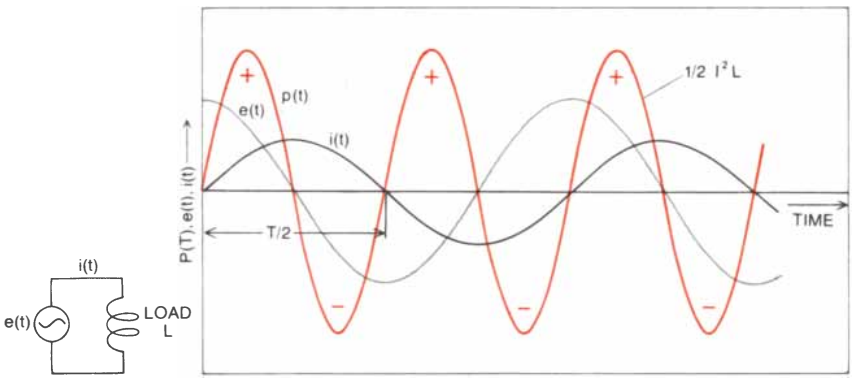
If the frequency and voltage of a power system are held within close limits by these two control mechanisms, the demand for power is met automatically. In addition to certain implicit protective functions the frequency and voltage controllers control quality, that is, they have a certain time of response and a certain accuracy and they are fully automatic. As single-purpose devices, however, they cannot respond effectively to all possible incidents in a power system; indeed, they are unable to recognize incidents as such. Accordingly higher-level control functions must be provided at



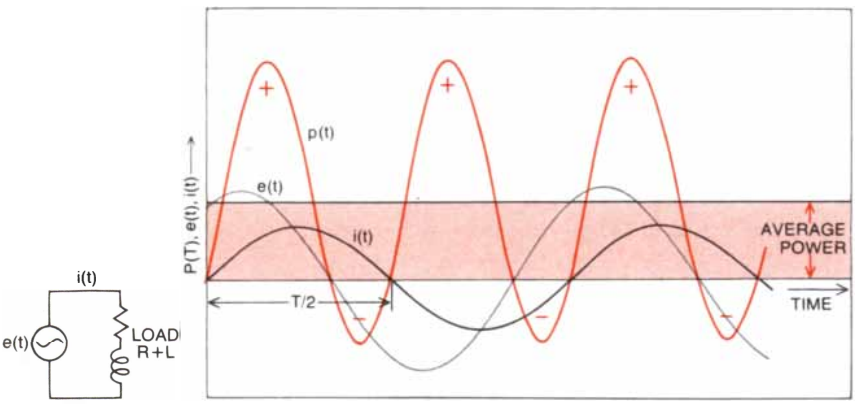
POWER FLOW in an a.c. system has two components: an average real component, P, also known as active power, and an average fictitious component, Q, which represents reactive power. The oscillating real power, $p(t)$, is the product of the oscillating voltage, $e(t)$, and the oscillating current, $i(t)$. The quantity $p(t)$ oscillates with twice the frequency of the voltage. The component $p(t)$ is plotted by introducing a phasor quantity, S, which is the complex power supplied to the load, and affixing another vector $\tilde{S}$ of equal length to its end that rotates at twice the voltage frequency again in a complex plane. The projection of $S + \tilde{S}$ on the real axis yields the oscillating active power, and its average is the useful active power. The projection of $S + \tilde{S}$ on the imaginary axis yields the fictitious oscillating reactive power $q(t)$. Its average is the reactive power Q, which is a measure of the physical power exchanged between storage devices, such as capacitors and inductors, in the power loop. If the loop consists only of resistors, Q is zero but $p(t)$ still oscillates on the real axis.



PURELY RESISTIVE LOAD, represented by *R* in the circuit diagram at left, results in the highest average real power flow (*area tinted in color*) for a given flow of current at a given voltage. For such a hypothetical load the sinusoidal curves for power, $p(t)$, current, $i(t)$, and voltage, $e(t)$, oscillate in phase. The average real power, *P*, equals one-half the maximum current times maximum voltage. In this case there is no reactive load on the generator.



PURELY INDUCTIVE LOAD, *L*, results in a zero flow of real, or active, power, *P*, because the instantaneous real power, $p(t)$, oscillates symmetrically around zero on the real axis. The inductive load shifts the voltage, $e(t)$, 90 degrees out of phase with the current, $i(t)$. Now when current and voltage are multiplied, taking this phase relation into account, the product (P) is zero. A customer who owned such a purely inductive device would not have any electric bill, but he would not be able to extract any work from the device either.



REALISTIC TYPICAL LOAD combines both resistance and inductance so that the voltage, $e(t)$, is shifted by something less than 90 degrees out of phase with the current, $i(t)$. Now when average voltage and average current are multiplied, the product—average real power (P)—is positive. Moreover, the generator "feels" both an active and a reactive load.

the power stations and the switching stations.

One obvious control function involves the means of displaying and recording the status of the generating units, switching stations and interconnecting lines in a defined region. Working with information about the status of the system, human operators can interact with the system by switching generators on and off the line, by transferring power into and out of their area and by changing "set points," or control values (for example by reducing the voltage slightly when it has risen during periods of light load).

Another kind of control function is discharged automatically; it is called load-frequency control. This type of control applies to an isolated area or to an area embedded in an interconnected power system. Its objective is to maintain the frequency within an area served by several generating stations and to maintain the sum of all active tie-line power exchanges between the area and its neighbors [*see illustration on page 42*].

The input to the load-frequency controller is a linear combination of the deviations in frequency and power measured at each tie line. It can be shown that the frequency of the entire interconnected system and all power exchanges is maintained if all area controllers keep their input at zero. The area controllers act on the set points of the speed governors of the generating units within the area, thus raising or lowering their active power outputs. In that way the loads within each area of the power system are balanced by the generator outputs at a preset frequency and with a given rate of power exchange among the various areas. In discharging this task the load-frequency control system plays a crucial role in ensuring the security of the entire power supply network.

In the minute-to-minute operation of a power system it is necessary to decide which of several power stations in an area, a region or a large network is selected to cover a given increase in load. The decision involves considerations not only of economy but also of system security. In making such decisions one approaches the heart of the power-system control problem.

The objective of allocating generating units or increments of active generation is to supply the total load at minimum cost. At the same time the security of the supply is guaranteed by

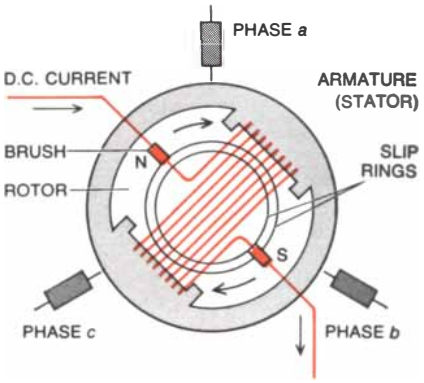
observing limits of line flows and voltage magnitudes and by keeping reserves in the generating units, which place restraints on lowering the cost. The entire complex of activities is usually called dispatching. Traditionally dispatching requires decisions made by human operators: setting priorities, initiating the start-up or shutdown of generators, changing transformer taps, judging security margins and so on.

The control tasks described so far, including the gathering and presentation of information about the system needed for dispatching, can be realized in principle by analogue control circuits, electronic devices with fixed-wire logic, strip-chart recorders, illuminated network diagrams, annunciator boards, telecontrol devices and the like. Within the past few years, however, these discrete functions have increasingly been taken over or supplemented by computers.

What are the properties of the computer that recommend it for power-control applications? Does the computer have drawbacks that have retarded its acceptance? Recognizing that the computer is basically a machine for performing logical operations according to a stored program and that it has a large capacity for storing information, one can readily visualize the following broad uses for the computer in the control of power systems: data processing, the support of graphical and alphanumeric displays on cathode ray tubes and the solving of mathematical equations related to control problems in real time.

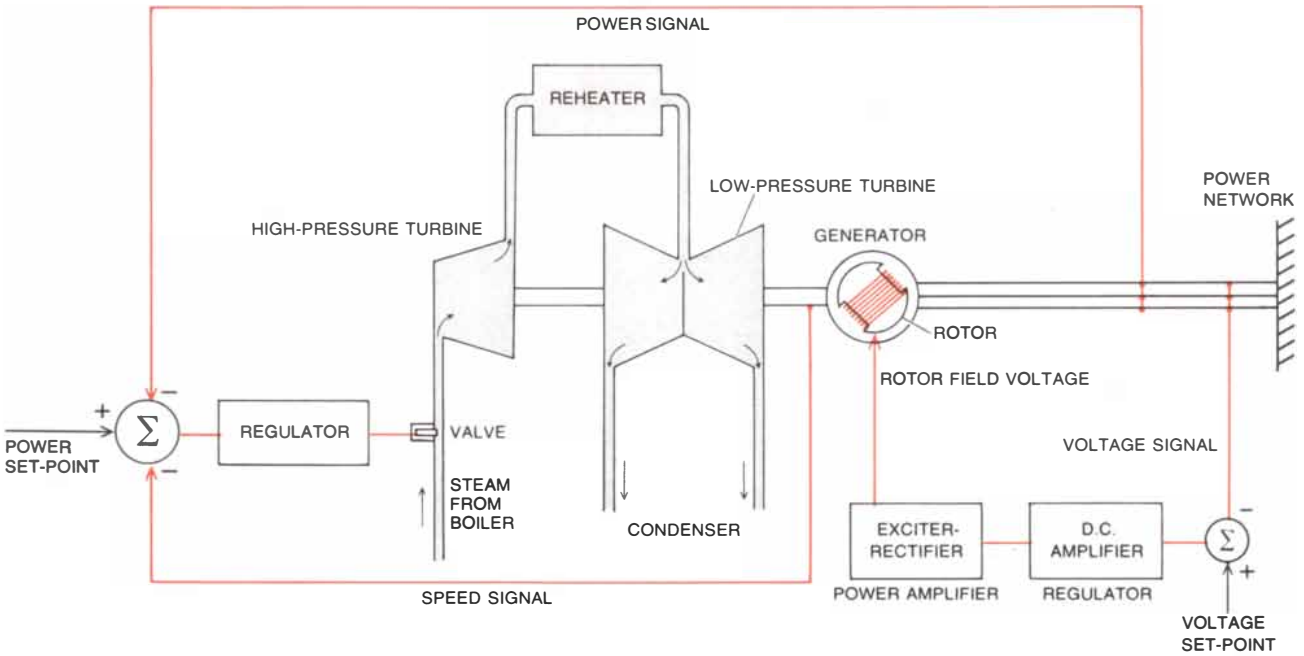
The data-processing capability is of course well known and widely exploited throughout commerce and industry. An electric-power system generates vast quantities of data at various levels that need to be assembled, synthesized and recorded. It was to help in this task that process computers were first introduced into power systems. The task is also one for which their use is most easily justified.

By facilitating the display of data on the screen of a cathode ray tube the computer can give a power-plant operator quick access to the significant variables that reveal at a glance whether the system is in a normal state, is in an emergency state or is being restored to normal from an emergency. As power networks have become bigger, involving more interconnected components, larger loads and greater interdependence of events, operators have needed a more detailed insight into the status of the system to determine its margin of security. The information has to be provided at a speed of response that only fully electronic equipment can offer.



THREE-PHASE GENERATOR consists of a rotor and an armature, both wound with coils. The rotor is supplied with a direct-current "excitation" current that creates a north and south pole (in a two-pole arrangement). When the rotor's magnetic lines of force cut through the three equally spaced windings (phases) of the armature, an oscillating voltage is induced in each phase. The prime mover that turns the rotor must overcome the electrical torque produced by the load currents in the armature windings.

The third use for computers in power systems—the solving of equations, usually in the form of particular algorithms—was first introduced for off-line applications. Until considerable experience was gained in writing programs and checking computed results, power-



CONTROL OF STEAM TURBOGENERATOR requires the automatic regulation of three quantities: the power output, the rotational speed of the machine (which determines the frequency of the a.c. output) and the output voltage. The power delivered to the network is established by a set point, or reference value, selected either manually or automatically. When the power flow measured at the generator terminals deviates from the set-point value, a regulator operates a valve that adjusts the flow of steam into the turbine. If the turbogenerator loses or gains speed, the speed signal is multiplied by an appropriate constant to yield an equivalent power signal that corrects the speed deviation. The voltage is maintained by the regulation of the current flow to the generator rotor.

plant operators would not risk jeopardizing the security of their system by allowing a computer result to have a direct effect on the running of their unit. Moreover, even when electronic speed was desirable for solving a control algorithm in real time, it was often less costly to install a special-purpose device with analogue circuitry or fixed-wire logic than to use a general-purpose computer. As integrated circuitry has reduced computer costs, however, the digital computer has found increasing favor in real-time applications.

Perhaps the main obstacle to the acceptance of digital computers in real-time applications has been the concern about their reliability. In installations made a few years ago it was not unusual to see two or even three central processing units tied together to ensure reliable operation. Today, as confidence in the computer has increased, the trend is to integrate small digital computers into the outlying parts of power control systems, such as telemetering systems. In such installations the computer is a decentralized component of a multicomputer system, speeding the flow of data to a large computer in the central station.

Let us examine some typical functions of the computer in the control of power systems. The data base required for smooth operation is collected from remote points by telemetering devices. Typical quantities of interest are active and reactive line flows, nodal voltages (the complex voltages at critical branch points in the distribution network) and the position of circuit breakers. Since these quantities are dependent on one another, the computer in the central location can check the data, determine if any are missing and suppress bad data. This activity, termed state estimation, utilizes algorithms based on probability theory. (State estimation has largely replaced a more heuristic routine termed a plausibility check.) Basic requirements of state-estimation algorithms are a mathematical model of the power flow and sufficient redundancy in the set of measured quantities.

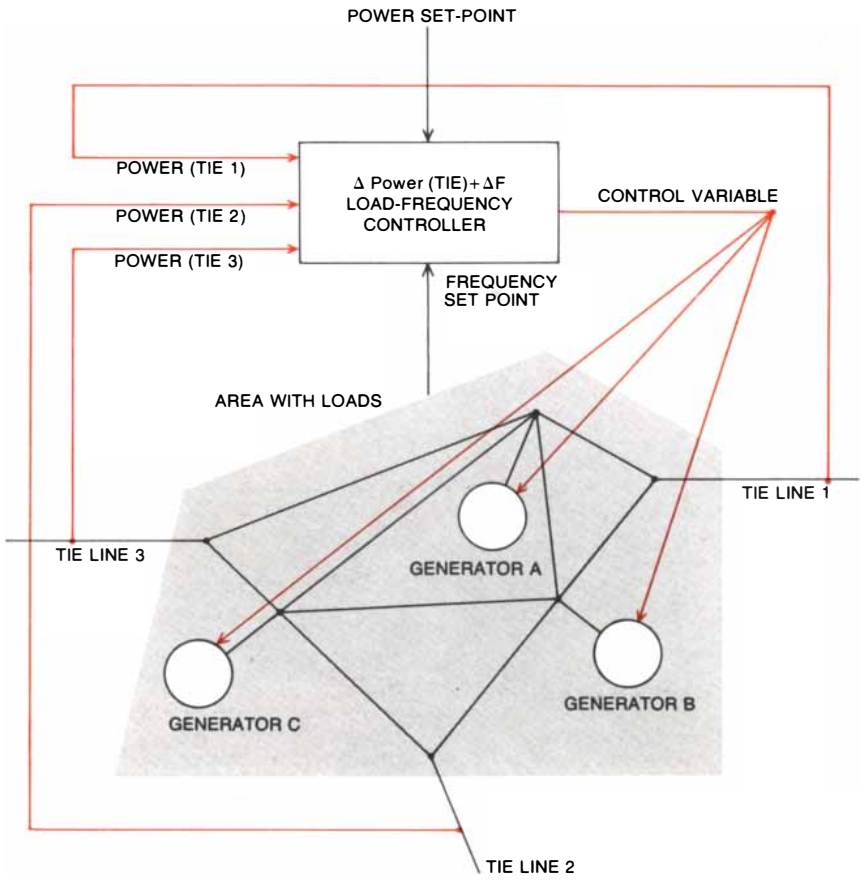
Once the variables that determine the state of the system have been calculated, a wealth of dependent quantities can be derived. The complex nodal voltages represent the state variables; line flows, nodal inputs, losses and currents are the derived quantities. Once the state variables and derived variables have been subjected to state estimation and verified they are stored in the computer for further use.

The data base, supplemented by less critical items of information (such as the upper and lower loading limits of lines, transformers and cables), can be assembled to establish a "replica" of the power system inside the computer. The next function of the computer is to present the salient features of the replica to the operators in the central control room. The presentation is on two levels: the essentials of the network and certain "global" quantities are shown on a large mimic board, and a wide spectrum of specific displays can be called up on demand to the screens of cathode ray tubes [*see illustrations on pages 35 and 36*].

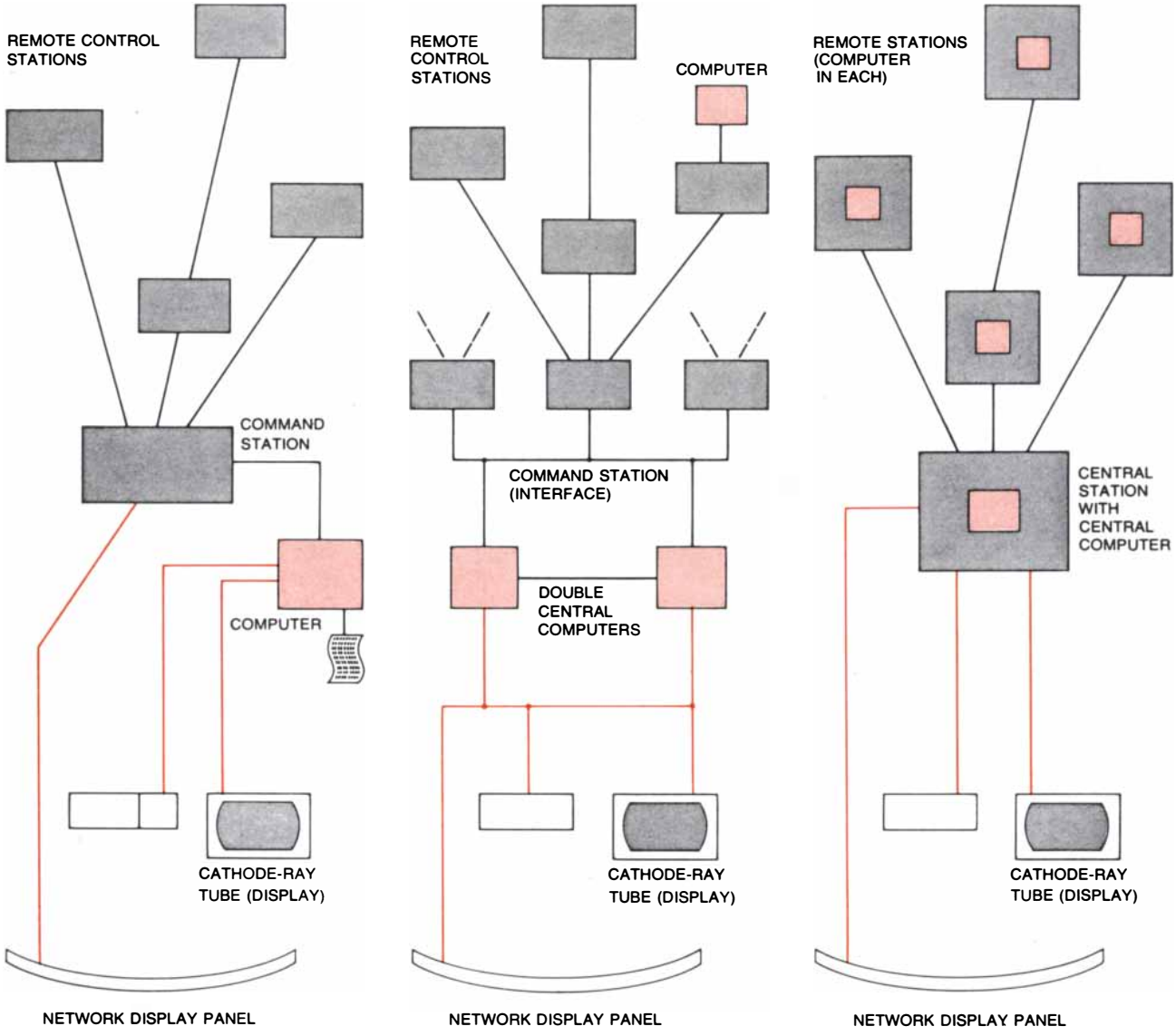
One class of cathode-ray-tube displays includes structural diagrams of portions of the power network, voltage profiles and the line flows in megawatts and megavars (volt-amperes reactive). Auxiliary tables are available to help the operator find a particular piece of information. Another class of displays is generated automatically when something requires the operator's immediate attention. These displays are alarm tables in alphanumeric code that tell what has happened or where intervention is needed. Since not all disturbances are of equal concern, the items are keyed with respect to urgency so that the operator can assign them a priority for treatment. A complete record is kept of all events, and a hard copy of the record is available on demand.

In peak-load periods a dispatcher is required to make about 20 decisions an hour, most of which will involve some physical alteration in the system. For example, the dispatcher may start up or shut down a generating unit, raise or lower the output of a generator, change the voltage in a node of the network or initiate a switching operation.

Here is how the computer would support the operator in a switching operation. First he would call for a display showing a structural diagram of the



AREA CONTROL SCHEME maintains the power flows and frequencies of all tie lines entering or leaving the area at a predetermined value. The power flows and frequencies on each tie line are monitored and the deviations are fed into a load-frequency controller. The controller generates a corrective signal that is distributed to the various generating units. In order for the concept to work all neighboring areas must use a similar scheme.



TRENDS IN COMPUTER INTEGRATION in the control of power systems are represented in three diagrams. In the first stage (*left*) the conventional telemetry system was connected to a computer that did some logging and display of data. In the second stage (*middle*) small computers were sometimes added in the remote stations for data processing. At the central station a large computer system (usually doubled for reliability) was given the task of processing the incoming data from the telemetry system and of displaying the results. In the final and current stage (*right*) computers have been integrated into the telemetry system at all levels. At the central station there may be more than one large computer for on-line data processing, display and overall control.

actual state of the system. He would then check displays indicating the load flow and the situation in regard to reserves. Let us suppose he wants to take a transformer out of service, which involves opening two circuit breakers and operating several disconnect switches. He proceeds by identifying the transformer and other elements on the display screen, either by manipulating a stick control in a ball socket, which moves a marker on the screen, or by placing a light pen directly against the symbol of the selected element. He can also type in specific information about the proposed switching operation by using functional and numeric keys on a keyboard. This operation is protected so that he cannot type in alphanumeric words that would give rise to errors or repetitions.

The information system reacts by flashing the symbol of the chosen element or by changing its color. This is proof that the operator has selected the correct component. Next he identifies the desired operation. The computer responds by checking to see if the operation is feasible. It may perform both logic checks and security checks. For example, if the operator wants to open a circuit breaker that is already open, the computer will write a message to that effect on the screen. A security check will consist in computing the consequences of opening the circuit breaker, assuming the network is to remain in service. If the proposed action would overload a neighboring component in the system, a warning will appear on the screen. Such a security check is already a fairly complex computing operation, involving the calculation of one or more load flows. Calculating a load flow is a standard analytic technique when it is

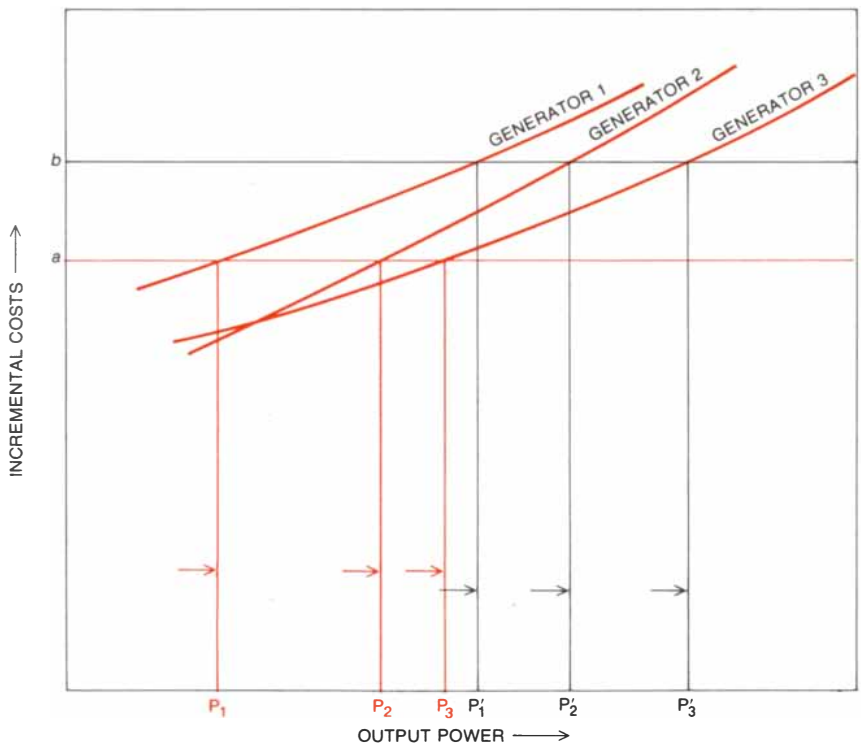
done off line, but it must be specially modified when it is done as part of an on-line control sequence.

If the computer approves the desired operation, it will produce an appropriate acknowledgement. Only then can the operator press the "Execute" button. The operation will be effectuated by the computer, using a series of programmed commands to the circuit breaker and to the associated disconnect switches. The successful end of the operation will be indicated on the display screen, logged in the daily shift records and placed on file in the computer.

The economic allocation of generating capacity is another function that is readily handled by computer. An algorithm for the performance of this task is feasible only if the power system is in a steady state. Under typical conditions the algorithm will make new allocations in power production between three and 30 times per hour.

The objective of the algorithm is to minimize the total cost of producing power. If the costs of operating individual units as functions of the output power are known, the minimum total figure will be achieved if an additional load is distributed so that the incremental outputs of each unit have an equal cost [*see illustration below*]. Once the computer has calculated how an additional load should be distributed for maximum economy, the result is expressed through the load-frequency control scheme I have described here. Today, however, the control of load frequency is also handled by the central computer by means of a suitable algorithm. It will be recalled that the load-frequency controller provides a direct means for adjusting the output of individual generating units.

Another group of algorithms are designed to assist the operating staff in evaluating the security of the system. In power-system terminology security refers to the ability of the system to withstand a certain set of disturbances at a given time. Since the definition of "security" can vary from one dispatcher to another it cannot be tackled by a single algorithm. Security consists, rather, of activities that proceed both with and without the operator's participation.



ECONOMIC DISPATCHING OF POWER can be achieved by calculating incremental cost curves for each generator in a system. The minimum overall production cost is realized when the generating units are operated in such a way that the incremental power obtained from each unit has the same cost. The minimum-cost operating point is easily found by moving a horizontal line up and down along the cost curves until the sum of the generated powers matches the sum of the loads. In the example shown, in going from total output power P_3 to P'_3, the least cost is achieved when generators No. 1 and No. 3 pick up most of the incremental load. Computers can make new load allocations up to 30 times per hour.

A primary requirement is security assessment, that is, determining the minute-by-minute security of the system. In conducting this analytic activity the computer control system functions in two ways. First, the computer displays, automatically and on demand, all the pertinent variables, such as excess loadings, drops in voltage and fluctuations in frequency. Second, the computer can be used to simulate a disturbance for the existing load condition. For example, it might show what would happen if a heavily loaded line were to fail.

For this "contingency checking" special load-flow algorithms are employed. The contingency check may be initiated by the operator, by an event in the power system or by a command that is part of an automatic cyclic routine. If the simulation should reveal that an overload might occur as a result of the assumed disturbance, the computer will display a message warning the operator that the system is in a vulnerable state.

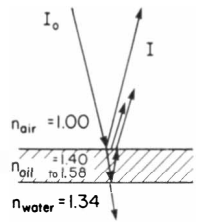
Drawing on his experience, the operator may decide that the load will probably drop or that his "spinning" reserve (provided by a generator on line but unloaded) will increase within a short period or that the risk of incurring the contingency is very low. If he should conclude, on the other hand, that the situation is serious, he must take appropriate action to increase the system's security. If an actual disturbance has thrown the system into an insecure state (for example if a generator has failed), a swift rearrangement of the power flow becomes necessary. This can be initiated by the operator, after alarms have brought the situation to his attention, or by a preprogrammed sequence on the computer.

Considerable effort is being made to improve the security of power systems. In the analytic phase it would be desirable to have faster algorithms to assess the state of security in less time than it now takes. To this end computer specialists are studying not only new load-flow routines but also techniques for recognizing critical patterns. In the control phase one would like to have the computer aid in the search for solutions to problems of maintaining power flow when a vulnerable situation has been encountered. The aim of various new techniques is to support the operator in his task of maintaining a secure system and to develop fully automatic security routines. One of the outstanding problems is to define security in a quantitative and functional form that will lend itself to treatment by computer.

Oil on the water

Visually it was not detectable. But you don't need special film. We used ordinary KODAK PLUS-X AEROGRAPHIC Film 2402 (ESTAR Base) with an ordinary KODAK WRATTEN Filter, No. 39. The camera lens should transmit down to about 340 nm. Some do, some don't.

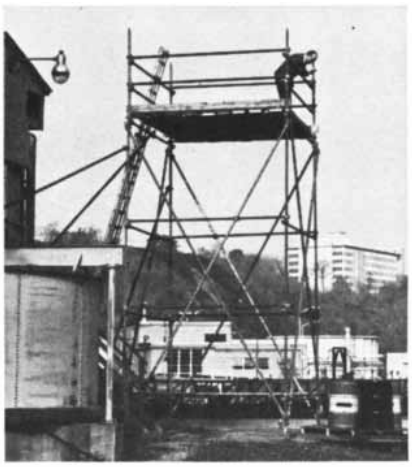
It was only a few gallons of diesel fuel that got away from someone up the Genesee River. The Coast Guard had declared it properly cleaned up, and indeed it was. No tale of horror, no villain. The oil-on-troubled-waters bit did not apply. To create a conspicuous oil slick that smooths the ripples requires a certain deplorable thickness. Far less thickness is required for this

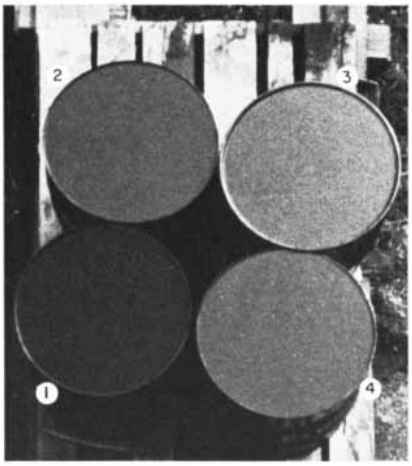


Normal reflectance from an oil-free water surface runs around 2%; from an oil surface of refractive index 1.44, around 3%. If the oil layer contains heavier components at its bottom, reflectance from the second surface could run as high as 0.7%. Fluorescence from benzenoid components in the oil, added to the reflections from the two surfaces, can bring up the return radiance to 4% of incident, if viewed at the right wavelengths. That's twice as much as from oil-free water.

And there we are, well within the ability of conventional photography to discriminate.

And there it was, slipping into Lake Ontario past the river mouth, not long after we had completed some studies with a set of internally blackened drums of river water bearing (1) nothing, (2) diesel fuel, (3) gasoline, (4) spent lubricating oil:





We have some indication that plots of density difference between oil and no-oil as a function of solar angle are characteristic of the kind of oil, but we are not sure enough to blow bugles (or whistles). We are, after all, only photo technologists. Other technologists who want to try confirming, denying, or extending are invited to correspond with E. G. Tibbils, Technical Photography Markets, Kodak, Rochester, N. Y. 14650.

Not all oil on water is of man's doing. Sometimes it might just encourage man to start probing around.

Kodak

Jonathan Livingston

BUICK SKYLARK S/R. From the very beginning, the automobile has been a supreme source of individual freedom.

And while the automobile may have changed with the years, the exhilaration it provides—of having exchanged the surly bonds of the immediate for what lies beyond the next hill—is the same.

We are all free at heart; all we really need is the means to express the fact.

And with that somewhat prosaic introduction, we offer you Buick Skylark.

Or, in this case, Buick Skylark S/R. A craft of amazing versatility.

In all, Skylark S/R is quite a tourer. Powered by a 3.8 liter V-6 engine—a Buick design that actually shares more

GM

MARK OF EXCELLENCE

Automobile.

in common with a V-8 than with a conventional Straight-6. Radial shod. And borne along by special firm-ride springs and shock absorbers.

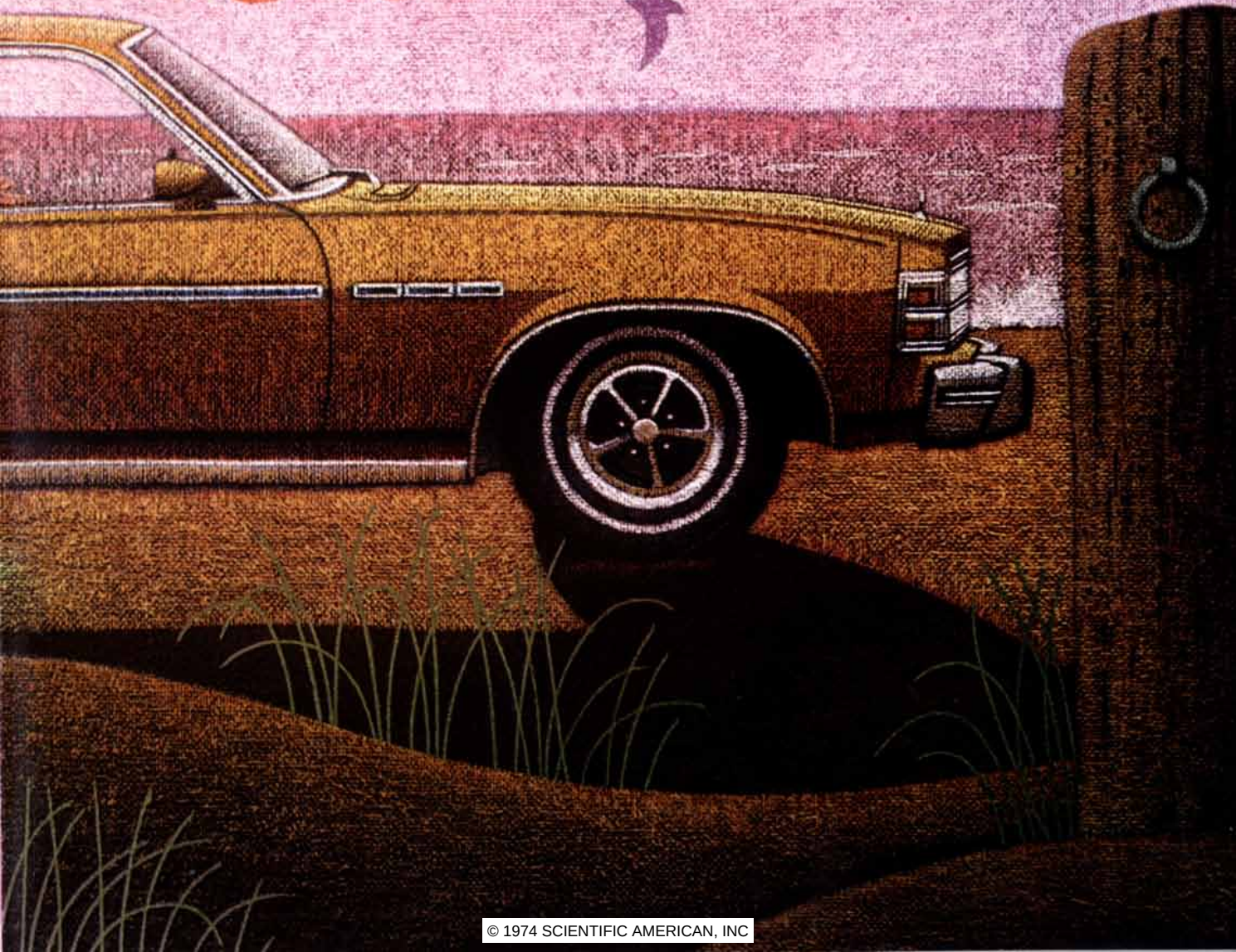
As a matter of fact, the interior looks like it came right out of an expensive European touring car. Corduroy bucket seats and all.

Moreover, Skylark is a real buddy—a docile, dependable, business-like conveyance that unflaggingly shoulders all sorts of errands and loads, despite its sporty demeanor.

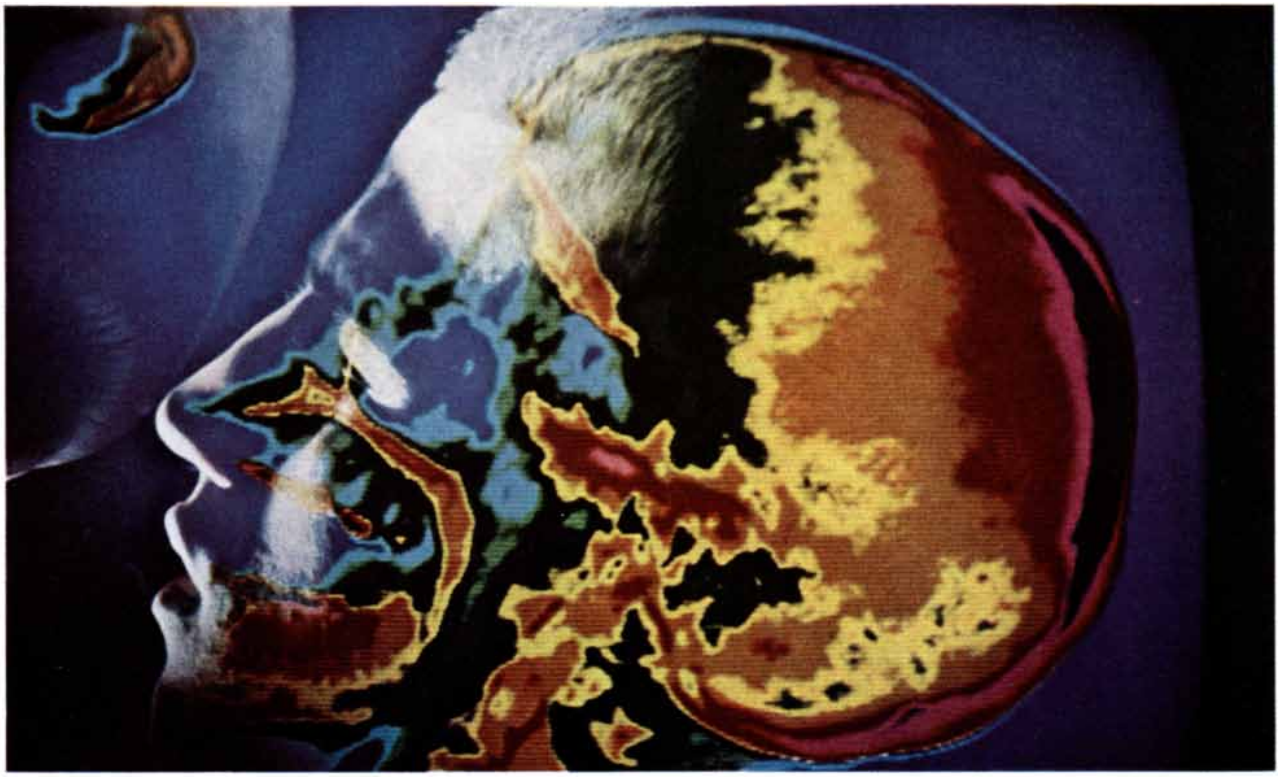
Come on now, life was meant to be explored. Why not do it with a companion of real capability?

Skylark is at your Buick dealer.

BUICK *Dedicated to the Free Spirit in just about everyone.*



Why jump into a specialized field until you've studied all the possibilities?



If you're a new physician, you might not have decided on a field of specialization yet. That's easy to understand. But while you're deciding, you can be getting valuable experience and expert guidance towards that decision as a physician in the U.S. Air Force. Air Force physicians are exposed to many fields of medicine. They practice with highly professional people in modern facilities. And all Air Force physicians have seemingly unlimited opportunities for furthering their education and professional growth. Air Force graduate medical education programs are available. And because Air Force physicians participate in Group Practice (a collection of specialists in different fields complementing each other by expanding total capability) they all expand their individual ability and horizons with each new patient.

As an Air Force physician (and officer) you can apply for worldwide work assignments. The salary is excellent. And you get a 30-day paid vacation each and every year.

If you're still deciding on a medical specialty...or a future...look into the Air Force before you make a final decision. We think you'll like what you see. For more detailed information about Air Force opportunities in medicine please fill out and mail the coupon.

C-SA-114

Air Force Opportunities
P.O. Box AF
Peoria, IL 61614

Please send me more information on the Air Force Physician Program. I understand there is no obligation.

Name _____ Sex ☐ M ☐ F
(Please Print)

Address _____

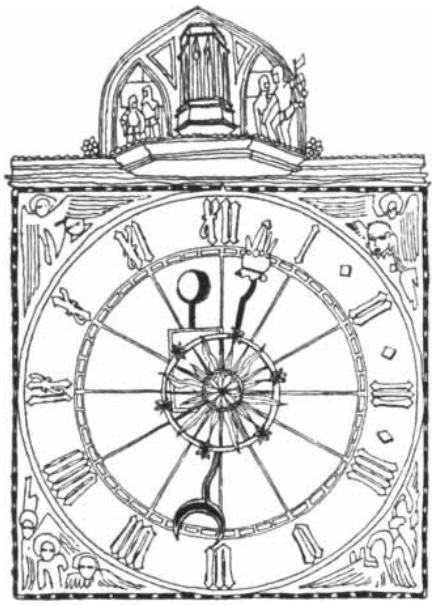
City _____

State _____ Zip _____ Phone _____

Soc. Sec. # _____ Date of Birth _____

Health Care at its best.
Air Force.

SCIENCE AND THE CITIZEN



Population? Development!

Several messages emanated clearly from the United Nations World Population Conference in Bucharest. The problem is not population growth as such; it is development. Population is a factor in development, but so is international economic equity. Where the rate of growth is too high it can and should be reduced soon—but only on the decision of the country involved, with due regard to the international implications and with international cooperation and assistance.

The opening paragraph of the "plan of action" adopted by consensus by the delegates of 136 governments emphasized that "the basis for an effective solution of population problems is, above all, socioeconomic transformation." That idea is recurrent in the document: high fertility rates cannot be lowered by the mere provision of family-planning information and materials; declines in birth rates and family size are associated with development and modernization, processes that the international community, and the developed countries in particular, urgently need to promote in the underdeveloped parts of the world. Population, moreover, is not the critical source of pressure on the earth's resources and environment. It is consumption that matters, whether by large populations of poor countries or by high per capita consumption and waste in the rich countries. "It is imperative that all countries, and within them all social sectors, should adapt themselves to more rational utilization of natural resources, without excess, so that some are not deprived of what others waste."

Equally firm language was addressed to the subject of reduction of mortality rates: "Countries with the highest mortality levels should aim by 1985 to have an expectation of life at birth of at least 50 years and an infant mortality rate of less than 120 per thousand live births," with "particularly vigorous efforts" to reduce infant and maternal mortality. No such specific language was addressed to fertility control, however. "Countries which consider their birth rates detrimental to their national purposes are invited to consider setting quantitative goals and implementing policies that may lead to the attainment of such goals by 1985." The primary reason for vagueness on fertility control appears to have been a highly sensitive defense of national sovereignty, a refusal to have outsiders set targets for population and dates for attaining them, or optimum family sizes; there were, in addition, some specific pronatalist feeling and religious opposition to contraception.

If the plan of action was not a clarion call for worldwide birth control, it was nevertheless far from being against fertility regulation. It recommended that all countries ensure "the right of persons to determine, in a free, informed and responsible manner, the number and spacing of their children" and that all countries encourage education concerning responsible parenthood "and make available to persons who so desire advice and means of achieving it." It laid down some guidelines for family-planning services and their relation to other health services and called for research in a number of specific areas. It recognized that "trends of population growth... can... create additional difficulties" for development. It pointed out that fertility rates have not declined in parallel with mortality rates and that the consequent 2 percent rate of worldwide population growth would, if sustained, double the population in 35 years. It stated that the rate of growth can—and implied that it should—be cut to about 1.7 percent by 1985; this would require a reduction of the birth rate in the underdeveloped countries from 38 to 30 per 1,000, which would necessitate "substantial national efforts." It recognized that the population policies of individual countries have effects on other countries and called for international cooperation and for "considerable expansion of international assistance in the population field."

In broader perspective the population conference marked the entry into the international political arena of issues that have hitherto been attended to largely by specialists. The same transition took place for environmental concerns at the Stockholm conference in 1972 and will take place for issues of food supply and distribution at the World Conference on Food in Rome this month. Political conferences rarely produce the tidy results that specialists prefer, but the transition to the political level is essential if widespread action is to be undertaken. The population conference itself, with its exposure and high-level consideration of complex and sensitive issues, is considered to have been a valuable first step. Moreover, it seems likely that many underdeveloped nations, having succeeded in anchoring population in a context of economic development and social justice, will now be more ready to take steps to limit population growth where necessary.

Collagen-Cutter

Collagen is a helical protein molecule that accounts for nearly 40 percent of all the protein in the human body. Collagen fibers form the fabric of tissues such as the skin, ligaments, tendons and blood vessels, and it is the major constituent of cartilage, bone and the cornea. It has long been believed there are enzymes that degrade collagen, but it was not until 1962 that the first such enzyme was discovered in the tail of the tadpole. Since then many different collagenases have been found in man and other mammals. According to Edward D. Harris, Jr., of the Dartmouth College Hitchcock Medical Center and Stephen M. Krane of the Harvard Medical School, writing in *The New England Journal of Medicine,* it appears that an increased production of collagenase may be responsible for some of the symptoms of diseases such as rheumatoid arthritis, corneal ulcer and skin cancer.

It is not yet known if the same cell that synthesizes collagen can manufacture the enzymes that degrade it. There

is evidence, however, that there are distinctly different collagenases in different tissues and that each collagenase is produced by cells in the immediate region of its activity. Collagenase cleaves through the three chains of the collagen helix at a specific locus. If the cleaved molecule is not cross-linked to other molecules, it immediately dissolves in the extracellular fluid and is thermally denatured into gelatin. Other enzymes or phagocytes then degrade the gelatin. If the collagen molecules are cross-linked, it is thought that successive cleavages of adjoining chains will eventually split a fragment from the collagen fiber, which is then degraded by phagocytes.

Collagenase obtained from the fluid of the synovial membrane around joints is capable of degrading cartilage molecules in solution. Measurements of collagenase in patients with different kinds of arthritis suggest that collagenase production is related more to the degree of inflammation than to a specific pathology. In normal skin little collagenase is produced by the epidermis; most of the enzyme is synthesized by the upper dermis. When the skin is injured, however, the epidermis manufactures large quantities of collagenase, which are required to resorb the collagen around the wound edges as healing progresses.

Collagenase plays an important role in the growth and remodeling of bone in adults. It also is involved in the loss of bone and the destruction of connective tissue around the teeth in periodontal disease. Large amounts of collagenase have been extracted from malignant tumors growing in muscle, but it is not known whether the enzyme originates in the tumor or in other cells reacting to the tumor. Collagenase has also been found in the cells of various kinds of skin cancer.

Harris and Krane note that considerable progress has been made in understanding the mechanisms of collagen breakdown. With detailed study of the activity of specific collagenases, they suggest, control of many diseases of the connective tissue might be more readily accomplished.

Fair Test

Most medical care in the U.S. is based on the principle that one goes to a physician when one is ill and that a fee is paid for the specific service rendered by the physician. In recent years medical care in a few parts of the country has been organized on a different principle: the health-maintenance organization, which in return for an annual fee from the subscriber undertakes not only to treat his illnesses but also to try to keep him well by regular attention to the state of his health. Although the various health-maintenance organizations collectively enroll a considerable number of people, the concept has had to struggle against tradition and legal restrictions and therefore has not gained a substantial foothold in the delivery of medical care. A committee of the Institute of Medicine of the National Academy of Sciences has studied the situation and has concluded that "the HMO concept deserves the opportunity to prove itself in what we have chosen to describe as a 'fair market test.'" The committee, whose 10 members are from a variety of disciplines, recommended a number of governmental actions that, it said, "can considerably reduce the obstacles that presently hinder HMO development, leaving HMOs, individually and generically, to succeed or fail on the basis of their performance."

At present, the committee found, "a fair market test of the HMO concept is impossible to obtain... because numerous legal, financial, practical and other difficulties have impaired the ability of HMOs to enter the market or compete on equal terms." Citing a number of these obstacles, the committee provided in each case a recommendation for dealing with the problem. A legal obstacle noted by the committee is that "a number of states have enabling acts for Blue Cross and Blue Shield plans that exclude virtually all types of HMOs." The committee recommended that the states amend these laws and that Congress pass a Federal law overriding restrictive state laws so that state legislatures will be encouraged to adopt enabling acts "consistent with the committee's recommendation that HMOs be given a fair market test." The committee found in addition that many states also have laws or court decisions directed against the "corporate practice of medicine." It recommended that "profit-oriented HMOs be permitted to enter the health care marketplace."

Under the heading of professional obstacles the committee noted that medical education tends "to emphasize acute episodic care of complex disease problems to the detriment of sufficient attention to the health maintenance and personal problems of the whole patient over a period of time." These attitudes must be changed "before a physician can perform effectively in an HMO environment." Noting the difficulty that HMO physicians often have in obtaining hospital-staff appointments, the committee recommended the employment of "all available means" to assure such physicians of equal treatment.

Governments can also assist health-maintenance organizations in meeting their needs for capital, in enrolling members and in advertising their services, the committee said. "A fair market test of the HMO concept," the committee concluded, "would do more to improve the functioning of the American health care delivery system than any other policy step which could be taken in the near future. Benefits of HMO development would accrue not only to those consumers who chose to enroll in HMOs but to other consumers as well, for the HMO has demonstrated a capacity to stimulate desirable changes and increased efficiency in the entire health care system."

Spatial Relativity

An attribute known as "spatial ability," loosely defined by psychologists as skill in dealing with the relations of objects in a spatial context, is a cognitive characteristic that can be assessed by means of specially designed tests. Because it is an aptitude of obvious usefulness to the readers of blueprints or the operators of machines, this ability has been tested for half a century. The tests have generally been given to men, even though such stereotyped female roles as working from dress patterns or interior decoration involve the same cognitive skill. When both males and females were tested, the findings that implied a superior male performance were the ones that endured in the technical literature of psychology. A high-water mark for the hypothesis may have been the declaration in 1965 by Leona E. Tyler, a psychometrist at the University of Oregon, that "males are clearly superior on tests of mathematical reasoning, spatial relationships and science."

Not long ago the hypothesis attracted the attention of Jerome Kagan, a Harvard University psychologist concerned with child development, and Ann Karnovsky, then one of Kagan's graduate students. Just when during maturation, they wondered, did this supposed male superiority first become evident? To what extent were the reported test results representative? Were the inferior female performances possibly attributable to the subject content of existing tests? Karnovsky designed a simple test of spatial ability and, with the cooperation of local school authorities, supervised the testing of 222 boys and 223 girls in the first, second, third and fourth grades in Lexington, Mass., and the sev-

enth grade in Newton, Mass. The test required selecting from among four rotated figures the one figure identical with a specific sample figure presented to the child at the same time. Two of the four possible choices were wrong because they differed in detail from the sample figure; the other wrong figure was a mirror image of the sample.

The tests were conducted by the children's arithmetic or mathematics teachers during regular classes. To test the influence of subject content two kinds of figures were presented: simple geometric shapes and outline drawings of such common objects as a dog, a bicycle or a house. Following display of three practice figures the child was asked to solve 12 "problems" of each kind. For every group of a given age that was first tested with drawings a matching group was first tested with shapes.

The investigators found no sex difference in test results based on either drawings or shapes, with one exception. In the low-ability and medium-ability division of the Newton seventh-grade mathematics class, although not in the high-ability division, the boys' performance was significantly superior to the girls'. Karnovsky and Kagan conclude that the accepted hypothesis of an intrinsic sex difference in spatial ability is invalid and that males and females are potentially of equal competence in this respect. The lower scores of some seventh-grade girls Karnovsky attributes to the effect of cultural conditioning. The competitive atmosphere, she suggests, adversely affects adolescent girls "who are already in some conflict about the compatibility of competition and femininity."

NxP!

The first world computer chess championship was recently won in Stockholm by a Russian program called Kaissa, with four victories and no defeats. Three programs, two from the U.S. and one from Canada, each lost one of its four games, creating a three-way tie for second place. The tie was broken on the basis of the fewest total moves and a play-off game, with the result that second place was awarded to the four-time U.S. national champion, Chess 4.0 from Northwestern University. Third place went to Ribbit, the Canadian champion from the University of Waterloo, and fourth place to Chaos, written by programmers at Sperry Univac. The other U.S. programs, Ostrich from Columbia University and Tech II from the Massachusetts Institute of Technology, respectively ended up in fifth place and

sixth place. There were 13 entries from eight countries, including Austria, Hungary, Norway, Switzerland and Britain. The Stockholm event was held in conjunction with the triennial congress of the International Federation for Information Processing (IFIP).

Until the last minute it was not certain there would be an entry from the U.S.S.R. because the Institute of Control Science in Moscow, believed to have the leading Russian chess program, reported that it lacked the money to send a participant (human). The money was raised privately, enabling the U.S.S.R. to be represented by 26-year-old Mikhail Donskoy, who said he had been working full time on Kaissa for about two and a half years with several part-time assistants. Kaissa is evidently descended from a program that easily defeated a Stanford University program in 1966, the only previous encounter over the chessboard between American and Russian computers. The moves in the Stockholm tournament were relayed to Moscow over an open telephone line, where the Kaissa program was implemented on a British-made computer, an ICL 4/70, comparable to an IBM 360/65. Only two computers (a Data General Nova 840 and a Hewlett-Packard 2100) were actually at the site of the tournament, the Birger Jarl Hotel; the rest, much larger, were linked by teletype and telephone.

Kaissa's margin of victory was a narrow one. During the four-round Swiss tournament, in which winners in each round were paired with other winners and losers with losers, Kaissa defeated a program called Frantz from the Rechenzentrum Graz in Austria in 34 moves in the first round, Tech II in 33 moves in the second round, Chaos in 36 moves in the third round and Ostrich in 67 moves in the fourth round.

Kaissa's matches with Chaos and Ostrich had some exciting moments. Chaos entered the Kaissa match fresh from its victory over Chess 4.0, previously undefeated in machine competition. Kaissa, with the white pieces, opened with P-K4 and Chaos replied with a Sicilian Defense (P-QB4). Both programs followed a standard "book" opening, recorded in the capacious memories of their computers, for seven full moves. Through move No. 13 Chaos appeared to have the upper hand and merely had to castle routinely on move No. 14 to whisk its king out of harm's way. Instead, to the consternation of one of its programmers, Joseph Winograd (who was sitting at a Univac computer at Bergen in Norway to which Kaissa's moves were being relayed), Chaos not only failed to castle but instead advanced its king to the second rank (Q-K2), toward unknown perils in the center of the board. After that the game was no contest, and Kaissa eventually mated Chaos' king on the 36th move.

Later that evening Winograd returned to his computer and reentered the board position as it had stood after Kaissa's move No. 14 to learn why Chaos had blundered. This time Chaos prudently castled to the queen side, the preferred side under the circumstances. The blunder during the match was the result of a complex interaction between Chaos' time-control logic and a last-minute modification in its program, which ironically had been designed to enhance the king's security. On the rerun Chaos made the right move because the time-control parameters were slightly different from what they had been during the match.

In the final-round match between Ostrich and Kaissa, Ostrich opened with the "hypermodern" N-KB3, popularized 50 years ago by Richard Reti. Several book moves followed quickly. Ostrich then made some uninspired moves that weakened its pawn structure, but Kaissa failed to capitalize on them. On move No. 21 Ostrich sharply forked Kaissa's queen and rook with its knight.

In order to save its queen Kaissa had to lose a major piece (a rook), gaining only a minor piece (a knight) in return. Fourteen moves later Ostrich had a forced mate, which was pointed out to the excited audience by David Levy, the British international master who served as tournament director and commentator. (Levy has wagered £1,000 that no computer program will be able to beat him in a match by 1978.) Unfortunately the forced mate was too deep (seven and a half moves) for Ostrich to "see" in its analysis; the mate required the sacrifice of a rook. Ostrich missed another deep forced mate on move No. 39 and eventually lost the game. Ostrich was developed at Columbia by Monroe M. Newborn and George Arnold.

Since the tournament failed to bring Kaissa and the U.S. champion, Chess 4.0, together, a special exhibition was arranged. At the end of 65 moves, with Chess 4.0 holding only a rook against Kaissa's rook and knight, the match was declared a draw. In the view of U.S. participants Kaissa's program is a careful piece of work, exhibiting sound tactical play. Throughout the tournament it avoided many of the typical blunders to which computers are prone. Kaissa also incorporates a feature not found in any of the other Stockholm entries: it "thinks" (continues to compute and analyze the position) on its opponent's time, with the result that it often responded in seconds when its opponent made a move it had anticipated.

If a brilliancy prize had been awarded, it would surely have gone to Chaos for its second-round victory over the previously undefeated Chess 4.0. Chaos is programmed to open with P-Q4 [*see illustration on this page*], which sets up

CHESS 4.0 / BLACK

CHAOS / WHITE

POSITION BEFORE 16 NxP!

QUEEN'S GAMBIT ACCEPTED

	WHITE CHAOS	BLACK CHESS 4.0		WHITE CHAOS	BLACK CHESS 4.0
1	P-Q4	P-Q4	16	NxP!	PxN
2	P-QB4	PxP	17	QxPch	B-K2
3	N-KB3	N-KB3	18	R-K1	Q-Q1
4	P-K3	P-K3	19	B-KB4!	K-B1
5	BxP	P-B4	20	QR-Q1	R-R2
6	Q-K2	P-QR3	21	R-QB1?!	N-KN1
7	O-O	P-QN4	22	QR-Q1	P-QR4
8	B-N3	B-N2	23	B-Q6	BxB
9	R-Q1	QN-Q2	24	QxBch	N-K2
10	N-B3	B-Q3	25	N-B5	B-B4
11	P-K4	PxP	26	P-N4	Q-K1
12	NxQP	Q-N1	27	B-R4	P-N6
13	P-N3	P-N5	28	PxB	PxP
14	N-R4	BxKP	29	BxN	P-R8=Q
15	P-B3	B-N3	30	RxQ	R-R3

(WHITE'S WIN ASSURED)

Board position and moves in computer chess

Only one cassette deck stacks up with the best components.

Pioneer's new CT-7171 cassette deck with built-in Dolby, is undoubtedly the most extraordinary instrument of its type. Its sound reproduction is so exceptional that it not only eclipses the performance of other cassette decks, but it rivals the finest open-reel units.

To complement this remarkable performance, Pioneer has designed the CT-7171 with an important difference. All controls are up front so you can stack other components directly on top of it and beneath it. Even the illuminated cassette compartment is front loading, for easy access and visibility.

Performance features stack up, too. The CT-7171's illuminated VU meters, combined with a peak level indicator, refuse to let you over-record. A light emitting diode glows instantly when the signal peak level is too high. Then, to prevent "clipping" distortion, a studio-type switchable Level Limiter handles those unpredictable program source peaks.

No matter what type of tape you use — standard, low noise or chromium dioxide — the CT-7171 delivers optimum recording and playback with an assist from bias and equalization switches. With the new Ferrichrome tape, this unit performs beyond the limits of credibility.

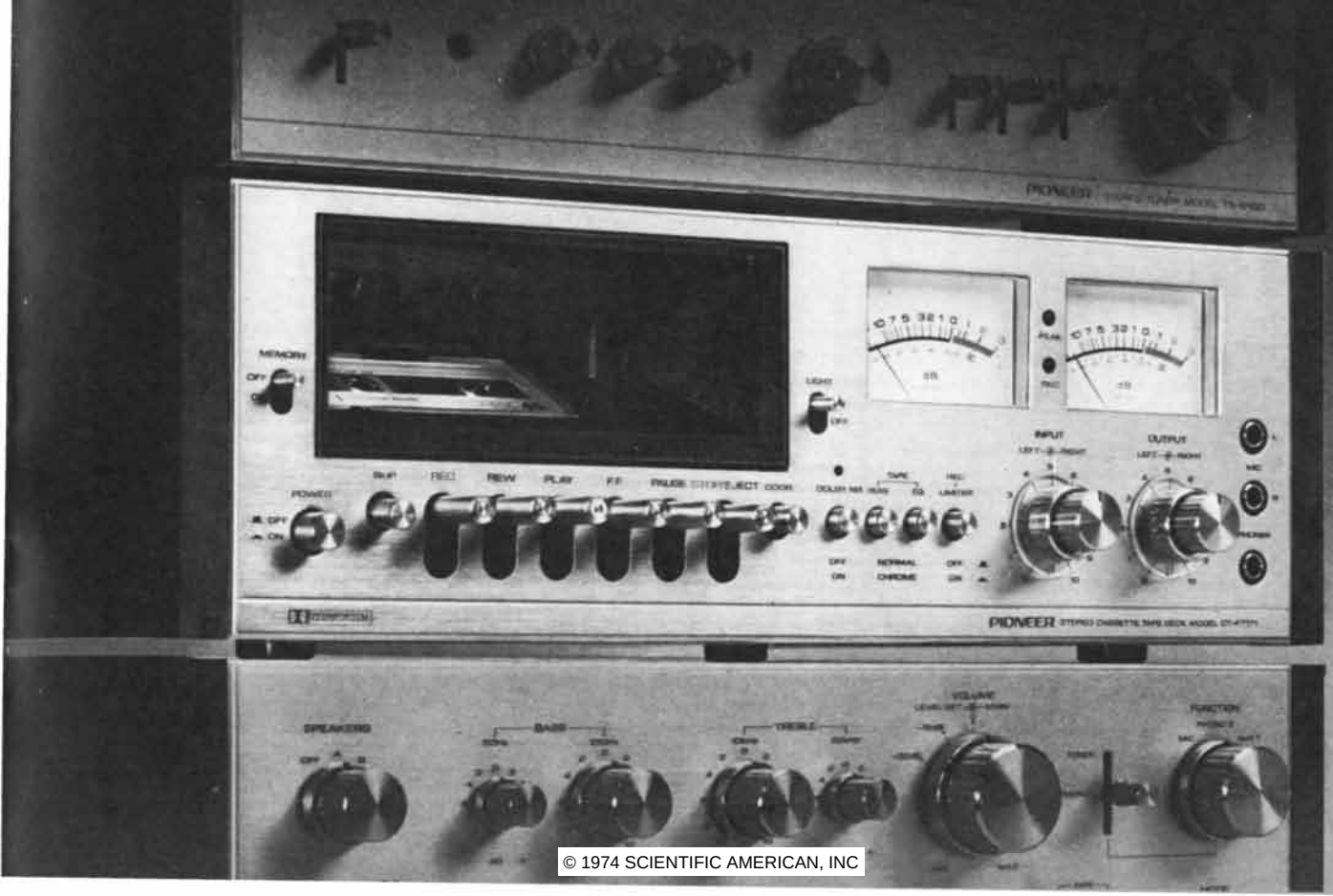
Precision cueing has never been easier than it is with the CT-7171. You can actually pinpoint a recorded passage on a cassette with the combination of a memory rewind switch, the 3-digit tape counter and an exclusive Skip button that lets you monitor audibly at accelerated speed.

The CT-7171 also highlights an electronically controlled DC servo motor, two solid ferrite heads, automatic tape-end stop, dual concentric level controls, separate mic/line inputs, pause control, plus many other features to make it the most sophisticated cassette deck yet produced.

Because of its convenience, price and performance, the CT-7171 virtually obsoletes the 7-inch open-reel deck. And at $369.95, it's an unexcelled value for studio-quality reliability, design and versatility.

U.S. Pioneer Electronics Corp., 75 Oxford Drive, Moonachie, New Jersey 07074
West: 13300 S. Estrella, Los Angeles 90248 / Midwest: 1500 Greenleaf, Elk Grove Village, Ill. 60007 / Canada: S. H. Parker Co.

PIONEER®
when you want something better



the well-known queen's gambit: the opponent can either accept the gambit (by taking the pawn) or reject it. Chess 4.0 accepted the gambit, leading to a rapid-fire exchange of book moves (following a game played in the Russian championships in 1961). After Chaos' book move No. 13 (P-N3) Chess 4.0, having exhausted its memory of the 1961 game, went off on its own with P-N5. Since it had accumulated a large reserve of time, Chaos spent seven minutes deciding on move No. 14, three and a half minutes on No. 15 and nearly 10 minutes on No. 16 (NxP).

When Chaos made this move, in which it sacrificed a knight to win two pawns, Levy, like others in the audience, thought it was a typical questionable computer move, if not an outright blunder. In his written account of the match Levy now awards the move an exclamation point (NxP!) and observes: "This is the first ever example of a program making a positional piece sacrifice. The win is too deep for Chaos to have seen to the end of the combination—it gave up the piece on purely positional grounds." Well before move No. 30 black's position was shattered. Chaos, however, played a poor end game and did not succeed in mating Chess 4.0 until move No. 79. The Chaos program was developed evenings and weekends over a two-year period by Winograd, Ira Ruben, Fred Swartz, Victor Berman and William Toikka, all of Sperry Univac. The Chess 4.0 program, the latest version of a series initiated five years ago, was written at Northwestern by David J. Slate and Lawrence R. Atkin, with early help from Keith Gorlen.

Chekhov the Physician

Anton Chekhov is esteemed today for his plays, such as *The Seagull* and *The Cherry Orchard,* and for his stories, such as "The Duel." Another aspect of his life has been largely ignored: his work as a physician. There is reason to believe, from material that has only recently become accessible to English-speaking readers, that medicine and biology may have been as important to him as literature.

Chekhov received his medical training at the University of Moscow. He completed his studies in 1884, when he was 24, and was then entitled to practice as a "district physician." His doctoral degree was withheld pending the submission of a dissertation; planning to write on the history of medicine in Russia, Chekhov in the interim accepted a position with a provincial hospital. He never completed the dissertation and never received the degree.

Chekhov made no important contributions to medical science, but it appears that he was a physician of exemplary compassion and an opponent of superstition and irrationality in the treatment of disease. His example, if not his actual work, may well have been important in establishing medicine as a scientific enterprise in rural districts of 19th-century Russia.

In 1890, when he was already a well-known writer, Chekhov traveled across Siberia to the island of Sakhalin, where the government had established a penal colony. He spent three months on the island and took a census of its 10,000 inhabitants, giving special attention to the health of those he interviewed. His statistics on disease among the convicts eventually led to the improvement of their condition.

Two years later he organized a relief program during a famine, urging farmers not to slaughter their horses for food, since without horses the fields would not be plowed the following year and the famine would be prolonged. During a subsequent cholera epidemic he served without pay as the medical advisor to a district comprising "25 villages, four factories and a monastery." The treatment he recommended, which included hypodermic injections of a salt solution, was based on principles still followed in the control of the disease. On other occasions he argued for the humane treatment of venereal diseases, successfully campaigned to reduce the working day of miners from 12 to eight hours and supported the endowment of a marine biology laboratory on the Black Sea.

Recent interest in Chekhov's medical career has been stimulated by the publication of a collection of his letters, translated by Michael Henry Heim and annotated by Simon Karlinsky (*Letters of Anton Chekhov,* Harper & Row). Alexander Macdonald of the University of Aberdeen comments on the letters of medical and scientific interest in *The Journal of the American Medical Association.* Macdonald points out the importance of the ethical and humanitarian views expressed in Chekhov's fiction to his practice as a physician. Chekhov himself pointed out the influence of his scientific training on his literary work. The study of medicine, he wrote, "broadened the scope of my observations and enriched me with knowledge whose value for me as a writer only a doctor can appreciate."

Dodge is right on target with the '75 Dart Special Edition. It's a lot of luxury in a little car.

If you've found that a lot of small cars today are pretty small on comfort and style, then the '75 Dart Special Edition is the small car for you.

It has an array of standard features that are usually anything but standard. Seats covered with crushed velour upholstery. Plush carpeting on the floor, halfway up the door, and even in the trunk. Map pockets are standard. So are color-keyed wheel covers. And front disc brakes. And power steering. Even the radio is standard.

In other words, on the '75 Dart Special Edition, luxury comes as standard equipment.

And, as on all the '75 Darts, there are a lot of money-saving engineering features such as Electronic Ignition and electronic voltage regulator and, now for 1975, an optional fuel pacer that can help you save gas.

Today, over one million satisfied owners are already sold on Dart. The '75 Dart Special Edition is one beautiful way to make sure there'll be one million more.

CHRYSLER MOTORS CORPORATION

Extra care in engineering makes a difference in Dodge. Depend on it.

Dodge

Dodge Trucks

The Effects of Ice on Scotch

How fast a drink of Scotch whisky over rocks loses its flavor depends on the proof of the Scotch and the richness of its blend. These two factors are optimized for "on the rocks" Scotch drinkers in 90-Proof Famous Grouse, a venerable old brand from Scotland only recently introduced to America.

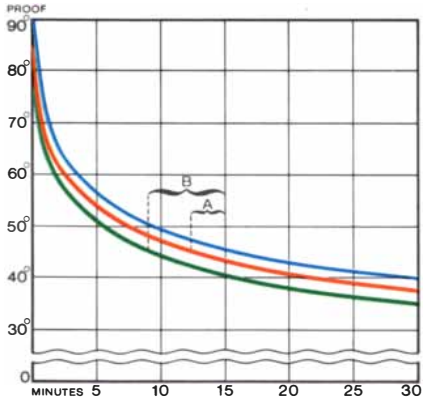
by Allen Mac Kenzie

In countries where Scotch has been consumed for centuries, ice and whisky rarely mingle. But on this side of the Atlantic, the picture is quite different. While a small percentage of American Scotch drinkers take it neat, better than 35% drink it "on the rocks." The rest of us add varying amounts of water, club soda, etcetera. And ice. Always plenty of ice—the great American drink requisite.

It would seem then that the American Scotch devotee, particularly our on-the-rocks fancier, has a right to raise a serious question: *Is the Scotch I drink ideally suited to enjoyment over ice?*

Pursuing a Perfect Proof

Let's turn our attention first to the proof at which Scotch whisky is bottled. Consider, if you will, the hypothesis that there is indeed a better proof for on-the-rocks Scotch drinking than that of the brand you currently favor.



DILUTION BY ICE OF SCOTCH AT THREE DIFFERENT PROOFS (72°F). 80 Proof 86.8 Proof 90 Proof Alcoholic content drops rapidly during the first minute whisky is chilled by ice, less rapidly after initial cooling. Interval A shows that 86.8 Proof Scotch dilutes to a proof of 46 approximately 2½ minutes earlier than 90 Proof *Famous Grouse*. Interval B shows that 80-Proof Scotch dilutes to 46 proof 6 minutes earlier.

Practically every Scotch sold in this country is bottled at 80, 86, or 86.8 Proof. So at the instant you pour your Scotch over ice, it contains between 40% and 43.4%

alcohol by volume. (Proof is double the percentage of alcohol.) The chilling effect of the ice is accompanied by dilution. And when your drink has been properly cooled by the ice—in 30 seconds' to a minute's time—you achieve what one Scotch connoisseur refers to as "the ideal sip." From that point on, the Scotch drinker's enjoyment typically runs downhill, as the drink loses its freshness.

While there is no way to preserve that fresh Scotch flavor indefinitely, we submit that you can sustain the freshness substantially longer with 90-Proof *Famous Grouse*. If you have never heard of this brand, we are not surprised. It is a well established name in Scotland, but has only recently been introduced to America. So far as we know, *Famous Grouse* is the only Scotch now available in this country at 90 Proof.

A Revealing Experiment

To demonstrate the merits of a slightly higher proof, we performed a simple experiment in which 50 millilitres of Scotch (about 1.7 ounces) was chilled with 100 cc of ice (6 one-inch cubes). The ensuing dilutions at 80, 86.8 and 90 Proof are charted in the accompanying graph.

You'll notice that after 15 minutes on the rocks, the proof of *Famous Grouse* is diluted to a level which occurs after 12½ minutes when the Scotch is 86.8 Proof, and after 9 minutes when it is 80 Proof. In essence, the *Famous Grouse* brand has remained about 2½ minutes fresher than 86.8-Proof Scotch, 6 minutes fresher than 80-Proof Scotch. (If you are in the habit of "nursing" a drink longer than 15 minutes, the advantages of 90-Proof Scotch will be even more pronounced.)

The Masters of Perth

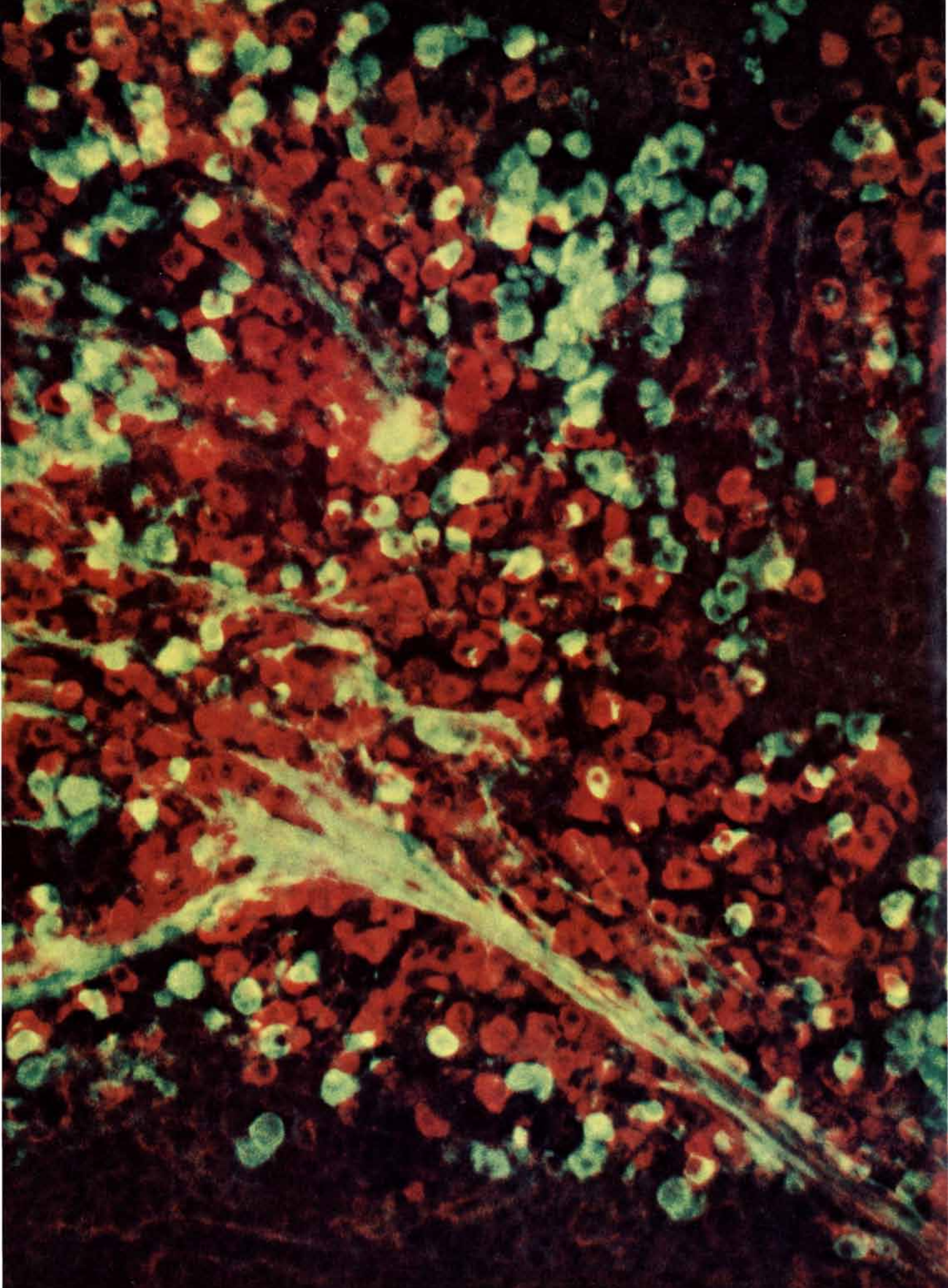
Proof, of course, is not the only thing that influences the flavor of a blended Scotch. The proportion of malt to grain whiskies, the origins of the malts, the methods of aging—these are also important factors that determine the relative richness of Scotch flavor.

The makers of *Famous Grouse*—Matthew Gloag & Son of Perth, Scotland—have been practicing their Scotch-making craft in the same family for six generations. And they have performed their most noble feat in the rich blend they created for *Famous Grouse* Scotch. Its flavor—so remarkable at the outset—holds firmly to its character during prolonged contact with ice.

Knowledge of Scotch, however, cannot be indefinitely pursued in the abstract. Your learning process must ultimately include a leisurely sip of *Famous Grouse* on the rocks. For Scotch drinking is one of those pleasures enjoyed most, not in the pursuit, but in the conquest. Scotland's greatest bard, Robert Burns, said it best:

"Gie me a spark o' Nature's fire,
That's a' the learning I desire."

The author considers this advertisement to be the opening statement of a dialogue with like-minded Scotch drinkers. We invite your comments and suggestions for future experiments. Write Mr. Allen Mac-Kenzie, c/o Austin, Nichols & Co., Inc., 733 Third Avenue, New York, N.Y. 10017.



The Development of the Immune System

The highly diversified cells that defend the body against foreign substances derive from a single kind of precursor. Differentiation of the cells is controlled by the environment in which they mature

by Max D. Cooper and Alexander R. Lawton III

Two systems of immunity protect the body from the hazards of infection and cancer. One is the cell-mediated immune response, which combats fungi and viruses and initiates the rejection of tumors and foreign tissues, such as transplanted organs. The other is humoral immunity, which is effective against bacterial infections and viral reinfections. Although the two mechanisms are not entirely independent, and cooperation between them is sometimes important, they are distinct.

The ultimate basis for this division of labor in the immune system lies in two populations of cells native to lymphoid tissue but also found in other parts of the body, particularly in the blood. During development the two lines of lymphoid cells look alike; they cannot be distinguished by mere inspection. Moreover, both derive from the same primitive precursors: the hemopoietic stem cells, which also give rise to several other kinds of blood cells. In spite of their common origin and superficial resemblance the cells do differ; they play dissimilar roles in the body's response to foreign materials and tumor cells.

In addition to the division of the immune system into two classes of lymphoid cells, there is great diversity within each class. In both classes each cell is capable of recognizing a particular antigenic determinant: one of the chemical groupings by which biological substances such as proteins communicate their identity. There are millions of possible antigenic determinants, and apparently there are immunologically active cells capable of recognizing each of them.

Investigations of how this diversity springs from the apparent uniformity of the stem cells may help us to discover how the immune system is constructed and how it works. We may also gain a better understanding of cell differentiation in general, one of the principal challenges of modern biology. Finally, a working knowledge of these mechanisms is needed if we are to devise ways of correcting disorders of the immune system, many of which seem to arise from flaws in cell differentiation.

Thymus and Bursa

The twofold nature of the immune system was delineated in a series of experiments performed by Merrill W. Chase and Karl Landsteiner of the Rockefeller Institute for Medical Research. (Landsteiner is better known for an earlier discovery: in 1900 he established the A, B and O blood types.) Chase and Landsteiner demonstrated that some kinds of immune reaction could be transferred from one animal to another only by the exchange of living cells, whereas others could be transmitted by blood serum. The cells required in the former experiment are lymphocytes: small, unpigmented cells included with several other types among the leukocytes, or white blood cells. Up to that time the function of lymphocytes had been unknown.

The serum component capable of transferring immunity consists of the protein molecules called antibodies, which combine with foreign substances. A few years earlier it had been discovered that the antibodies belong to that part of the blood serum called the gamma-globulin fraction. Antibodies are secreted by plasma cells, which are descendants of lymphocytes, but not the same lymphocytes, it was eventually discovered, that effect cell-mediated immunity [see "How Cells Make Antibodies," by G. J. V. Nossal; SCIENTIFIC AMERICAN, December, 1964].

That the functional duality of the immune system might have a developmental basis was suggested by the discovery of certain immunodeficiency diseases; the disorders might be considered experiments of nature. Ogden C. Bruton, a pediatrician at the Walter Reed Army Medical Center, identified the first—an impairment of humoral immunity—in a young boy afflicted with multiple bacterial infections. The disease is characterized by a lack of plasma cells and a consequent inability to make antibodies. Lymphocytes of the cell-mediated system, on the other hand, are abundant, and they enable the patient to resist viral and fungal infections quite well.

SPECIFICITY OF CELLS in the immune system is illustrated by the stained section of tissue from the spleen of a mouse that is shown in the illustration on the opposite page. The tissue was stained with two fluorescent dyes attached to antibodies to specific classes of immunoglobulins. Antibodies to immunoglobulin M were labeled with the green dye fluorescein, those to immunoglobulin G with the red dye rhodamine. The labeled antibodies bind selectively to plasma cells bearing the appropriate immunoglobulins on their surface. The fact that none of the cells were stained with both of the dyes indicates that each mature plasma cell produces only one class of immunoglobulins. The photomicrograph, which enlarges the section of tissue about 2,500 diameters, was made by one of the authors (Lawton).

The obverse pattern of immunodeficiency—an impairment of cell-mediated immunity—has also been detected. Individuals with this condition, who are vulnerable to viruses and fungi, have fewer than the normal number of lymphocytes, but they have plasma cells and produce circulating antibodies. Some children are born lacking both lymphocytes and plasma cells; without either system of immunity they quickly succumb to infection by a variety of microorganisms.

The explanation of these conditions has been achieved mainly through experiments with mice and chickens. In 1961 Jacques F. A. P. Miller, then at the Chester Beatty Research Institute in London, and Robert A. Good and his colleagues, then at the University of Minnesota Medical School, simultaneously discovered that removal of the thymus gland from newborn mice and rabbits prevents normal development of the immune system. Branislav D. Jankovic, Barry G. W. Arnason and Byron H. Waksman, then at the Harvard Medical School, showed that the thymus plays a similar role in rats. The immunodeficiency produced by neonatal thymectomy is particularly severe in mice because the immune system of the mouse is comparatively immature at birth.

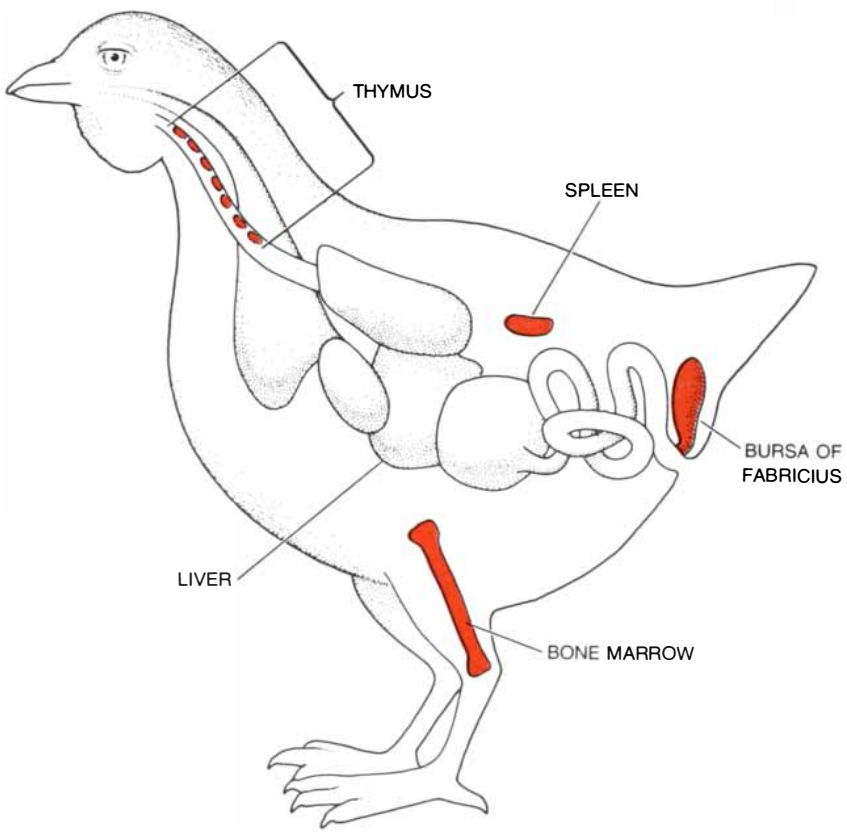
The thymus is a gland that in man lies in the chest just below the sternum; its function had long been a puzzle to biologists. A solution to the puzzle began to emerge when it was demonstrated that mice deprived of a thymus have reduced numbers of lymphocytes and a marked deficiency in cell-mediated immunity, as revealed by their impaired ability to reject grafts of skin and other tissue from unrelated mice. In mice thymectomy also inhibits the production of antibodies to most antigens. For this reason it was at first thought that the mammalian thymus controls the development of precursor cells for both cell-mediated and humoral immunity. The theory had to be modified, however, when it was found that mice without a thymus have an abundance of plasma cells and display a vigorous antibody response to certain antigens.

Immunologists were led to a more precise definition of the role of the thymus by an earlier (and for a time generally ignored) observation made by Bruce Glick, who was then a graduate student at Ohio State University. Glick and his associates had discovered that the development of humoral immunity in chickens could be severely stunted by the removal shortly after hatching of a lymphoid organ called the bursa of Fabricius. The bursa is a small pouch found only in birds, attached to the intestine near the cloaca; it is named for the 16th-century Paduan anatomist Hieronymus Fabricius ab Aquapendente, who first described it [*see illustration on this page*].

It was later shown that another technique that inhibits the development of the bursa, treatment of chick embryos with the male sex hormone testosterone, also depresses antibody production, usually without diminishing the animals' capacity to reject foreign skin grafts. A small proportion of chicks subjected to this "hormonal bursectomy," however, are tolerant of foreign skin, an anomaly first noted by Noel L. Warner and Aleksander Szenberg of the Walter and Eliza Hall Institute of Medical Research in Melbourne. In these birds, they discovered, the thymus as well as the bursa is poorly developed. Because testosterone has multiple deleterious effects on embryos the treated chicks are sickly and usually die soon after hatching. In order to clarify the results of their experiments Warner and Szenberg excised the thymuses of chicks; the result was lymphocyte deficiency and feeble graft rejection. Their conclusion, that in birds the thymus and the bursa exert different influences on immunological development, was the first suggestion of a developmental division of the immune system [see "The Thymus Gland," by Sir Macfarlane Burnet; SCIENTIFIC AMERICAN, November, 1962].

The polarity thus established in chickens could not, however, be immediately extended to mammals. Some aspects of the separation of cell-mediated and humoral immunity in chickens were not in accord with those seen in human immunodeficiencies; in addition the mouse thymus seemed to govern all cell-mediated immune functions, whereas the chicken thymus seemed to exercise only partial control. Refined techniques were necessary to resolve these discrepancies.

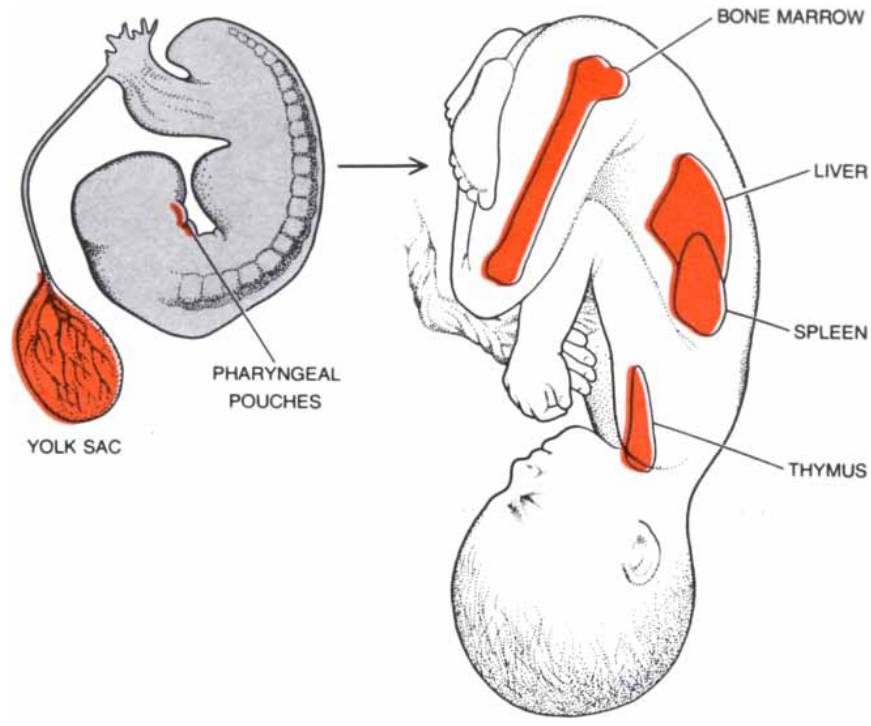
Neither of the methods employed previously was entirely satisfactory. Removing an organ at birth or at hatching cannot ensure the elimination of its influence, since it may have produced immunologically competent cells during embryonic life. Hormones, on the other



IMMUNE SYSTEM OF BIRDS is centered in two organs, the thymus and the bursa of Fabricius. The thymus, which consists of seven pairs of lobes alongside the trachea, controls the development of cell-mediated immunity. The bursa, a pouch that is found only in birds and that is attached to the intestine near the cloaca, influences the immunoglobulin-secreting cells that effect humoral immunity. The lymphocytes that pass through the thymus are called *T* cells, those from the bursa are called *B* cells. Lymphocytes also colonize the bone marrow and the spleen, but only after their residence in either the thymus or the bursa.

hand, even when they are applied to the fertilized egg early enough to suppress immunological functions, affect both bursa and thymus and thereby allow only imperfect discrimination between the two systems. In order to avoid these difficulties one of us (Cooper), working with Good and Raymond D. A. Peterson at the University of Minnesota Medical School, employed another approach. Either the thymus or the bursa was surgically removed from newly hatched chicks; then, to destroy any cells influenced earlier by these organs, the birds were exposed to X rays. After the animals had recovered from the irradiation the structure and function of their immune systems were examined.

These experiments made plain several parallels between avian and mammalian immunology. The effects of thymectomy and irradiation on the immune system of chickens were remarkably similar to those of thymectomy alone in mice. The treated birds were runty and deficient in lymphocytes; all cell-mediated immune functions were suppressed. In addition they were unable to produce antibodies as well as control birds with intact thymuses. Birds subjected to bursectomy and irradiation, on the other hand, like the antibody-deficient boy described by Bruton, had plenty of lymphocytes and normal cell-mediated immune responses but lacked plasma cells and their products: the circulating antibodies. Plasma-cell function could be restored by the injection of lymphocytes from the bursa of an untreated bird. It had been shown earlier in mice that grafts of thymus tissue or injections of large numbers of lymphocytes taken from the thymus could restore cell-mediated immunity to mice lacking thymuses.



MAMMALIAN IMMUNOLOGICAL DEVELOPMENT can be illustrated through the anatomy of the human fetus. The precursors of lymphocytes originate early in embryonic life in the yolk sac and subsequently migrate through the spleen and liver to the bone marrow. Also early in development, cells from two of the embryonic structures called pharyngeal pouches migrate into the chest to form the thymus, which in mammals as in birds controls cell-mediated immunity. Mammals have no bursa of Fabricius, however; in mammals immunoglobulin-secreting cells may develop in the fetal liver and possibly in the spleen.

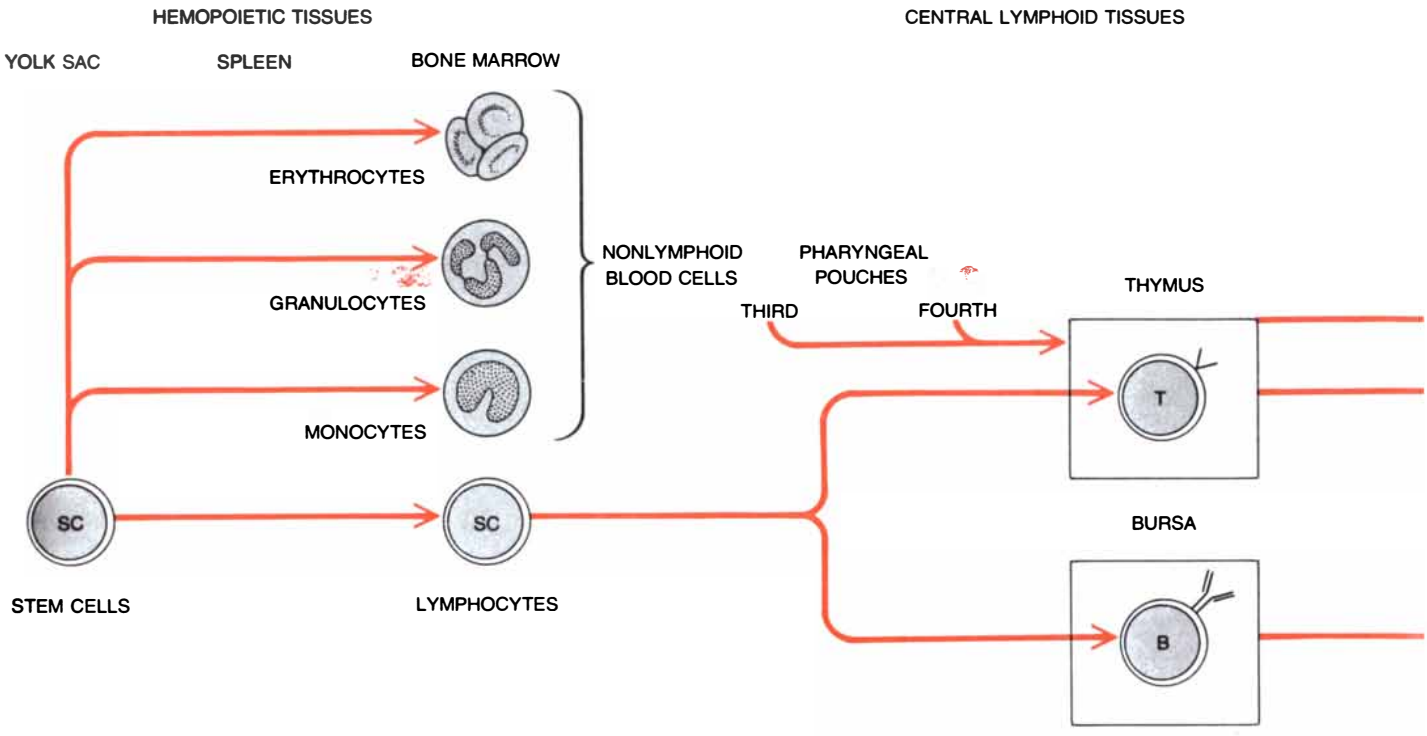
T Cells and *B* Cells

The view of the separate developmental pathways followed by thymic and bursal lymphocytes provided by these experiments accorded well with the observations of other investigators. E. C. Ford and his colleagues at the Harwell Radiation Research Institute in England had employed chromosomal markers to trace the migration of precursor cells in mice from the bone marrow to the thymus and thence to the spleen and peripheral lymph nodes. Their results implied that the precursors of a second population of lymphocytes, made up of cells that do not pass through the thymus, are also present in the bone marrow of mice. Other studies, in particular those of James E. Till and E. A. McCullough of the Ontario Cancer Institute and John J. Trentin of the Baylor College of Medicine, revealed that the descendants of a single stem cell can include both kinds of lymphocytes as well as other blood cells.

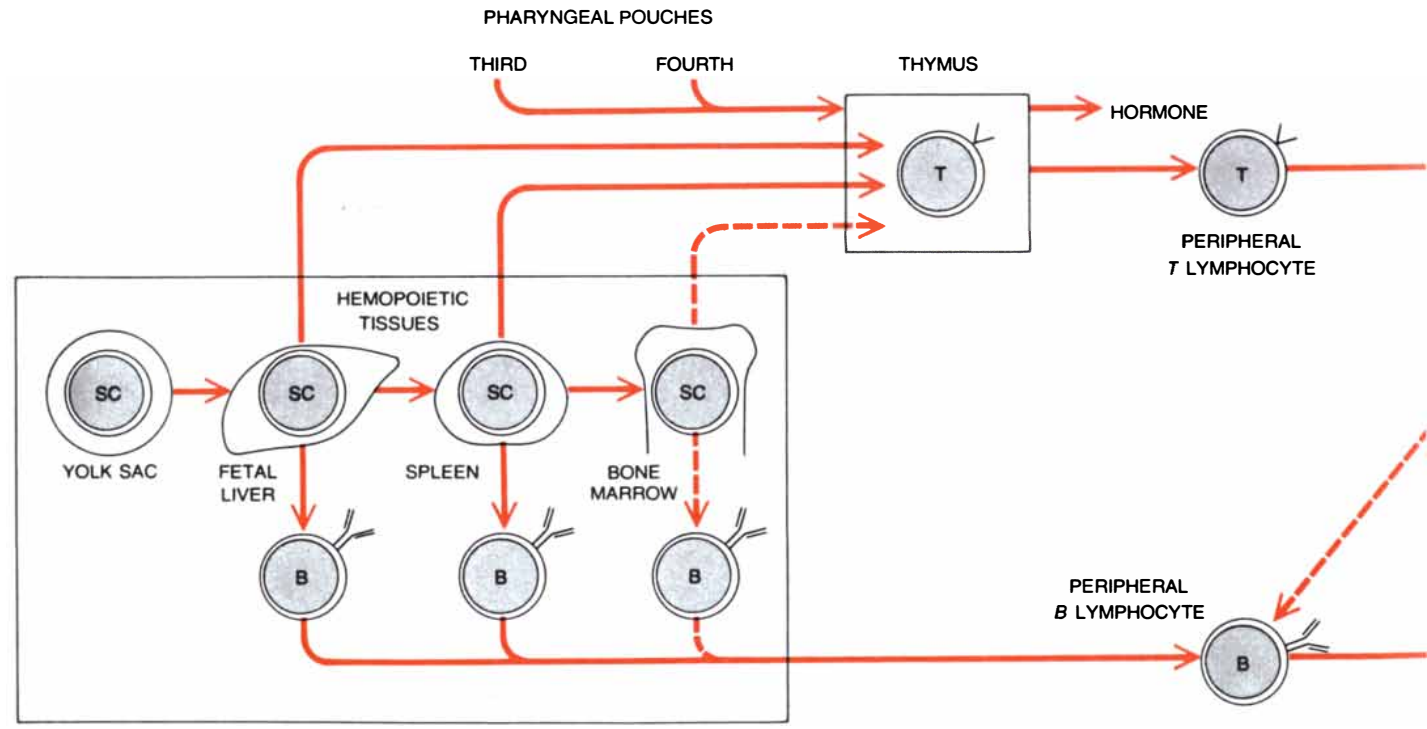
Several years earlier Jacob Furth of the Oak Ridge National Laboratory had discovered that early removal of the thymus prevents the development of a lymphoma (a cancer of lymphoid tissue) that appears spontaneously in a certain strain of mice. Many other mouse lymphomas proved to be dependent on the thymus, apparently because the thymus is the sole source of cells susceptible to the lymphoma-producing effects of certain viruses and chemicals. A related effect was reported in chickens by Peterson and Ben R. Burmester, who were working at the Department of Agriculture Regional Poultry Research Laboratory in East Lansing, Mich.; they found that bursectomy, but not thymectomy, prevents the development of a virus-induced lymphoma in chickens. In this case the virus is one that can infect many types of cells and replicate in them; only in the bursa, however, does it encounter lymphoid cells at a stage of differentiation where they are susceptible to malignant transformation.

By 1965 it was possible to construct a model of the development of the immune system in chickens and mice based on the differentiation of cells into thymic and bursal lines [*see illustrations on next two pages*]. The model implied that immunodeficiency diseases could be viewed as the consequences of defects in stem cells or of the failure of the cells to develop along one or the other pathway. The model also suggested that lymphoid malignancies could be regarded as abnormalities in the differentiation of cells belonging to either the thymic or the bursal system.

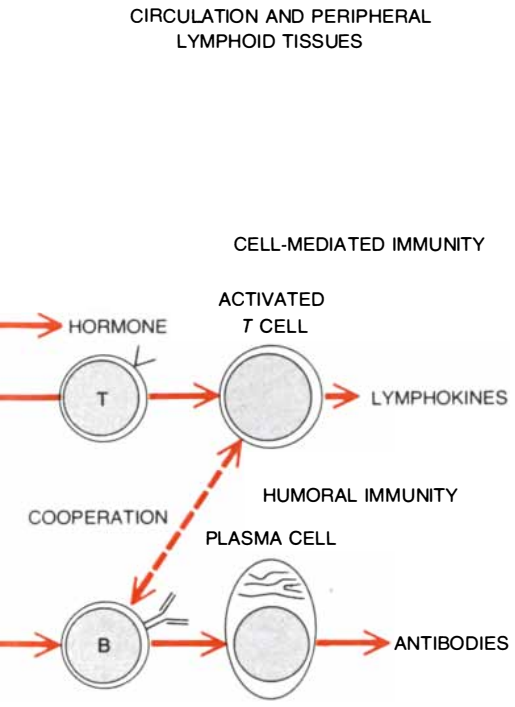
That the model could be extended to the human immune system was soon confirmed by Angelo M. Di George, a pediatrician at the Temple University School of Medicine, who discovered that children born without a thymus are deficient in lymphocytes and lack cell-mediated immune functions. Plasma cells and circulating antibodies are present in such children, suggesting that in man antibody-producing cells do not originate in the thymus. In mice additional support for the theory was obtained in further experiments with animals subjected to thymectomy and irradiation. The mice were given infusions of stem cells bearing genetic markers different from those of the host animal.



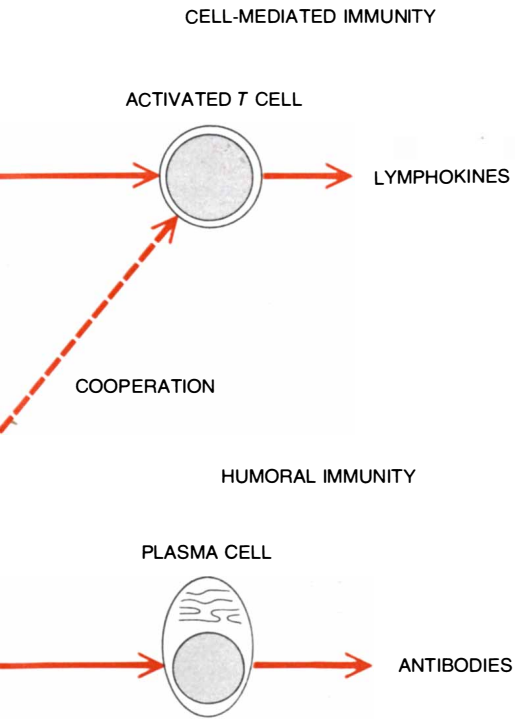
DIFFERENTIATION OF LYMPHOCYTES in birds follows a pathway discovered mainly through experiments with chickens. In the embryo the precursor cells called hemopoietic stem cells migrate from the yolk sac through the spleen to the bone marrow, where they divide and diversify, producing many kinds of blood cells. Those that are eventually to become lymphocytes must undergo further differentiation outside the bone marrow. Some pass through the thymus and are transformed into *T* cells; when activated by an antigen, they secrete molecules called lymphokines, which participate in an attack on the antigenic material. Stem cells that migrate to the bursa of Fabricius instead of the thymus are induced to become antibody-making *B* cells; when these are stimulated by an antigen, they divide repeatedly, giving rise to a clone of plasma cells that secrete large quantities of antibody. *T* cells



DEVELOPMENT AND DIVERSIFICATION of mammalian lymphocytes follows a program similar to but not identical with that in birds. The ultimate source of immunologically active cells is again the yolk sac, but stem cells from that embryonic structure travel through the fetal liver as well as the spleen before taking up residence in the bone marrow. As in birds, the influence of the thymus is essential to the generation of *T* cells, but the site at which stem cells are induced to become *B* cells has not been unambiguously identified. The fetal liver may be the first organ in which immunoglobulin-bearing cells appear. Mammalian stem



may be influenced by a thymic hormone after they have left the gland itself, and they may cooperate in stimulating *B* cells to proliferate. The symbols on the surface of the lymphocytes represent antigen receptors; in *B* cells these are immunoglobulins; the nature of the receptor on *T* cells is unknown.



cells, like those of birds, are the precursors of other kinds of blood cells in addition to the lymphocytes. Cooperation between the two classes of lymphocytes in the response to certain antigens has been demonstrated.

The markers could be detected later in antibody-producing cells and their products, indicating that the humoral immune system had been reconstituted in the absence of the thymus.

The formulation of a model of immunological development based on the notion that there are two distinct lines of lymphoid cells offered numerous insights into the behavior of the immune system. Many observations remained to be explained, however, such as the fact that in mice and chickens deprived of a thymus the humoral immune system is apparently insensitive to certain antigens, even though plasma cells and antibodies are present. The observation could be accounted for by postulating the need for thymus-derived cells to cooperate with cells from the bursa. That there is such cooperation was demonstrated in a classic series of experiments performed by Henry N. Claman, E. A. Chaperon and R. F. Triplett of the University of Colorado School of Medicine, A. J. S. Davies of the Chester Beatty Research Institute and Graham F. Mitchell and Jacques Miller, then working at the Walter and Eliza Hall Institute. They found that in the presence of an antigen thymus lymphocytes promote the transformation of thymus-independent lymphocytes into plasma cells.

This model of lymphocyte differentiation has dominated immunology during the past 10 years. All the tenets of the doctrine have been confirmed repeatedly by experiment. The elucidation of the mechanisms by which lymphoid cells diversify and through which the two classes interact has become a central problem in immunology.

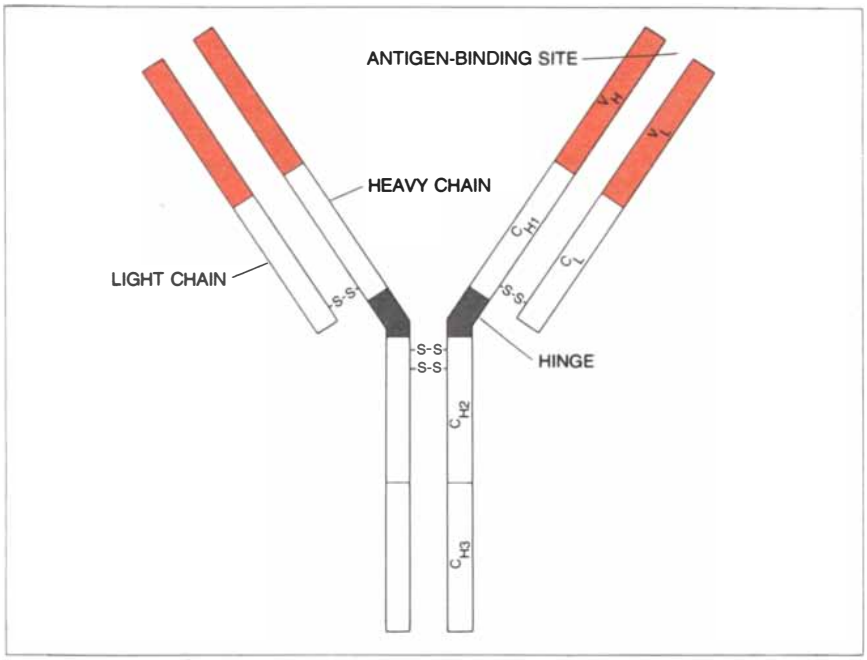
For convenience lymphocytes developing in the thymus are designated *T* cells; antibody-producing cells, developmentally dependent on the avian bursa or its mammalian equivalent, are called *B* cells. As we have mentioned, the two types of cell are identical in appearance, but they can be distinguished by an array of markers that have been discovered on their surfaces. Some of these markers are antigens roughly analogous to the blood-group antigens found on the surface of red blood cells. Because their expression is confined to certain cell types they are called differentiation antigens, a term coined by Edward A. Boyse and Lloyd J. Old of the Sloan-Kettering Institute for Cancer Research. The theta antigen in mice, for example (there is a similar antigen in humans), is present on both mature and immature *T* cells but not on *B* cells, and thus it serves as a convenient marker for one cell line. *B* cells possess other surface antigens, such as the "mouse-specific *B* lymphocyte antigen." Martin C. Raff, then working at the National Institute for Medical Research in England, was the first to demonstrate that *B* cells and *T* cells can be discriminated by markers such as these.

Since both *B* cells and *T* cells (and other cell types as well) have a common ancestry in the hemopoietic stem cells, it seems probable that their differentiation is controlled at least in part by factors external to the cell. In birds and mammals stem cells first appear in the yolk sac, a membranous structure connected with the intestinal cavity of the embryo. Later in embryonic development they migrate through the bloodstream to colonize the liver (in mammals) and spleen (in both birds and mammals) before moving on to settle permanently in the bone marrow. The pattern of differentiation that a stem cell eventually assumes is thought to depend on influences exerted within the microenvironment of the site to which it migrates. There is some evidence to suggest, however, that the stem cells ancestral to lymphocytes may be committed to the production of either *T* cells or *B* cells before they migrate to the organs in which these cells are formed.

The Development of *T* Cells

In considering the development of *T* cells the central question is: How do a relatively few stem cells give rise to a large and heterogeneous population of *T* lymphocytes? This question has so far defied attempts to provide a precise answer because the nature of the antigen receptor on *T* cells has not yet been defined. Without knowledge of the receptor the functioning of the *T* cell cannot be adequately described. Nevertheless, much information on the development and functioning of *T* cells has been gained; the evidence to date suggests that the heterogeneity of the cells arises primarily in the thymus.

The structural framework of the thymus (but not of the lymphocytes the gland contains) is formed from epithelial cells that initially line the third and fourth pharyngeal pouches, which are embryonic structures in the region that eventually becomes the throat. Early in the embryonic development of most mammals these epithelial cells begin to specialize and migrate down the neck into the chest, where some of them complete their development to form the thymus. It was once thought that thymus epithelial cells were themselves transformed into lymphocytes, but stud-



IMMUNOGLOBULIN MOLECULE consists of four polypeptide chains, each made up of many amino acid units. Two of the chains are longer and are designated heavy chains; the smaller ones are called light chains. The molecule is held together by disulfide bonds (–S–S–) but can flex in the region of the hinge. In part of each chain the amino acid sequence is the same in all molecules of the same type; this is called the constant region. There are three or four constant domains in each heavy chain (C_{H1}, C_{H2}, C_{H3}) and one in each light chain (C_L). The genes specifying the constant region may have evolved through the duplication of a primordial gene the size of a single domain. In the variable regions (*color*) the amino acid sequence differs from molecule to molecule. The immunoglobulin binds antigens at clefts formed by folds in the variable regions of the heavy and light chains.

IMMUNO-GLOBULIN	LIGHT CHAIN	HEAVY CHAIN	OTHER CHAINS	STRUCTURE
IgM	KAPPA OR LAMBDA	MU	J	
IgG	KAPPA OR LAMBDA	GAMMA 1 GAMMA 2 GAMMA 3 GAMMA 4		
IgA	KAPPA OR LAMBDA	ALPHA 1 ALPHA 2	J,SC	
IgD	KAPPA OR LAMBDA	DELTA		
IgE	KAPPA OR LAMBDA	EPSILON		

CLASS OF AN IMMUNOGLOBULIN is determined by the type of heavy chain in the molecule. There are five types—mu, gamma, alpha, delta and epsilon—and subclasses of gamma and alpha. In addition each immunoglobulin can have either of two kinds of light chain: kappa or lambda. Some of the immunoglobulins form oligomers, or associations of a few subunits in a single molecule. IgM is ordinarily a pentamer, with five subunits and with an additional "joining" chain, or *J* chain, shown here as a black dot. IgA occurs as a monomer, dimer and trimer, with respectively one, two and three subunits. The *J* chain is present in oligomeric forms, and the dimer, when found in secretions such as saliva and tears, is bonded to yet another polypeptide: the secretory component (*SC*), shown here as a gray disk.

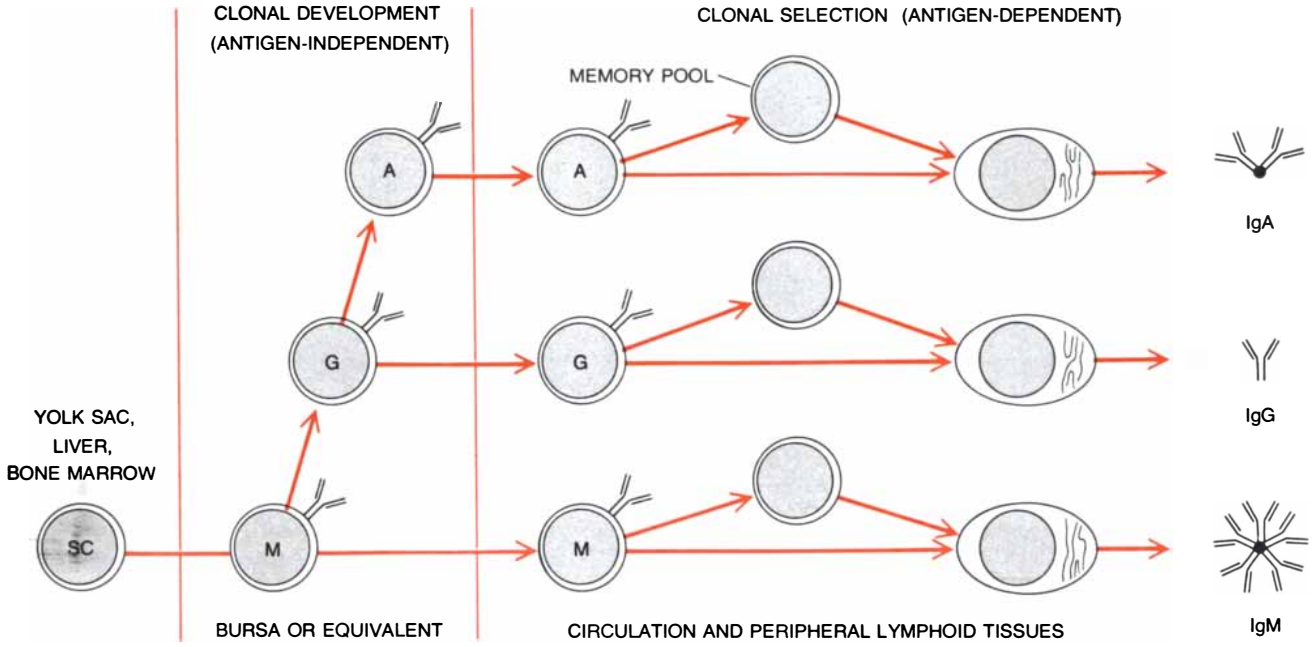
ies by Malcolm A. S. Moore and John J. T. Owen at the University of Oxford have since proved that the provenance of *T* cells is in the yolk sac.

At a time when only a few primitive precursor cells have entered the thymus, the gland can be removed and the tissue grown in culture. When that is done, each stem cell gives rise to thousands of *T* lymphocytes. Thymus lymphocytes are among the most rapidly proliferating cells in the body, dividing about three times in a day. One possible factor favoring the high rate of lymphocyte production is the need to supply the rest of the body with *T* cells. Another is the need to provide conditions suitable for the generation of diversity.

There is a considerable body of evidence suggesting that stem cells must actually pass through the thymus in order to become *T* lymphocytes. The thymic epithelium could influence stem cells by direct contact or by hormones active within its tissues. Hormones from the thymus have been shown to promote the maturation of *T* cells after they have left the thymus, thus providing a mechanism by which the parent (or foster-parent) organ can maintain control over its wandering offspring. Evidence obtained recently suggests that thymic hormones may even be able to influence the differentiation of cells that have not yet entered the gland.

Lymphocytes found within the thymus are called thymocytes, to distinguish them from the *T* cells released by the thymus to the peripheral tissues. Most thymocytes are functionally immature, but a small subpopulation is capable of recognizing and responding to antigens. If these cells are confronted with cells from another individual, they are activated; they enlarge, divide and release large molecules called lymphokines that participate in the elimination of the foreign material. *T* cells can also enlist the aid of macrophages, large digestive cells, in destroying pathogens, and mature thymocytes may release factors that stimulate *B* cells to respond by increasing the production of antibodies. The specificity of thymus lymphocytes can be readily demonstrated. If an antigen is rendered highly radioactive, *T* cells recognizing it are killed in the encounter, but other *T* cells, which presumably recognize other antigens, are not harmed. By this phenomenon of "antigen suicide" Anthony Basten and his co-workers at the Walter and Eliza Hall Institute showed that thymus cells propagate in diverse clones, lines of cells that are genetically identical.

T cells leave the thymus by way of



MATURATION OF *B* CELLS takes place in two stages. The first requires an inductive microenvironment, such as that of the bursa, but does not require stimulation by antigens. The "virgin" *B* cells initially synthesize immunoglobulin of a particular light-chain type and antigen specificity; the heavy-chain class is at first invariably mu, and the immunoglobulin is therefore IgM. Most of the progeny of these cells migrate to the peripheral lymphoid tissues, but some remain behind to develop further. They stop making the mu heavy chain and begin to make the gamma chain, and thus switch from IgM to IgG synthesis. The light-chain type and the specificity of the molecules are not altered. These IgG-making cells also have many descendants, some of which later switch from IgG to IgA synthesis by the same mechanism. In the second stage of development a clone of *B* cells is "selected" by an encounter with the antigen for which it is specific. The selected clone proliferates, and some of the progeny develop into plasma cells, which secrete antibody copiously. Others serve as memory cells, which can reinforce the immunological response in subsequent encounters with the same antigen.

the bloodstream and seldom return to their birthplace. Their main route of migration has been elucidated by James L. Gowans of Oxford. The *T* cells slip between the epithelial cells that line the venules (the small blood vessels on the venous side of the capillary bed) and enter special regions of the lymph nodes and the spleen called thymus-dependent zones. Here a cell that has encountered an antigen that corresponds to its receptor will divide repeatedly, expanding the clone of cells responsive to the same antigen. After temporary residence in the thymus-dependent zones the *T* cells make their way into the lymphatic circulation and reenter the bloodstream in the neck, where the main lymphatic vessel, the thoracic duct, empties into the subclavian vein. The circulation of the cells through the body greatly increases the probability that they will encounter any foreign substance or malignant cells present.

The Development of *B* Cells

Tracing the life history of the *B* cell is made easier by the availability of its products: the humoral antibodies. After a *B* cell completes its terminal differentiation and becomes a plasma cell it synthesizes and secretes about 2,000 identical antibody molecules per second until it dies, usually within a few days after reaching maturity.

The determination of the structure of antibody molecules was an important achievement that has made possible many of the subsequent advances in immunology [see "The Structure of Antibodies," by R. R. Porter, SCIENTIFIC AMERICAN, October, 1967, and "The Structure and Function of Antibodies," by Gerald M. Edelman, SCIENTIFIC AMERICAN, August, 1970]. Antibodies belong to the family of proteins collectively called the immunoglobulins (Ig). Each antibody molecule consists of two pairs of polypeptide chains (chains of amino acid units); because the chains of one pair are longer and have a higher molecular weight than those of the other, the chains are classified as heavy and light. In the molecule the four chains are related by bilateral symmetry [*see top illustration on opposite page*].

The light chains can be either of two types, kappa or lambda, although in any one molecule both light chains are always of the same type. There are five types of heavy chain (mu, gamma, alpha, delta and epsilon), which determine the immunoglobulin class of the antibody (IgM, IgG, IgA, IgD and IgE). Some immunoglobulins also have additional polypeptides, and some form oligomeric associations of from two to five units (each unit consisting of paired light and heavy chains). In addition there are within some of the classes multiple subclasses, and there are allelic variations, that is, alternative forms of genes at a particular locus on a chromosome. Several alleles may be present in a population, and an individual may inherit different ones from his mother and father [*see bottom illustration on opposite page*].

Both the light and the heavy chains of the antibody molecule can be subdivided into constant regions (C_L and C_H), in which the amino acid sequence is essentially invariant, and variable regions (V_L and V_H). Much of the variability in the *V* regions is found in three small areas, which are called hypervariable. X-ray-crystallographic studies by L. M. Amzel and his colleagues at the National Institutes of Health have shown that the polypeptide chains fold in such a way that the hypervariable regions of each V_L and V_H chain interact to form a cleft or pocket. It is these clefts—there are two per molecule—that bind to antigens. The amino acid sequence of the constant regions thus determines the class of an immunoglobulin, and therefore its biological role, whereas the variable regions

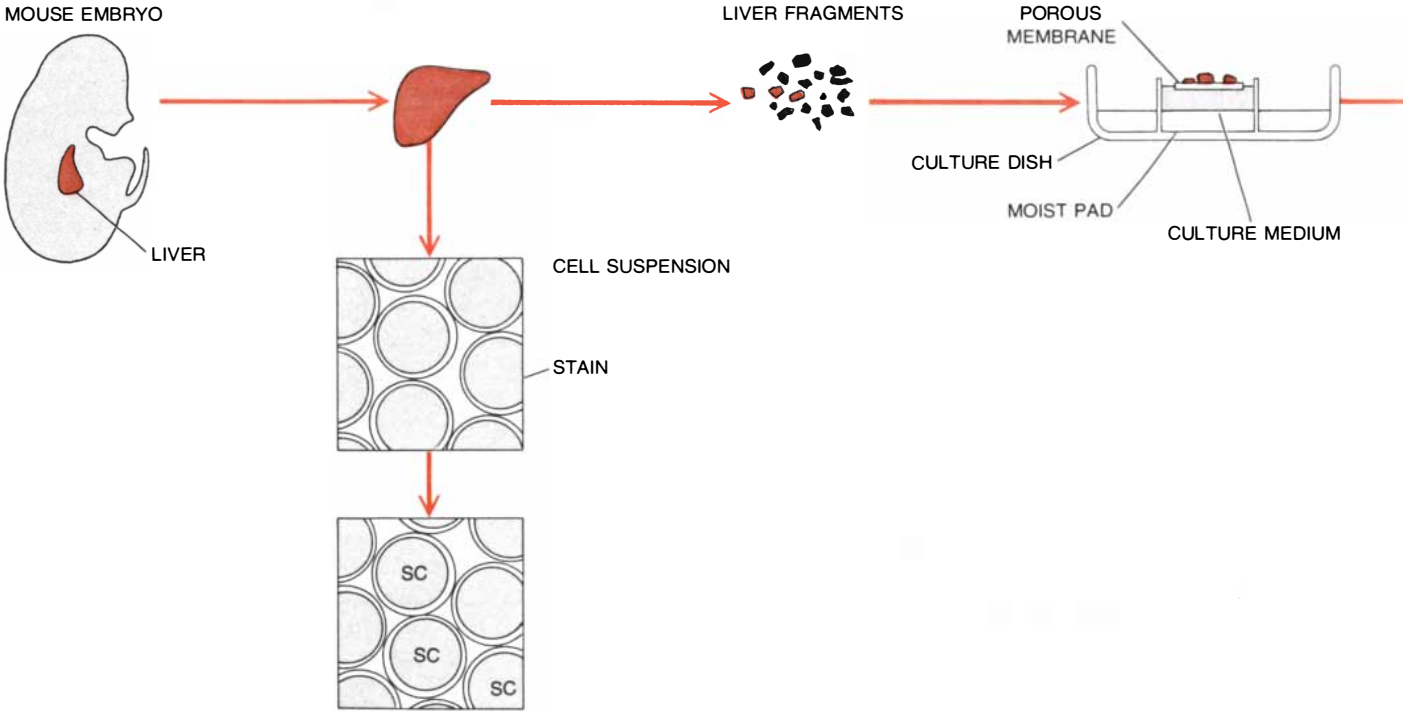
determine its specificity. These characteristics of the molecule are in turn determined by genetic events in the *B* cell that synthesizes it, and the diversity of immunoglobulins merely reflects the remarkable genetic diversity of *B* cells. With certain exceptions each *B* cell is confined to the production of antibody of a single class, subclass, light-chain type, allelic type and specificity.

In chickens, and probably in all birds, stem cells are induced to become *B* cells in the bursa of Fabricius. Moore and Owen have shown that stem cells begin migrating into the bursal epithelium by the 13th day of embryonation, which is about eight days before chicks hatch. By the next day some of the immigrant stem cells have been transformed into lymphoid cells producing IgM. A few days later a smaller proportion of bursa lymphocytes begin to synthesize IgG, and just before the time of hatching still fewer begin making IgA. *B* cells at this time are rich in polyribosomes, the intracellular bodies on which proteins are synthesized, but they lack the well-developed secretory organelles that characterize mature plasma cells. The relatively small amounts of immunoglobulins produced by the rapidly dividing cells are not yet secreted but are incorporated into the cell membrane.

In the peripheral lymphoid tissue the sequence in which plasma cells develop recapitulates that of cells in the bursa: first IgM is synthesized and secreted, then IgG and finally IgA. (The events controlling the production of IgD and IgE are less well understood.) Each type of plasma cell ordinarily does not appear, however, until several days after the corresponding *B* cell. Exposure to high concentrations of antigens hastens the maturation of plasma cells in peripheral areas, and maintaining the experimental animal in a germ-free environment retards it. Inside the bursa neither condition has much effect on the initiation of lymphocyte formation.

That the bursa controls the capacity of chickens to produce the several classes of immunoglobulins was learned by studying the effects of bursectomy at various times during embryonic development. Removal of the organ on the 16th or 17th day of development frequently results in the permanent absence of all *B* cells and their mature plasma-cell progeny. The result is often complete and permanent agammaglobulinemia: a lack of the gamma-globulin fraction of the blood serum, which contains the antibodies. When the bursa is removed at about the 19th day, IgM is usually present in the mature bird, but IgG and IgA are not. When bursectomy is performed at hatching (21 days), IgM and IgG are delayed in reaching normal concentration but may eventually exceed normal levels; IgA, on the other hand, is often permanently lacking. The effect of these procedures is to arrest the development of the bursal line of lymphocytes at intermediate stages of differentiation. They can tell us two things about the development of humoral immunity: first, in chickens the bursa appears to be the exclusive site for the formation of *B* cells and, second, individual *B* lymphocytes are irrevocably committed to the synthesis of IgM, IgG or IgA when, in that order, they leave the parent organ.

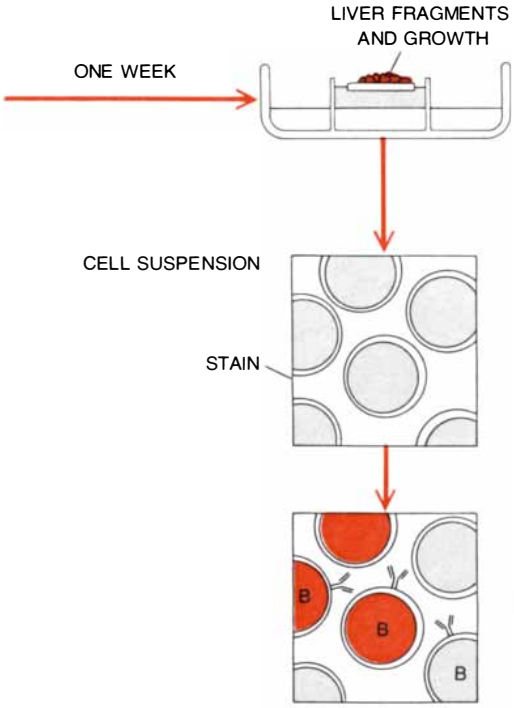
Two competing theories could explain the generation of class diversity among *B* lymphocytes. Within the bursal environment different stem cells might be induced to begin synthesizing the immunoglobulins IgM, IgG and IgA, or lymphocytes that initially express IgM could be made to switch to IgG and later to IgA. In a series of experiments in our laboratory at the University of Alabama in Birmingham Medical Center, Paul W. Kincade demonstrated that the latter is the more likely explanation. He found that in the bursa the cells containing IgG frequently contain IgM as well (a situation that is not common in any other part of the body). This pattern suggested that while a cell is in the bursa it can change products; it was confirmed



POSSIBLE MAMMALIAN EQUIVALENT of the avian bursa of Fabricius was identified in an experiment showing that *B* cells (lymphocytes bearing immunoglobulins) can develop from stem cells in the fetal liver. Livers were removed from mouse embryos 12 to 15 days old, cut into fragments and grown in a culture dish. *B* cells were not present initially, but they could be detected after a week's growth. Their presence was revealed by staining a suspension of cells with labeled antibodies specific for the heavy chains of immunoglobulins; the stained cells were then examined under a microscope. The *B* cells developed in the same sequence that is ob-

by experiments in which chick embryos were treated with foreign antibodies capable of recognizing the heavy chain of IgM as an antigen. (Since that is the mu chain, the antibodies are called anti-mu antibodies.) Anti-mu antibodies temporarily suppressed not only IgM-containing cells but also all *B* lymphocytes, a result consistent with the theory that IgG and IgA cells are merely the progeny of IgM cells. Subsequent removal of the bursa permanently obliterated all traces of the entire *B*-cell line, again indicating that there is only one population of bursa-derived lymphocytes, which manufactures the immunoglobulins in the sequence IgM, IgG, IgA.

A further conclusion about the development of humoral immunity could be drawn from these observations. It appears that the signals controlling the generation of lymphocytes within the bursa are different in kind from those mediating the further differentiation of the cells once they leave the bursa. The former are intrinsic to the bursa, whereas the latter must include the influence of exogenous antigens. From these concepts we derived a general model for *B*-cell differentiation [*see illustration on page 65*]. It is an elaboration on the clonal selection theory proposed by Sir Macfarlane Burnet, in which antigens select preexisting cells bearing the appropriate receptors and stimulate them to proliferate, thereby increasing production of the antibody specific to that antigen [see "The Mechanism of Immunity," by Sir Macfarlane Burnet; SCIENTIFIC AMERICAN, January, 1961].



served in living animals: first to appear were those bearing IgM, then IgG and finally IgA. The experiment was performed at University College London by John J. T. Owen, Martin C. Raff and one of the authors (Cooper).

A Model of Cell Differentiation

Before a cell can be selected by an antigen it must be generated from an undifferentiated precursor and induced to manifest the appropriate antibody. In our model this process begins with the migration of a stem cell into a particular environment: the avian bursa of Fabricius or its mammalian equivalent. The first detectable step in differentiation is the synthesis of IgM antibodies, most of which are incorporated into the cell membrane, where they serve as receptors for a single antigen.

Still under the influence of the inductive microenvironment, the clonal precursor undergoes a series of mitotic divisions, producing from one cell a great many identical offspring. The majority of the daughter cells migrate to the peripheral tissues, but at some point one or more of those remaining in the bursa (or its equivalent) take a second step in differentiation by switching from IgM synthesis to IgG synthesis. The change is believed to involve only the expression of the two genes that specify the constant regions of the mu and gamma heavy chains; the cell merely stops manufacturing the mu chain and begins making the gamma chain. The light-chain type of the clone is not altered, nor are the variable regions of either chain, so that the specificity of the molecule for its antigen does not change. It is proposed that precursor cells committed to IgA synthesis arise from a similar mechanism in which the cell switches from gamma to alpha heavy chains. Precursor cells for IgD and IgE and the various subclasses could develop in the same way, but too little is known of their origin for them to be explicitly included in the model.

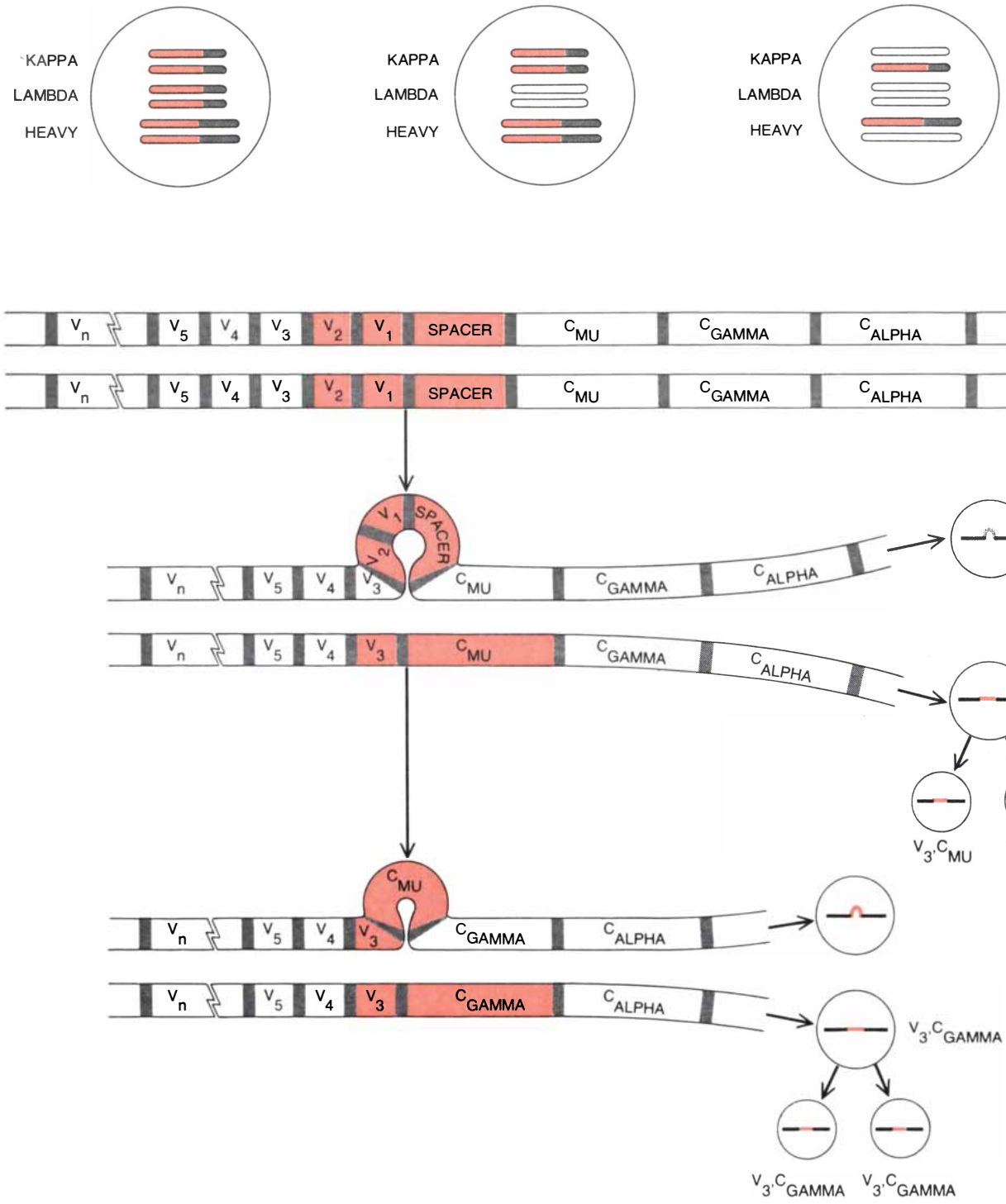
Further *B*-cell differentiation is initiated by external factors, primarily environmental antigens, in most cases with the cooperation of other types of cells, such as *T* lymphocytes and macrophages. The second stage begins when immunologically competent "virgin" *B* lymphocytes are stimulated by contact with an antigen to proliferate and thereby form either plasma cells or additional *B* lymphocytes called memory cells. The production of memory cells is a mechanism for the expansion of selected clones; it enables an individual who has been exposed to an antigen once to respond more promptly and vigorously in a second encounter. *B* cells are transformed into plasma cells through an intermediate form called a lymphoblast. The large quantities of antibody secreted by the mature plasma cell initiate the elimination of the antigens, usually by activating the group of enzymes collectively called complement [see "The Complement System," by Manfred M. Mayer; SCIENTIFIC AMERICAN, November, 1973].

The way in which antigens induce *B* cells to divide and mature is not entirely clear, but two types of signal are thought to be involved. One is the direct interaction of antigens with antibodies on the surface of the lymphocyte, presumably through some correspondence of shape. Antigens with closely spaced, repeating antigenic determinants, such as polysaccharides (chains of sugar units), are most efficient in this mode of stimulation. Another signal is communicated by activated *T* cells, and factors from *T* cells may reach *B* lymphocytes by way of the surface of macrophages. A secondary stimulus augmenting the antigen seems to be more important for triggering the terminal differentiation of *B* cells into plasma cells than it is for inducing the formation of memory cells. The requirement for *T*-cell cooperation also varies with the class of immunoglobulins. IgM immune responses are the least dependent on thymus-derived cells, and IgA responses are the most dependent.

A final stage in the control of the humoral immune response is the prevention of excessive proliferation of *B* cells and the overproduction of specific antibodies. This is accomplished by a feedback mechanism in which an antibody inhibits the proliferation of the clone of cells that produced it. Recent evidence suggests that a special class of "suppressor" *T* cells may also be important in modulating the immune reaction.

Because mammals have no identifiable bursa, it is not now possible in experiments with mice to surgically remove the source of newly formed *B* cells. Many of the experiments that helped to elucidate the development of the immune system in birds can therefore be carried out in mammals only with modified techniques. One of these techniques consists in attacking the *B* cells *in situ* by repeated injections of foreign antibodies beginning at birth; the antibodies are specific for antigenic determinants on the heavy chains of immunoglobulins.

With Richard M. Asofsky of the National Institutes of Health, we found that anti-mu antibodies given to newborn



HYPOTHETICAL GENETIC MECHANISM for the generation of diversity among *B* cells postulates the repression of certain genes and the formation of loops in DNA. Three independent families of genes specify the polypeptide chains of immunoglobulin molecules (*circled diagrams at top*). One family codes for kappa light chains, another for lambda light chains and a third for the various classes of heavy chains. Each family consists of genes in tandem on a pair of chromosomes for constant regions (*black*) and variable regions (*color*). The first stage in the differentiation of the cells is the repression of the genes for one light chain; here the lambda chain is deleted. Next, one set of genes in each remaining family is repressed. The information expressed by the cell thus consists of a set of genes for one kind of light chain, in this case kappa, and a complement of genes for all the heavy chains. In the lower illustration the heavy-chain genes are shown in detail. They can be considered domains in tandem array on a long sequence of DNA; the genes for variable regions are separated from those for constant regions by a spacer, and each of the genes is bounded by zones called recognition units (*black bands*). The constant-region genes are arranged in the order mu, gamma, alpha. A variable-region gene is selected for expression when a loop forms in the DNA (*colored segment*), bringing the gene for the third variable region (V_3) into contact with the one for the mu-chain constant region (C_{mu}). The loop is stabilized by the recognition units of the two genes. When this segment of the DNA replicates during cell division, the genetic information in the loop is deleted, and the daughter cells therefore produce immunoglobulins with the mu heavy chain (IgM) and of specificity determined by variable-region gene V_3. In a later generation another loop forms, this time excising the mu-chain genes and leading to progeny cells that make IgG. Loops formed in later generations could explain the development of IgA-secreting cells and the expression of all the remaining variable-region genes.

mice led to the almost complete elimination of *B*-cell activity, whereas *T*-cell development and function were unimpaired. After the treatment fewer than 2 percent of all spleen cells were found to bear the surface marker for *B* cells, compared with about 45 percent in control mice. Serum concentrations of all classes of immunoglobulins were depressed. Even when challenged with potent antigens, the treated animals were incapable of producing antibodies. The results of this investigation and similar results obtained independently by Dean W. Manning and John W. Jutila of Montana State University were entirely consistent with those of experiments in birds.

If the proposed mu-gamma-alpha sequence of gene expression for the constant regions of the heavy chains is correct, then elimination of IgG precursors as they first appear should block IgA synthesis as well. An experiment testing this hypothesis was complicated by the fact that during gestation maternal IgG is transferred across the placenta to the fetus, making it difficult to suppress IgG synthesis. In only one of several experiments did repeated injections of anti-gamma antibody completely eliminate IgG production. IgA-producing cells were suppressed in the IgG-deficient mice, but they were present in those mice making normal amounts of IgG. In all the animals IgM production was unimpaired. Inhibition of IgA synthesis by injections of anti-alpha antibodies had no effect on either IgM or IgG. Because the experiment in which IgG synthesis was suppressed has been so difficult to reproduce, the mu-gamma-alpha sequence cannot be considered proved. It is clear, however, that all *B* cells are the progeny of cells that have synthesized IgM at an earlier stage of development.

There is other evidence in mammals indicating that a change in the expression of genes for the constant regions of the heavy immunoglobulin chains (C_H) is responsible for the change in the class of immunoglobulins synthesized by *B* cells. In studies of a man with a myeloma (a cancer of the bone marrow) that resulted in excessive proliferation of cells producing IgM and IgG, An-Chuan Wang and H. Hugh Fudenberg and their colleagues at the School of Medicine of the University of California at San Francisco found that only the constant regions of the heavy chains distinguished the products of the two kinds of cancerous cells. The light chains and the variable regions of both heavy and light chains were identical in amino acid composition, even though the two classes of immunoglobulins were being manufactured by separate populations of malignant plasma cells. These and other observations indicate that a C_H gene switch is at least possible.

The Mammalian Bursa Equivalent

One of the principal impediments to the study of *B*-cell development in mammals has been our ignorance of where the development takes place. In the search for a mammalian equivalent of the bursa of Fabricius many kinds of tissue have been considered—for example the bone marrow and the spleen. One theory that for a time seemed promising was proposed by one of us (Cooper), Good and our colleagues; it held that the appendix and certain other intestinal lymphoepithelial tissues were the mammalian sites of *B*-cell induction. The theory has since turned out to be wrong, at least to the extent that these regions cannot be the only sites of *B*-lymphocyte formation.

In mammalian embryos lymphocytes bearing surface immunoglobulins appear first in the blood-forming organs. In mice having a gestation period of 20 days *B* cells appear in the liver and the spleen at 16 or 17 days. Several days earlier hemopoietic stem cells stream from the yolk sac into the liver and then the spleen. Recently Owen, Raff and one of us (Cooper), working at University College London, have shown in an organ-culture study that *B* cells arise *de novo* in these hemopoietic tissues [*see illustration on pages 66 and 67*].

Livers were removed from mouse fetuses between the 12th day and the 15th day of gestation, cut into small fragments and floated in a culture medium atop a porous membrane. Receiving nutrients from below and oxygen from above, liver fragments will grow in such an environment for several days. During the first week in culture *B* cells appeared in the same sequence as the one in which they emerge in the living fetus. IgM- and IgG-bearing cells were detected at almost the same time; they were followed by IgA cells. As in chick embryos and newborn mice, anti-mu antibodies blocked the development of all *B* lymphocytes.

Whole spleens can also give rise to immunoglobulin-bearing lymphocytes. Whether or not the lymphoid stem cells in the spleen have already been influenced by passage through the liver is for now not known. The primacy of the liver as a *B*-cell induction site does seem to be a possibility, in part because its origin, like that of the avian bursa, is in epithelial tissue; the spleen, on the other hand, is derived from embryonic mesenchyme.

As is predicted by our model, the various immunoglobulin classes of *B* cells develop as well in media free of exogenous antigens as they do in culture media containing antigenic materials, such as calf-serum proteins. Class diversity also develops normally whether or not *T* lymphocytes are present in the culture. These factors would be expected to influence only the second phase of *B*-cell differentiation: that which takes place as a response to an antigen.

Other investigations of the influence of antigens on *B*-cell diversity have approached the question differently. Joan L. Press and Norman R. Klinman of the University of Pennsylvania School of Medicine have shown that the precursors of cells bearing antibodies to a specific antigen appear with comparable frequency in the spleens of fetal mice and mature mice. Because the antigen would not be encountered in fetal life, their findings support the view that clonal diversity in *B* cells arises independent of contact with antigens. Patricia G. Spear and her colleagues at Rockefeller University have reached a similar conclusion through experiments employing a different technique for detecting antigen-reactive *B* lymphocytes in fetal and adult animals. For now it cannot be stated with certainty that "intrinsic" antigens (such as the histocompatibility antigens that are the major determinants of self-recognition) play no role in the ontogeny of *B* cells, but there is an abundance of evidence to suggest that the development of diversity in *B* lymphocytes is not a response to random contacts with antigens from the external environment.

The Genetics of Immunity

As the experiments recounted above imply, there is every reason to believe that the primary differentiation of stem cells into a diverse population of *B* cells and other cells follows an orderly program encoded in the genes, and that the program operates without prompting from the external environment. For this reason it is essential that an explanation of immunological development be based ultimately on genetic principles.

In most proteins a single gene encodes all the information for the synthesis of a single polypeptide chain; this is not so in the case of the immunoglobulins, as was first suggested by William J. Dreyer and J. Claude Bennett of the California Institute of Technology. Hereditary studies and the amino acid sequences of immunoglobulins both sug-

gest that the constant and the variable regions of each polypeptide chain are specified by different genes, and that there are in fact three distinct families of structural genes for antibody molecules. Each family consists of a number of genes in tandem array coding for the variable regions of heavy or light chains and, nearby on the same chromosome, a smaller number of genes for the constant regions. One family specifies kappa light chains, the second lambda light chains and the third the various classes and subclasses of heavy chains. The genes within each family are linked, but the three families are not; they are probably located on separate chromosomes.

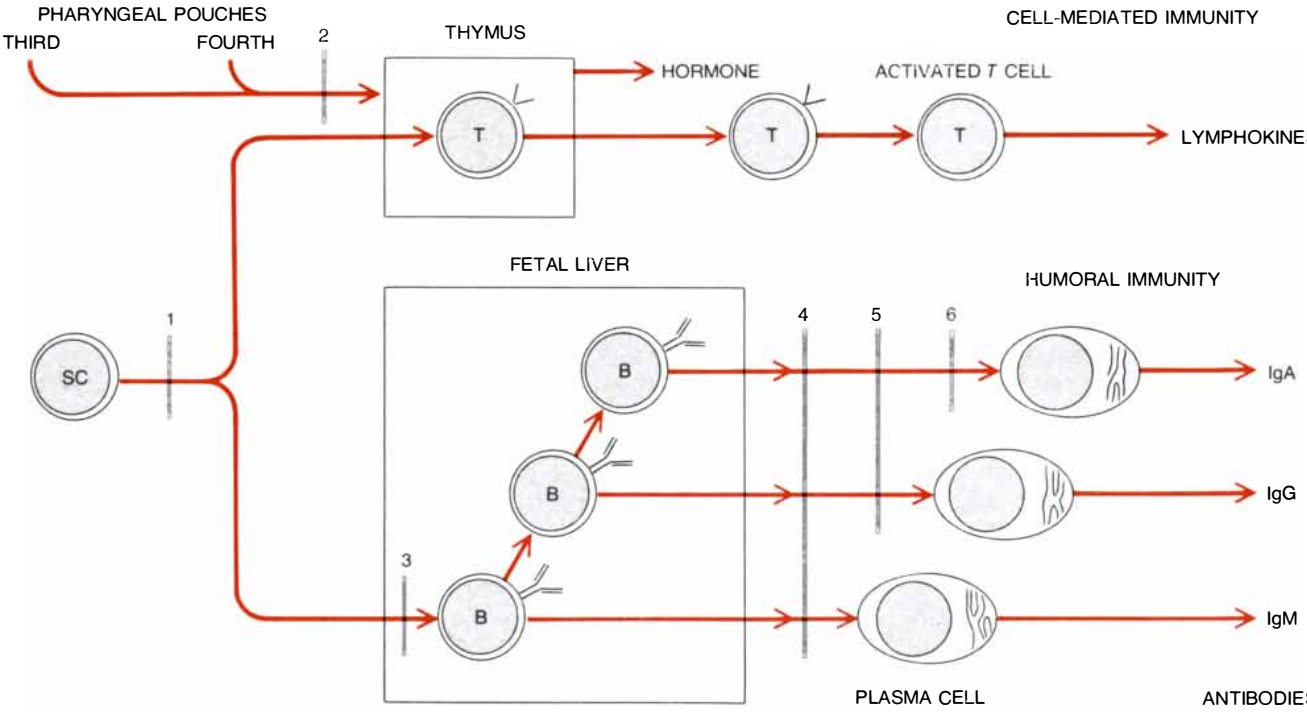
The chromosomes are of course paired, but information from only one chromosome of each pair is expressed. The repression of one set of genes in each pair is necessary if the model is to account for the observed behavior of plasma cells; even in an individual that is heterozygous for a genetic marker on an immunoglobulin, each plasma cell expresses only one of the alleles, a phenomenon called allelic exclusion.

The first step in constructing an immunoglobulin from this genetic program is therefore the functional repression of the immunoglobulin genes on one of the paired chromosomes bearing each gene family. The mechanism must then select which light-chain family, kappa or lambda, is to be expressed. Two families of genes then remain: one family for light chains and one for heavy chains; the latter determines the class of the immunoglobulin.

The next decision is the selection of a particular set of variable-region genes for both the heavy and the light chains; these will together determine the specificity of the antibody. The number of inherited variable genes remains a matter of controversy, but most investigators agree that it must be fairly large, and it could be enormous. Advocates of one theory, called the germ-line theory, argue that all the necessary variable-region genes are inherited. Others hold that much of the variability of the molecule is generated by somatic mutation or recombination of genes, in which case they would not be passed on to offspring. There is evidence suggesting that the genes specifying the variable and constant regions are joined in the DNA in the cell nucleus, and that a single RNA message is transcribed from the DNA and employed to direct the synthesis of each polypeptide strand in the antibody molecule.

Several models for the splicing together of variable-region and constant-region genes have been proposed. One that might account for both the joining of *V* and *C* genes and for the sequential switch from one class of immunoglobulins to another assumes that the C_H genes are linked in the order mu, gamma, alpha. Loops formed in the DNA would excise each of these genes in sequence; when the looped DNA was transcribed or replicated, the information in the loop would be deleted, so that separate clones of cells making each class of antibody would be created in turn. The same mechanism could also account for the selection of one gene for the variable regions from the pool of many genes, thereby determining the specificity of the molecule [*see illustration on page 68*].

One potential method of choosing between the various theories of gene splicing and selection is through the study of apparent exceptions to the rule that a single *B* cell can produce only one class of antibodies at a given time. Benvenuto Pernis of the Basel Institute for Immunology has demonstrated that rabbit *B* cells producing IgG may have IgM on their surface; with David S. Rowe of the World Health Organization labora-



IMMUNODEFICIENCY DISEASES can be considered defects in the differentiation of lymphocytes and lymphoid tissues. The absence of both *B* cells and *T* cells suggests a failure of lymphocyte precursors and can be repaired by transplanting stem cells (*1*) from the fetal liver or the bone marrow. Individuals born without a thymus (*2*) lack cell-mediated immunity; the functions of this system can be restored by the transplantation of a fetal thymus. The failure of stem cells to develop into *B* lymphocytes (*3*) is a congenital, sex-linked disorder first described by Ogden C. Bruton; presumably it derives from a defect of the *B*-cell-induction site, probably the fetal liver. In other disorders of antibody production *B* cells are present but they are not stimulated by antigens to divide and develop into mature plasma cells. The arrest of differentiation may be absolute, and therefore lead to a deficiency of all classes of immunoglobulins (*4*); it may involve cells making IgG and IgA (*5*), or it may be confined to IgA-secreting cells only (*6*).

"My tastes are very simple. I only want the very best of everything."

An eminent British prime minister was quoted as having made that statement.

Well, we guess just about everybody would like to have the very best of everything.

But for most of us, that just isn't possible. We can't afford a Rolls-Royce (with chauffeur), servants, summer and winter homes, etc.

But it is interesting to note that even those who can afford all those things still cannot buy or serve a better whisky than Maker's Mark.

And, as for the rest of us, no matter what our means, we can at least enjoy the very best of some things. One of those things is love, another is companionship. And speaking more materially, another is whisky.

Moderation is key.

If you drink in moderation, then the extra cost of Maker's Mark is amortized over quite a period. We'd be the first to admit that immoderate drinkers probably can't afford Maker's Mark. But then they really can't afford any whisky, can they?

Maker's Mark was intended to be enjoyed in moderation. It is not, and never will be, mass produced. It is made, little at a time, slowly, thoughtfully, and is meant to be consumed in the same manner.

Not for everyman.

So, Maker's Mark will never compete for the mass market.

Maker's Mark Distillery, Loretto, Ky., Ninety Proof–Fully Matured.

It was never Bill Samuels' desire to do so. Bill, founder of Maker's Mark Distillery, is a fourth-generation Kentucky distiller who knew exactly what he wanted when he started making his own whisky back in 1953.

All he hoped for was to find the pride of self-achievement in making a whisky of singular character for those few who understood whisky well enough to enjoy a truly outstanding distillation.

For you?

Though it's not for everyman, it could very well be for you.

Free booklet.

When you're in our neck of the woods, we cordially invite you to visit our little distillery on Star Hill Farm near Loretto. Meanwhile, if you have an interest in the history of whisky-making in the Bluegrass state, write for a free copy of our little booklet, "The Wonderful World of Kentucky Whisky."

tory in Lausanne he has gone on to show that human *B* lymphocytes may apparently make IgM and IgD simultaneously.

Pernis' findings in rabbits could be explained by the presence of a long-lived messenger molecule for mu chains, which might remain active after the transcription of DNA had switched from the mu-chain to the gamma-chain gene. The second case is more difficult to explain and may represent an instance of simultaneous transcription of genes for antibodies that are of different classes but share the same specificity. Pernis and Maxime Seligmann of the Hôpital Saint-Louis in Paris have discovered in a patient with a *B*-lymphocyte malignancy IgM and IgD molecules on the cell surface that share activity against IgG. The expression of specificity to the same antigen can be interpreted to mean that the variable regions of the heavy chains of both immunoglobulins are identical. If it can be unequivocally demonstrated that the same V_H gene can be transcribed simultaneously with two C_H genes, the model presented here would be excluded in favor of one that makes provision for more than one copy of each V_H gene. Deciphering nature's solution to the problem of generating diversity in the immune system should be of tremendous importance in understanding the differentiation of other kinds of cells.

Abnormal Development

Knowledge of how lymphoid cells differentiate also offers insight into disorders of the immune system, and in some cases it may reveal at what point the system has gone awry. Markers that can be employed to detect *B* lymphocytes, for example, have helped to show that most boys with Bruton's disease (the sex-linked congenital deficiency in plasma cells and circulating antibodies) are virtually devoid of *B* cells in all stages of differentiation. This observation suggests that the disease might be caused by a flaw in the organ of *B*-cell generation, perhaps the fetal liver. Patients who develop a deficiency in plasma cells and antibodies later in life, on the other hand, often have normal numbers of *B* lymphocytes bearing immunoglobulins of all classes. In this case it appears that the defect is in the later stages of differentiation and prevents the maturation of *B* cells into plasma cells.

In other immunodeficient individuals the development of one class or more but not all classes of antibody-producing cells is arrested. In isolated IgA deficiency, a condition in which only that class of immunoglobulins is lacking, *B* cells bearing IgA are almost always found in the bloodstream. The defect is present in one of every 500 people of European ancestry. L. Y. Frank Wu of our laboratory has found that *B* cells from some IgA-deficient patients can be stimulated to mature and secrete antibodies by growing them in a culture with an extract from pokeweed, a plant that contains several substances that influence the behavior of lymphoid cells. The pokeweed extract can also stimulate the differentiation of lymphocytes from some individuals who are deficient in all classes of immunoglobulins. Such discoveries inspire hope that in the future it may be possible to correct life-threatening immune disorders. Infants born without a thymus have already been successfully treated with thymus grafts, and infants lacking both *T* and *B* cells have been immunologically repaired through transplants of bone marrow and fetal liver.

Markers peculiar to *T* and *B* cells also make it possible to identify the cells involved in lymphoid cancers. Some cases of acute lymphocytic leukemia, for example, appear to be *T*-cell malignancies. Malignant proliferation of *B* cells occurs at several stages of differentiation. Myelomas are characterized by uncontrolled growth of clones of mature plasma cells, whereas chronic lymphocytic leukemia and Burkitt's lymphoma involve *B* lymphocytes. The macroglobulinemias of Waldenström, named for Jan Waldenström of the General Hospital at Malmö in Sweden, represent an accumulation of cells in transition from *B* lymphocytes to antibody-secreting cells.

The virus-induced lymphoma of bursal cells in chickens resembles Burkitt's lymphoma in man, a malignant disease that also appears to be caused by a virus. The tumorous lymphocytes invariably produce IgM, regardless of their location in the body. It therefore seems plausible that the virus that precipitates the cancer transforms the cells during clonal differentiation, interrupting the usual course of gene expression at the time when the cell would ordinarily change from the synthesis of IgM to the synthesis of IgG. Because the cells seem to be susceptible to the oncogenic effects of the virus only at a particular stage of differentiation, it appears that the development of the malignancy depends on what part of the host-cell genome is being expressed. Whether or not these speculations prove to be correct, they hint at potentially valuable concepts that may be refined through further study of developmental processes in the immune system.

Introducing Voyager.

For some, there's the station wagon. For some, the common van. And now, for others, there's something more. The Voyager.

For openers, Voyager holds anything a standard-size station wagon can hold and a whole lot more, like half a neighborhood on its way to school.

There's an optional seating arrangement for 15 people. The most the competition from Ford and Chevrolet can seat is 12.

There's more. Every Voyager is built to last with Chrysler Corporation engineering features. Such as an Electronic Ignition System that means more miles between ignition tune-ups than conventional systems.

The Voyager has a tighter turning diameter and a bigger fuel tank than Ford or Chevrolet.

It handles as easily as a full-size station wagon.

It comes with power front disc brakes. And much more.

The new Plymouth Voyager. It gives you more to look into. Now at your Plymouth Dealer's.

CHRYSLER

Plymouth

Extra care in engineering . . . it makes a difference.

The new Plymouth wagon.

Portrait of a boy: by Po

It's as if there were nothing between you and your subject. You'll want to take picture after picture, exploring every angle, every facet of your subject's personality. (And since you look directly through the lens, the picture you see is the picture you are going to get.)

No other camera discovers so many

laroid's SX-70 and you.

ways to see others. You can focus from a scene miles away to a baby as close as 10.4 inches. Press the button and whoosh! There's your picture developing in minutes before your eyes.

Make a portrait study of someone close to you with the SX-70 Land camera.

The image area is 3 1/8 x 3 1/8 inches.

Polaroid® SX-70™ in optional leather carrying case.

Introducing Eclipse.
Suddenly a lot of computers don't look so bright.

The most expensive part of a computer isn't the computer anymore.

It's the people who work with it.

So Data General is introducing a family of medium scale computers that cut down on the work people have to do.

Eclipse.

You won't have to clean up the mistakes this computer makes. Eclipse has automatic memory error correction.

You won't have to rewrite complicated instructions every time you need them. Eclipse's microprogrammed architecture includes a comprehensive new set of instructions so powerful they do the work of entire subroutines.

You won't have to lose speed doing special subroutines with software. Eclipse has a Writeable Control Storage Unit that lets you keep them in the hardware.

You won't have to use assembly language to make your programs go fast. Eclipse is so fast it can run high level languages at assembly language speeds. (It has a bipolar memory cache that makes semiconductor memory a lot faster. Plus core and semiconductor memory interleaving for even more speed. And the fastest Floating Point Processor in the industry.)

And even though Eclipse is a brand new computer, you won't have to write a lot of systems software or jury-rig your peripherals. Eclipse is upwards compatible with the Nova line. So all the software and peripherals we've already made can go right to work on the Eclipse.

Write for our brochure. And see how bright an Eclipse can be.

DataGeneral

The computer company you can understand.

Data General Corporation, Southboro, Massachusetts 01772, (617) 485-9100. Data Gen of Canada Ltd., Hull, Quebec, J8Y3S6, Data General Europe, 116 Rue de la Tour, Paris 75016 France. Data General Australia, Melbourne (03) 82-1361/Sydney (02) 908-1366.

MUSICAL DYNAMICS

Contrasts in loudness make music exciting. Many performers do not, however, produce the variations composers expect from them

by Blake Patterson

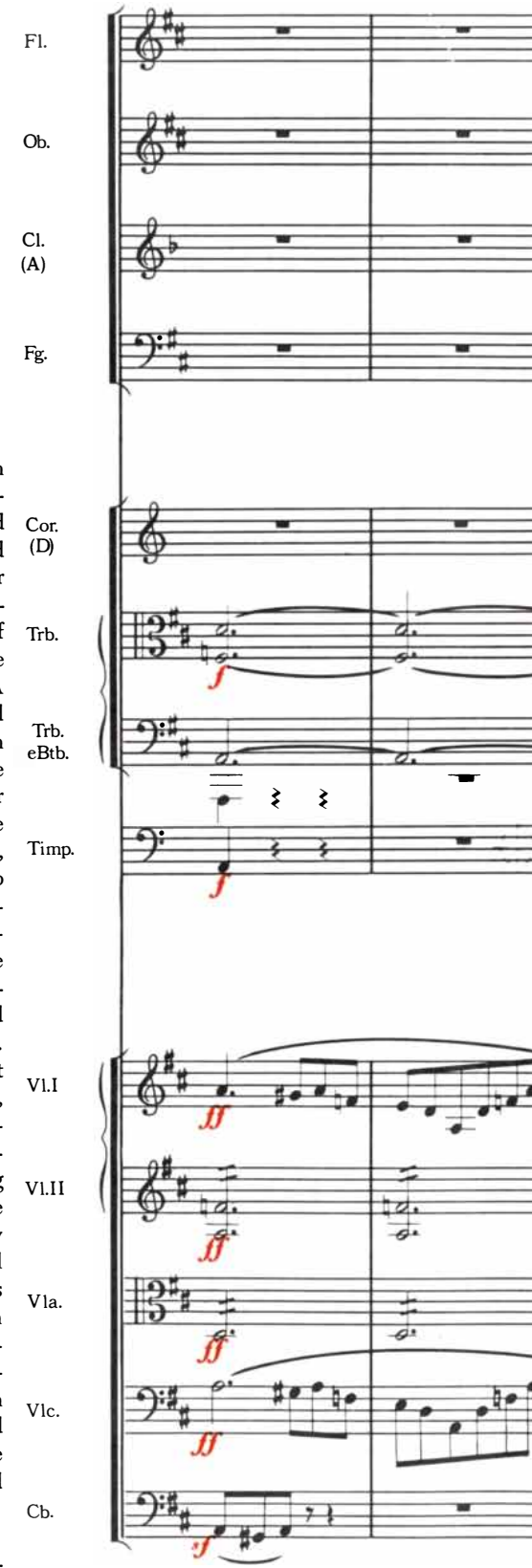
Among the numerous components of musical performances are variations in loudness or, more technically, changes in sound pressure. Such variations have a distinct psychological purpose. Consider two contrasting musical experiences. Few Americans have escaped exposure to the first: "canned" background music. It surrounds us today in restaurants, in shopping centers and even in elevators. Not everyone may realize why this kind of sonic wallpaper is so insipid. The reason is that the purveyors of canned music process their tapes to eliminate variations in loudness. The product masks the clatter of dishes but is unlikely to engage anyone's interest; it even provides a subtle stimulus to eat quickly and leave.

Consider next what one hears when a symphony orchestra is in full flight performing, for example, Beethoven's Violin Concerto. One is aware of not only the strong contrast between the loud and the soft passages of the solo instrument but also the contrast between the loudness of the solo instrument and that of the various orchestral voices. At one point the strings and woodwinds may barely whisper; at another they may almost shout. The brasses and the percussion instruments of course produce louder sounds. A quiet passage demands the listener's concentration. A loud passage is capable of inducing in him a feeling of exultation. It is precisely to capture and sustain the audience's attention in this fashion that the composer varies the mood of his music by calling for widely contrasting levels of loudness. For example, in a brief passage in his Symphony No. 2 Brahms demands that the players perform at each of the six standard levels of musical dynamics, from pianissimo to fortissimo [*see illustration at right*].

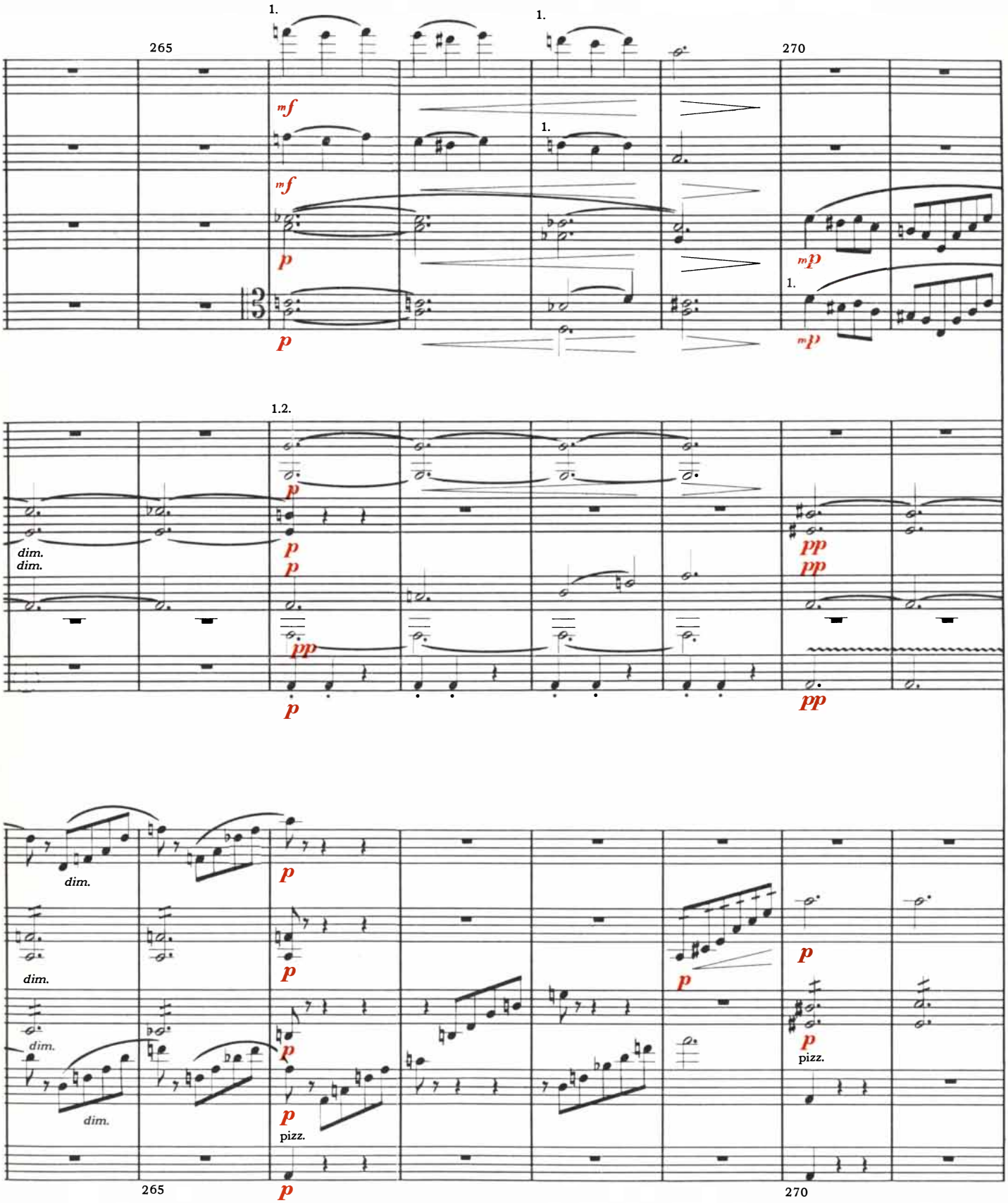
The search for better ways of achieving dynamic contrasts is easily traced in the history of music. The baroque composers, in particular Bach, Vivaldi and Telemann, favored the sweet-voiced recorder. The pitch of the recorder changes markedly, however, if the pressure of the player's breath changes; if the instrument is to remain in tune, the pressure must remain nearly uniform. A recorder player is therefore quite limited in achieving variations in loudness. In contrast to the recorder, the transverse flute is a flexible instrument. Its player can, by carefully changing the relative positions of the blowhole and his lips, not only maintain correct pitch but also play softly or loudly as the notation requires [*see illustration on page 90*]. Because of its superior expressiveness the transverse flute quickly eclipsed the recorder and has remained the standard orchestral flute since the time of Mozart.

The harpsichord, another instrument much admired during the baroque era, suffered a similar eclipse. The mechanism of the harpsichord plucks the instrument's strings rather than striking them, and the string is displaced the same distance regardless of how gently or forcefully the keys are struck. For all its great tonal beauty the instrument has a very limited potential for variations in loudness. Almost from the time of its invention a later device, named the pianoforte in a combination of the Italian words for "soft" and "loud," supplanted the inflexible harpsichord as the favorite keyboard instrument of musicians and composers.

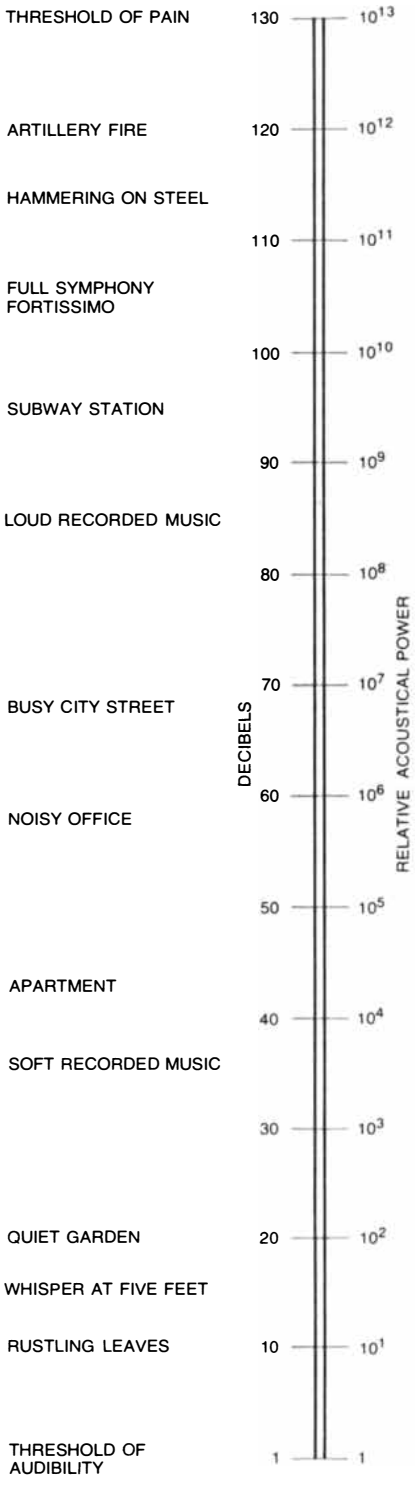
Considering how much of musical drama stems from variations of loudness it is scarcely surprising that composers have invented symbols to indicate the levels of loudness they wish the performers to achieve. Known collectively



fff	FORTISSIMO	VERY LOUD
f	FORTE	LOUD
mf	MEZZOFORTE	MODERATELY LOUD
mp	MEZZOPIANO	MODERATELY SOFT
p	PIANO	SOFT
pp	PIANISSIMO	VERY SOFT



CHANGES IN LOUDNESS, indicated to orchestral performers by a six-symbol system of notation (*see key*), are those found in a brief passage from Brahms's Second Symphony. In these nine measures Brahms called at least once for each of the six dynamics, from fortissimo (first indicated for the strings at measure 262) to pianissimo (first indicated for some brasses at measure 266). Composers have used this means of calling on instrumentalists for varying degrees of loudness in their performances since the time of Mozart.



DECIBEL SCALE, a proportional measure of acoustical power, progresses logarithmically in much the same way that the human ear responds to increases in sound intensity. Each 10-decibel increase corresponds to a tenfold rise in acoustical power, but it only produces what the average ear hears as a "doubling" of subjective loudness. In the laboratory a change as small as a third of a decibel can be perceived. In a musical performance, however, changes of less than five decibels go unnoticed. Levels assigned to these examples are only approximations.

as musical dynamics, the signs have been six in number since Beethoven's day: *pp* for pianissimo, or very soft, *p* for piano, or soft, *mp* for mezzopiano, or moderately soft, *mf* for mezzoforte, or moderately loud, *f* for forte, or loud, and *ff* for fortissimo, or very loud. The desirability of the variations in loudness that the system of notation implies has been universally accepted for some 200 years. It is therefore both surprising and ironic to find that comparatively few instrumentalists, professional or amateur, actually perform in a manner that audibly differentiates among the six dynamics. A brief excursion into the history of modern acoustics will show how this curious fact came to be recognized.

During the 1930's Harvey Fletcher and W. A. Munson of the Bell Telephone Laboratories conducted pioneer experiments that measured the human ear's response to variations in sound intensity. The subject has continued to be of interest both to acoustical engineers and to psychologists. A typical experimental procedure exposes a listener to a tone that is fixed in frequency and invariant in timbre, that is, harmonic content, and is heard against a uniform background noise. The tone is then altered in intensity and the listener's response is noted. Under these controlled circumstances a listener can perceive an intensity change as small as .3 decibel, which is no more than a 4 percent increase in vibrational amplitude. Parenthetically, the decibel is a logarithmic unit of measurement expressing the ratio between the intensity of an observed sound pressure and a known reference pressure. It is useful as a measure of relative loudness in more ways than one. The response of the human ear to variations in intensity is also approximately logarithmic. In addition, a decibel measurement of variations in intensity is much the same whether the source of the sound is near or far away.

To recognize changes of loudness in a musical context is a far more formidable task than doing so in the laboratory. The ear now encounters tones that vary in both frequency and timbre and are heard against background noise that is decidedly heterogeneous. Perhaps the best way to assess the ear's response to complex musical sounds is by first analyzing the loudness characteristics of musical instruments. In 1962 Paul R. Lehman, while a graduate student at the University of Michigan, did this with respect to the bassoon. He recorded in an anechoic chamber the performances of 11 professional bassoonists employed by the symphony orchestras of Berlin, Boston, Cleveland, Detroit and Philadelphia.

Each performer was asked to play a chromatic scale, beginning with the third A sharp below middle C (about 58 hertz, or cycles per second) and terminating an octave above middle C (about 523 hertz). The scale was played at two levels: pianissimo (the softest volume the player could comfortably produce) and fortissimo (the loudest volume the player found consistent with his concept of "good tone"). Since bassoonists are frequently called on to play at these two levels they soon find their average pianissimo and fortissimo performances "comfortable." Thus Lehman's data represent the customary dynamic gradations used by experienced professional musicians. To preserve anonymity Lehman identified the participants in his study only by letters of the alphabet. Reproduced here are the two extremes he encountered: the performances of player *C* and player *H*.

Player *C* showed the least dynamic range of any of the 11 bassoonists [*see top illustration on page 84*]. His variation in intensity from pitch to pitch at supposedly "constant" levels three times exceeded nine decibels. Nonetheless, the "smoothness" of player *C*'s performances satisfies audiences, conductors and colleagues. When a scale that acute listeners find satisfactorily smooth is shown by laboratory measurements to be remarkably irregular, one reaches an inescapable conclusion. In a musical context a variation in intensity of five decibels or even more can go unnoticed by the human ear.

Let us assume that the "intensity scatter" at any one dynamic (that is, the width of an "average" band that would embrace the data points of that dynamic) would extend 2.5 decibels above and below a smooth curve fitting the data points, so that the width of the band totals five decibels. A listener evidently identifies any note that lies within the pianissimo band as one of "pianissimo" intensity, and so forth. Accepting this premise, it is clear that player *C*'s pianissimo and fortissimo performances are not very different in loudness; indeed, they approach overlap. A few of *C*'s fortissimo notes even fall in the pianissimo band and vice versa.

Lehman found that player *H* exhibited the largest dynamic range among the 11 players tested [*see bottom illustration on page 84*]. This professional produced an intensity scatter similar to *C*'s in each dynamic but achieved a

Nikon helps separate people from population.

In an age when people are identified by number and lumped together in population statistics, photography helps you rediscover the individual.

You see examples of it every day. In your newspaper, where an incisive photograph can mirror the impact of a history-making event in the joy or agony expressed by a human face. In popular magazines, where the fascination of exotic culture is reflected in a colorful portfolio on the daily life of a single family.

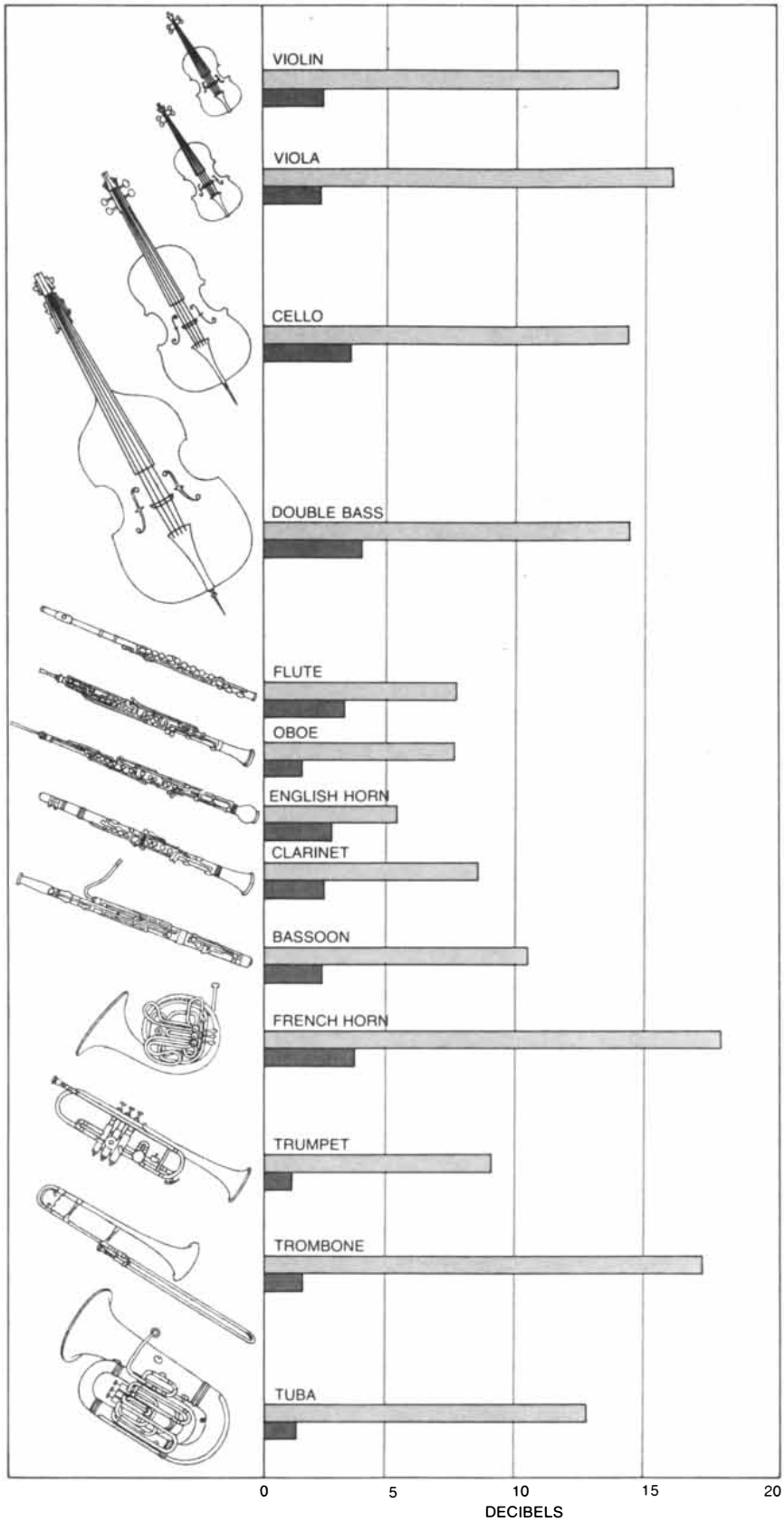
The camera used more than any other to portray our world in human terms is Nikon. In fact, it was the speed, the responsiveness and the versatility of the compact Nikon 35mm camera that enabled the pioneers of modern photojournalism to keep their lenses focused on the individual.

Today's Nikon system makes it easy to capture the moods and personalities of the people you see. There's nothing to match its array of more than forty magnificent Nikkor lenses. High-speed optics, for shooting in even the dimmest available light. Telephoto lenses, for unposed "candids" from a discreet distance. Macro lenses that can fill the entire frame with a human eye. Fisheye Nikkors for a touch of the bizarre, and more.

Plus hundreds of precision accessories that bring every picture within easy reach of your Nikon camera.

Incidentally, people photography is one of the most popular subjects taught at the Nikon School, the famous weekend short course that travels to cities all over the country. Ask your Nikon dealer about it while he is showing you the Nikon F2 and its great system. Or write today for Folio 10A. Nikon Inc., Garden City, New York 11530. Subsid. of Ehrenreich Photo-Optical Industries, Inc. (In Canada. Anglophoto Ltd., P.Q.)

81



TALENTED AMATEURS in the Boston area played chromatic scales "as smoothly as possible" at dynamic levels that they considered appropriate for "typical orchestral music." None of the players achieved the minimum requirement for six dynamic levels: a fortissimo 30 decibels louder than pianissimo. The experiment was conducted at the Massachusetts Institute of Technology. Upper bar in each pair shows players' average dynamic range; lower bar shows players' average variation in intensity even though playing was "smooth."

greater average separation between the pianissimo and the fortissimo bands. None of the notes played at either dynamic was so aberrantly loud or soft as to stray near the other dynamic. Nevertheless, this player's average dynamic range was less than 17 decibels and the average range of all 11 professionals was only 10 decibels.

If differences in loudness must exceed a minimum of five decibels to be perceptible, a question follows: What range of intensity variation across the spectrum of all six dynamics would allow recognition of each individual step from pianissimo to fortissimo? One can work toward the answer in two ways. The first is to propose that a six-decibel change in intensity is perceptible; on this assumption the total dynamic range from pianissimo to fortissimo must be at least 30 decibels, or a thousandfold increase in acoustical power. The second is to require that the five-decibel scatter bands for each of the six dynamics be separated from one another by a one-decibel gap. This guarantees that the intensities at one dynamic will differ by at least one decibel from the intensities at adjacent dynamics; as in the first instance, the average fortissimo level will exceed the average pianissimo level by 30 decibels. In practice a good musician should be able to vary his intensity even more than that; specific musical situations often demand a fortissimo louder than normal and a pianissimo softer than normal.

Those familiar with acoustics will recognize that what Lehman was measuring in his bassoonists' performance was the intensity of the sounds they produced, that is, their average acoustical power. This is a simple yardstick. As psychologists are fond of reminding acoustical engineers, it is perhaps too simple. The loudness, or "perceived level," of a sound depends not only on its acoustical power but also on the relative strengths of its harmonic components. For example, a raspy musical sound may seem louder than a mellow one, even though the latter is actually of greater intensity. It is the difference in timbre that produces the subjective impression. This leads to a hitherto ignored possibility. Lehman's bassoonists were certainly not producing, even by minimum acoustical standards, the full range of dynamics that composers are accustomed to call for. Were they nonetheless providing a substitute for dynamic gradations by means of careful variations in timbre? An experiment conducted at the Massa-

Discover for yourself why this Karl Böhm recording has won three major awards!

Enjoy MOZART'S SIX GREATEST SYMPHONIES in your home for 10 days free. All three Deutsche Grammophon recordings yours for less than the price of 1!

Mozart – music's greatest natural genius!

Wolfgang Amadeus Mozart – divinely gifted beyond any other musician who ever lived! And into his six greatest symphonies he poured a multitude of his most astonishingly beautiful, incredibly moving inspirations!

Symphony No. 41, "Jupiter"
Symphony No. 40 in G-minor
Symphony No. 39 in E-flat
Symphony No. 38, "Prague"
Symphony No. 36, "Linz"
Symphony No. 35, "Haffner"
Extra! Symphony No. 32

Now you are invited to hear these miraculous works in their finest recording . . . interpreted with extraordinary empathy by Karl Böhm . . . played to perfection by the Berlin Philharmonic Orchestra . . . captured in unsurpassed stereo realism by Deutsche Grammophon. So outstanding is this recording that it has won *three* of the music world's most eagerly sought honors: the Grand Prix International du Disque, Edison Award and Deutsche Schallplatten Prize!

Now enjoy and keep these 3 superb albums for less than the price you'd pay for 1!

Because Mozart's Six Greatest Symphonies by Karl Böhm has met with almost unprecedented acclaim, it has been chosen to introduce you to the Great Awards Collection, a totally new concept in home listening. You may enjoy all six masterpieces, on three superb-quality, imported records, for 10 days absolutely *free*. Then keep all three if you wish, for only *$6.98 (that's less than the price you'd pay for just one record)! Simply mail the attached coupon today.*

Collect the world's greatest music – only in award-winning albums!

As a member of the Great Awards Collection you will receive only the finest recordings of prize-winning concert performances by top orchestras, conductors and soloists. Distinguished jurors each year select, from the hundreds of classical releases, the "golden few" that will be offered to members of the Great Awards Collection. Every month you'll enjoy free 10-day audition privileges on each award-winning single LP. Of course, you have the option of keeping or returning each one so you'll never waste a penny on disappointing purchases!

Special half-price bonus offer saves you money!

In addition to great music, you'll enjoy great savings with our half-price plan. For every record you buy you may choose another one from a list of award-winners and other critically acclaimed LP's and pay just half the regular members' price! An economical way to build your library of superb classical recordings.

How many records are you committing yourself to buy when you return the attached coupon? *None at all!* Even your introductory set of *Mozart's Six Greatest Symphonies* comes to you *on approval*. Audition it free for ten days, then either return it – or keep it for only $6.98 for all three records, (plus a small postage/handling charge and sales tax where required).

Here at last is the ideal way to acquire, in easy stages, a connoisseur's record library without wasting a penny on disappointing purchases. You listen at home to every award-winning selection before deciding whether to buy it! Please act today! Begin your money-saving, no-obligation membership in the Great Awards Collection by mailing the attached coupon for your free trial, with 3 for less than the price of 1 purchase option of Mozart's Six Greatest Symphonies – a recording for the ages!

Seven ways the Great Awards Collection helps you enjoy fine music more than ever!

1. Greatest music by the immortal composers.
2. A major, award-winning recording each month.
3. Superior imported LP's – silent surfaces.
4. Free ten-day trials of all selections.
5. Big savings through Half-Price Bonus Plan.
6. No obligation to buy – no minimum purchase.
7. Money-saving introductory offer.

Send no money now – Mail coupon TODAY!

Q58

Listen for 10 days free. Keep all 3 for less than the price of 1!

Great Awards Collection
175 Community Drive
Great Neck, N.Y. 11025

Please send for my free audition the triple award-winning recording of *Mozart's Six Greatest Symphonies* by Karl Böhm. I may return it after ten days and owe nothing, or keep it and pay only $6.98 for all three Deutsche Grammophon records (plus a small postage/handling charge and sales tax where required).

I will also receive a free ten-day audition each month of another award-winning recording of great music. For every one of these records I buy at your members' price (always below suggested retail), I may also choose one record at half that price from your special list. I am not obligated to buy any minimum number of records. I may cancel my membership at any time.

NAME _____ (please print)

ADDRESS _____

CITY _____

STATE _____ ZIP _____

19137/Q58

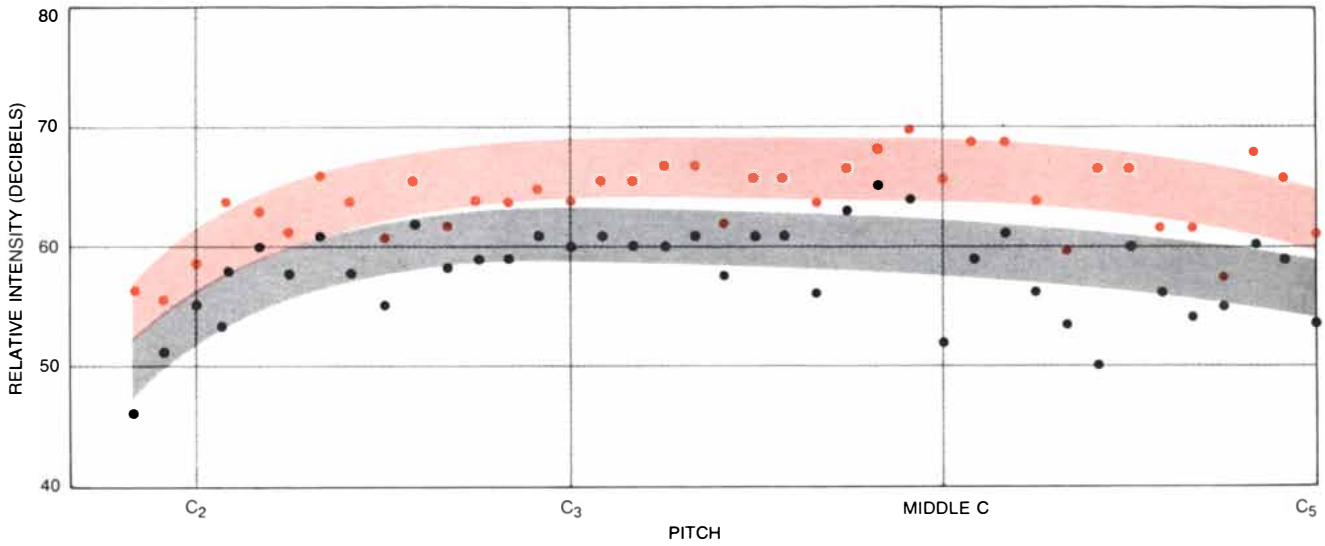
Offer limited to the U.S. and its possessions. Offer expires 1/31/75
Limit: One membership per household – only new members eligible.

chusetts Institute of Technology a decade ago suggests otherwise.

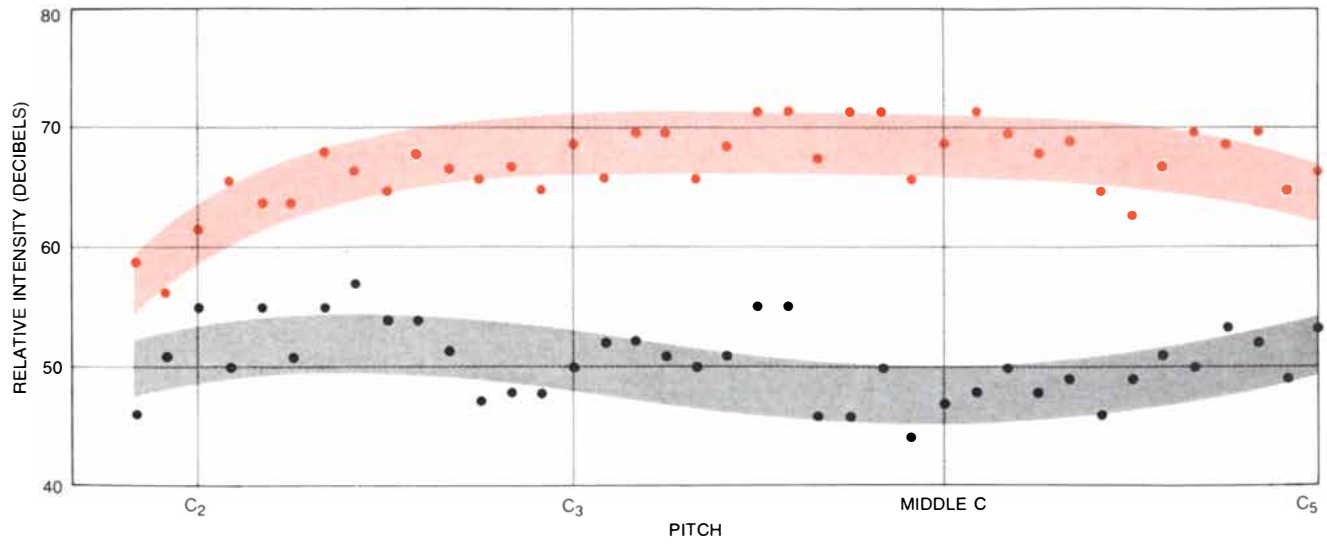
In the 1960's Melville Clark and Paul Milner made recordings of musical tones that were performed at three different dynamics: pianissimo, mezzoforte and fortissimo. They then replayed individual notes at a constant level of loudness to an audience of musically competent listeners and asked them to identify the original dynamic of each note. The listeners were generally unable to identify the original dynamic correctly even though the timbre differed from note to note. Evidently whereas both acoustical power and timbre provide aural clues to dynamic change in music, variations in timbre alone are no substitute for variations in intensity.

In this connection, although Lehman's data as presented here indicate intensities only, he also made harmonic analyses of his bassoonists' playing. If one converts this information into a subjective scale of loudness, using the method developed a few years ago by S. S. Stevens of Harvard University, a plot of the resulting perceived-level scatter looks just like the illustrations below, which depict objective rather than subjective measurements. Thus, at least with respect to the bassoon, the perceived level depends primarily on acoustical power. This means that Lehman's data are capable of predicting the loudness discrimination of a listener in a musical context even though they depict objective values rather than subjective ones.

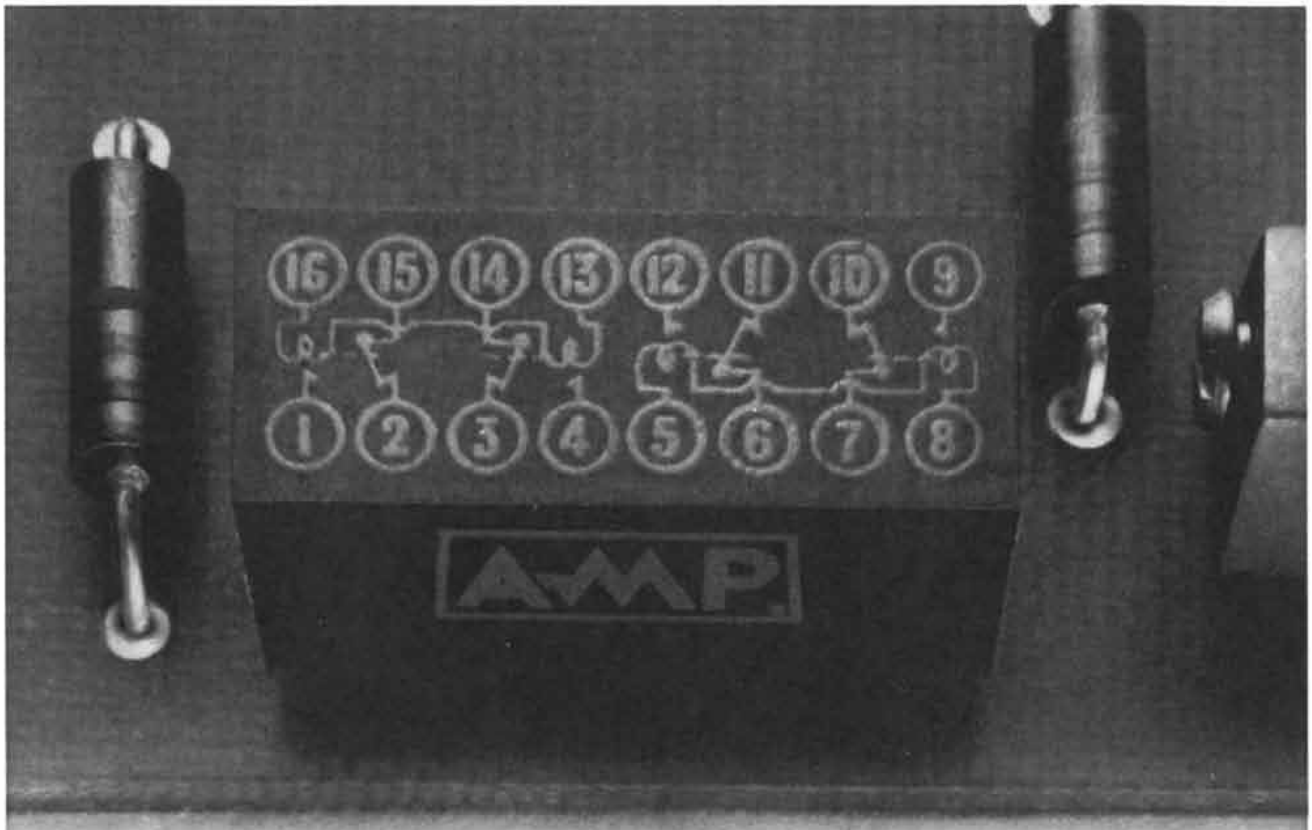
No analysis as detailed as Lehman's exists regarding other professional instrumentalists. At M.I.T., however, Clark and another colleague, David Luce, recorded a number of amateur instrumentalists selected from among the best musicians in three Boston-area orchestras. The performers included, among the string players, violinists and double-bassists and, among woodwind and brass instrumentalists, clarinetists, flutists, French hornists and trumpeters. All the participants in the experiment



PROFESSIONAL BASSOONIST, identified as Player *C* in a study conducted by Paul R. Lehman at the University of Michigan, displayed an average dynamic range even smaller than that of the amateur bassoonists recorded at M.I.T. Although a spread of as many as 10 decibels separated some adjacent notes in player's pianissimo scale, his performances were considered "smooth" by colleagues.



ANOTHER PROFESSIONAL recorded by Lehman, Player *H*, had the greatest dynamic range of any of the 11 symphony bassoonists who participated in the experiment. In the middle register, where the performer's range was at its maximum, the average fortissimo was 20 decibels above the average pianissimo. This is nonetheless below minimum range needed for perception of all six dynamics.



What has 16 legs, 8 switching functions, and runs all day on milliwatts?

The AMP Dual-DIP relay. Function-for-function, the most economical, DIP-size, IC-controllable relay on the market today.

Its 16-lead, pluggable package contains *two* independent DPDT electromechanical relays. Providing a total of eight switching functions, with maximum operating time of only 5 ms. and maximum release time of just 4 ms.

Low-resistance, gold-plated contacts are perfect for "dry circuit" as well as general use.

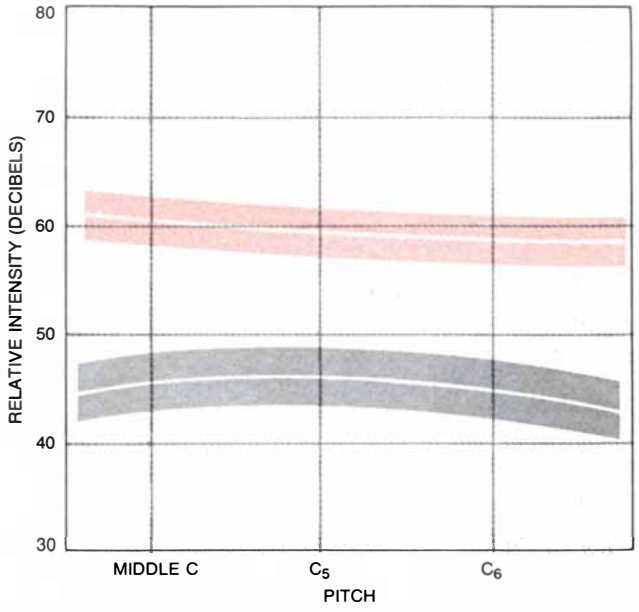
AMP Dual-DIP relays can be soldered directly to pc boards. Or "plugged" in with a variety of AMP standard or low-profile DIP headers or standard or miniature spring-type receptacles...some posted, for automatic wiring.

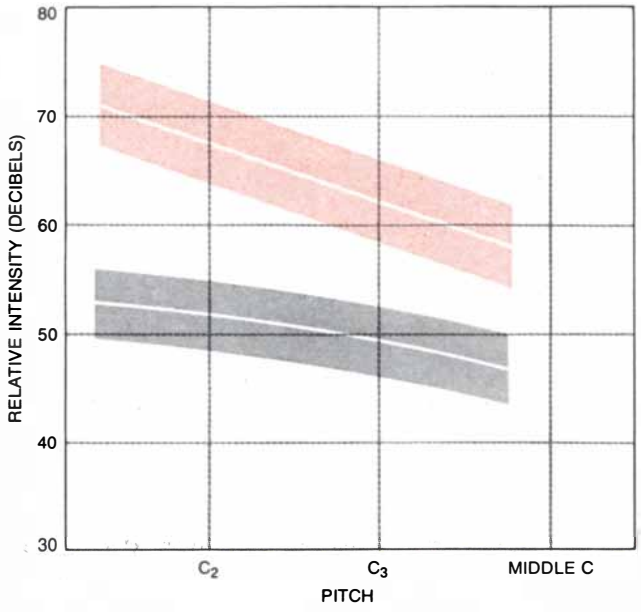
If you have a low-level switching application—and limited board space—the AMP Dual-DIP relay is your logical choice. Function-for-function.

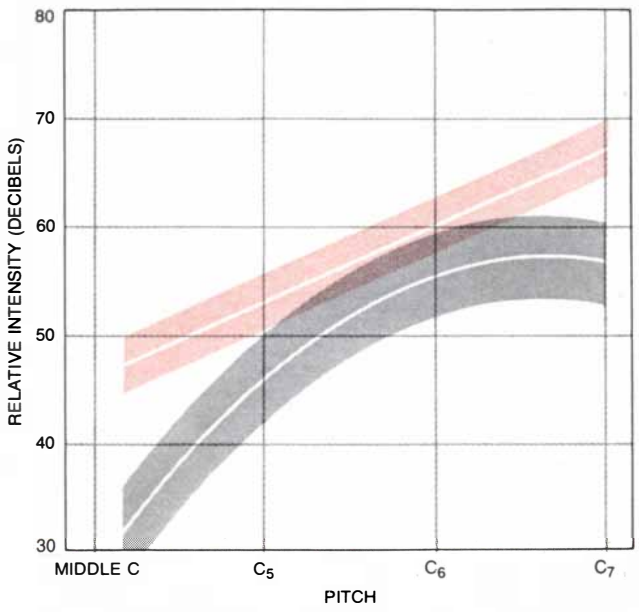
For more information, write for relay data sheet: AMP Incorporated, Harrisburg, Pa. 17105.

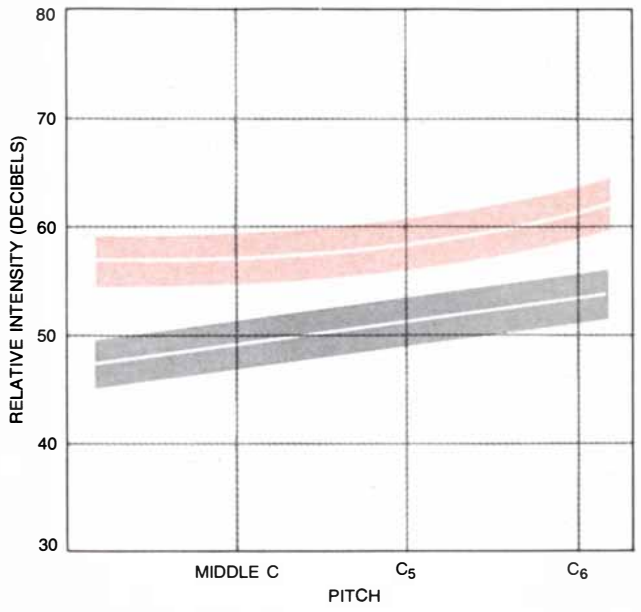
AMP
INCORPORATED

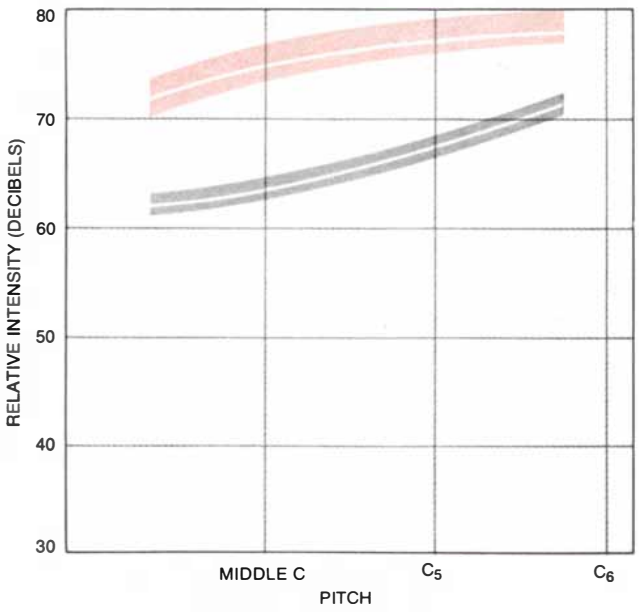
AMP is a trademark of AMP Incorporated.

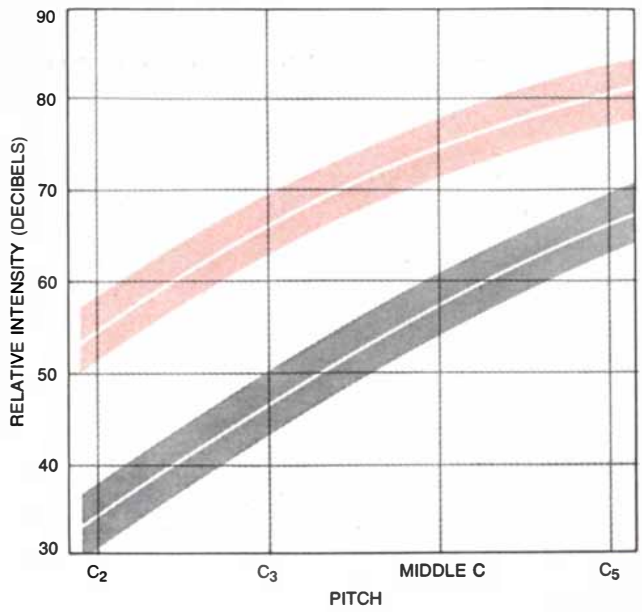












were asked to play "as smoothly as possible" chromatic scales at the pianissimo and fortissimo dynamics. The players did so at levels that each subjectively judged to be appropriate for "typical orchestra music."

Now, most amateur musicians learn their craft from a teacher who is a professional. In the process the amateur's faults, including any inadequacy in dynamic range, are monitored and corrected by the teacher. One can thus expect to find a strong similarity between the dynamics characteristic of a good amateur and those characteristic of a typical professional. Indeed, the Boston amateur bassoonists showed the same average 10-decibel dynamic range that Lehman's professionals did.

Rather than publishing their data in Lehman's note-by-note fashion, Clark and Luce computed best-fit parabolas for the values they recorded at each dynamic and then calculated the average deviation in intensity above and below those smoothed curves [*see illustration on opposite page*]. As with Lehman's data, of course, quite a few of the actual data points fell outside their averaged pianissimo and fortissimo bands. The fact is that the player can do little to avoid this kind of variation in loudness. Just as the average person finds a tape recording of his own voice surprising because it differs from what he hears when he is talking, so a musician hears irregular responses from his instrument that are quite unlike the irregularities heard by the audience. The musician's ears receive the sound of the instrument from many sources. Vibrations from a wind instrument are transmitted to the ear through the player's facial tissue, beginning at the lips, and through the air from a variety of instrument openings. For a violin or viola the vibrations transmitted through the player's head from the chin rest compete with the vibrations transmitted through the air. Because the sounds from these different sources may reinforce one another at one pitch and cancel one another at another pitch the player hears only a distorted impression of what the audience hears. A conductor or a colleague may on occasion point out a player's weak notes, but the "smoothest" playing probably results when the musician assumes that a constant effort produces a constant acoustical output.

As was the case with Lehman's bassoonists, the different instrumentalists who performed for Clark and Luce showed an intensity scatter of about five decibels as they played chromatic scales at nominally uniform levels. Among the strings the deviation may have been due to resonant effects in the instrument's wooden plates and cavities. The brasses that Clark and Luce recorded included the trombone and the tuba in addition to the trumpet. All exhibited substantially less deviation. This seems attributable to the more consistent shape of these instruments' resonant and radiating systems. Here a uniform effort yields a smoother output. In any event the players studied by Clark and Luce resembled Lehman's bassoonists in one important respect: all of them fell far short of the minimum required separation of 30 decibels between pianissimo and fortissimo.

One can, of course, somewhat invidiously attribute the results of Clark and Luce's experiment to the likelihood that any keen amateur musician in the Boston area would study with a member of the Boston Symphony. To judge from Lehman's data, Boston Symphony bassoonists, at least, would be prone to accept or even encourage a limited dynamic range in their pupils' performance. At the same time another question arises: Are the instruments of the modern orchestra able to produce a 30-decibel dynamic range? There are some answers to this question. For example, the strings can easily achieve this large a range.

In March of last year I measured the dynamic range of seven members of the string-bass ensemble class conducted at the Juilliard School by David Walter. They played pianissimo and fortissimo appropriate for the scherzo of Beethoven's Symphony No. 5. Although the average range among the seven musicians was only 18 decibels, one of them demonstrated a 30-decibel range without difficulty. As regards the violin, I have measured the performance of amateur players at the University of California at Berkeley, who demonstrated dynamic ranges exceeding 40 decibels. Violin virtuosos, of course, can do even better. For example, when Isaac Stern played Beethoven's Violin Concerto with the New Jersey Symphony Orchestra in April, 1973, he displayed an enormous dynamic range. If, as seems possible, it reached 50 decibels, then his fortissimo was 100,000 times more powerful than his pianissimo. The effect enthralled his audience.

Brass instruments can also produce a dynamic range of more than 30 decibels. The trumpet soloist of the New Jersey Symphony, Zachary Shnek, has demonstrated a range of 36 decibels at intermediate pitches and of 31 decibels in the low and high registers. The first trombonist of the same orchestra, Stewart Taylor, has a dynamic range of between 31 and 38 decibels over a corresponding spectrum of pitches.

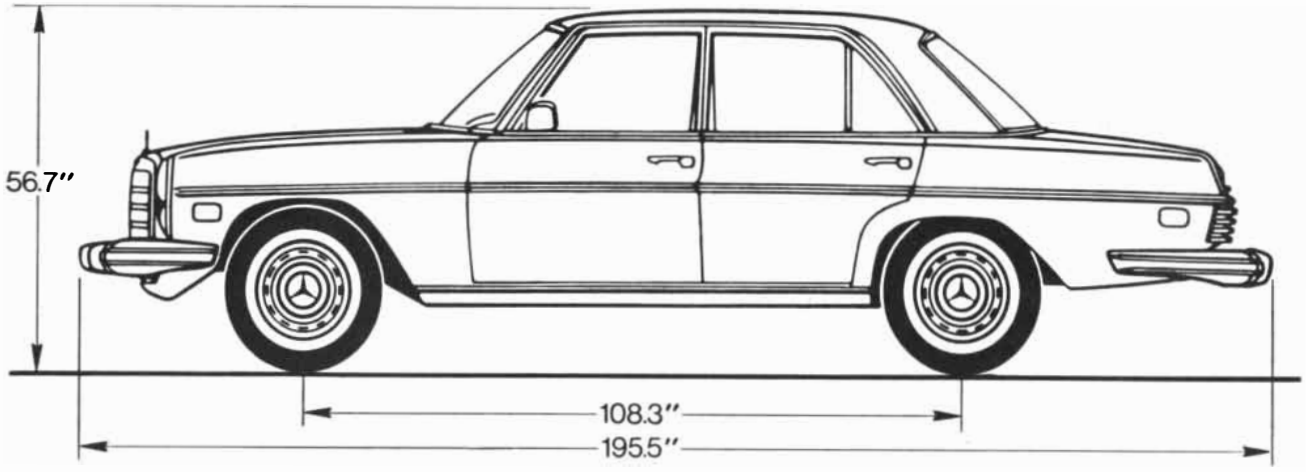
Among woodwind players the clarinetist finds dynamic control relatively simple; I have measured a range of 45 decibels for this instrument. Players of the other orchestral woodwinds, however, face considerable difficulty in achieving such control. For example, although the flute outperforms the recorder, it is far from being a trouble-free instrument. Nevertheless, I have measured dynamic ranges greater than 20 decibels among flutists, and a colleague of mine who plays chamber music can manage a 30-decibel variation on some notes of her flute.

My own instrument is the bassoon. Early in my career as a bassoonist I played under a conductor, Henri Nosco, who was formerly a concertmaster in Arturo Toscanini's famous NBC Symphony. Nosco insisted on effective dynamic contrasts, and I was forced to develop the widest possible variations in loudness. I learned special fingerings, contrived to adjust my reeds and was soon able to play louder and softer than is normally done. Now, the potential dynamic range of the bassoon exceeds 40 decibels [*see illustration on page 95*]. This means that the four intermediate degrees of loudness can fit comfortably between pianissimo and fortissimo and that their respective scatter bands, each five decibels wide, are separated by a gap of not one decibel but as many as four. All in all, that is three to four times the dynamic range of the other bassoonists whose performances are reproduced here.

Of all instrumentalists the woodwind players demonstrate the least dynamic range. In most orchestras they customarily play important solo passages mod-

DYNAMIC RANGES of three classes of instruments appear in the graphs on the opposite page. They are (*left to right*) violin and double bass (*top*), flute and clarinet (*middle*) and trumpet and French horn (*bottom*). The performers are the Boston amateurs of the M.I.T. experiment. The French hornists demonstrated the greatest dynamic range. The trumpeters' "scatter," that is, width of band surrounding a best-fit parabola, was the least of the six. That is probably because constant muscular effort with this instrument produces uniform output.

The Mercedes-Benz 280. This year, some new American cars look surprisingly like it. On the outside.



The original: the Mercedes-Benz 280. The "Look-alikes" tried to imitate its exterior. But essentials like its engine, brakes and suspension system continue to escape them.

The "Look-alikes" are here...sedans whose shapes and sizes are remarkably close to that of the Mercedes-Benz 280. It was bound to happen. We expected it. The silhouette may look the same, but that is where the similarity ends.

You simply can't make a car into a Mercedes-Benz by imitating its appearance. Or its interior. Or any other single element.

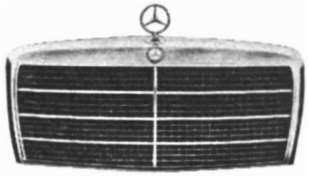
You, the driver, can prove this to yourself. Test drive a 280 Sedan. Then put any of the newcomers through the same demanding test. The difference will be driven home. The *engineering* difference.

We don't fault others for trying to follow the lead of the 280. In fact, we applaud the move toward sensibly sized sedans. That's progress.

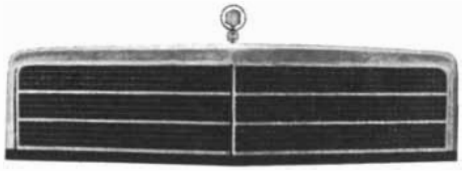
But we really must question the idea that another car is like a Mercedes-Benz because it has a grille like one. Or a silhouette like one. An automobile either is a Mercedes-Benz, or it isn't.

The Emperor's new clothes

Look beyond the new suits of clothes that the imitators are sporting. It's the same old story.



Mercedes-Benz 280 grille.



American "Look-alike" grille.

Take the engine. You'll find little that's new. These cars may still offer you engines designed long ago. That may be hard to believe, but it's an engineering fact.

It's a different story with Mercedes-Benz. The contemporary engine in the 280 Sedan was designed specifically for the 280 Series; designed as an integral part of the automobile.

This modern, twin overhead

camshaft engine directly meets demands of today's driving. It gives you fuel economy without sacrificing performance. No "Look-alike" domestic sedan has anything like the engine in a Mercedes-Benz 280. You'll instantly feel the difference on your first test drive.

No place to compromise

Look closely at the rear suspension on any of these "all-new" domestic sedans. They still feature simple wagon axles. The axles are one piece and suspended by groups of leaf springs. When one rear wheel hits a bump, the other is jolted too.

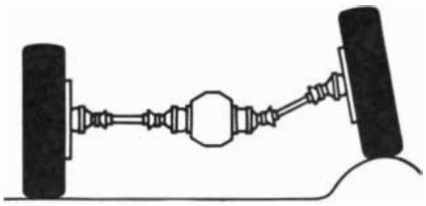
Now look at the Mercedes-Benz 280. Its rear suspension is completely different. Each wheel has its own independent suspension system. That way, each wheel reacts to the road surface independently. This design—fully independent suspension—is also a safety feature. It gives you the security of control because it helps the standard radial tires stay on the road, where they belong.

Although 4-wheel independent suspension is far more expensive to engineer into an automobile, it is the no-compromise way. And at Mercedes-Benz, we don't feel suspension and handling are places to cut corners.

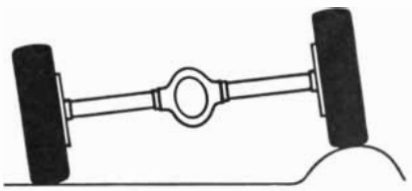
The only way

The same can be said for brakes. Certainly no area to compromise. Here is one area where American sedans have made great strides. The "Mercedes-style" new cars you will see in 1975 will probably have disc brakes. But where? On the front wheels. Why are disc brakes confined to their front wheels?

We have no answer to that question. At Mercedes-Benz, we have designed 4-wheel disc brakes into all of our automobiles for years. Every wheel on every Mercedes-Benz has a disc brake to stop it—4-wheel disc brakes. We wouldn't engineer an automobile without them. At Mercedes-Benz, it's the only way.



The 280: independent rear suspension so a bump on the right can't jounce the wheel on the left.



The "Look-alike:" wagon-type rear suspension so a bump on the right must jounce the wheel on the left.

You get what you pay for

To be sure, a Mercedes-Benz 280 is more expensive than the domestic newcomers that will try to challenge it. Consider the basic differences already mentioned. Add some others like safety engineering, resale value and the Mercedes-Benz commitment to quality. These are fundamentals you can't just "add on." In a Mercedes-Benz you get what you pay for.

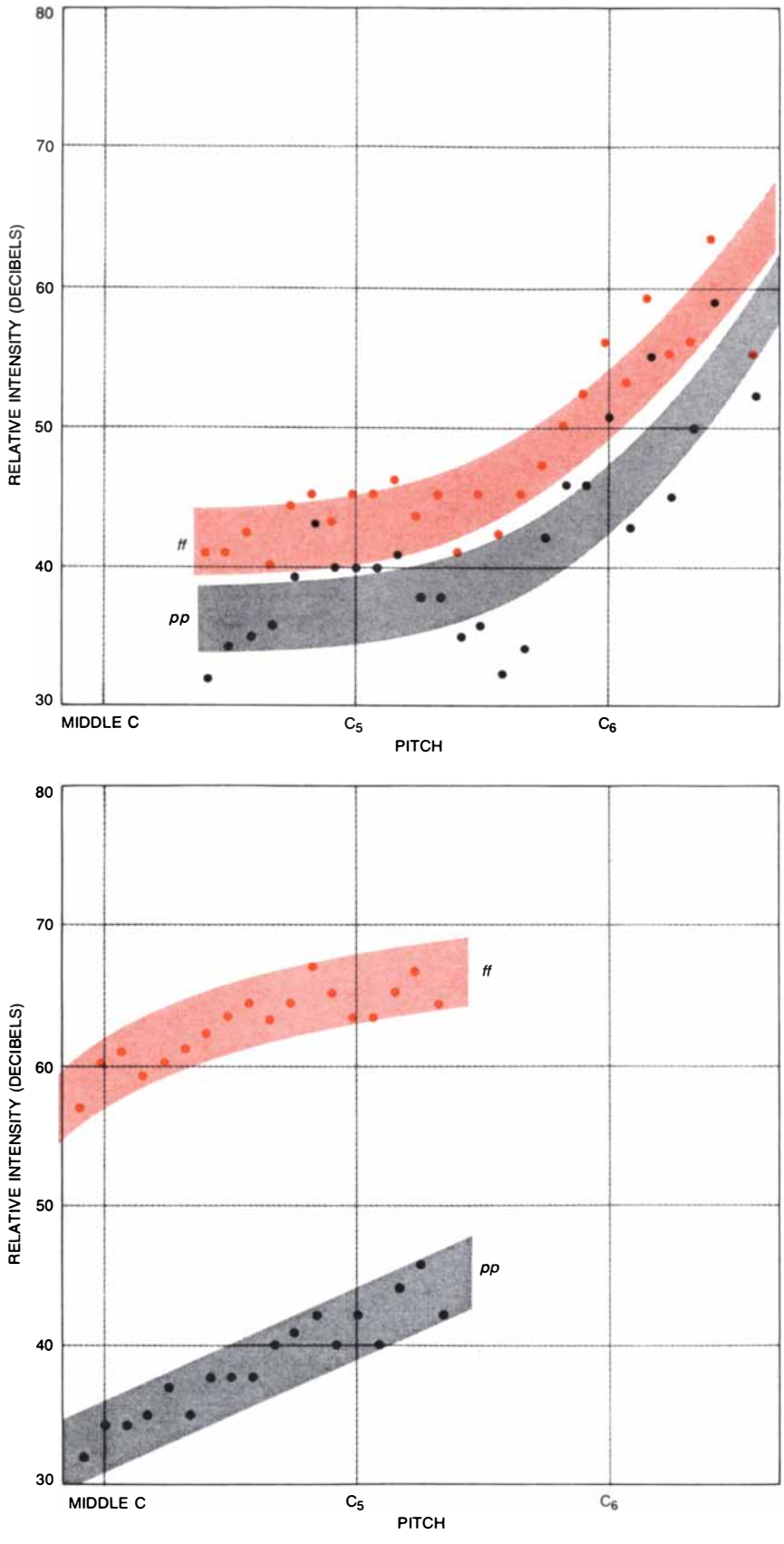
More and more you hear about cars that have this or that "just like a Mercedes-Benz." But you don't make a Mercedes-Benz by just trying to copy it.

The Mercedes-Benz 280 Sedan. Make an appointment to test drive one. See why a Mercedes-Benz has become the standard other manufacturers measure by.

Mercedes-Benz

Engineered like no other car in the world.

The Mercedes-Benz 280 Sedan: the standard the others measure by.



BAROQUE FAVORITE, the recorder (*top*), was displaced by the transverse flute (*bottom*) during the 18th century because of the superior dynamic range of the flute. As the upper graph shows, even an extremely adept player has a very small dynamic range with the recorder; the reason is that variations in air pressure cause changes in pitch. With flute, as the lower graph shows, same player's fortissimo averaged 25 decibels louder than pianissimo.

erately loudly and subsidiary passages somewhat more softly; in both instances they pay little attention to the composer's dynamic notation. There is good cause for this. To play an effective woodwind fortissimo frequently makes the instrument's pitch go awry. Similarly, in sustaining a pianissimo tone the performer treads a delicate line between too much vibration and a complete loss of vibration. It is no wonder that many elect a safe mezzoforte rather than risk the note's not "speaking" and that they never try to play a real pianissimo in public.

Psychophysical effects also cause musicians to limit their dynamic range. They often do so quite unconsciously. Instrumentalists spend years learning to coordinate the muscles needed to coax an appealing tone from their instrument. One consequence of that is a tendency to equate the relative loudness of their playing with the amount of muscular effort they expend. What feels to the musician like an ample increase in intensity, however, may be barely noticeable to the listener. The phenomenon has been studied with respect to singers. When asked to double the loudness of a continuous vowel sound, singers on the average only increase their intensity by about five decibels. Yet as far as the listener's ear is concerned a singer must achieve a 10-decibel increase in acoustical power before a doubling of loudness is apparent.

In this connection, any reader who knows a musician, amateur or professional, can conduct a simple test that will demonstrate whether or not the musician's dynamic range is large enough to include the six basic dynamics. The test requires no equipment beyond the musician, his instrument and a listener; its basis is the demonstrated fact that an acute listener readily remembers the loudness levels that correspond to the six basic dynamics.

The musician should select a pitch and play the selected note to the best of his ability at each of the six dynamic levels, holding the note for a few seconds at each level. He should then repeat the performance but in random order (as specified, for example, by shuffled flash cards). If the listener has difficulty naming the random levels accurately, this demonstrates that the musician's dynamic range is too small. For example, in the context of a performance an audience would be unable to distinguish between the player's transition from forte to piano and his transition from forte to pia-

Announcing a mid-size car in the Thunderbird Tradition.

THE 1975 FORD *Elite*

Elite shown with optional WSW tires, deluxe bumper group, glass Moonroof and deep dish aluminum wheels.

Ford Elite combines the operating economy of a mid-size car with styling and luxury in the Thunderbird tradition. And in the Thunderbird tradition of value, Elite comes to you complete. Unique twin opera windows and grained vinyl roof. Driving conveniences standard, like 351 CID V-8, power steering, power front disc brakes, SelectShift transmission and steel-belted radial ply tires. Elite is available with power-operated Moonroof and other Thunderbird inspired options. And it's designed with a big 26½ gallon fuel tank which means a cruising range you can really rely on. The personal luxury mid-size Ford Elite for 1975. Built for the way you drive today.

Elite Interior Decor Group option with AM radio, automatic speed control.

THE CLOSER YOU LOOK, THE BETTER WE LOOK.

FORD ELITE

FORD DIVISION Ford

What we're doing for your health is a lot more comforting than a bowl of chicken soup.

When you're sick, you need a good bowl of soup, a tender hand on your hot brow, sympathy and understanding. Little things at home relieve a lot of your misery.

But a big corporation offers human solace too. Many of the medicines you find at your drugstore are made with our chemicals.

Aspirin to bring down your burning fever, lozenges to soothe your poor sore throat, sedatives to let you fall asleep at last.

We help you get through a case of the sniffles. But we're also involved in more serious things.

We make radioactive diagnostic materials that pinpoint cancer.

And plastic for heart valves human beings can live with.

We invented an Oxygen Walker. It helps people with emphysema breathe a lot easier. And move freely around again.

Once, blood cells could be stored only a few weeks. With our Cryogenic freezing equipment and liquid nitrogen, the time is now years.

Our CentrifiChem® blood analyzer helps a hospital make more than 20 vital blood tests with up to 300 chemical analyses an hour.

Much of the life-saving oxygen in a hospital is ours.

We make gases that sterilize surgical equipment.

And batteries for hearing aids.

And we constantly experiment. Because one innovation often leads us to another.

We are 123,000 involved human beings who work all around the world on things and ideas for every basic need.

So today, something we do will touch your life.

And may even help save it.

UNION CARBIDE

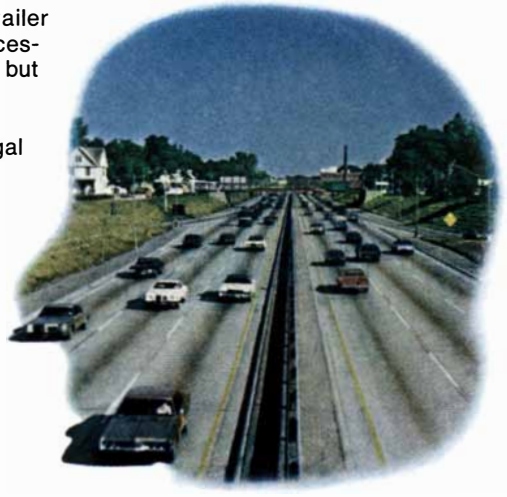
Today, something we do will touch your life.

Because it's aluminum, this transport helps hold down fuel costs —by delivering more per trip.

A trailer's empty weight determines how much gasoline it can deliver when it's full—without exceeding weight limitations. So, in most states, trailers built with aluminum components can carry as much as 780 gallons more per trip. Safe, sound and legal. Enough to "fill up" the 20-gallon tanks of 39 extra cars.

You are looking at an aluminum trailer that weighs 9,450 pounds with accessories. A trailer of equal capacity, but made of a heavier material, could weigh as much as 15,720 pounds. That's why the mathematics of legal load limitations favor aluminum. Even when the trailer is running empty, fuel savings mount up because of its lighter weight.

Bonus payloads have always been one of the big reasons why so many over-the-road trailers are made of lightweight aluminum. Alcoa® aluminum disc wheels and truck components of aluminum can reduce weight even more. And now when saving energy is more important than ever, aluminum continues to help truckers deliver greater payloads and save energy.



Strong, lightweight aluminum alloys can also help cars become lighter and less expensive to operate. Saving gas, brake wear, tire costs and even registration in some states.

Aluminum helps save energy in your home, too. When properly applied over reflective aluminum foil, Alcoa Siding forms a protective insulating envelope that can help reduce heat loss through your walls. You can be more comfortable the year 'round and cut down on heating and cooling bills. Clearly, aluminum is its own best advocate. A metal that's basic to our way of life. If you would like to know more about how aluminum is helping to conserve energy, write for our free brochures. Write Aluminum Company of America, 352-L Alcoa Building, Pittsburgh, PA 15219.

The reasons for using aluminum are found in aluminum itself.

ALCOA

nissimo, and so the composer's intended message would be lost.

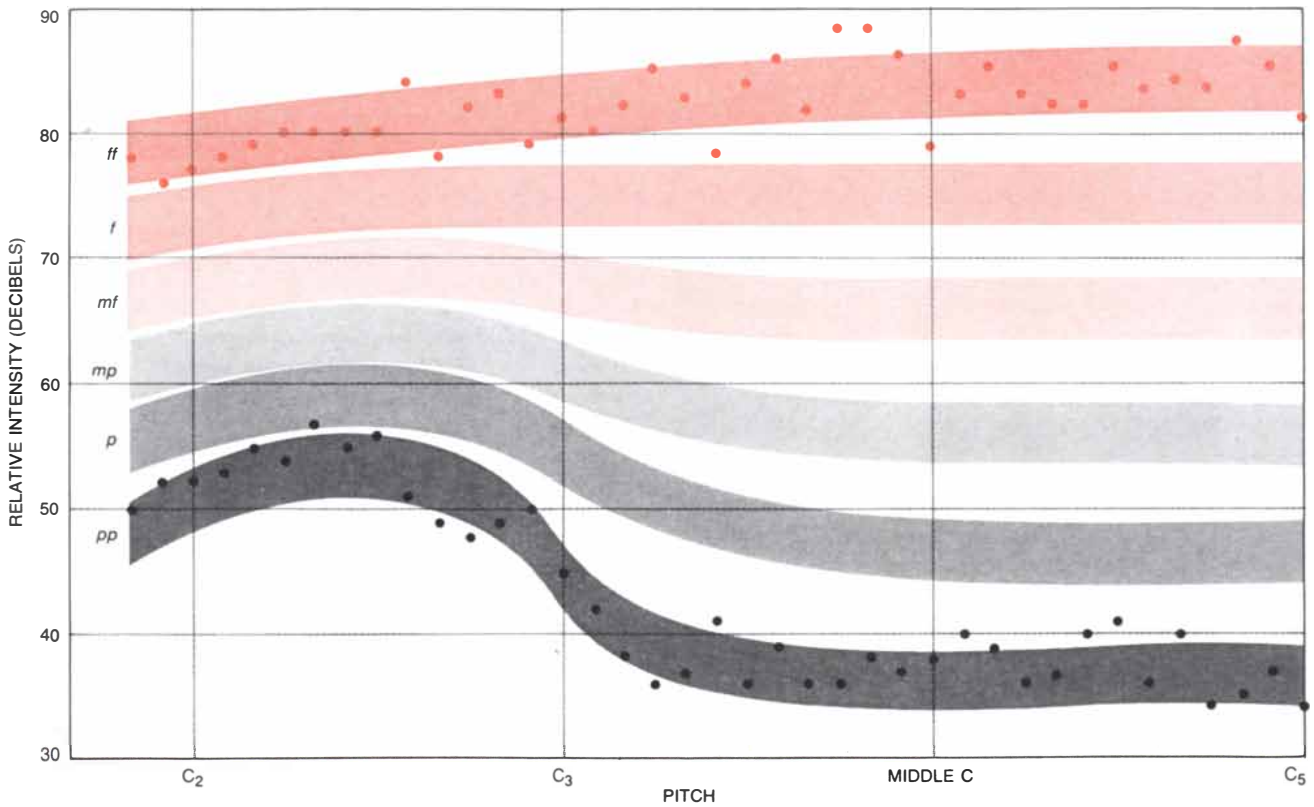
The artificial blandness imposed on canned music by the suppression of variations in loudness is by no means the only technological injury being inflicted on music today. Many will remember the title sequence in the film "Fiddler on the Roof." The silhouette of a distant rural village at dusk is seen against a red-gold sky and the eye is drawn to—what else?—the figure of a fiddler on a rooftop. The film's sound track then entirely destroys the appealing image by acoustically depositing the fiddler in our laps. The crime is committed in reverse a few reels later when we are surrounded by peasant instrumentalists and boisterous singers in a wedding scene: the carefully moderated sound altogether fails to support the exuberant imagery on the screen.

Television is an even greater offender. In a televised orchestral concert one is likely to be presented with a solo oboe passage that is just as loud as the fortissimo of the entire orchestra. What the composer hopes to use to evoke an emotional response the broadcast engineer views as a deficiency to be corrected; the loud passages overload his equipment and the soft ones become buried in noise. The engineer uses electronic devices called "compressors" to correct the supposed deficiencies by making fortissimo and pianissimo identical.

Many listeners attribute the poor quality of television sound to the smallness of the loudspeaker in their set. The loudspeaker usually does have a poor frequency response, but the ear can compensate for that kind of distortion. For example, we recognize a 100-hertz trombone note even though it is reproduced by a loudspeaker that excites no frequencies below 300 hertz. But television sound still lacks vitality even when it is played through a high-fidelity system; the ear cannot compensate for variations in loudness that have been suppressed, and it soon finds the constant dynamic level monotonous.

Current technology has a solution to this difficulty. If receivers were equipped with "expansion" devices to decompress the broadcast engineer's compressed signal (and regulation would be required to ensure that the compression at the broadcast end was uniform), the dynamic range of the orchestral performance could be restored. Alternatively the broadcaster could transmit a completely compressed audio signal along with an auxiliary signal that specified the original intensities. Conventional receivers would reproduce the music as they do now, but those who wished to equip their sets with a decoder and a variable-gain amplifier could restore the panorama of loudness variations that existed in the original performance.

Even such innovations as these, of course, will be of little value unless conductors insist on a minimum quantum of audible change in loudness on the part of their instrumentalists. In some instances this may not be practical. For example, the findings of Clark and Luce suggest that oboists seldom achieve a dynamic range of more than 7.4 decibels. Because the ear ignores variations of five decibels or less this means that only exceptionally skilled oboists can play at more than two different degrees of loudness. Perhaps as far as this instrument is concerned a convention could be established so that the three notations pianissimo, piano and mezzopiano would be played at the oboist's soft level, and the notations mezzoforte, forte and fortissimo would be played at the loud level. I personally would prefer to see the integrity of the time-honored system of notation preserved by developing more skilled oboists, a solution that would benefit performer and audience alike. After all, it is effective dynamic contrast that makes music exciting.



GREAT DYNAMIC RANGE, with a fortissimo in the upper register that averages 45 decibels louder than pianissimo, can be achieved with the bassoon, as this graph shows. The instrumentalist was encouraged to develop as great a dynamic range as possible by a conductor who emulated Arturo Toscanini. Even in the lower register the spread leaves room for the intermediate dynamics.

THE PHYSIOLOGY OF THE GIRAFFE

The head of the animal is so far above the heart and the lungs that the task of supplying it with oxygenated blood calls for a remarkably high blood pressure and unusually deep breathing

by James V. Warren

The giraffe, the spectacular mammalian adaptation to browsing on tree leaves, has been an object of curiosity since prehistoric times. There is archaeological evidence that it was then found not only in Africa but also in southern Europe and the Near East. Although the species later receded to Africa as its sole habitat, the animal continued to be known in the ancient world around the Mediterranean as one of the wonders of nature and was imported for exhibition. Historical accounts record that Julius Caesar paraded giraffes in the Colosseum, and that other heads of state presented the animal as a unique gift to a distinguished visitor (as the panda has on occasion been presented in recent years).

We are no less intrigued by the giraffe in our own time, but it is a curious fact that not until comparatively recent decades was any question raised about the physiological puzzles presented by this improbable animal. The first physiologist to ask such a question, as far as the record shows, was the late August Krogh of Denmark, winner of the Nobel prize in physiology and medicine in 1920 for his studies of capillary blood vessels. In the Silliman Lecture at Yale University in 1929 Krogh wondered about the great pressure the capillaries in the legs of the giraffe must bear because of the high column of blood weighing on them. Pointing out that the giraffe's heart is eight feet or more above its feet, he observed that the effect of gravity, added to the heart's pumping action, should be expected to make the blood pressure in the legs so high that it would force fluid out of the capillaries.

"It would be extremely interesting," Krogh remarked, "to know just how the giraffe avoids the development of filtration edema in its long legs. Unfortunately, we have not found it possible to obtain giraffe blood for determination of the osmotic pressure." Nor was Krogh ever able to obtain a giraffe for study.

Krogh's question did not arouse wide interest at the time, and it was not revived until nearly two decades later. This time the query was put in another form: How does the giraffe manage to pump blood up its long neck to its brain? In a giraffe standing upright the head is between seven and 10 feet above the heart, whereas in man the vertical distance from the heart to the brain is only a foot or so, and in most other animals, including large ones, it is little more.

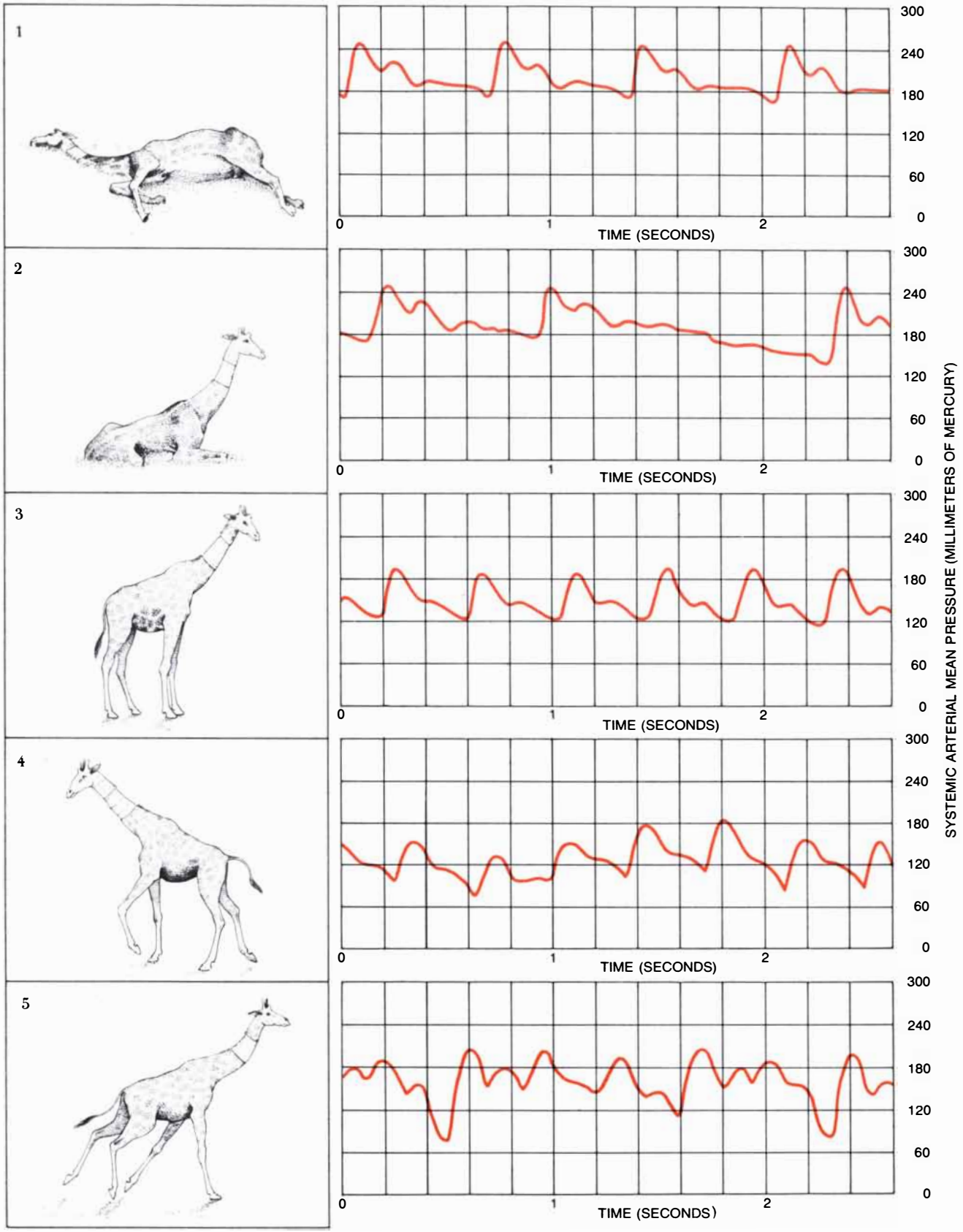
The performance of the giraffe's heart and circulatory system in driving the blood against gravity to such a height above the heart was quite remarkable when one thought about it. The phenomenon attracted the attention of physicians interested in problems of aviation medicine during World War II. They calculated that the gravitational force a giraffe must overcome to supply blood to its brain corresponds roughly to the force of acceleration, amounting to several *g*, that fliers encounter in maneuvering high-speed military aircraft. In order to prevent blacking out because of the great change of blood pressure in the brain under those circumstances a "*g* suit" that buffered the acceleration impact had been developed for fliers. Medical investigators thought it might be worth while to look into the natural mechanisms with which the giraffe handles its severe circulatory challenges. Here was a living experiment of nature presenting highly unusual capabilities. Study of the giraffe's cardiovascular system might be expected to yield new and perhaps useful information.

Interest in the problem persisted after World War II. When John L. Patterson, Jr., Otto H. Gauer, Joseph T. Doyle and other investigators in the U.S. learned of a similar interest on the part of Robert H. Goetz and his colleagues in South Africa, they suggested setting up an international study group. In the late 1950's the American group visited South Africa and subsequently did studies in the U.S., using cows as the experimental animals, to get comparative data on circulatory and respiratory functions. More recently an American team that included Robert L. Van Citters, Dean L. Franklin, Stephen F. Vatner, Thomas E. Patrick and me undertook further field investigations in Kenya. By the use of telemetry we obtained direct measurements of blood pressure and blood flow in giraffes roaming free in the field.

The height of a large adult giraffe is commonly in the range from 15 to 18 feet. The animal's heart lies approximately midway between its head and its feet, that is, usually seven feet or more below its brain. For analysis of the operation of the giraffe's circulatory system the comparative blood pressures at two significant levels were needed: at the heart and at the brain. Our group arranged to obtain measurements of these pressures, and of the blood flow as well, under a variety of natural circumstances: with the animal lying flat on the ground, standing quietly erect and actively moving about.

For direct and accurate measurement of the blood pressure we used a sensitive pressure gauge implanted in a carotid artery. The amount of pressure, sensed by a diaphragm in the device, was transduced into a radio-frequency signal that could be picked up by a receiver as much as a third of a mile away. The animal was followed during the period of measurement, and a record of the blood-pressure variations was made on magnetic tape and charted later.

The subjects were wild giraffes cap-



PRESSURE AND HEARTBEAT vary in accordance with the activity of the giraffe. When the animal is lying down (*1*), with its heart and its brain at the same level, the blood pressure in the carotid artery ranges from 180 to 240 mm. Hg. (millimeters of mercury). The heart rate, with four major peaks in 2.5 seconds, is about 96 beats per minute. As the animal raises its head (*2*) the blood pressure stays much the same but the heart rate slows temporarily. Standing (*3*) and walking (*4*) raise the heart rate to some 150 beats per minute, while arterial blood pressure falls to a range of from 90 to 150 mm. Hg. Galloping (*5*) brings the heart rate to maximum: 170 beats per minute. Highest blood pressures in galloping are 220 mm. Hg.; deep drops in pressure coincide with front-hoof beats.

tured by lasso from a fast-moving vehicle on the Kenya plains. After the giraffe was captured and tied down flat on the ground the pressure gauge was implanted in the animal's neck through a small slit made under local anesthesia in the carotid artery. In a giraffe the carotid is usually more than six feet long, is relatively straight and has few branches. The gauge was placed in the upper part of the neck near the head. At the same time a small ultrasonic flowmeter, measuring the velocity of blood flow by means of the backscattering of high-frequency sound waves from the red cells, was implanted. The apparatus, including a small transmitter and mercury batteries, was taped onto the giraffe's neck. At the end of the period of observation the animal was recaptured, the instruments were removed, the incisions were repaired and the giraffe was released unharmed to join its fellows in the bush.

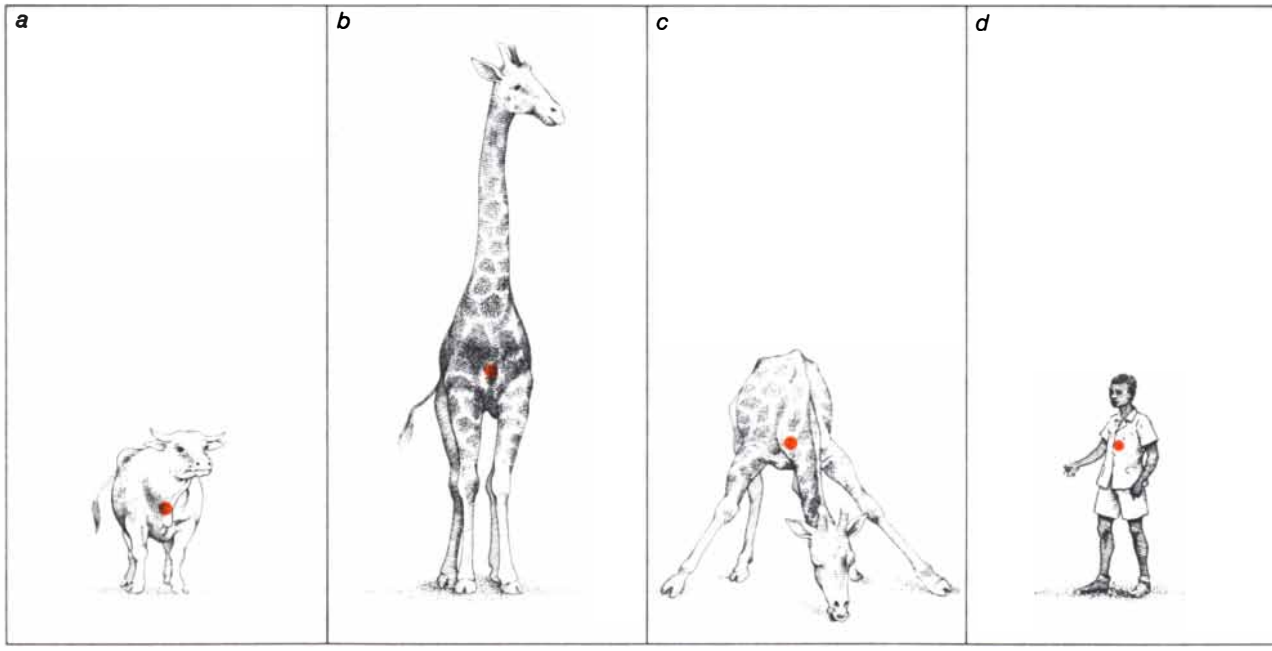
The initial blood-pressure measurement, made while the giraffe was still lying on the ground, could be considered to represent the pressure generated at the animal's heart level, even though the gauge was near the head. Obviously in an animal stretched out on the ground the blood circulation is not much influenced by gravity; therefore the blood pressure in the giraffe's carotid artery should be about the same near the heart as near the head. (Experiments with the gauge implanted in the carotid at the base of the neck have confirmed this.)

Not surprisingly, the giraffe's blood pressure at the heart level proved to be very high—higher, indeed, than that recorded in any other animal. The systolic pressure at the heart level ranged from 200 to 300 millimeters of mercury and the diastolic pressure from 100 to 170; the average was 260/160. Compared with man, the giraffe is "hypertensive": even at 200/100 millimeters of mercury its blood pressure is far above the 120/80 average in a man at rest. The giraffe's hypertension, however, is not hypertensive vascular disease but a necessary condition for supplying the brain with blood at sufficient pressure when the animal stands erect. Other factors may also be involved in the circulation to the brain, as we shall see.

When the giraffe was freed, it usually raised its head and remained in a squatting position with its legs under its body for a few seconds before rising to its feet. Conceivably this pause may be a behavioral adaptation to allow time for adjustment of the circulation. It is well known that in man an individual with low blood pressure sometimes suffers dizziness or even blacks out after standing up abruptly from a reclining position. At any rate, the blood pressure in the giraffe's carotid was substantially less after it stood up than it was when the measurement was recorded at heart level. Taking into account that the instrument was implanted in the neck 14 inches below the brain, calculations based on recordings when the giraffe was standing quietly indicated that the pressure of the blood entering the brain itself averaged approximately 120/75. That is about the pressure at which blood perfuses the brain in man and in most other animals. Apparently the barostat, or pressure control, is set at about the same reading in most mammals, thereby providing that the brain will generally be bathed with blood at a pressure of about 120/80.

Blood pressure, of course, is by no means constant; it fluctuates rather widely even in "normal" individuals not affected by hypertensive illness. The pressure is influenced by many kinds of physical or mental stress. After a giraffe was released and had run off to rejoin its herd, its blood-pressure records generally reflected the nature of its activities. While it was standing still or walking, the carotid pressure ranged between 140/90 and 180/120. During a hard run, as when it was being chased for recapture, the pressure rose to about 220/150. That was still considerably lower than the pressure recorded when the animal lay prone.

What happens when a giraffe bends its neck down to drink? The pressure within the blood vessels of the brain and the eyes should then be higher than that at the level of the heart. Why does the high pressure not rupture those delicate vessels or at least force leakage from



HEART OF A GIRAFFE is located from seven to 10 feet below its brain when the animal is standing (*b*). In an average quadruped, a cow in this example (*a*), and in man (*d*) the distance between the heart and the brain is far shorter. In a giraffe the brain's supply of blood is ensured by "abnormally" high blood pressure. This might be a severe handicap when the animal is drinking (*c*), except that its posture reduces the distance between the heart and the brain. The back pressure of the cerebrospinal fluid is added protection.

NOW $69.95

The Sinclair Scientific just solved your biggest problem. Price.

(Logs, trig, arithmetic. Scientific notation, too.)

The Sinclair Scientific is the only pocket calculator that offers scientific capacity at a truly affordable price. And look how much you get:

log and anti-log (base 10)
sin and arcsin
cos and arccos
tan and arctan
automatic squaring
automatic doubling
x^y, including square and other roots
four basic arithmetic functions
plus scientific notation (10^{-99} to 10^{+99}).

All for an incredible $69.95.

What makes a scientific calculator scientific?

To be a really valuable tool for engineers, scientists, technicians and students, a calculator must provide all of the above.

Clearly, a scientific calculator without scientific notation severely limits the size of numbers with which you can work easily.

And scientific notation without transcendental functions is little more than window dressing on an arithmetic calculator.

Granted, there are companies other than Sinclair offering excellent units with all the essential ingredients.

But they sell at much higher prices.

What's more, the Sinclair Scientific isn't just portable. It's pocketable.

Less than ¾-inch thin. And 3¾-ounces light. It's the world's thinnest, lightest scientific calculator.

actual size

What makes the Sinclair Scientific so inexpensive?

Two important technological breakthroughs.

First, the British-built Sinclair Scientific has a single integrated circuit. Engineered by Sinclair.

Second, Sinclair's exclusive keyboard has only four function keys. All of which provide "triple-action" by changing from standard to upper or lower case mode.

Old hands at small miracles.

Sinclair has been an innovator in calculator miniaturization right from the start.

In the last two years Sinclair brought to America the Sinclair Executive and Executive Memory – the world's thinnest, lightest calculators – as well as the Cambridge.

The Sinclair Scientific is backed by an unconditional one-year replacement warranty.

Sinclair also maintains a service-by-return mail operation in the U.S. (and everywhere else in the world) to handle any product problems.

How to get your Sinclair Scientific.

The Sinclair Scientific may be ordered by phone or mail. And you may charge it to your American Express, Diners Club, Master Charge or BankAmericard account.

If you're not completely satisfied, you may return the unit within 2 weeks of receipt for prompt refund.

Just fill in the coupon and mail it to: Sinclair Radionics, Inc., 375 Park Avenue, New York 10022. Or call (800) 223-5764, toll free.

sinclair™
SCIENTIFIC
The logical choice.

Specifications

Functions:
4 arithmetic
2 logarithmic
6 trigonometric

Keyboard:
18 key format with 4 "triple-action" function keys using standard, upper and lower case operation.

Display:
5-digit mantissa
2-digit exponent
(both signable)

Exponent:
200-decade range, from 10^{-99} to 10^{+99}

Logic:
Reverse Polish, with post-fixed operators for full flow chain calculations.

Power Source:
Battery operated with 4 inexpensive AAA penlight batteries, providing over 25 hours of use.

Size:
4⅜" high;
2" wide; 11/16" thick.

Weight:
3¾ oz.

Warranty:
1 year.

ORDER FORM

For credit card phone orders call (800) 223-5764, toll free. (New York residents call (212) 688-6623.)

To: Sinclair Radionics, Inc. 375 Park Avenue, New York, New York 10022

Please send me _____ Sinclair Scientific(s) at $69.95 (plus $1.50 per unit, shipping and handling) including batteries, carrying case, instruction booklet and warranty. New York residents add sales tax.)

☐ Enclosed is my check for _____.

☐ Please charge my credit card account.

Credit Card _____

Account No. _____

Expires _____

Master Charge Code # (4 digits) _____

Signature _____

Name _____

Company _____

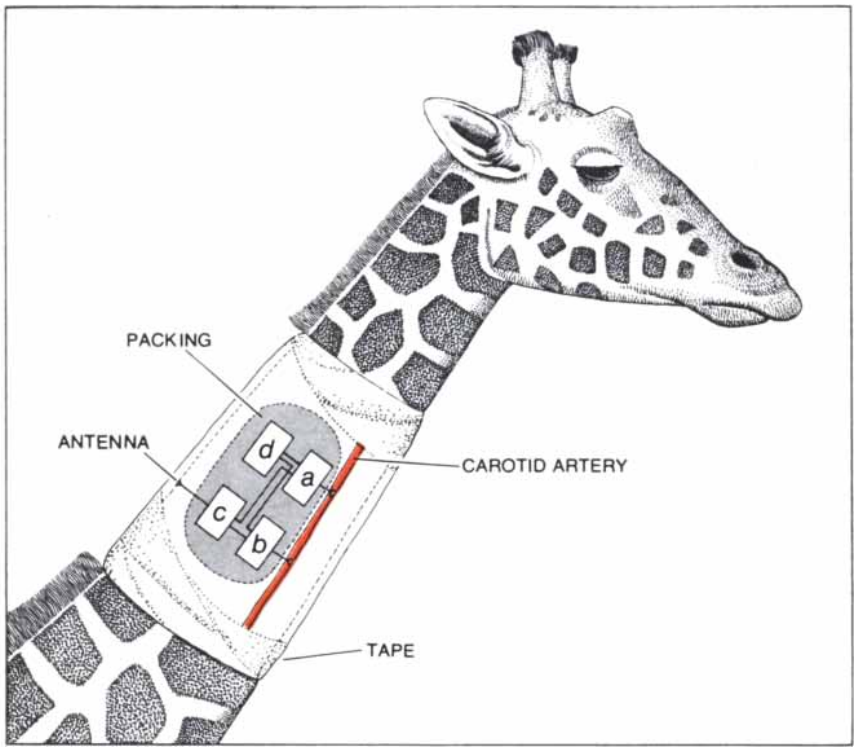
Address _____

City _____

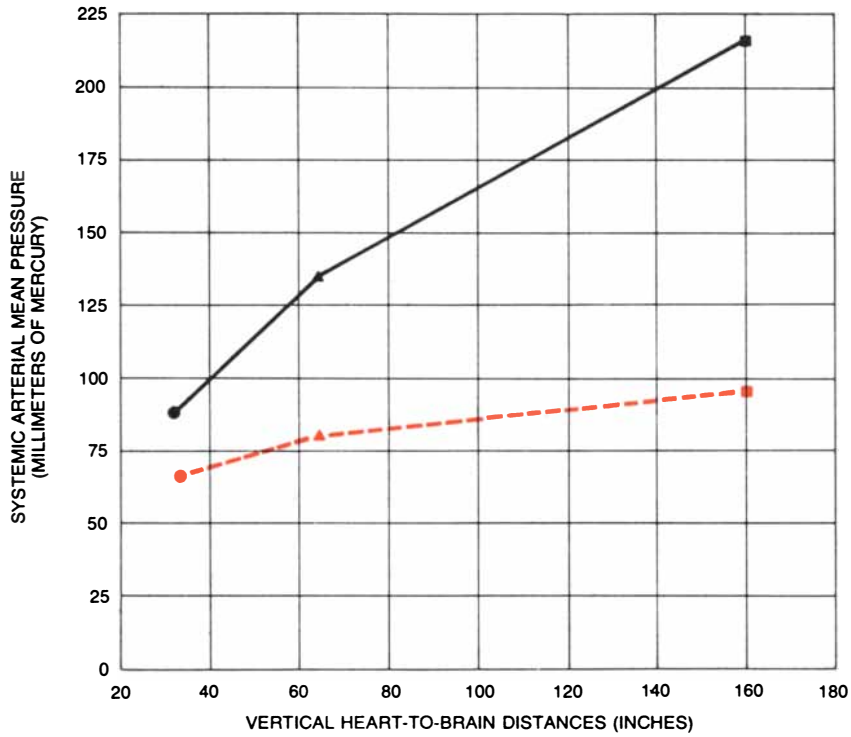
State _____ Zip Code _____

16 D

In the United Kingdom: Sinclair Radionics, Ltd., London Road, St. Ives, Huntingdonshire.
In Germany: Sinclair Elektronik GmbH., 8012 Ottobrunn (Munchen), Rosenheimer Landstrasse 39.



TELEMETRY PACKAGE included a pressure gauge (*a*) containing a sensing diaphragm that transduced pressure variations into radio-frequency signals, a flowmeter (*b*) that sensed blood velocity by means of the backscattering of high-frequency sound waves from red blood cells and signaled a radio transmitter (*c*) accordingly, and the batteries (*d*) that powered the transmissions. Auxiliary components were protected from shock with foam-rubber padding. The gauges were implanted through separate incisions in the carotid artery.



COMPARATIVE BLOOD PRESSURES at the level of the heart (*black*) and the brain (*color*) show a consistent increase in relation to heart-brain distance. In man, with an assumed heart-brain distance of 34 centimeters, a mean arterial pressure equal to 90 millimeters of mercury at the level of the heart suffices to deliver blood to the brain at a mean pressure of about 65 mm. Hg. In the giraffe the equivalent values are 215 mm. Hg. at the level of the heart and 90 mm. Hg. at brain level. The equivalent values in the cow are closer to man's.

them? This brings us to the question originally asked by Krogh: How does the giraffe avoid the development of edema in its long legs? On the basis of established facts we must consider what mechanisms may control the blood circulation and pressure in the giraffe.

Analysis of giraffe blood has shown that its chemistry is not grossly different from that of human blood, and so it is unlikely that its composition makes it unusually resistant to passing through the blood-vessel walls. In the giraffe the walls of the arteries (and of the heart itself) are thicker than they are in other mammals. This would not, however, prevent leakage through the walls of the finer blood vessels in the event of a large difference in pressure between one side of the wall and the other. We are therefore led to the reasonable hypothesis that in the giraffe a heightened pressure within the blood vessels is counterbalanced in some way by an increase in the pressure outside the vessels. In the brain such a function may be served by the cerebrospinal fluid that bathes the brain and spinal cord. In effect this fluid, in which the blood vessels are immersed, serves as a *g* suit buffering the impact of the downward rush of blood when the giraffe bends down to drink. The animal also employs a behavioral device that minimizes the gravity problem: when it bends to drink, it spreads its front legs wide so that its chest is lowered, bringing the heart closer to the ground.

It seems likely that the capillaries in the giraffe's legs are similarly protected; the high pressure within the vessels is counterbalanced by a corresponding external pressure. In this case the *g* suit is provided by the general extracellular fluid bathing the body tissues. The giraffe has a thick, tight skin that easily sustains these high pressures.

In short, part of the answer both to Krogh's query and to the bending-to-drink problem is rather simple: The principal factor preventing edema below the heart level seems to be high extravascular pressure counteracting the high pressure within the blood vessels. Quite clearly, however, that is only part of the story.

In the giraffe as in other animals, including man, the pumping action of the muscles plays an important part in assisting blood circulation and thus relieving the pressure in the legs. When a person has been sitting or standing motionless for some time, it is not uncommon to find that his ankles have begun to swell; this slight edema results from the sluggishness of the circulation in the

The ideal

To tap Alaska's vast reserves
of vitally needed energy resources
while preserving its unique environment.

The real

To tap Alaska's vast reserves
of vitally needed energy resources
while preserving its unique environment.

AtlanticRichfieldCompany

Save up to 60% on Christmas gift books

Here is the perfect way to please everyone on your Christmas gift list . . . call toll-free, use coupon below or send purchase order

Books By Phone has gathered a magnificent collection of the most beautiful books ever published...the kind you would be proud to display in your home.

These richly bound original editions are available to you from Books By Phone, America's telephone bookstore at substantial savings from original publishers' prices.

Order them for your clients, your associates, your family. They'll be a lifelong reminder of your good taste.

Credit Card, Check or Purchase Order
Charge books to your American Express, BankAmericard, Master Charge, Diner's Club credit card. You can also reserve your books and send a check, or send a company purchase order and we will bill you. Postage and handling and any sales tax are charged with purchase.

Call Toll-Free — We Never Close
Call our helpful operators any time, days, nights, Sundays, holidays—from your home, your office. We serve every phone in America toll-free.

Free Gift Card With Your Personal Message
We mail books anywhere in the world and will include an attractive gift card with your personal message at no extra cost.

Shipped Promptly
You don't have to wait to make your selections. Just pick up the phone anytime.

Order All Books This Convenient Way
You can also order all current books—over 200,000 books from 3,000 publishers—from Books By Phone—at regular bookstore prices.

N101. THE ART OF WALT DISNEY. From Mickey Mouse To The Magic Kingdoms, by Christopher Finch. A full account of Disney's career, illustrated with hundreds of previously unpublished drawings, paintings and photographs. Shows clearly how animated films are made—with authentic story sketches, layouts, animation drawings and background paintings.
Orig. Pub. at $45.00 *Special* **34.98**

N102. THE SHELL. Five Hundred Million Years of Inspired Design by H. & M. Stix, photography by H. Landshoff. This is a literal trip through a great art gallery—with 203 exciting illustrations including 82 hand-tipped plates in full color—shows clearly why people are fascinated by owning, collecting and depicting shells in art and jewelry.
Orig. Pub. at $28.50 *Special* **22.98**

N103. NORMAN ROCKWELL, Artist and Illustrator, by Thomas S. Buechner. Through wars, depression, strife and the exploration of space, Rockwell has depicted average America with an eye for the everyday happenings of which lives are made. This tremendous volume with many large foldout spreads includes 600 illustrations, all 317 Saturday Evening Post covers, and ads, posters, story illustrations—a Rockwell's eye view of sixty years of American social history.
Orig. Pub. at $60.00 *Special* **44.98**

N104. THE PRO FOOTBALL EXPERIENCE by David Boss. The most remarkable and beautiful sports photography ever assembled—with more than 200 studies in full color, several in double foldout spreads opening to a full 3½ feet. The emotional and physical impact of the game comes alive with almost unbelievable reality.
Orig. Pub. at $25.00 *Special* **19.98**

N105. ANDY WARHOL. By Rainer Crone. This lavishly illustrated book—the first compendium of Warhol's creations—provides comprehensive descriptions and evaluations of all his paintings, graphic sculpture, films up to the 1970's. 332 pages, 256 illustrations (16 in full color).
Orig. Pub. at $22.95 *Special* **8.98**

N106. DALI. Edited and arranged by Max Gerard. Superbly printed illustrations including startling details and many works never before reproduced, juxtaposed with Dali's own thoughts—all wrapped in a candy box cover. A breathtaking panorama of the genius of surrealism.
Orig. Pub. at $37.50 *Special* **29.98**

N107. CURRIER & IVES Chronicles of America. Ed. by John Lowell Pratt. 220 beautiful color prints recapture the unsophisticated, sentimental era in America through the magic of the lithographic art of Currier & Ives.
Orig. Pub. at $17.50 *Special* **6.98**

N108. AFRICA: Images and Realities. By Eric Robins and Blaine Littell. A superbly illustrated look at Africa's landscape, the rich diversity of its peoples and cultures, the splendors of black African history and the psychological legacies of white imperialism and the slave trade.
Orig. Pub. at $18.50 *Special* **8.98**

N109. HISTORY OF WORLD WAR I. Editor-in-Chief, A. J. P. Taylor. Over 350 photographs, many in color. A conflict beyond all previous experience—which destroyed European life as it had been. Written by a team of leading military historians from many countries, traces the campaigns of World War I on both Fronts, from Sarajevo to the Treaty of Versailles. 11¼"x9", 288 pages.
Special **9.98**

N110. HISTORY OF WORLD WAR II. Editor-in-Chief, A. J. P. Taylor. Over 350 photographs, many in color. World War II was the most terrifying reality of modern times and it affected the lives of everyone on earth. In this book, a team of eminent historians analyzes its course from the Third Reich to the atom bomb at Hiroshima.
Special **9.98**

N111. THE GREAT BOOK OF WINE. The most complete and beautiful book on wine ever produced. Illustrated in full color with 44 specially prepared maps of wine regions, complete information on how to read a wine label (54 of which are shown in color) and how to recognize the quality of the wine you buy. A complete encyclopedia, perfect gift book, a must for any wine lover's library.
Orig. Pub. at $50.00 *Special* **19.98**

N112. THE DOLL by Carl Fox, photography by H. Landshoff. Enchanting, exciting, vivid view of the tremendous variety of dolls. Victorian, French, Oriental, American Indian, etc., dolls from many ages and cultures. An unending feast for lovers of dolls, art, sculpture, toys, antiques. Hundreds of full page plates—bound in luxurious velvet.
Orig. Pub. at $35.00 *Special* **27.98**

N113. INDIAN ART IN AMERICA: The Arts and Crafts of the North American Indian. By Frederick J. Dockstader. The full range and beauty of the arts of the many Indian tribes of the U.S. and Canada are shown in vivid detail. 70 color and 180 black and white illustrations of their paintings, sculpture, masks, costumes, tools, household articles, ceremonial equipment, ornaments, weapons.
Orig. Pub. at $27.50 *Special* **10.98**

N114. VINCENT VAN GOGH. By Marc Edo Tralbaut. The most comprehensive study of Van Gogh ever published—an intensely moving and revealing account of his life and work, his crises and defeats. Contains reproductions of drawings and paintings never before in any book. Hundreds of reproductions in black and white and full-color, 10"x12".
Orig. Pub. at $42.50 *Special* **19.98**

We made 832,000 slide changes on our projector. Without changing our projector.

There are 36 Sawyer's® Rotomatic® Slide Projectors in the G A F exhibit at Disneyland that have made 832,000 slide changes a year.

Yet we have never had to change them. Because none of them has had a single mechanical breakdown. All they've ever needed during a year's operation is an occasional new bulb and stoppage for dusting.

And not only do we make our slide projectors dependable, we were smart enough to make them with a number of intelligent features. Like the Pop-up Editor, for instance. Automatic focus and timer. Remote control. And an exclusive 5-way slide handling system.

If you've been considering any other slide projector, isn't all of this enough to change your mind?

Another fine product from gaf®
140 W. 51 Street, N.Y., N.Y. 10020

Sawyer's Rotomatics. The Dependable Ones.

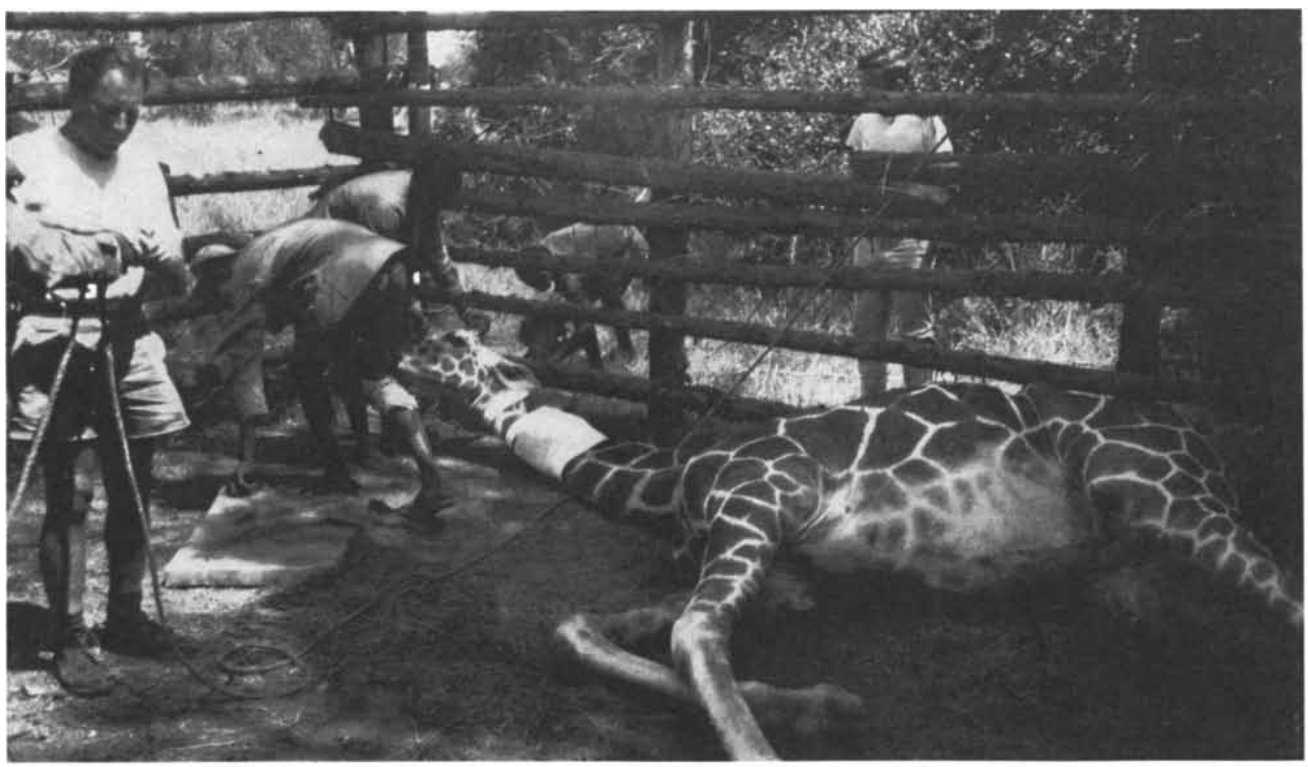
inactive legs. Movement of the legs or exercise of the body as a whole is indeed a major factor in the pumping of blood from the legs back to the heart. (In individuals with certain types of varicose veins the mechanisms responsible for aiding the circulation may operate inadequately.) The force required to raise the blood from the legs to the heart is not great, either in man or in the giraffe, because the artery-vein system from the heart to the legs and back again simulates a *U*-tube. That is to say, on the same principle as the operation of a sump pump, little pressure is needed to bring the blood back up the return arm to the same level as the source of the pumping.

As for the question of how the giraffe drives blood from the heart up to the brain, it appears that this remarkable performance can be accounted for fully by the high pressure at which the blood is discharged into the arteries by the heart. Conceivably the artery-vein system in the long neck might make a contribution to the circulation by acting as an inverted *U*-tube, producing a siphonlike effect. There is no evidence, however, that such assistance is needed. The arterial pressure itself is sufficient to deliver the blood to the brain at a pressure adequate to nourish it.

It has been suggested that the giraffe's carotid arteries possess an interesting special feature. Before entering the brain each of these arteries apparently divides into a network of fine vessels that resembles a system found in certain other animals: the rete mirabile, or "wonderful net." In some animals this network serves as a countercurrent heat exchanger that enables species such as wading birds to maintain a normal body temperature even though their extremities become very cold; blood returning from the extremities is warmed before it reenters the general circulation. Similar networks have been found to perform other exchange functions, such as transferring oxygen or electrolytes. It may be that the rete mirabile at the entrance to the giraffe's brain acts in some way to regulate the blood pressure in the brain. This is a question that has not yet been satisfactorily answered.

In addition to circulatory problems the giraffe is burdened with certain other challenges. One of the most interesting has to do with respiration. The trachea in the giraffe's long neck may be more than five feet long and two or more inches in diameter, so that its total capacity may amount to 2.5 quarts or more. This is "dead space" in the sense that, although each breath of air must fill the windpipe as well as the lungs, the air in the pipe serves no useful purpose for gas exchange. If man had to deal with such a large dead space, he would almost suffocate. His inhalation of a breath of fresh air would hardly suffice to fill his windpipe, hence none would reach the lungs; conversely, the carbon-dioxide-laden exhalation from the lungs would be trapped in the windpipe and come back into the lungs in the next inhalation. The giraffe solves this problem by hyperventilation, breathing more deeply and more rapidly than man. Giraffes even at rest have been found to have a respiration rate of more than 20 breaths per minute, whereas the corresponding rate in man is 12 to 15. In contrast to man and other mammals, the giraffe spends more time in inhalation than in exhalation. Nevertheless, its arterial blood carries a marginally low content of oxygen. It has been found that giraffes show distress in situations where the air is low in oxygen, as at high altitudes. They are much less adaptable than man is to such conditions.

The giraffe is a fascinating anomaly of nature. Investigators have learned much from unusual kidneys in primitive fish, from the urine-concentrating ability of desert rats for water conservation, from the electrocardiograms of whales and from heart failure in cattle at high altitudes. The giraffe too, as odd an animal as any in man's eyes, probably has a great deal to tell us about how we are put together.



CAPTIVE GIRAFFE lies outstretched in a corral in Kenya while experimenters implant a pair of gauges in a neck artery. The animal is one of several giraffes that carried telemetering apparatus so that observers could record natural variations in blood pressure.

Contrast and Spatial Frequency

The visible details of an object often consist of contrasting areas with a regular spacing, or spatial frequency. The visual system is more sensitive to certain of these frequencies than it is to others

by Fergus W. Campbell and Lamberto Maffei

The ability of men and other animals to perceive the details of objects and scenes is determined to a large extent by how well their visual system can discern contrasts: the differences in brightness of adjacent areas. The size of the visual image on the retina also plays an important role in the perception of detail. We all know from experience that as an object recedes from us and becomes smaller, details with low contrast become difficult to perceive. The reason for this loss in contrast perception is not that the relative brightness of adjacent areas changes but rather that the visual system is less sensitive to contrast when the spacing of the contrasting areas decreases. If the spacing of the contrasting areas is regular, it can be called a spatial frequency. It is a remarkable fact that the visual system is much more sensitive to contrast at certain spatial frequencies than it is to contrast at other spatial frequencies, just as the ear is more sensitive to certain frequencies of sound than it is to others.

The simplest sound signal is a pure sine wave. In vision the equivalent is a grating pattern whose brightness varies in a simple sinusoidal manner [*see "a" in illustration on opposite page*]. The contrast of the grating is defined as the modulation of its brightness around a mean level. Spatial frequency can be described as the number of whole cycles of contrasting areas over some unit of distance. In dealing with the visual system it is convenient to define spatial frequency as the number of cycles of the grating that subtend one degree at the eye of the observer [*see top illustration on page 108*].

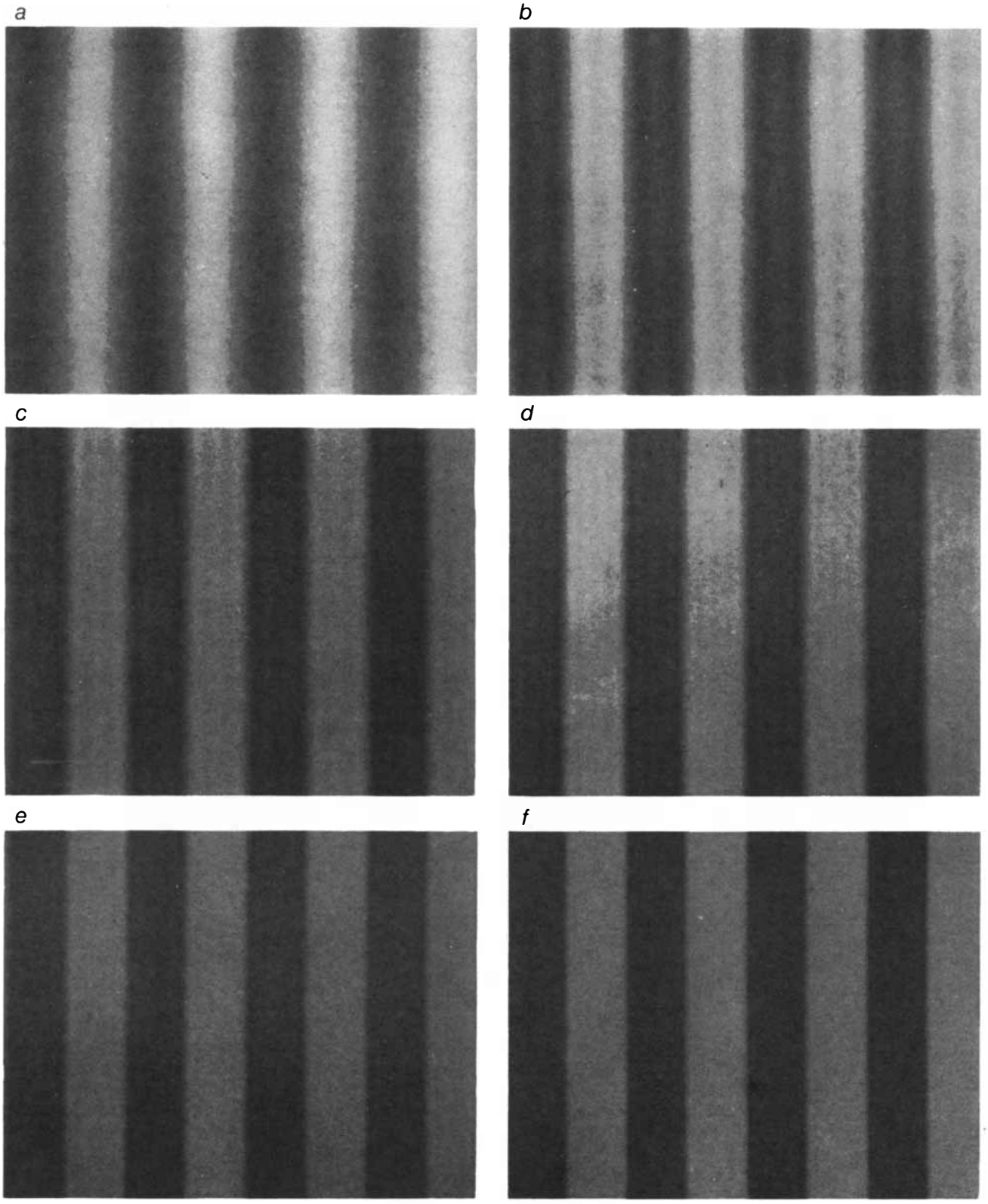
One can build up a complex spatial waveform by adding together a number of sinusoidal waveforms. For example, if one begins with a simple sine-wave grating and adds a third harmonic with a third the amplitude and three times the frequency of the initial sine wave, the resulting grating appears to have additional light and dark bands [*see "b" in illustration on opposite page*]. The addition of a fifth harmonic, a seventh and so on will eventually give rise to a square-wave grating with abrupt changes in contrast between the dark and the light areas. If we begin with the assumption that the visual system analyzes a spatial frequency in terms of the simple sum of the harmonics in it, the first step is to study the responses of the system to simple sine-wave gratings. Understanding may then come of how the visual system deals with more complex waveforms.

In order to obtain accurate information on the relation between the size of the bars of a grating and the contrast at which they can just be detected, it is convenient to display a grating on a cathode ray tube and have the subject adjust the contrast until the bars of the grating can no longer be seen. In this way the threshold of contrast perception can be determined for a series of different gratings ranging from very high spatial frequencies to very low ones.

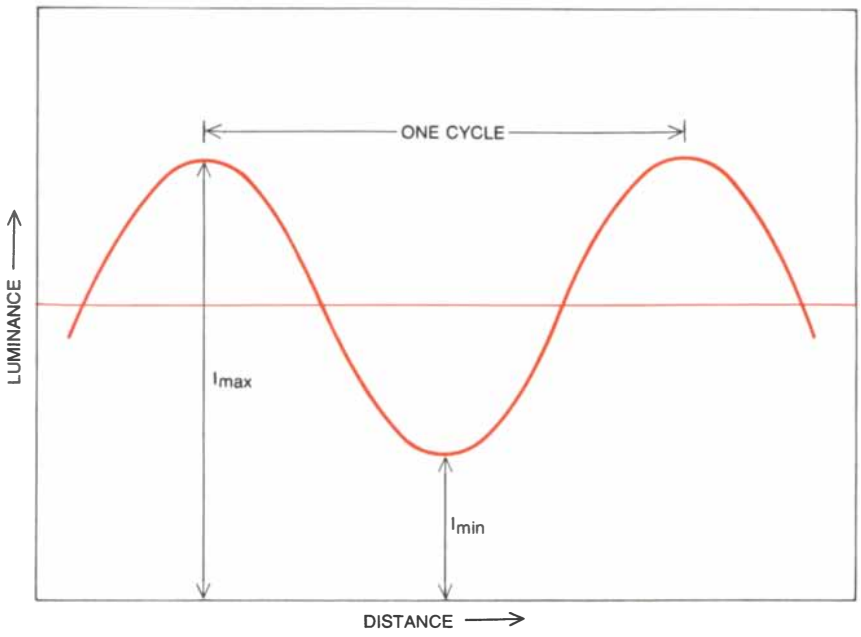
John G. Robson, who was working with one of us (Campbell) at the Physiological Laboratory of the University of Cambridge, found that the best sensitivity to low contrast in the human visual system occurs with simple sine-wave gratings that have a spatial frequency of about three cycles per degree. If maximum contrast is 1, at this frequency the contrast can be as low as .003 [*see top illustration on page 111*]. As the frequency of the grating is increased, contrast sensitivity drops. The highest spatial frequency the human eye can perceive is about 50 cycles per degree. For this frequency to be perceived very high contrast is required. Contrast sensitivity also decreases as the spatial frequency is decreased below the optimum of three cycles per degree.

It may be surprising at first that the bigger the bars of the grating become, the less sensitive the eye is in detecting them. This can be demonstrated by viewing the grating on page 108 from a distance of about three feet. At that distance the grating has a spatial frequency of about three cycles per degree, and the reader should be able to detect the grating pattern at very low contrast; indeed, the grating is visible right up to the top. Now move closer, say to a distance of 12 inches, and the grating in the low-contrast region will disappear. At that distance the grating has a frequency of less than three cycles per degree. This method of measuring contrast sensitivity is rather crude, however, because the photographic process required to reproduce the grating introduces a loss of contrast, particularly at the higher spatial frequencies.

When an optometrist tests our visual acuity by having us look at black letters on a white background, he is measuring our acuity only for very high contrast. Most of what we view in daily life has a much lower contrast; in fact, the contrast level can go down to the point where we cannot detect the pattern or object at all. Alice, in *Through the Looking Glass,* remarked, "I see nobody on the road," and the White King replied, "I only wish I had such eyes to be able to see nobody and at that distance too." This effect can be demonstrated by viewing the bottom illustration on page 108 from a distance of 30 feet. From that distance no portion of the grating is visible. As one approaches



GRATING PATTERNS shown here are photographs of patterns produced on the screen of a cathode ray tube by a voltage-modulating generator. A simple grating (*a*) is produced by a single sine-wave signal from the voltage generator. The brightness of each vertical bar in this simple grating varies in a sinusoidal manner in the horizontal direction across the pattern. A more complex grating (*b*) is formed by the addition of the third harmonic of the fundamental sine wave. The third harmonic has three times the frequency and a third of the amplitude of the fundamental wave. As the frequency of the light and dark bands increases with the addition of the fifth harmonic (*c*), the seventh (*d*) and the ninth (*e*), the individual bands formed by the harmonics become progressively more difficult to see. With the addition of the 15th harmonic only a square-wave pattern is perceived (*f*). Studies of contrast perception with simple and complex grating patterns such as these indicate that the visual system possesses a number of separate "channels," each channel tuned to detect a relatively narrow range of spatial frequencies and each with its own range of sensitivity to contrast.

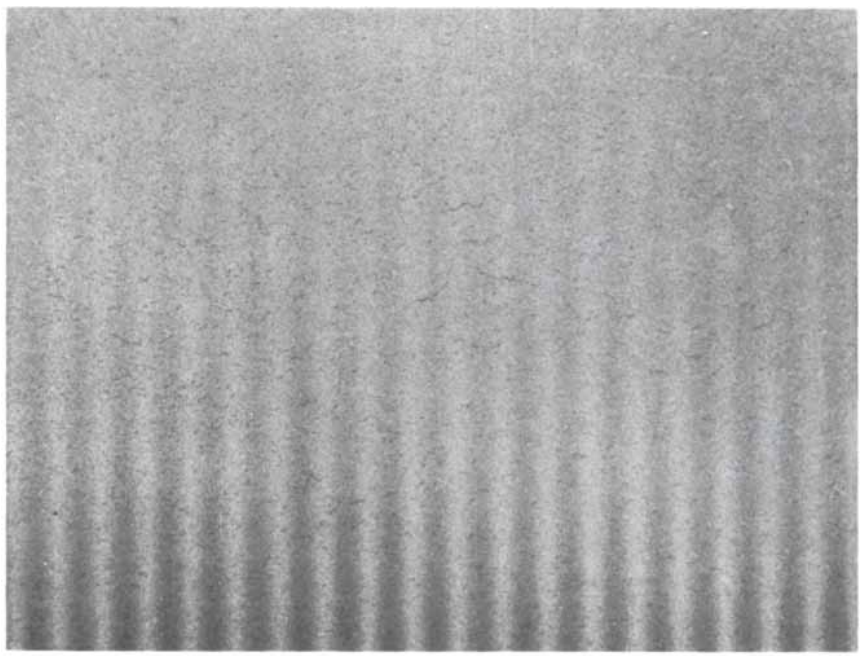


SINE WAVE depicts the sinusoidal variation in the brightness of a simple sine-wave spatial grating. Contrast of the grating is defined as $(I_{max} - I_{min}) / (I_{max} + I_{min})$. The spatial frequency is the number of cycles of the grating that subtend one degree at eye of the observer.

the grating it is the high-contrast part at the bottom that becomes visible first.

Sensitivity to contrast is thus a function of spatial frequency. The advantage of the contrast-sensitivity thresholds determined by the sine-wave-gratings technique is that they describe how the eye performs at all contrast levels and not just at very high contrast. The threshold curve also delineates the boundary of a low-contrast world we never perceive. Is there some way of measuring thresholds other than asking someone if he sees a pattern? Such a method does exist; it involves recording small electrical signals, called evoked potentials, that arise from the visual cortex of the brain at the back of the head.

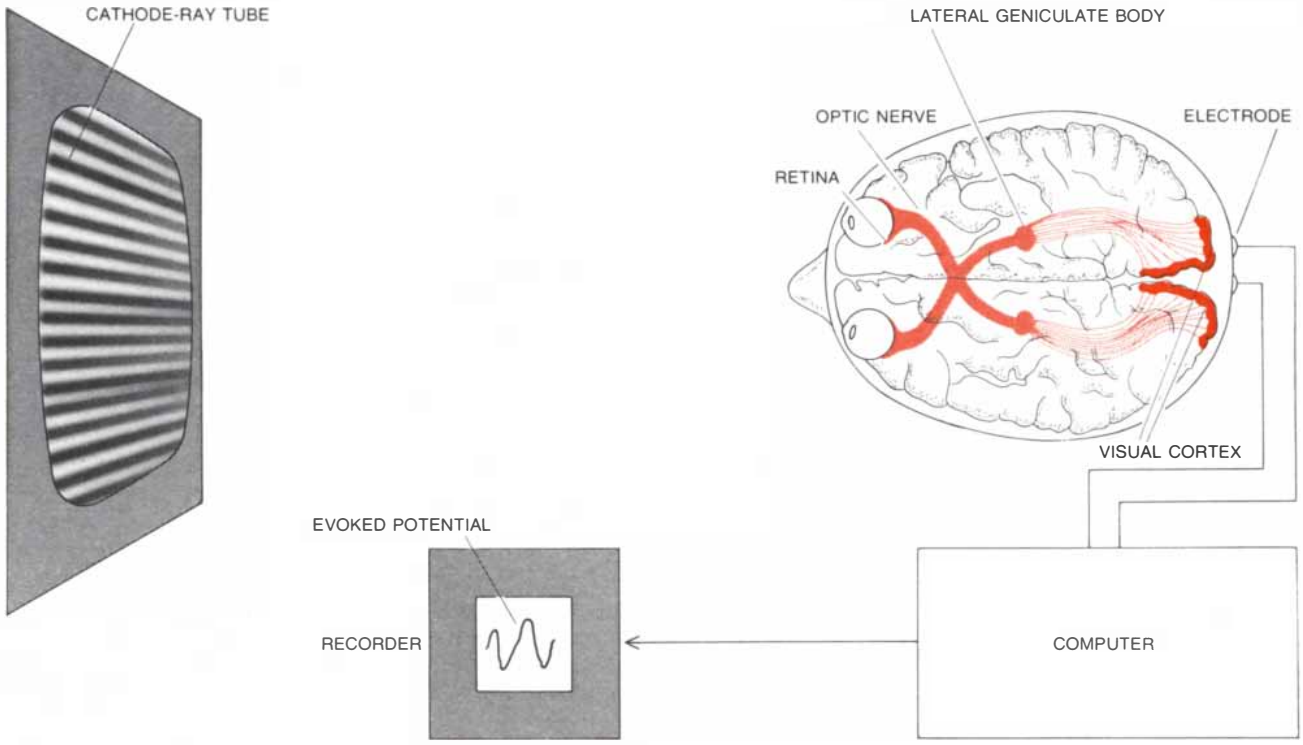
The subject looks at an oscilloscope screen on which a grating flashes on and off at the rate of eight times per second. The overall luminance of the screen is the same whether the grating is present or absent. Each time the grating appears a small evoked potential is generated. Because individual evoked potentials are masked by signals from other parts of the brain, the signals are fed into a computer where the evoked potential can be retrieved by an averaging technique [*see top illustration on opposite page*]. We recorded the evoked potentials generated by gratings with low, moderate and high spatial frequencies. The contrast of each grating was varied from high to low. We found that the higher the contrast, the greater the amplitude of the evoked potential. More important was the finding that when the evoked potentials for a specific spatial frequency were plotted against the contrast level (with the contrast level on a logarithmic scale), they fell on a straight line. By extrapolation to zero voltage the theoretical threshold could be obtained. These extrapolated thresholds correspond quite well with the thresholds obtained by asking the subject to indicate when the grating is no longer perceptible. Thus it is possible to find the subject's threshold objectively without asking him any questions. In this case we have been able to take the "psycho" out of psychophysics.



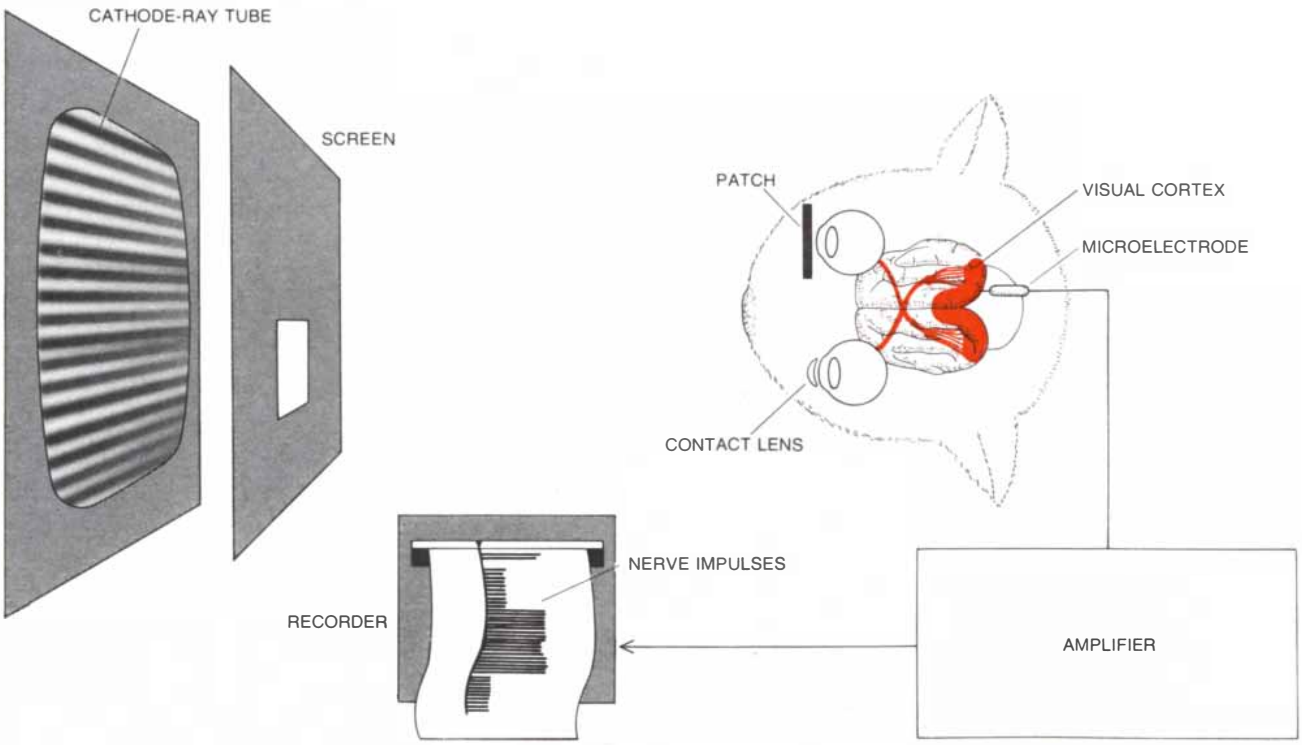
CONTRAST OF SINE-WAVE GRATING decreases logarithmically from the bottom to the top. When the grating is viewed from a distance of three feet, it has a spatial frequency of about three cycles per degree, and the grating is visible to very low contrasts. When the grating is viewed from a much closer range, say one foot or less, the spatial frequency is much lower and the grating in the low-contrast region near the top is no longer visible.

This may seem to be a roundabout and complicated way of obtaining a threshold, but we are interested not only in how human beings see contrast but also in how animals do so. Alice said of her cat, "If they would only purr for 'yes' and mew for 'no,' or any rule of that sort, so that one could keep up a conversation! But how can you talk with a person if they always say the same thing?"

We applied the evoked-potential technique to a cat and came up with some interesting results. The amplitude of the potential we obtained was plotted against the logarithm of the contrast of the grating involved. We extrapolated the curves to zero voltage and assumed that this contrast level is the threshold for the cat, as it is for human beings [*see bottom illustration on page 110*]. When the contrast thresholds for cats are plotted together, the curve is very similar to the threshold curve for humans, except that it is displaced toward the lower



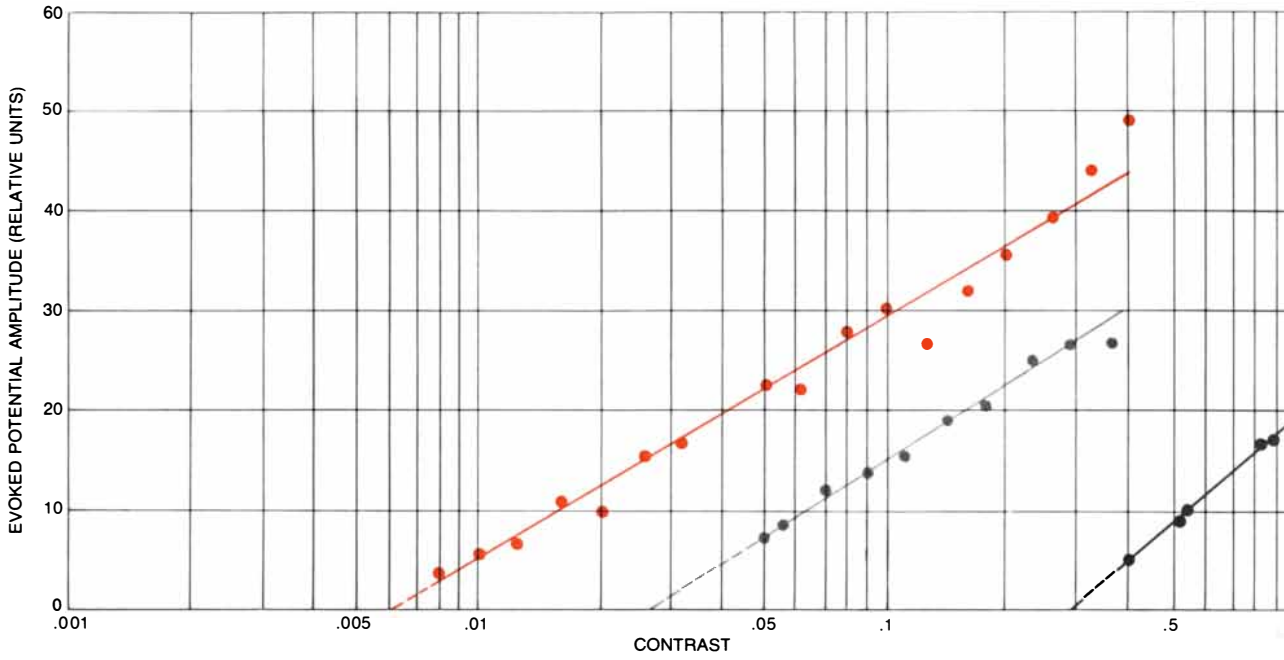
EXPERIMENTAL ARRANGEMENT for recording electrical potentials evoked in the brain by a grating is depicted. When a grating on the screen is flashed on and off at the rate of eight times per second, a characteristic evoked potential is generated in the visual cortex. These potentials are small and are masked by electrical signals arriving from other parts of the brain. Electrodes at the back of the head pick up the signals and transmit them to a computer, which extracts the evoked potential from background noise by an averaging technique. For a given spatial frequency the amplitude of the evoked potential is proportional to contrast of the grating.



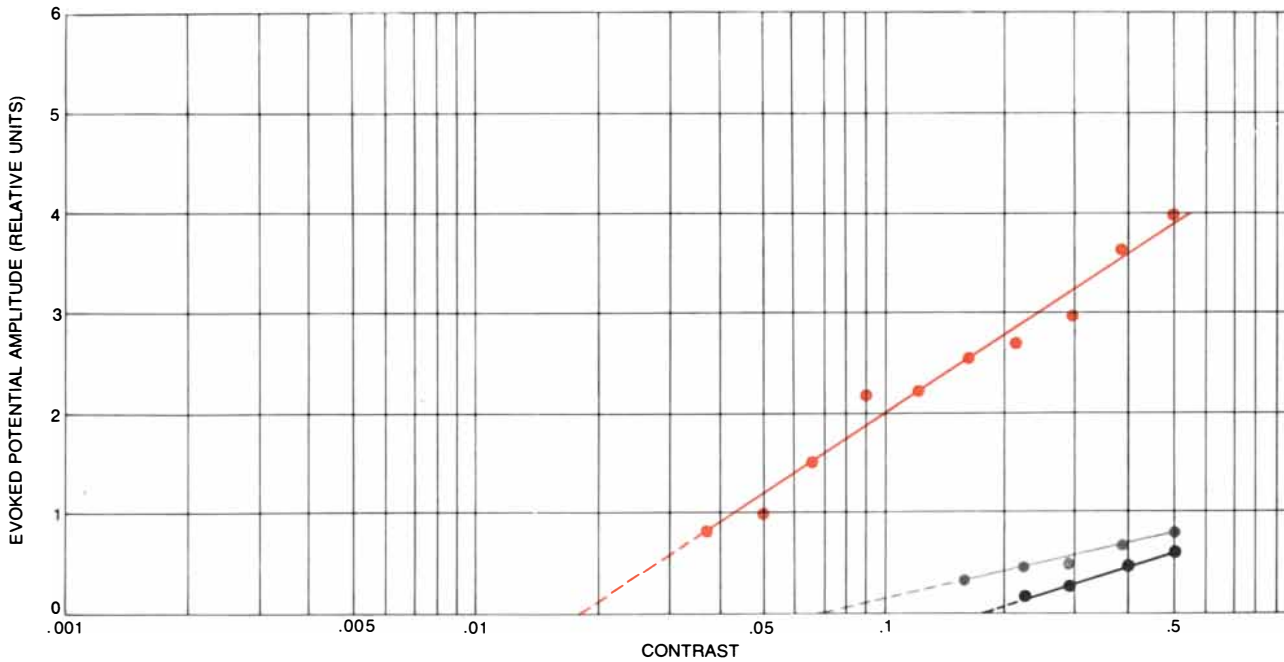
ARRANGEMENT FOR MEASURING the response of cells in the visual cortex of the cat during stimulation by grating patterns is shown in simplified form. The microelectrode is surgically implanted while the cat is anesthetized. As the cat views a grating pattern on a cathode ray tube the elecrical discharges of individual cells are picked up by the microelectrode, amplified and recorded. The results of several studies show that there are single cells in the visual cortex that respond to a small range of spatial frequencies.

spatial frequencies [*see bottom illustration on opposite page*]. Where the human sensitivity to contrast peaks at three cycles per degree, the cat's best sensitivity is about .3 cycle per degree. At frequencies above .5 cycle per degree the contrast sensitivity of cats is less than that of human beings. This means that at the higher spatial frequencies the cat can see only high-contrast details. On the other hand, at the lower spatial frequencies the cat can see detail at lower contrast than human beings can. One could summarize these results by saying that the cat is attuned to seeing spatial frequencies some 10 times lower than those human beings can see, and that at the lower frequencies a cat sees low-contrast details that a human being cannot perceive at all.

David H. Hubel and Torsten N. Wie-



HUMAN EVOKED POTENTIALS for three different spatial frequencies show a regular decrease in their amplitude as the contrast decreases. The evoked potentials were obtained while subjects viewed gratings with spatial frequencies of 3.5 cycles per degree (*color*), nine cycles per degree (*gray*) and 18 cycles per degree (*black*). Extrapolation to zero amplitude (*broken lines*) yields the theoretical contrast threshold for each spatial frequency. These extrapolated thresholds correspond well with the subjective thresholds obtained by asking subject to indicate the lowest contrast at which a grating of a particular spatial frequency is just perceptible.

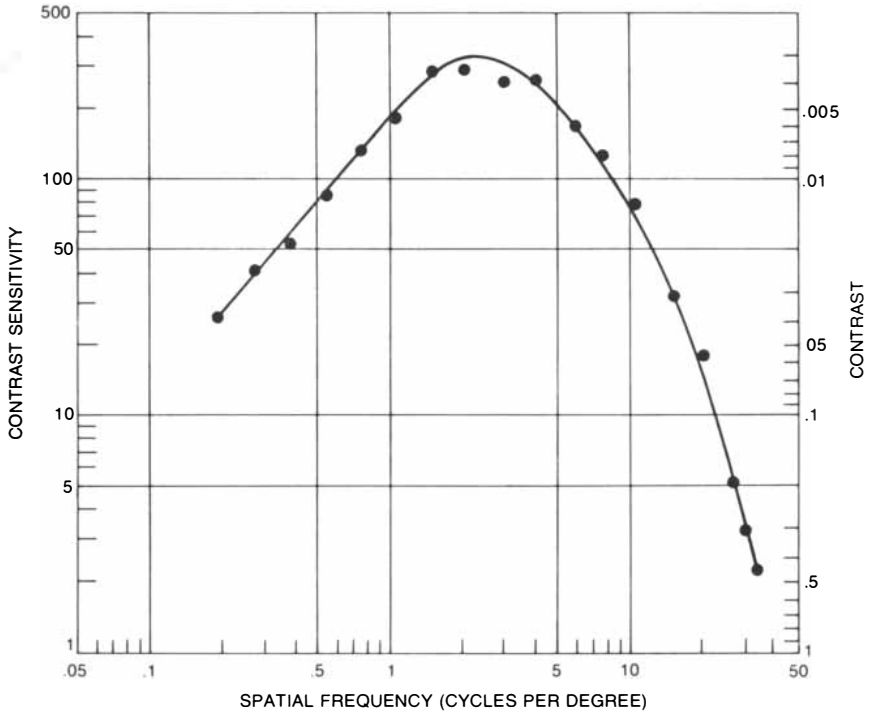


EVOKED POTENTIALS FROM CATS are plotted against the logarithm of the contrast of the gratings and extrapolated to zero amplitude in order to determine the threshold contrast sensitivity of the cat for each spatial frequency. These evoked potentials were obtained from cats viewing gratings of .6 cycle per degree (*color*), three cycles per degree (*gray*) and 5.5 cycles per degree (*black*).

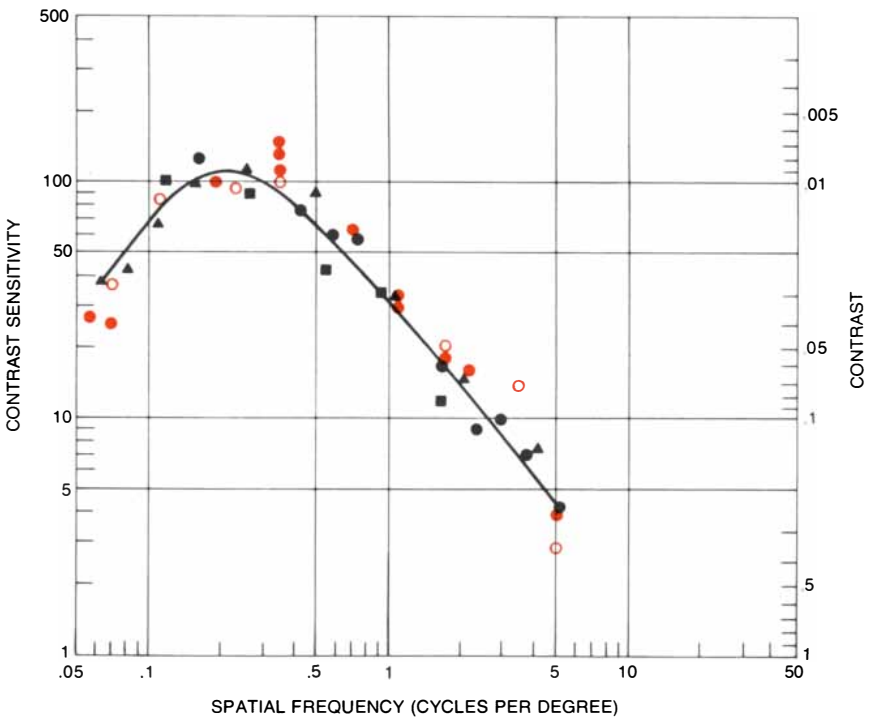
sel of the Harvard Medical School, working with microelectrodes implanted in the brain, discovered that in the visual cortex of the cat and the monkey there are cells that respond to edges or bars of a particular orientation or a particular direction of motion [see "The Visual Cortex of the Brain," by David H. Hubel; SCIENTIFIC AMERICAN, November, 1963]. Robson, Grahame F. Cooper and one of us (Campbell), working in Christina Enroth-Cugell's laboratory at Northwestern University, applied the microelectrode techniques to determine the response of individual cells in the cortex (and other parts of the visual system) of the cat to gratings of various spatial frequencies. The results revealed that there are individual cells in the visual cortex of the cat that respond to a fairly narrow range of spatial frequencies. Each cell that was tested was tuned to a particular part of the spatial-frequency spectrum. The response of each cell peaked at one frequency and fell off rapidly when the frequency was higher or lower. We also found individual cells in other parts of the visual system (the lateral geniculate body and the retina) that respond to specific spatial frequencies.

Even though it is not possible to ask a cat if it sees something when a particular cortical cell fires or when an evoked response is generated, it is possible to train a cat to give a sign when it sees a grating on the oscilloscope screen. This is accomplished by giving the cat a food reward when it responds correctly. If the animal responds when the grating is not present, no reward is given. Once the cat is trained, it is possible to find the threshold of contrast sensitivity for a grating by progressively reducing the contrast of the grating. Sylvia Bisti, working with one of us (Maffei) at the University of Pisa, has directly measured the contrast threshold for two cats. The training takes many months and requires great patience and persistence. There is good agreement between the results obtained in a few hours with the evoked-potential technique and those obtained with the lengthy behavioral method.

How, then, does the visual world of the cat compare with ours? Since the contrast sensitivity of the cat compared with that of human beings is displaced to lower spatial frequencies by a factor of 10, it could be argued that to detect a small object the cat would have to be 10 times closer to it than a man would need to be. One might suspect that the smaller size of the cat's eye accounts for the



CONTRAST SENSITIVITY OF A HUMAN SUBJECT is plotted as function of spatial frequency. The scales are logarithmic. Very high contrast is given a value of 1, and contrast sensitivity is the reciprocal of contrast. The human visual system is more sensitive to contrast with sine-wave gratings that have spatial frequencies of about two or three cycles per degree. Contrast sensitivity drops off at higher and at lower spatial frequencies. Data were obtained by asking the subject to indicate when a particular grating could just be seen.



CONTRAST-THRESHOLD CURVE FOR THE CAT is similar to the curve for man (*see illustration at top of page*), but it is displaced toward the lower spatial frequencies. Below .5 cycle per degree the cat sees low-contrast detail that man does not perceive. Above .5 cycle per degree man sees low-contrast detail that is not visible to the cat. Cat data were obtained from evoked-potential responses of three cats to grating patterns (*black symbols and curve*) and from conditioned behavioral responses of two other cats (*colored symbols*).

Needed: a nationwide power grid

Our country, once a land of isolated communities, is bound together today by networks of many kinds—highway, railroad, television, telephone, radio.

Missing, however, is one highly important network . . . a system for sending electricity to where it's needed, when it's needed . . . shuttling millions of kilowatts from sleeping California to up-and-about New York, and back again when required.

We of America's consumer-owned rural electric systems believe a nationwide power grid—an extra high voltage system—capable of quickly moving large blocks of power anywhere in the country—north, south, east or west—is long overdue.

It becomes clearer each day that if we, as a nation, are to solve our complex and persistent energy problems, we must take this and other steps—using to the fullest extent technical capabilities now available—that will help maximize the efficient use of our power generating facilities and energy supply.

We believe such a grid system can best be achieved within the present pluralistic ownership structure of the electric industry. But size of profit or feasibility of investment should not be the all-determining factors. *Performance in the public interest*—that must be the principal purpose and value. This means every element of the electric utility industry—and government—must carry its fair share of the financial responsibility.

To enable our nation to use energy resources more wisely . . . to help match supply with demand and reach the primary objective of ensuring reliable electric service for all Americans . . . and for national security and consumer health, safety and convenience, we advocate speedy development of a nationwide power grid.

America's Rural Electric Systems

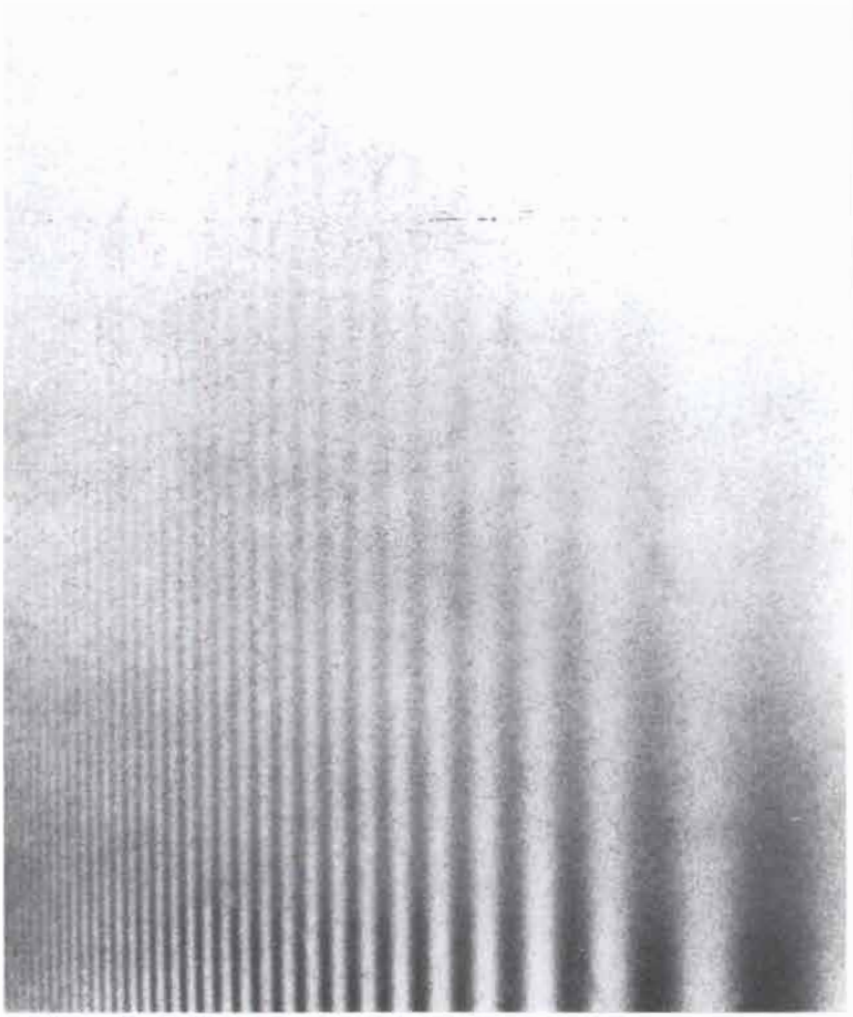
We care . . . we're consumer owned ®

If you would like more information on America's rural electric systems and their suggestions for reaching solutions to the nation's energy problems, *please write for "Energy . . . and the consumer,"* National Rural Electric Cooperative Association, 2000 Florida Ave., Northwest, Washington, D.C. 20009.

difference, but for a given object at a given distance the size of the image on the cat's retina is only 1.3 times smaller than the image on a man's retina. Hence the size of the eye cannot account for the difference in the perception of spatial frequencies.

In order to understand the cat's visual world let us start with the familiar situation in which we are viewing an eye-test chart from a distance of 20 feet. If we can read what is called the 20-foot line, we have normal visual acuity (20/20 vision). Since the cat's resolving power is lower by a factor of 10, it should be able to "read" only the large letter on the 200-foot line (20/200 vision). We can try to simulate the cat's vision by placing in front of our eyes lenses that will render them myopic to the point where we can discern the 200-foot line at 20 feet only. If we then look at a distant scene with such a degree of myopia, everything will be quite blurred, even objects we can discriminate. The myopic lenses act as a spatial filter that attenuates the higher spatial frequencies more than it does the lower frequencies. The sensation of blurring is the result of the relative inactivity of the visual nerve cells that are stimulated by the higher frequencies. The cat, however, does not possess nerve cells attuned to these higher spatial frequencies, and so its distant view cannot be blurred and cannot be simulated by artificial myopia.

Let us seek a more realistic and fruitful simulation. Instead of blurring our vision, let us look at the test chart through a pair of binoculars with a magnifying power of 10. If we reverse the binoculars and look at the chart from 20 feet away, we will be able to read only the 200-foot line but there will be no blurring of the remainder of the chart. In order to read the 20-foot line we



SINUSOIDAL GRATING with a logarithmic variation in spatial frequency and in contrast demonstrates the loss of contrast sensitivity at low and high spatial frequencies. The contrast decreases from the bottom to the top, but at any one height it is the same for all spatial frequencies. When the grating is viewed, it is apparent that the intermediate spatial frequencies are visible to much lower contrast than either the low or the high spatial frequencies.

would have to go 10 times closer, to a distance of two feet, and refocus the binoculars. Although the binocular analogy of cat vision is better than the blurring one, it is not entirely satisfactory because it introduces a change in perspective. The reversed binoculars make everything 10 times smaller. We do not know if the cat sees everything 10 times smaller. Its peripheral vision could be wired up so that its perspective is the same as ours.

It could be assumed that cat vision is quite sharp and clear, just as our vision is, but that it is different from ours in being attuned to seeing well at much closer range, if seeing well means a mechanism for detecting low-contrast details at low spatial frequencies. An informal experiment can demonstrate the visual performance of a cat. Swing in front of a playful cat a small white ball on the end of a black thread. If the ball is about a centimeter in diameter, the cat will approach it from a distance of several meters and play at catching it. If we swing the ball away, the cat will chase after it even when we move it a considerable distance. If the ball is replaced with one that is four millimeters in diameter, however, the cat will not approach it until the swinging ball is less than a meter away. Even more convincing is to let the cat play for a while with the smaller ball and then swing the ball away suddenly to a distance of about a meter. The cat will stop playing and will look around for the ball without success. A person with normal vision, on the other hand, would have to move back to a distance of about eight meters before a moving four-millimeter ball would become invisible.

Let us assume that the cat sees slightly better in daylight because of the increased illumination and that it can detect a high-contrast object that subtends a visual angle of 10 minutes. Under such circumstances the cat should be able to detect a flying bird with a wingspan of 20 centimeters from a distance of 60 meters, although the details of the bird would not be visible. At dusk the cat should see the moon quite distinctly as a disk, since it subtends an angle of 30 minutes. It would not see any surface details on the moon.

We now have an inkling of what the visual world of the cat may be like. It may prove fruitful to use the evoked potential technique to study the contrast sensitivity of a number of animals, particularly those that are assumed to have a higher acuity than man, such as the eagle.

Wayne Sutterfield takes a lot of garbage

Look, we've all got to take a little sometime...but this guy goes looking for it.

Wayne Sutterfield is Refuse Commissioner for the City of St. Louis and he has 900 tons of garbage on his hands each day. So Wayne Sutterfield believes in new approaches to solid waste management.

The city's garbage is continually combed for steel cans. Sutterfield's powerful magnetic conveyor belts literally suck them right out of the garbage at the rate of about 78,000,000 a year. Steel's unique magnetic property makes it possible.

The reclaimed cans are marketed to a steel producer who recycles them during the production of new steel products. The economics help Sutterfield and the people of St. Louis 'clean up' in the bargain. The same thing is happening today in 20 cities across the country.

But steel can recovery isn't the only exciting thing that happens to the city's garbage. St. Louis burns some 300 tons of its combustible solid waste each day (mixed with coal) to generate electric power in a conventional boiler at the Union Electric Company. That power is enough to serve 25,000 homes. The program reduces air pollution, saves landfill and conserves coal.

St. Louis was the first American city to try it, but it won't be the last.

Sometimes it pays to take a little garbage.

For more information write, **Tinplate Producers, American Iron and Steel Institute, 1000 16th Street, N.W., Washington, D.C. 20036.**

...and cleans up in the bargain.

Steel the recycled material

Tinplate Producers
American Iron
and Steel Institute

TIME SPENT IN HOUSEWORK

As one might expect, working women spend less time in housework than their mothers and grandmothers did some 50 years ago. Women who are not in the labor force, however, spend just as much time

by Joann Vanek

One would suppose, in view of all the household appliances that have been introduced over the past 50 years, that American women must spend considerably less time in housework now than their mothers and grandmothers did in the 1920's. I have investigated the matter and found that the generalization is not altogether true. Nonemployed women, meaning women who are not in the labor force, in fact devote as much time to housework as their forebears did. The expectation of spending less time in housework applies only to employed women.

Certainly the reasons for thinking that the time spent doing housework must have diminished are abundant. Most of the household appliances that have come on the market since the 1920's have been marketed as (and have generally been regarded as) laborsaving devices. Many other products and services designed to ease the homemaker's task have been put on the market during the past 50 years. In addition to these technological changes one can cite several other factors that would seem to indicate a shorter work week in the household. They include the movement of families from the farm; the decline in boarding; changes in the birth rate that cause women to spend fewer years in the direct care of children; the fact that fewer members of the family come home for lunch, and the pronounced increase in the number of married women in the labor force.

Fortunately information is available about time spent in housework. It is not as complete as an investigator might wish or as readily comparable from one period of time to another, but it does provide data on how women budget time for their daily activities.

In 1925 the Federal Government made money available (under the Purnell Act) for research in home economics. One of the results was a series of studies of how women budgeted their time. My analysis is based on about 20 of these studies. They are reasonably comparable because they were conducted under a set of guidelines developed by the U.S. Bureau of Home Economics. Although most of the studies were made in the 1920's and 1930's, the guidelines were also applied to a few studies conducted in the 1940's, 1950's and 1960's. For detailed analysis of the contemporary period I have employed the *United States Time Use Survey,* a study made in 1965 and 1966 by John P. Robinson and Philip E. Converse of the Survey Research Center at the University of Michigan. In this study women were asked to keep a diary of activities at 15-minute intervals for a full day. In the earlier studies women kept a diary of activities at five-minute intervals for at least a week.

Only the Robinson-Converse survey is based on a national sample. The studies made under the aegis of the Bureau of Home Economics involved certain localities and tabulated primarily the activities of rural women. To infer national averages from such limited studies is open to question. It is significant, however, that the findings of the earlier studies were much the same, which lends support to the supposition that they reflect national patterns.

At first the primarily rural composition of the early samples appears to be a limitation. Actually it is an advantage. During the 50 years under consideration the scene of household activity—in terms of the preponderance of women—shifted from the farm to the city. Thus one comparison I want to make is between time spent in homemaking by rural homemakers 50 years ago and time spent by urban homemakers today. Several of the early studies included town and city samples, so that it is also possible to make comparisons between rural and urban women in the 1920's.

Let us turn first to nonemployed women [*see illustration on page 118*]. In 1924 such women spent about 52 hours per week in housework. The figure differs little (and in an unexpected direction) from the 55 hours per week for nonemployed women in the 1960's. It is remarkable that the amount of time devoted to household work by such women has been so stable, varying only within the range from 51 to 56 hours. It is also noteworthy that the work week of homemakers is longer than the work week of the average person in the labor force.

A comparison of rural and urban women yields another unexpected finding: Rural homemakers spend no more time in household work than urban ones. At least in part this consistency may be due to the way the early researchers distinguished between housework and farm work. Farm work included all tasks connected with the home that were not commonly carried on by both rural and urban women. Among the tasks defined as farm work were gardening, dairy activity and the care of poultry. In this way rural and urban women were compared on the same set of tasks.

Notwithstanding the distinction between household work and farm work, one would suppose that at least in the early period urban women would have spent less time on the job than rural women, inasmuch as a number of differences in working conditions remained between them. For example, urban homes were more likely than rural ones to have electricity, running water and

laborsaving machines. In addition urban women could make more use of markets and commercial services, simply because they lived closer to them. Another factor was that the farm household produced a larger proportion of the family's material needs than the urban household. (A study in 1924 showed that rural families produced about 70 percent of their own food, compared with 2 percent for urban families.) In spite of all these differences urban and rural women have spent about the same amount of time in household work throughout the 50-year period. Urbanization reduced women's work only by eliminating the 10 hours per week spent in farm tasks.

Perhaps trends affecting the household have created as much work as they have saved. If less time is required for producing food and clothing, time must be added for shopping. It is not difficult to think of a number of other time-consuming household tasks that must be done now but that were nonexistent or rare 50 years ago. Therefore the figure for time spent on housework probably conceals a shift in the amount of time devoted to various tasks.

The data do show that the nature of household work has changed [*see top illustration on page 119*]. The time spent in the tasks classified as shopping and managerial has increased. So has time devoted to family care. Less time is spent preparing food and cleaning up after meals, although together these activities continue to be the most time-consuming aspect of housework. No change has occurred in general tasks of home care such as cleaning.

Probably no aspect of housework has been lightened so much by technological change as laundry. In the 1920's a great many houses lacked hot and cold running water. A large variety of soaps and detergents and automatic appliances have come on the scene, and the once burdensome requirement of ironing has been greatly reduced by wash-and-wear fabrics. Nonetheless, the amount of time spent doing laundry has increased [*see bottom illustration on page 119*]. Presumably people have more clothes now than they did in the past and they wash them more often.

Time spent on child care has also increased. The change reflects postwar modifications in standards of child care. Today's mother is cautioned to care for the child's social and mental development in addition to the traditional concerns of health, discipline and cleanliness.

More time is spent today in the tasks associated with consumption. They include shopping, household management and travel connected with the household. Contemporary women spend about one full working day per week on the road and in stores compared with less than two hours per week for women in the 1920's.

Although technological change has

KITCHEN OF THE PAST contained few of the conveniences that are commonplace today. The only electrical device evident in this photograph, which was made about 50 years ago, is the light over the sink. The sink appears to have only a cold-water tap; presumably the hot water was heated on the coal stove at right. Adjacent to the kitchen, at far right, is what appears to be a pantry.

created new time demands in homemaking, this factor alone does not explain the consistently large amount of time devoted to housework. If it did, all women would spend long hours in housework. The data I have analyzed show that they do not. Employed women spend considerably less time in housework than nonemployed women.

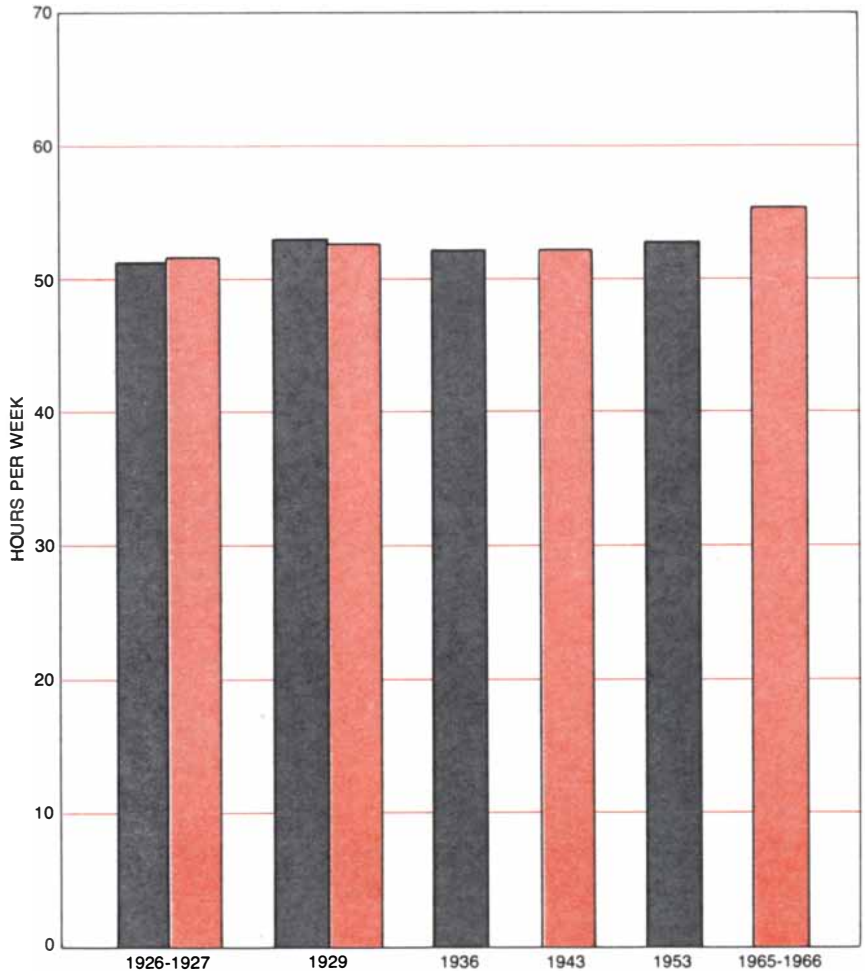
In contrast to the 55 hours per week that nonemployed women spend in housework, employed women spend only 26 hours. In other words, employed women devote about half as much time to household tasks as nonemployed women. Technological change has in fact liberated some women from a certain amount of household work.

The time patterns of employed women become more significant when trends in the employment of women are taken into account. During the past 50 years women have entered the labor force in increasing numbers. Moreover, since World War II the increase has been caused primarily by the dramatic rise in the employment of married women. In 1920 it was rare to find married women working outside the home; today about 40 percent of them are in the labor force. Proportionately fewer women are full-time homemakers. Notwithstanding the stability of housework time for nonemployed women, therefore, the shift in the proportion of women employed signifies a reduction over the years in the amount of time women spend in housework.

Although the impact of social change on time spent in housework is thus clarified, the question remains of why nonemployed women spend so much time in homemaking. It is possible that this finding can also be explained in a fairly straightforward way. Perhaps nonemployed women have larger families and younger children and therefore more work than employed women. In addition the nonemployed women may have less household assistance.

It has been shown by other investigators that a woman's decision to work is limited by the presence of children, particularly young children. In other words, women are less likely to work when the burden of household tasks is greatest. I tested this argument with an analysis drawing on employment, marital status, socioeconomic status (family income and woman's education) and family composition (number and age of children) as points of comparison.

The technique enables one to see whether or not a difference between employed and nonemployed women remains if the distribution of women is the same on the other points of comparison. Assuming that the distribution of women according to social class, family composition and marital status is the same, nonemployed women would still spend considerably more time in housework than employed women. Although these adjustments somewhat reduce the time differences between the two groups of women, the major amount of difference remains.

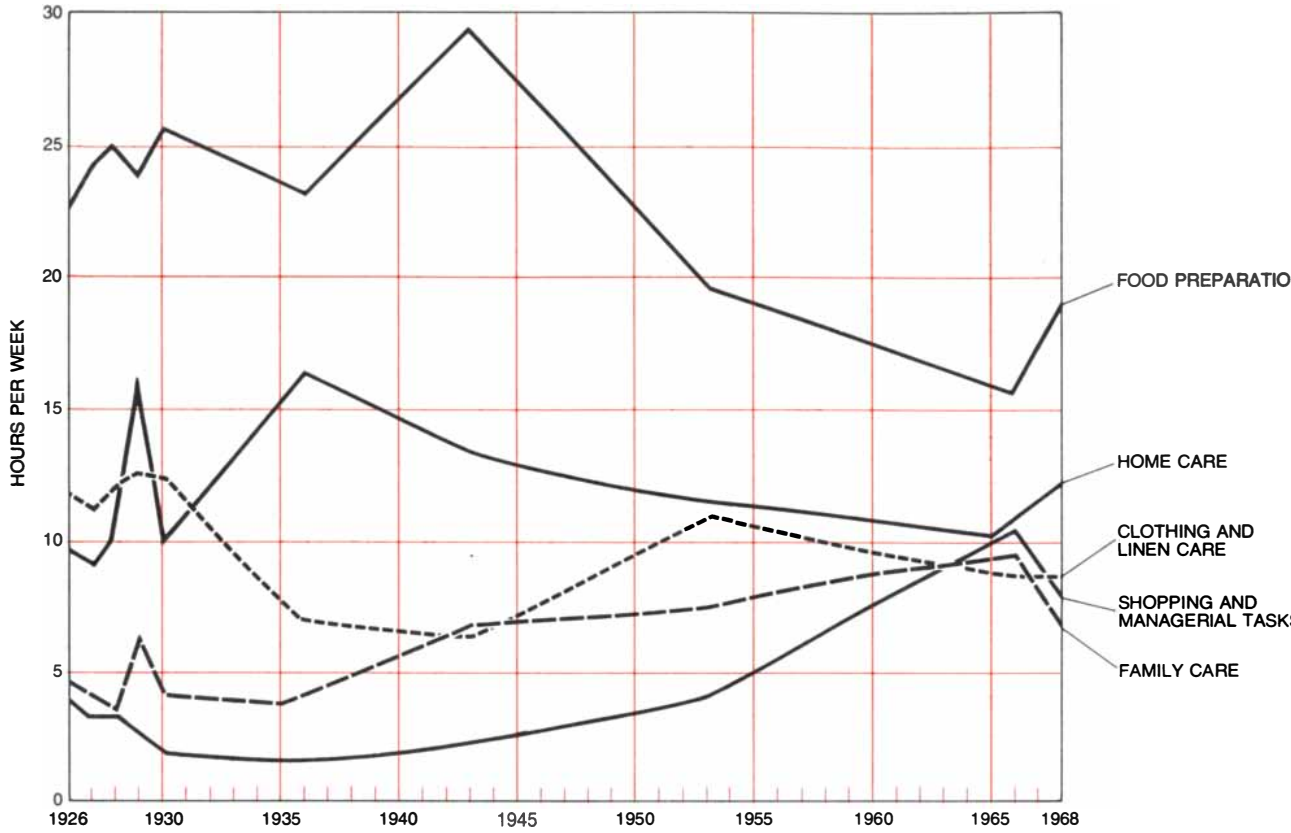


HOURS PER WEEK devoted to household work are charted for rural women (*gray*) and urban women (*color*) on the basis of surveys made in the years cited. The women covered by the chart were solely homemakers, having no outside employment. Notwithstanding the many social and technological changes affecting housework during the period covered by the data, the time these women devote to homemaking has remained remarkably stable.

Another explanation is a reflection of the amount of assistance the homemaker receives. The employed wife may be able with her earnings to buy laborsaving devices and the services of others. In addition she may have another, perhaps subtler resource: help from other members of the family. The fact that she works outside the home may give her leverage to call on them for help.

However plausible this explanation appears to be, information from the Robinson-Converse study shows that differences in help with housework do not explain the time differences between employed and nonemployed women. Employed women made no greater use of paid help than nonemployed women. Furthermore, husbands of employed women gave no more help than husbands of nonemployed women. Contrary to popular belief, American husbands do not share the responsibilities of household work. They spend only a few hours a week at it, and most of what they do is shopping.

Other factors could explain the puzzle. Perhaps employed women receive more help from children, live in smaller dwelling units or rely more on commercial services and laborsaving devices. Unfortunately the Robinson-Converse survey did not cover these matters. Other studies, however, contain little evidence that such factors would explain



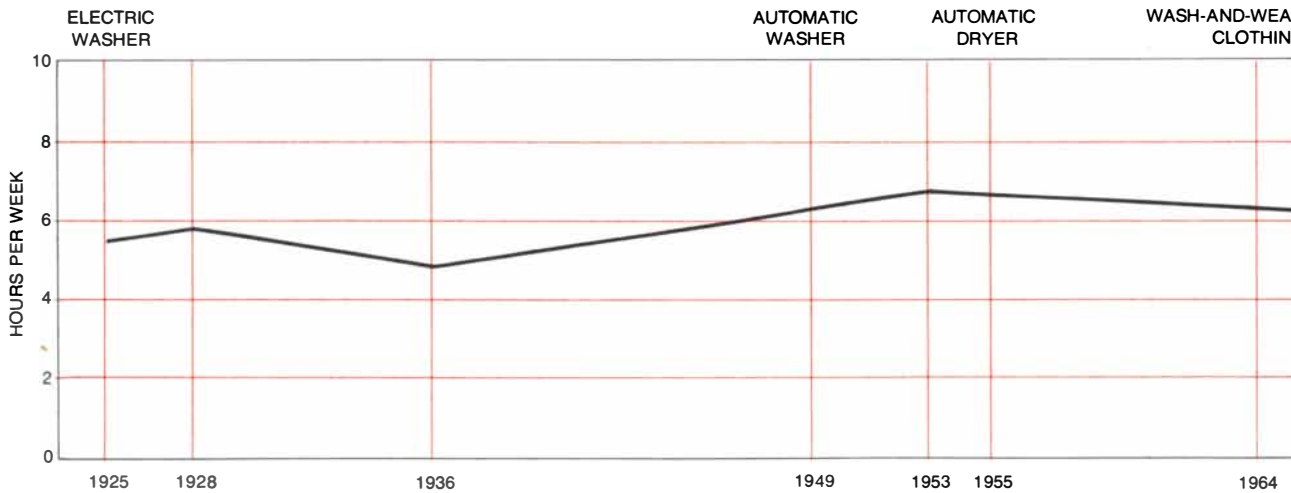
DISTRIBUTION OF TIME among various kinds of household work is traced from 1926 to 1968. The data relate only to nonemployed women, meaning women who did not have full-time jobs outside the household. Top curve includes cleaning up after meals.

the time differences between the two categories of women.

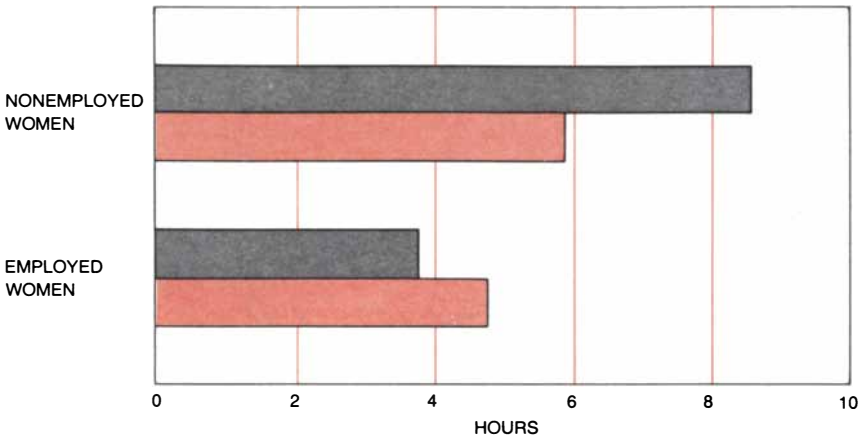
Apparently one must look deeper for the explanation. One clear contrast between employed and nonemployed women is that work in the labor market earns a paycheck whereas housework does not. In the families of nonemployed women this contrast underscores an imbalance in the economic roles of husband and wife.

This kind of imbalance was not always embedded in marriage. In the farm household of earlier decades there was little separation of domestic and productive roles. Both the husband and the wife contributed to the family's production, and their contributions were probably regarded as being equal. It seems unlikely that anyone would regard the bread, butter and clothing made by the woman as any less valuable than the man's work in the fields.

In modern society the homemaker's contribution to the family economy is less clear. Although cooking, cleaning and shopping for bargains are important to the family, one cannot find much evidence that they are regarded as contri-



TIME DEVOTED TO LAUNDRY has actually increased over the past 50 years, apparently because people have more clothes now and wash them more often. The dates shown for the various appliances and fabrics indicate about when they began to be sold widely.



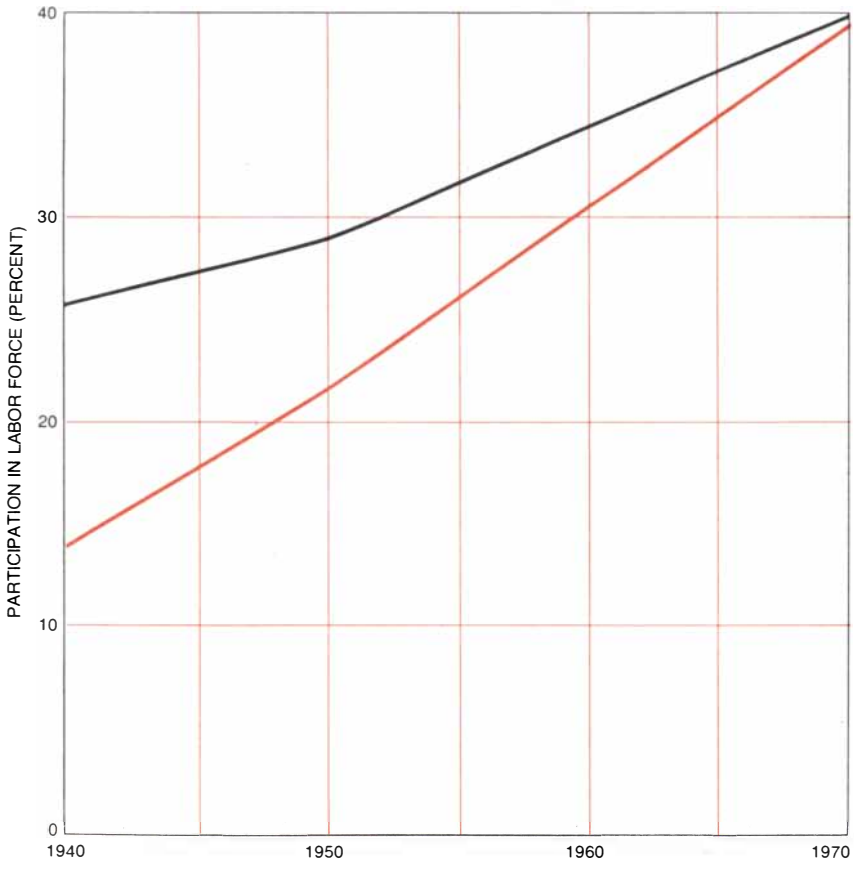
EMPLOYED AND NONEMPLOYED WOMEN are compared as to the amount of time they spend in housework on weekdays (*gray*) and weekend days (*color*). On weekend days both groups of women presumably have about the same amount of time available for housework.

butions equal to the wage earner's. As S. Ferge of the Sociological Research Institute in Budapest has written: "The results of housework do not serve this [economic] justification in a satisfactory manner because they are accepted as natural and are only noticed when they are absent. It is therefore the work itself whose existence must be felt and acknowledged; working long hours and working on Sunday can serve to demonstrate this. (These considerations are not conscious to those who are doing it; on the contrary, they are convinced of the functional necessity of this work.)"

Ferge suggests comparing women's housework schedules for weekdays and weekend days. I have done this and found that nonemployed women outdo employed women in housework on both types of day. Employed women "catch up" on housework on weekends. Nonetheless, they spend less time at it then than full-time homemakers who have all week to accomplish their work.

Perhaps the composition of the family has something to do with this finding; the presence of children, particularly young children, creates time demands that do not fit into a five-day week. I examined weekend time expenditures for women without children. Again nonemployed women spent about half an hour more per weekend day than employed women. The pattern is consistent with the view that nonemployed women schedule work so that it is visible to others as well as to themselves.

Since the value of household work is not clear, nonemployed women feel pressure to spend long hours at it. Time spent in work, rather than the results of the work, serves to express to the homemaker and others that an equal contribution is being made. Women who work in the labor force contribute income to the family and so do not feel the same pressure.



PARTICIPATION IN LABOR FORCE is charted for all women (*black*) and married women (*color*). It was once unusual for married women to work, but now 40 percent of them do.

There are, to be sure, additional factors that give rise to such high expenditures of time in housework. For example, in a consumption-oriented society the time involved in obtaining and taking care of household goods is far from negligible, although it is often assumed to be. Such tasks fall to the homemaker. Moreover, a large amount of time devoted to homemaking probably reflects a family's tastes and its preference for a particular quality of life.

Thus I am not suggesting that a homemaker's work is merely a matter of keeping busy, with no effect on the quality of the work performed. The enormous technological improvements affecting the household, together with the continued large amounts of time spent in housework, make it reasonable to assume that qualitative improvements have taken place. The example of laundry indicates that in this activity at least standards today are higher than they were in an earlier era.

It appears that modern life has not shortened the woman's work day. Farm work has been greatly reduced, but it has been replaced by work in the labor force. Indeed, for married women in full-time jobs the work day is probably longer than it was for their grandmothers.

The all-aluminum, no-deposit, no-waste can.

Reynolds pays you to return it.

We don't believe in waste.

Waste of America's aluminum resources. Waste of energy. Waste of any kind. That's why Reynolds is vitally interested in recycling aluminum products. Our far-reaching programs to recycle aluminum beverage cans, starting in 1967, show the extent of our commitment.

Last year, Reynolds paid Americans about 4.5 million dollars for bringing in used aluminum beverage cans. That was based on 10¢ per pound. Today, we're paying 15¢ per pound for aluminum scrap brought to our recycling centers.

Unlike container taxes or deposits, our program put 4.5 million dollars in *new* money into American pockets and purses.

And helped conserve one of America's most valuable resources — energy. That's because recycling takes only 5% of the energy needed to create aluminum from virgin ore.

We're recycling other forms of aluminum, too. From used Reynolds Wrap® to old utensils, lawn furniture, scrap from industry, etc. Into new aluminum products that cut fuel-energy consumption in automobiles and other transportation equipment. Into building products that save heating and cooling energy.

And Reynolds means to do even more. We have programs under way to recover aluminum from solid waste...to literally mine the garbage heaps of the nation.

Today's waste *can* be tomorrow's resources. *Reynolds Metals Company, P.O. Box LS, Richmond, Virginia 23261.*

REYNOLDS
where new ideas take shape in
ALUMINUM

Conserving our resources and energy.

MATHEMATICAL GAMES

Some new and dramatic demonstrations of number theorems with playing cards

by Martin Gardner

There is no end to the making of mathematical tricks, puzzles and other recreations that employ playing cards. This month we look at some new card problems and games, with emphasis on how they lead into significant areas of combinatorial theory.

Consider the following combinatorial way of dramatizing an important number theorem. Remove all the cards of one suit (say spades) from a deck and arrange them in serial order from ace to king. (The jack, queen and king respectively represent 11, 12 and 13.) Place them face down in a row with the ace at the left. The following turning procedure is now applied, starting at the left at each step and proceeding to the right:

1. Turn over every card.
2. Turn over every second card. (Cards 2, 4, 6, 8, 10 and Q are turned face down.)
3. Turn over every third card.
4. Continue in this manner, turning every fourth card, every fifth card and so on until you turn over only the last card.

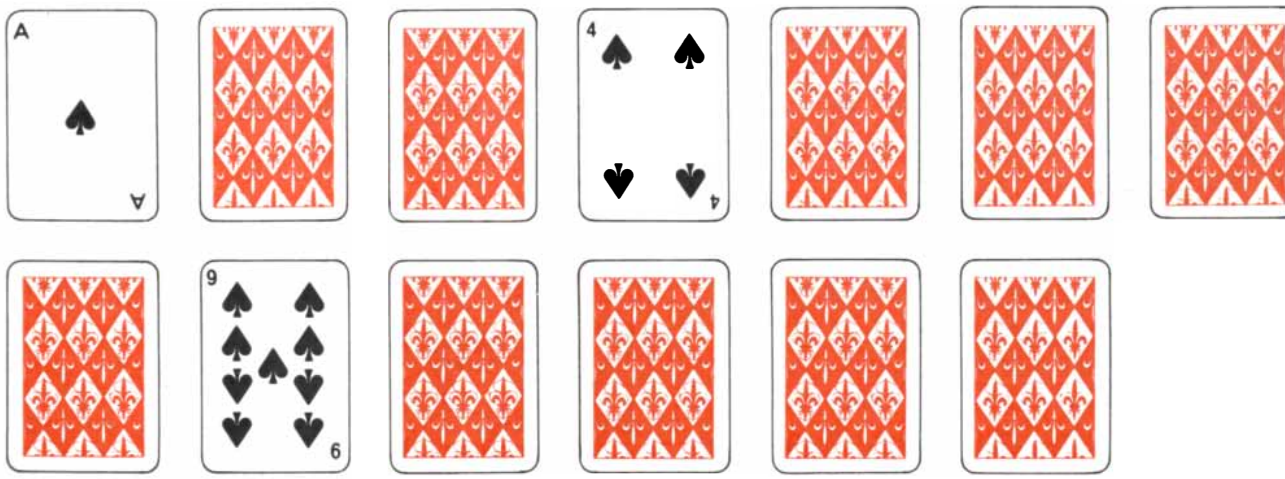
Inspect the row. Note that all the cards except the ace, the four and the nine are face down. These values happen to be square numbers. Is this an accident? Or is it an authentic hint of a general rule? A good classroom exercise is to prepare 100 small cards bearing numbers 1 through 100, stand them with their backs out in serial order on a blackboard ledge and apply the turning procedure. Sure enough, at the finish the only visible numbers will be the squares: 1, 4, 9, 16, 25, 36, 49, 64, 81 and 100. That is too large a sampling to be coincidental. The next step is to prove that no matter how large the deck, only squares survive the turning procedure.

A simple proof introduces one of the oldest and most fundamental of number theorems: A positive integer has an odd number of divisors (the divisors include 1 and the number itself) if, and only if, the number is a square. This is easy to see. Most divisors of a number come in pairs. Consider 72. The smallest divisor, 1, goes into the number 72 times, giving the pair 1 and 72. The next-larger divisor, 2, goes into the number 36 times, giving the pair 2 and 36. Similarly, $72 = 3 \times 24 = 4 \times 18 = 6 \times 12 = 8 \times 9$. The *only* divisor of a number that is not paired with a different number is a divisor that is a square root. Consequently all nonsquares have an even number of divisors and all squares have an odd number of divisors.

How does this apply to the row of cards? Consider the eight of spades in the first card-turning example. Since 8 is not a square, it has an even number of divisors: 1, 2, 4, 8. It will be turned four times: when you turn each card, each second card, each fourth card and each eighth card. An even number of turns applied to a face-down card will leave that card face down. Since every nonsquare card will be turned an even number of times, it will be face down at the finish. The only cards that are turned an odd number of times and left face up are those with an odd number of divisors, namely the squares. Is there a better way to etch this basic number theorem in the memory of a high school student than to have him witness such a demonstration?

Let us see how cards can be used for modeling a combinatorial problem that D. H. Lehmer once described as follows. Mr. Smith manages a motel. It consists of n rooms in a straight row. There is no vacancy. Smith is a psychologist who plans to study the effects of rearranging his guests in all possible ways. Every morning he gives them a new permutation. The weather is miserable, raining almost daily. To minimize his guests' discomfort, each daily rearrangement is made by exchanging the occupants of two adjoining rooms. Is there a simple algorithm that will run through all possible arrangements by switching adjacent occupants at each step?

The problem is easily modeled with cards. A row of spades, ace to king, corresponds to a 13-room motel. The number of permutations of n elements is factorial n. Our problem is to exchange two adjacent cards at each step and run through every possible permutation in just $(n! - 1)$ steps. (We subtract 1 from $n!$ because we begin with one permutation on the table.) Such an algorithm has important applications in computer sci-



Card algorithm for generating squares

ence. Many problems require a computer in order to run through all permutations of n elements, and if this can be done by exchanging adjacent pairs, there is a significant reduction in computer time.

It turns out that there is a simple, beautiful algorithm for doing this; it leads to the fastest-known way for a computer to permute n elements. The late Hugo Steinhaus, a Polish mathematician, was the first to discover it. It provides a solution for the abacus problem on page 49 of his *One Hundred Problems in Elementary Mathematics*, first published in Poland in 1958. In the early 1960's the procedure was independently rediscovered at almost the same time by H. F. Trotter and Selmer M. Johnson, each of whom published it separately.

Solving the problem for 13 cards would require $13! - 1 = 6{,}227{,}020{,}799$ steps (you can see why a fast computer algorithm is desirable); hence let us start with smaller sets. It is easy to find a solution for three cards, but four cards present difficulties. Besides, we want not just a solution for a specified number of elements but a general method that will apply to any number.

With two cards ($n = 2$) the solution is trivial [*see "a" in illustration on page 125*]. Simply move the deuce from right to left. For $n = 3$ we list each of the preceding permutations three times: 12, 12, 12; 21, 21, 21. The numeral 3 is now added to the list by a twisting procedure [*see "b" in illustration*]. The 3 starts at the right of the first permutation, weaves left through the series, pauses once at the left, then weaves back to end at the right of the final permutation. This generates the series 123, 132, 312, 321, 231, 213. If you start with an ace, deuce and trey on the table and run through the series, you will see that each permutation is derived from the preceding one by switching two adjacent cards. For $n = 4$ each permutation of the series for $n = 3$ is repeated four times. (The number of repetitions always equals n.) The numeral 4 is then added, weaving it left and right as before [*see "c"*].

The algorithm can be defined by a nonrecursive formula, but the recursive procedure just explained is easier to understand. The trouble with defining a procedure for any n is that when the weaving card pauses at each side, the position of the pair to be switched varies in a curious way. The procedure given here is recursive, of course, because for each n we must make use of the results obtained for $(n - 1)$. It works for all higher n. For $n = 5$ we obtain $5! = 120$ permutations, beginning with 12345, 12354, 12534, 15234, 51234, 51243, 15243... and ending with 21345. Note that a switch of the first two numerals of the final permutation will give the first permutation. This holds for all n. The procedure is cyclic, restoring the original sequence in one more step.

Are all the cards with colored backs jokers?

I am indebted to Donald E. Knuth for this means of displaying the recursive procedure, as well as for the algorithm's history. In the forthcoming fourth volume of his great series on *The Art of Computer Programming* he will discuss the algorithm and show how its "inversion table" is equivalent to what is called a reflected Gray code with mixed bases. The problem is a special case of a more general "motel problem," which in turn is a special case of what Lehmer calls the "traveling-burglar problem."

A few years ago John Horton Conway of the University of Cambridge invented a series of card problems and games based on the technique of permuting a set of elements by reversing the order of subsets according to various rules. Take, for example, the 13 spades from a deck, shuffle the packet and hold it face up in your left hand. Note the value of the uppermost card (we shall call it the top card) of the packet. Let us say it is a nine. Call the number out or to yourself, then with your right thumb slide nine cards off the packet one at a time into your right hand. This automatically reverses the order of the nine cards. Now put the nine-card packet on top of the cards in your left hand. A new card is on top. Note its value, call it out and repeat the same procedure. In other words, if n is the value of the top card, you always count off n cards, which reverses their order, and replace them face up on top. The game ends if an ace appears on top, because the ace produces a "one-loop" that consists in repeatedly counting off the ace and replacing it.

Must the game always end with the call of an ace? Yes, although it may take quite a while. It is impossible to get into a loop before the ace is called. If the game continues long enough without the call of an ace, a king might eventually be called. If this happens, however, the next reversal of cards puts the king on the bottom. Once the king is on the bottom there is no way it can leave. As the game continues, the queen might eventually be called. If this happens, the queen goes to the 12th position from the top, just above the king, and stays there. By mathematical induction the same thing must happen to the jack, then the 10 and so on (each card going to a position that corresponds with its value) until eventually, if not sooner, the ace is called and the game terminates. Indeed, each card can be called only once after the latest appearance of all higher cards.

The general form of the game involves one or more packets of n cards each. It is called k-swops if the kth card from the top is called. The called number gives the number of cards to be counted and replaced on top. It is called k-drops if the same procedure is followed except that the reversed set goes to the bottom.

When there is only one packet and k equals 1 (the top card) and the counted cards go on top, Conway calls the game topswops. That is the game we have analyzed. The same game with the counted cards going to the bottom is called topdrops. In topdrops the top card is called, the cards are counted and the reversed set is placed on the bottom. Topdrops is less interesting than topswops. You begin at once with a loop that may be long or short and that may or may not contain an ace.

When there is one packet and k equals n (the bottom card), the game is botswops or botdrops, depending on whether the counted set goes on top or on the bottom. Botswops is boring. If you play with 13 spades and the king is not on the bottom, you are immediately in a two-card loop. Suppose the bottom card is a four. It stays there while you repeatedly reverse the four cards on top. If the king is at the bottom, it goes to the top, and you find yourself in a similar two-loop based on the new bottom card.

Botdrops (call the bottom card, count and put the reversed set on the bottom) is more interesting. If you play it for a while, Conway writes, you might convince yourself that it always loops in a *KQKQKQ*... sequence, but that is not always the case. On rare occasions other

loops are possible. (Can you find one?) In this game, as in all the others, you start, of course, with a shuffled packet.

When the game is extended to two or more players, each with a packet, it becomes much harder to analyze. For instance, suppose two players have packets of 13 cards each. One has spades, the other hearts. They play topswops as follows. Each shuffles his packet. Player *A* calls his top card, then *B* counts that number off his packet and replaces the reversed cards on top of his packet. *B* now calls *his* top card, *A* counts and replaces the reversed cards on top of his packet. This continues with players alternating calls.

It is a curious fact, reports Conway, that as soon as an ace is called the calls go into a loop that starts with an ace, then a sequence, then an ace again (either the same ace or the other one), then the same sequence is repeated in reverse. For example, the first called ace might generate the following loop: 1–3–2–6–4–1–4–6–2–3–1. Note that the sequence between the first two ace calls is the reverse of the sequence between the second and third ace calls. It is an unproved conjecture (or was when I last heard from Conway) that in two-player topswops an ace is always called. It is not known if the game can conclude in a loop without an ace, although it is known that if a loop includes an ace, it includes it just twice.

Let it not be supposed that these Conway card games are trivial. They deal with the theory of set permutations and not only may provide deep theorems but also may have a bearing on practical problems that arise in seemingly unrelated fields.

I conclude with three unusual combinatorial card problems. The first is extremely difficult, the second is easy but elegant and the third is tricky.

1. A Langford problem. In November, 1967, I discussed a combinatorial problem, first posed by C. Dudley Langford, that could be worked on with a set of cards containing doublets of values from 1 to n. When the problem is extended to triplets, the smallest value of n for which a solution is known is 9.

Here is the task. Remove from a deck all the cards of three suits that bear values of ace through 9. Try to arrange these 27 cards in a single row to meet the following proviso. Between the first two cards of every value k there are exactly k cards, and between the second and third cards of every value k there also are exactly k cards. For instance, between the first and second sevens there must be just seven cards, not counting the two

sevens. Similarly, seven cards separate the second and third sevens. The rule applies to each value from 1 through 9.

2. A Silverman problem. David L. Silverman is the inventor of this puzzle. Remove the spades and hearts from a deck. Put the spades face up in a row in serial order with the ace at the left and the king at the right. Place a heart card under each spade so that the sum of the two cards is a square number. Prove that the solution is unique.

3. A Ransom problem. This comes to me through the courtesy of Tom Ransom, a Canadian amateur magician and puzzle collector whose tangram cards provided a striking color illustration in this department for September. This is how Ransom has been showing his puzzle to magician friends: Five cards are placed in a row as show in the illustration on page 123. All card backs, Ransom states correctly, are either colored or black. Are all the cards with colored backs jokers?

The problem is not to answer the question but to determine the minimum number of cards that must be turned over in order to answer it. In other words, assuming any possible variation of the hidden card sides (each joker may have a black or a colored back, the card with the visible colored back may or may not be a joker and so on), how many cards must you turn over before you can answer the question: "Are all the cards with colored backs jokers?"

It is a confusing problem and one that calls for careful reasoning. There is a surprise in the solution that is closely related to an old joke about three professors on a train in Scotland. Through the window they see a black sheep.

"How interesting," says the astronomer. "All sheep in Scotland are black."

"A totally unwarranted inference," the physicist replies. "We can conclude only that *some* sheep in Scotland are black."

"Correction," says the logician. "At least one sheep in Scotland is black on at least one side."

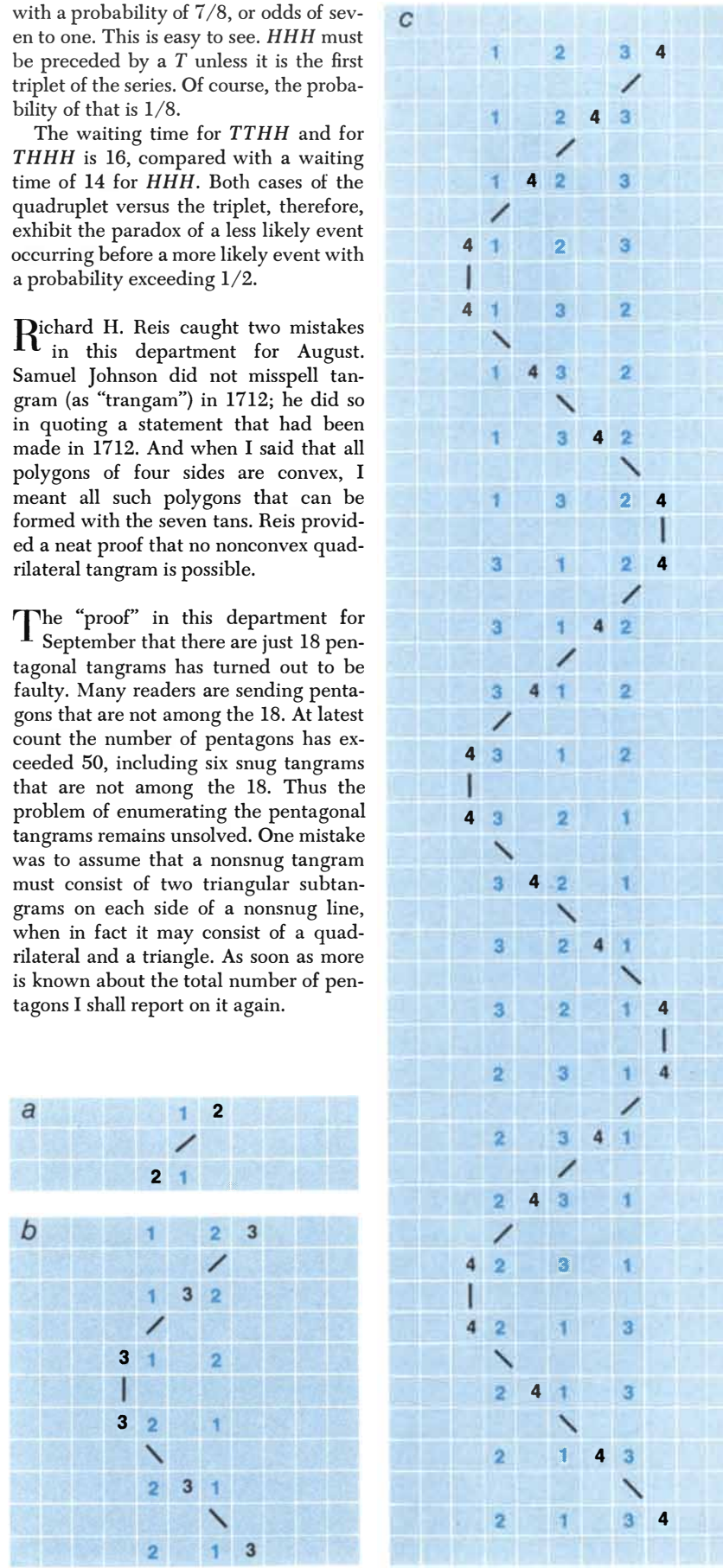
The three problems will be answered next month.

Last month's problem was to determine which pattern of heads and tails, *TTHH* or *HHH*, is more likely to appear first as a run when a penny is repeatedly flipped. Applying John Horton Conway's algorithm, explained last month, we find that *TTHH* is more likely to precede *HHH* with a probability of 7/12, or odds of seven to five. Some quadruplets beat some triplets with even greater odds. For example, *TTHH* precedes *HHH* with a probability of 7/8, or odds of seven to one. This is easy to see. *HHH* must be preceded by a *T* unless it is the first triplet of the series. Of course, the probability of that is 1/8.

The waiting time for *TTHH* and for *THHH* is 16, compared with a waiting time of 14 for *HHH*. Both cases of the quadruplet versus the triplet, therefore, exhibit the paradox of a less likely event occurring before a more likely event with a probability exceeding 1/2.

Richard H. Reis caught two mistakes in this department for August. Samuel Johnson did not misspell tangram (as "trangam") in 1712; he did so in quoting a statement that had been made in 1712. And when I said that all polygons of four sides are convex, I meant all such polygons that can be formed with the seven tans. Reis provided a neat proof that no nonconvex quadrilateral tangram is possible.

The "proof" in this department for September that there are just 18 pentagonal tangrams has turned out to be faulty. Many readers are sending pentagons that are not among the 18. At latest count the number of pentagons has exceeded 50, including six snug tangrams that are not among the 18. Thus the problem of enumerating the pentagonal tangrams remains unsolved. One mistake was to assume that a nonsnug tangram must consist of two triangular subtangrams on each side of a nonsnug line, when in fact it may consist of a quadrilateral and a triangle. As soon as more is known about the total number of pentagons I shall report on it again.



Recursive algorithm for solving motel problem

THE AMATEUR SCIENTIST

Of cross-staffs, paraboloids, sun viewers and other useful tools and experiments

Conducted by C. L. Stong

The following collection of simple projects illustrates the fact that many attractive and significant experiments and observations can be conducted with apparatus that calls for the expenditure of little time and money. The first project involves the construction of the handy instrument called the cross-staff. It is a primitive equivalent of the mariner's sextant.

The instrument measures the angle between distant objects. Its introduction into Europe during the 14th century by the Jewish philosopher Levi ben Gershon revolutionized navigation by enabling mariners to find their way at sea in rough weather. Unlike the astrolabe and the quadrant that had previously served navigators, the cross-staff does not require a plumb bob for finding the zenith. Its construction is described by I. L. Fischer, associate professor of physical science and mathematics at Bergen Community College (400 Paramus Road, Paramus, N.J. 07652).

"A year ago," Fischer writes, "I was attracted by the idea of having my astronomy students build their own instruments so that they could make observations at home instead of waiting for those rare occasions when the student was free, the weather was clear and the school's limited collection of instruments was available. Most students, including those without particular mechanical skills, managed to make and calibrate a cross-staff within two hours. Only a few spent money for materials.

"As its name suggests, the cross-staff consists of two elements: the staff, which resembles a yardstick, and the transversal, which is essentially a mask that makes a right angle with respect to the staff and slides along the staff [*see top illustration on opposite page*]. The staff is graduated in angular degrees.

"To make a measurement the user sights along the staff from one end while simultaneously adjusting the position of the transversal until the distant objects appear to line up with the ends of the transversal. The angle between the objects then corresponds to the graduation on the staff indicated by the position of the transversal. The students checked the accuracy of their instruments against a pair of lines that had been drawn on a blackboard with the aid of a sextant. Many instruments were accurate to within .05 degree, and virtually all came within .2 degree.

"When the cross-staff is employed in navigation, it is positioned so that the transversal is in the vertical plane. The cross-staff was the first instrument that involved the visible horizon in celestial observations. Latitude could be approximately determined by sighting simultaneously on the pole star and the horizon, thus eliminating the need to determine the zenith with a plumb bob.

"A serviceable cross-staff can be made with a sheet of stiff cardboard eight inches square, a smooth length of wood about the size of a yardstick, several rubber bands, scissors, a pencil and a ruler. The accuracy of the instrument can be increased by fitting the staff with transversals of two or more lengths, according to the size of the angles to be measured. The model I designed has transversals of two, four and eight inches.

"The transversals are formed from a single sheet of cardboard, which also is cut and folded to form a pair of braces that support the transversals at right angles with respect to the staff and constitute a cardboard sleeve on which the transversal unit slides on the staff. In the accompanying illustration [*bottom of opposite page*] the solid lines represent cuts and the dotted lines represent folds. The top inch of the cardboard serves as the four-inch transversal, the second inch is the eight-inch transversal and the bottom inch functions both as the brace to support the unit and as the two-inch transversal.

"One or two rubber bands hold the sleeve on the staff. The tension should be adjusted so that the transversal slides freely but remains in the position to which it is set. An additional rubber band holds the braces in position on the sleeve. Measure the length of the three transversals as accurately as possible.

"To calibrate the staff, mark one of its ends 'eye' on both sides. Measuring from the eye end, draw straight lines halfway across one side of the staff at distances listed in the accompanying table [*page 134*] for an eight-inch mask and label each line with the number of degrees that correspond to that distance. Then turn the staff over and similarly label the other side according to the part of the table that applies to the four-inch mask.

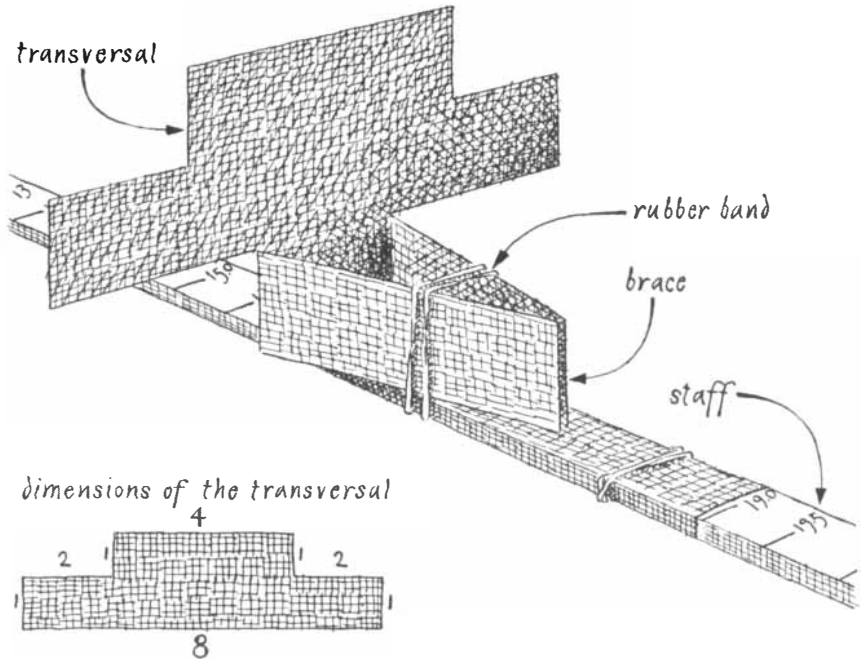
"A third set of graduations can be added on each side with ink of contrasting color to measure angles with the two-inch portion of the transversal. I leave to the experimenter the fun of calculating this table of distances. The distances are calculated by dividing the width of the mask (in inches) by two times the trigonometric tangent of one-half of the desired angle. For example, with the two-inch transversal at what distance from the eye position should the graduation be placed to indicate an angle of five degrees? According to the formula, the distance (d) equals the width (W) divided by two times the tangent (tan) of half the angle ϕ: $d = W / 2 \times \tan \frac{1}{2}\phi = 2 / 2 \times \tan 2\frac{1}{2}° = 2 / 2 \times .0437 = 22.9$ inches. The formula can of course serve for correcting the calibration scale if the transversals do not turn out to be exactly the specified four or eight inches and for deriving tables for transversals of any length.

"The cross-staff is suitable for any application that would normally involve a sextant. Indeed, for some purposes I find it superior to a sextant. For example, during observations at night it is difficult to keep track of a particular star unless its relation to surrounding stars is constantly evident. The cross-staff facilitates measurements involving stars because there is always a large field of view except for the small portion obscured by the mask.

"One of the interesting astronomical

projects that can be carried out with a cross-staff is plotting the path of the moon or the planets against the background of the fixed stars. The position of the moon can be determined by measuring the angle between it and three stars. By repeating this determination over an extended interval the path of the moon can be plotted on a star map with impressive accuracy. The direct and retrograde motions of the planets can be recorded in a similar way.

"When the cross-staff is constructed carefully, it is capable of splendid performance. Accuracies of better than .1 degree can be attained easily for angles of up to about 20 degrees. Hence it is desirable to mark additional lines on the staff at .1-degree intervals to facilitate reading the scale. With the four-inch transversal, for example, the difference between an angle of 10 degrees and one of 10.1 degrees amounts to more than .2 inch on the staff. In making observations brace the eye end of the staff against the cheekbone to ensure that error will not be introduced by holding the instrument at an indefinite distance from the eye."

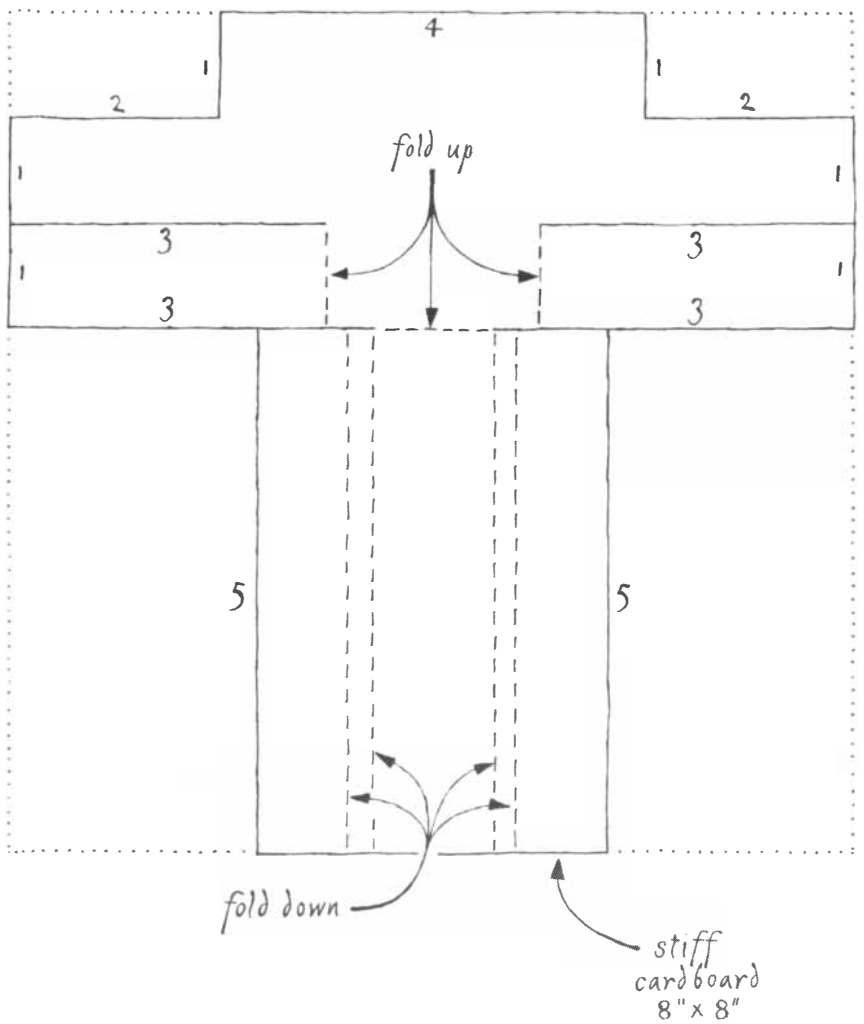


I. L. Fischer's cross-staff

Roger H. James, who is associated with Pratt & Whitney (400 Main Street, East Hartford, Conn. 06118), has developed a simple technique for making reasonably accurate paraboloids with a diameter of two feet or so. "As is well known," he writes, "the surface of any rotating fluid in a rotating container assumes the shape of a paraboloid of revolution. The height in inches (h) of a point r inches from the axis of revolution is approximately equal to the product of the square of the speed of the container in revolutions per minute (N) multiplied by the square of the radius in inches (r) divided by 70414: $h = N^2r^2 / 70414$. The focal point of the paraboloid, which is the distance from the apex of the paraboloid at which impinging parallel rays are reflected to focus, is equal to 17604 divided by N^2.

"I made a paraboloid by pouring melted paraffin into a pan of very hot water. The pan was 18 inches in diameter and rotated at 45 revolutions per minute on the turntable of an old record player. Several hours later, when the rotating paraffin had solidified, I had a wax paraboloid, which served as a mold for making a permanent paraboloid of fiberglass. Fiberglass and an appropriate epoxy for embedding the fibers are available as a kit at most hardware stores. Both the concave and the convex surface of the paraffin mold have the same shape.

"The depth of my parabola is about 2.3 inches and the focus is 8.695 inches



Pattern of the transversal

from the bottom. To find the slope of the paraboloid in angular degrees at any point from the apex multiply the focal length by 4 and divide 1 by the product. Multiply the resulting quotient by two times the radius in inches to the point of the desired slope. The product is the trigonometric tangent of the angle.

"For example, I have indicated that the focal length of my dish is 8.695 inches. The reciprocal of 4×8.695 is 1/34.78, or .02875. Hence the slope at the edge of my dish is arc tan $2 \times .02875 \times 9 =$ arc tan $.517 = 27.36$ degrees. The equations are valid for any liquid.

"For most practical purposes differences in surface tension can be neglected. Containers of any shape are satisfactory, and they need not be centered. The axis of the resulting paraboloidal surface will coincide with the axis around which the fluid rotates. With a cylindrical container that is centered the level of the fluid at the edge will rise by exactly the same amount that the level at the center drops. Containers of this shape can therefore be half-filled.

"The axis of rotation of the container must be exactly vertical, otherwise the fluid will not rotate uniformly. When the axis of rotation is truly vertical, a speck of dust resting on the bottom of the container near the axis does not move with respect to the bottom."

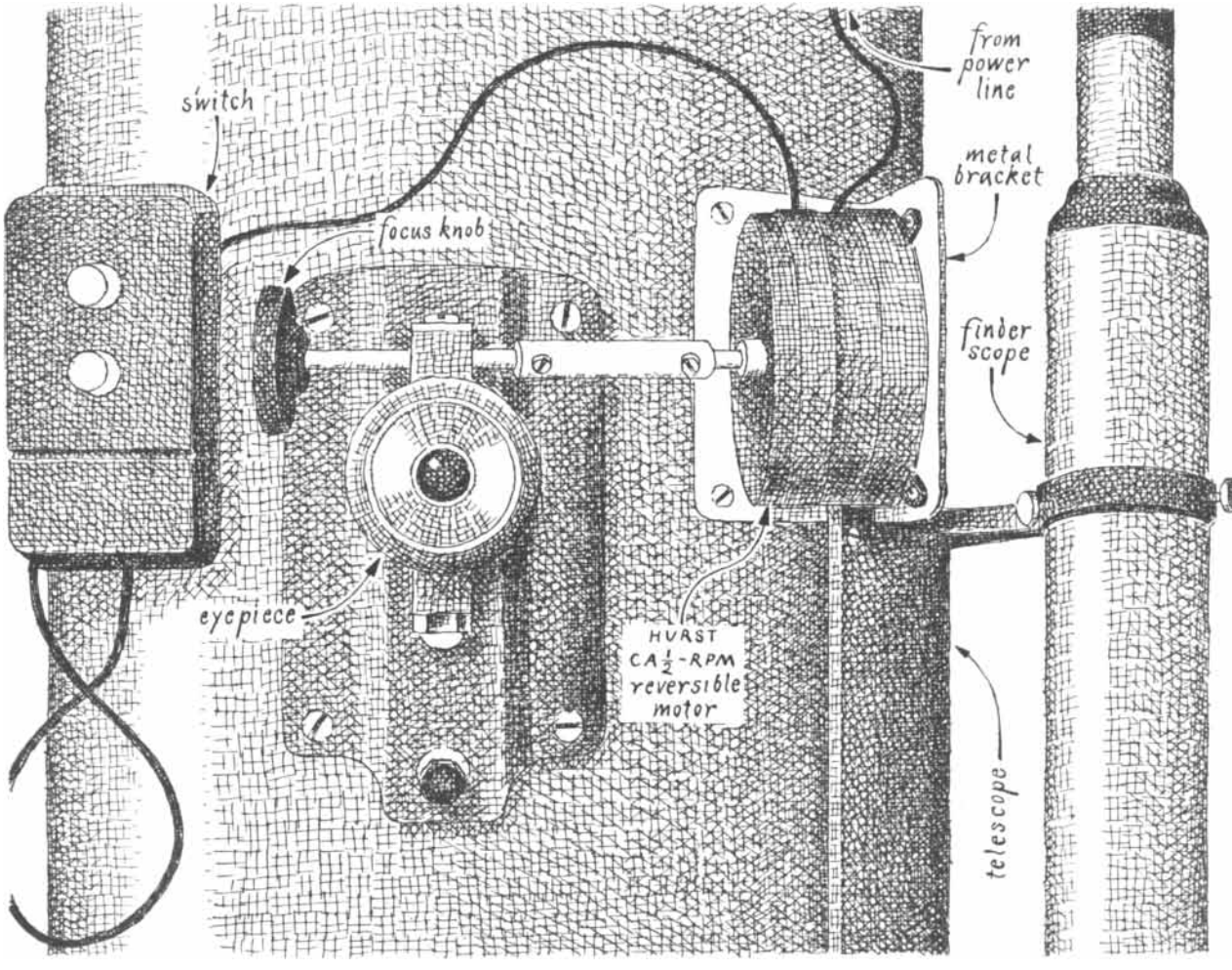
Incidentally, readers have called attention to three errors in the formulas previously presented in this department for constructing an approximate paraboloid with sectors of cardboard [see "The Amateur Scientist," SCIENTIFIC AMERICAN, December, 1973]. The rows of the table on page 127 should be numbered 0 through 10 instead of 1 through 10. The term $(y_1 - y)$ in the formula for z should be squared. A closer approximation of a true paraboloid will result by changing the formula for the base of the sector to $V_d - X_n \sin \text{pi} / N$, in which N is the number of sectors.

Most amateur astronomers have trouble focusing a telescope in cold weather. The rack-and-pinion adjustment is all but impossible to manipulate while the observer is wearing mittens. If the mittens are removed, fine adjustments are hard to make with stiff fingers. Charles W. Bowen of San Antonio, Tex., has solved the problem by providing the rack-and-pinion draw tube, which supports the eyepiece, with a motor drive.

"I installed a Model CA 1/2-RPM Hurst reversible motor on my eight-inch reflecting telescope," Bowen writes. "When I bought the motor, it cost $13.95. It is available from mail-order distributors.

"The motor can be switched on and off in either direction by a homemade control that has a push-button switch for each direction. The gearing allows the unit to develop a force of 150 inch-ounces at constant speed. I learned by experiment that a half-revolution per minute is the best rate at which to turn the focusing pinion. Focus is approached at a controllable speed with eyepieces in the focal-length range from 30 millimeters to four millimeters.

"The mechanical details involved in mounting the motor depend on the



Telescope-focusing arrangement devised by Charles W. Bowen

What would you do with a Statisti s and Number-Crunching Computer that starts at $7,400,* has 16K Hardw red Basic Language and 28 Major Peripherals?

Plenty!

The new Wang System 2200 is a System. It gives you the raw power and the peripherals you must have for a wide range of problem solving. For under $7,500 you get a CPU with 16K bytes of BASIC language instructions hardwired into the electronics . . . plus a 4K operating memory. You also get a big 16 lines (of 64 characters each) CRT display, a console mag tape drive and your choice of either alpha or BASIC Keyword keyboards.

Some Words About Language: The hardwired MOS ROM language in your System 2200 finally ends your dollar tradeoffs . . . economy systems that are costly to program or very expensive systems that are relatively easy to program. Many, if not most, of your people already know BASIC. They'll be solving problems the day your system is delivered (and, we can deliver in about two weeks). Most of your budget will go into problem solving; not system support.

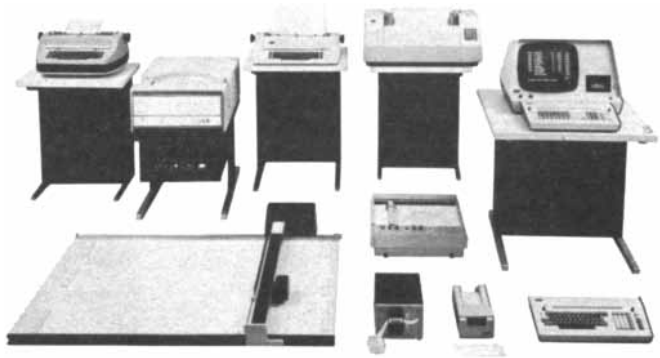
Try To Out-Grow It: Main memory is field expandable in 4K increments (at $1,600 per 4K). Up to 32K. You can choose from three kinds (and 7 price ranges) of printers . . . one even has a stepping motor for very precise 4-quadrant incremental plotting. Speaking of plots, we have a new, very large flatbed (31" × 48") for only $8,000 or a smaller one if you plot small. Both print alphanumerics and plot under full program control. Been appalled lately by disk prices? Starting at just $4,500, we offer you our new "floppy" disk in single, double and triple disk configurations (.25, .50 and .75 MB's). For big disk power, you can have 1, 2 or 5 megabyte fixed/removable disk systems. All peripherals, including punched or mark sense hopper card readers, paper tape readers and on- line BCD or ASCII controllers are easily added-on in the field so your System 2200 will grow with your needs.

The Wise Terminal: If you are now or may soon be getting into terminals, we have several new products that will instantly upgrade your System 2200 for telecommunications with any other System 2200 or a mainframe computer. And, you still have a powerful stand-alone system. Another approach, of course, is to justify it as a powerful terminal and get a "free" stand-alone computer. Wise?

We Do A Lot For You: System 2200 is backed by over 250 factory-trained Wang Service Technicians in 105 U.S. cities. Naturally, we guarantee or warranty everything you buy from us. If you want, there are free programming/operating schools here in Tewksbury, Massachusetts, almost every week. We have a growing program library on a wide range of statistics and math/science applications. Our user group (with the unlikely name of "SWAP") could help you cut programming costs even further. We do a lot for you.

* All prices U.S. List. If you're the entrepreneur type, we've just announced a new 7-module Basic Accounting System software package for the business end of your business like payroll, invoicing, inventory, receivables and some really fancy management reports.

WANG



Even if you call the Wang System 2200 a small system . . . you have to admit it's a big idea.

☐ Please send literature

☐ Please have your representative phone me:_____

Name_____ Title_____

Company_____

Address_____

City_____

State_____ Zip_____

Wang Laboratories, Inc., SA-11

836 North St., Tewksbury, Ma. 01876, Tel. (617) 851-4111

structure of the telescope. For my instrument, which is typical, I bent a bracket of sheet metal and drilled it to accept the mounting screws of the motor and to be attached by similar screws to the tube of the telescope [*see illustration on page 128*]. One knurled knob was removed from the shaft of the pinion and replaced by a short length of pipe that is the coupling to the motor. The ends of the pipe were drilled and threaded for setscrews that clamp the shafts.

"I cannot overemphasize the convenience of this focusing scheme. The observer can trim up the focus without touching the instrument and jiggling it. I made the installation in a few minutes less than two hours."

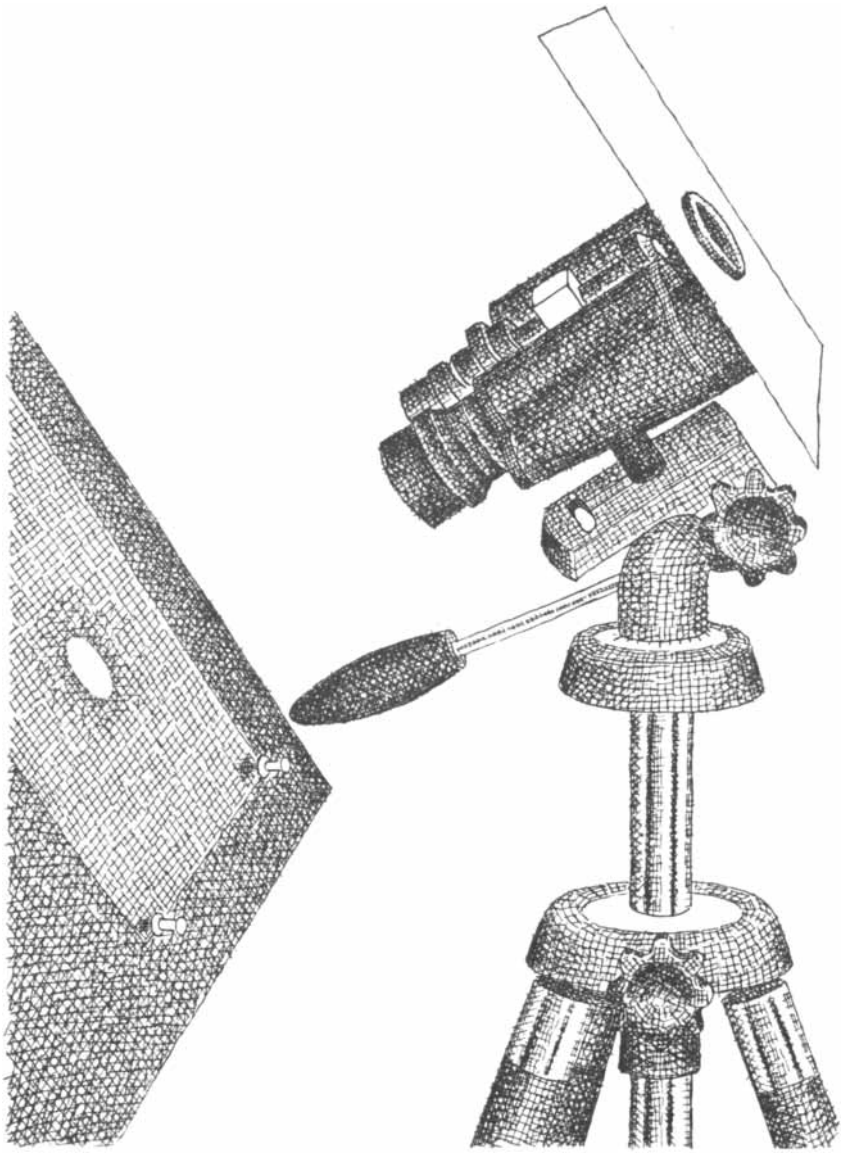
H. R. Crane, professor of physics at the University of Michigan, suggests a way to view the sun safely. It is perhaps the simplest and safest method of all. It makes use of a pair of binoculars and should be kept in mind against the time when the observer becomes interested in examining a big sunspot or an eclipse.

"Textbook diagrams of binoculars," Crane writes, "always show the image to be virtual, at 25 centimeters or more in front of the eye. As a practical matter, however, the focusing range of binoculars is made so wide (in order to accommodate users having all kinds of visual abnormalities) that a real image can be cast at any distance behind the eyepiece—from infinity to as close as 10 or 20 centimeters. The size of the image of the sun cast by my binoculars (they are seven by 35 millimeters) is about six inches in diameter at eight feet. If the image falls on a white card that is shaded from direct sunlight, its brightness is just right for comfortable observation. In lining up the binoculars the experimenter *must resist the temptation to look into the eyepiece*. Concentrated sunlight could destroy the retina.

"I fastened my binoculars to a tripod. I cut a two-inch hole in an 18-inch square of cardboard and pushed it onto the front end of one lens barrel of the binoculars [*see illustration on this page*]. The cardboard served both to shade the image from direct sunlight and to mask one of the telescopes so that only a single image was cast on the screen.

"Much fun can be had with the setup even when there is no eclipse. I have viewed sunspots clearly with the apparatus and have also photographed the spotted solar image with an ordinary camera. This kind of photography requires care. The spots are small and the contrast is not great. I did not succeed when I held the camera by hand. I made good pictures when I supported the camera with a second tripod and set the aperture small (*f*/22). The small aperture is necessary for increasing the depth of focus so that the camera can be positioned at an angle with respect to the plane of the screen.

"I found that it is important to maintain the optical axis of the binocular at a right angle in relation to the screen. Aberrations grow rapidly as the axis moves away from the normal. A way to increase the brightness of the image with respect to the background is to decrease its size by moving the screen closer to the binoculars, assuming that the camera can be focused to a short distance. Photographs of higher contrast can be made by enclosing the camera and screen in an improvised shadow box and by using high-contrast (copy) film."



Binoculars arranged by H. R. Crane for viewing the sun

Martin Gardner's recent illustration of hexagonal numbers as differences between consecutive cubes [see "Mathematical Games," SCIENTIFIC AMERICAN, July] brought to mind an identical cube that constitutes an optical illusion. The cube was devised a year or so ago by Fred Duncan (Box 264, Redway, Calif. 95560), who is a specialist in psychokinematic art. To make the cube, cut from light cardboard a figure according to the accompanying pattern [*page 132*]. Slit the cardboard and fold it as specified. Cement each lettered flap to the surface labeled with the matching circled letter. The result is a cube with one missing corner.

Hold the cube in one hand and with one eye look diagonally into the cube at the missing corner. Keep the other eye closed. After a second or two the missing

Announcing the first space magazine written to be understood...

Popular Astronomy: A new magazine. A special offer.

Explore the world around you, and the worlds beyond . . . . .

It's true that men have been walking on the moon for years. Yet, for the non-scientist, no single publication has been available to explain, in non-scientific terms, the mysteries of the space we've begun to explore.

POPULAR ASTRONOMY MAGAZINE IS GOING TO CHANGE ALL THAT

Each month, *Popular Astronomy* will unravel hundreds of awesome facts about the stars, planets and galaxies that surround us. In language that novice, hobbyist and amateur scientist alike, can understand.

Leading experts in the fields of astronomy and space technology will bring you up to date on the latest developments in their specialties, and provide you with hours of entertaining reading at the same time.

STUNNING COLOR PHOTOGRAPHY BRINGS THE BEAUTIES OF THE UNIVERSE INTO YOUR HOME

Unlike other astronomy publications designed specifically for the professional scientist, the feature articles in *Popular Astronomy* will be superbly illustrated. And, as an added bonus, each issue will contain a full color center spread you will want to collect and treasure. A grouping of these striking photographs will make a unique conversation piece for a recreation room or den . . . and identify you as an individual in pursuit of knowledge and understanding.

POPULAR ASTRONOMY PREVIEWS

In the months ahead, you'll read articles that deal with . . .

A star-by-star tour of the evening sky. Discover which planets are visible to the naked eye at certain times of the year, and the many other wonders that can be revealed with the use of binoculars or a small telescope.

Build-your-own telescope projects. Educational and lots of fun! Step by step illustrations insure success, even for the beginner.

Celestial Events. Up-to-the minute reminders of solar and lunar eclipses, meteor showers, occultations and other sky shows you can observe from your locale.

Product Reviews. Offer objective analyses of optical and astronomical equipment, where you can get it, and what you can expect to pay for it.

Club news and travel notes. You'll get reports of upcoming observation expeditions, openings of new planetariums, and the formation of astronomy groups in your locale.

If you've ever been the least bit curious about what exists in the skies above, you'll find *Popular Astronomy* an irresistible magazine. And, if you take advantage of this exceptional introductory subscription offer, you'll be automatically enrolled in the Galaxy Discount Society, compliments of *Popular Astronomy*.

SPECIAL CHARTER MEMBERSHIP OFFER

The first issue of *Popular Astronomy* will be published early this spring. If you subscribe now, you can save 1/3 off the regular price of $15.00 for twelve issues. You save $5.00 and are assured the lowest subscription rate when you renew. You will also receive a free membership for **Galaxy Discount Society**, which entitles you to attractive savings (a minimum of 10 per cent) on astronomical books, star maps and equipment of all types.

Popular Astronomy Magazine
245 East 25th Street - New York, N.Y. 10010

Yes, please enter my subscription. My check (or money order) for $10.00 is enclosed. I understand that I will become a charter subscriber, and that I will be entitled to a minimum discount of 10 per cent on astronomical supplies as a member of the Galaxy Discount Society. I also understand that you will refund my subscription at any time if I am not pleased with **Popular Astronomy** Magazine.

NAME _____

ADDRESS _____

CITY _____ STATE _____ ZIP. _____

☐ Please enter _____ gift subscription(s) and send special gift announcement card(s) with my name. I enclose a separate sheet of paper listing name(s) and address(es) of recipient(s).

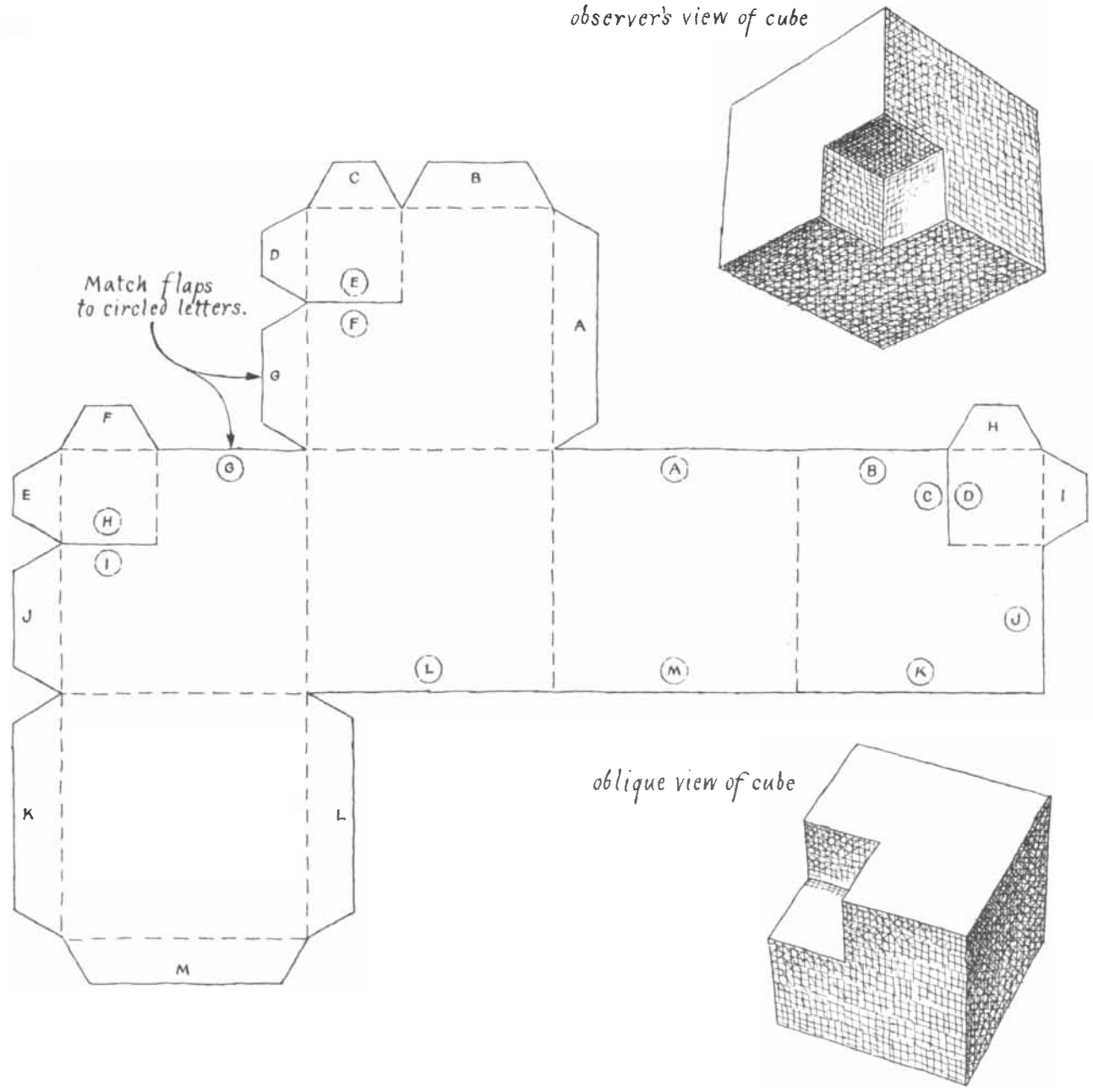
69SA

corner will seem to be replaced by a smaller cube projected from the corner of the larger one. Keep staring without changing your viewing angle. After perhaps a minute or two the larger cube will vanish, to be replaced by three mutually perpendicular planes, like two walls and the floor of a room. In the far corner of the "room" you will see the smaller cube that formerly occupied the near corner. The structure therefore comprises three illusions in one.

Cordless appliances ranging from electric hand drills and grass trimmers to shavers and hand-held calculators abound these days. Most of them run on nickel-cadmium storage batteries, which offer a number of opportunities for amateurs. Nickel-cadmium cells come in all the standard sizes of flashlight cells. They cost only from six to eight times more than expendable cells and can deliver far more current. They are available from the mail-order distributors of electronic supplies.

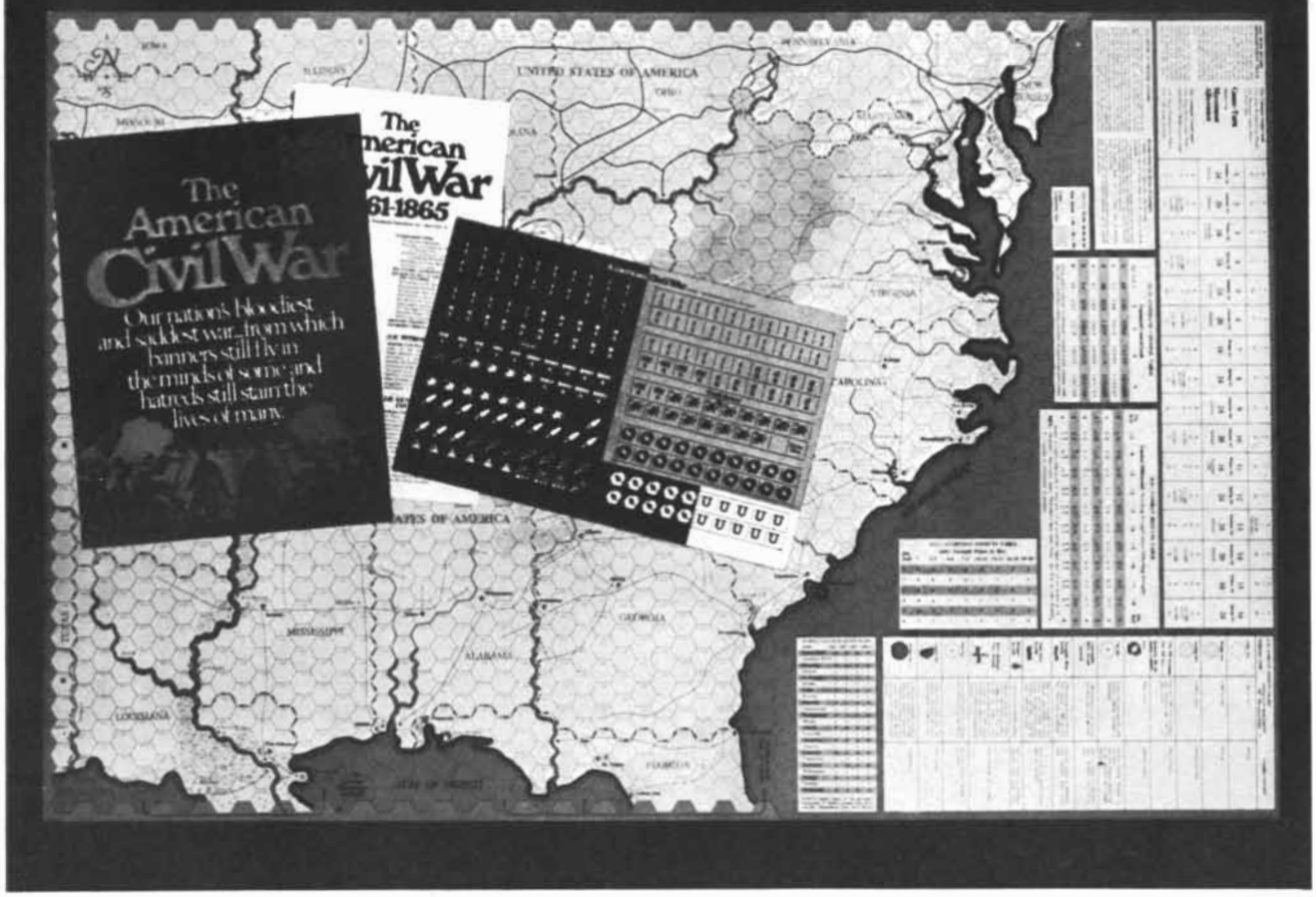
Notwithstanding these advantages, the batteries have not become popular with amateur experimenters. One explanation may be the difficulty of getting information about the characteristics of the cells, particularly their charging characteristics. The following data were accumulated by persistent interviews with specialists and by extended correspondence with manufacturers over the past six months.

First, there is no simple test by which you can determine the state of the charge in a nickel-cadmium cell. The rate at which a cell is charged depends on a number of factors and is usually specified by a data sheet supplied by the manufacturer. The sheet also states the capacity of the cell in terms of ampere-hours. The charging rate in amperes is usually specified as the quotient of C/T, in which C is the capacity of the cell in



Fred Duncan's three-in-one optical illusion

Strategy & Tactics



The paper time machine

STRATEGY & TACTICS is a magazine. It's also a tool: a time machine that enables you to replay the crucial events — past, present, and future — that shape our lives.

Now, instead of merely reading about what's happening, you can explore and experience the alternatives and decision points through the technique of Conflict Simulation.

What is Conflict Simulation?

Conflict Simulation is a way of analyzing a political or military conflict situation. A way that is as intellectually stimulating as a game of chess, and as thorough as a written analysis.

Through the use of the Conflict Simulation (or "game") format, the conflict situation is re-created — so that you are in a position to make the vital decisions and, in the game at least, change the way things were, are, or will be.

What you get

STRATEGY & TACTICS magazine is published bi-monthly. Each issue contains:

★ A ready-to-play conflict-simulation game with a 22" x 28" playing surface, die-cut playing pieces, and complete rules.

★ An analytical article on the same subject as the game in that issue.

★ Other feature articles on historical and military subjects.

★ Game and book reviews, commentary on existing games, and discussions of subscribers' questions.

The magazine is 48 + pages long, and all material is handled in a highly organized (and easily understandable) graphic format.

Games recently published in STRATEGY & TACTICS were: *GRUNT* (ground combat in Vietnam), *LOST BATTLES* (tactical combat in Russia, 1941-44), *USN* (the war in the Pacific, 1941-43), *COMBAT COMMAND* (tactical combat in Western Europe, 1944).

We also publish a separate line of conflict-simulation games, which you will find listed in the coupon.

Free to new subscribers

NAPOLEON AT WATERLOO, history's greatest battle presented in a game-design specially created to introduce new readers to Conflict Simulation.

Send check or money order to:
Simulations Publications, Inc.
Dept. **184** 44 East 23rd St., New York, N.Y. 10010

Please enter my subscription to S&T for
- ☐ *1 year* (6 issues)-$12
- ☐ *2 yrs.* (12 issues)-$22
- ☐ *3 yrs.* (18 issues)-$30
- ☐ *Current issue*-$4
- ☐ *6-month trial* (3 issues)-$8

Send me the following Simulations Games:
- ☐ *Red Star/White Star* (armor in the 70's)-$8
- ☐ *NATO* (Soviet invasion of Europe)-$8
- ☐ *World War II* (Europe, 1939-45)-$8
- ☐ *Sniper!* (street fighting, WWII)-$8
- ☐ *Solomons Campaign* (Pacific, WWII)-$8
- ☐ *Soldiers* (WWI tactics)-$8
- ☐ *Lee Moves North* (Civil War)-$8
- ☐ *American Revolution* (1775-83)-$8
- ☐ *Phalanx* (ancient tactics)-$8
- ☐ *Please send me your free brochure.*

Name_____

Address_____ Apt. #____

City_____ State_____ Zip____

ampere-hours and T is the charging time in hours.

Most cordless appliances that include a battery charger have the charging rate fixed between $C/15$ and $C/20$. Makers of some appliances specify the number of hours the cells should be charged, but most appliances come without any advice on the subject. Many experimenters have assumed that cells for which no charging time is specified can be charged indefinitely without damage. Supposedly the charger includes a regulator that reduces the rate automatically when the cells reach full charge.

All efforts to design a regulated charger have failed. In the absence of other instructions charge all nickel-cadmium cells at the $C/20$ rate. For example, a battery of one-ampere-hour capacity would be charged at the rate of 1/20, or 50 milliamperes. Assume a charging efficiency of roughly 50 percent. The fully discharged battery would recharge (at the rate of 50 milliamperes) in about 40 hours. It could be kept on a continuous charge without significant damage for 60 hours. One manufacturer states that its cells can be kept on continuous charge indefinitely at the $C/15$ rate, but the company does not mention what the cost is in terms of the life of the battery.

When a nickel-cadmium cell reaches full charge, the energy put in thereafter is expended partly to liberate oxygen, which oxidizes the cadmium electrode, and partly as heat. If the charging rate is more than about $C/15$, gas may evolve more rapidly than it can combine chemically with the metal. Pressure then increases explosively. Depending on the structure of the cell and the rate of charge, the pressure can build up to 125 atmospheres within minutes.

Most nickel-cadmium cells have pressure safety valves. When the valves open, the cells may lose their electrolyte (potassium hydroxide). This caustic substance can burn tissue and destroy apparatus. The lye can be neutralized with a 3 percent solution of boric acid. Usually excessive pressure ruins the cell.

Nickel-cadmium batteries can be discharged at much higher rates than conventional dry batteries but should never be fully discharged. The reason is that full discharge would risk applying current of reversed polarity to the weakest cell of the battery. Reverse charge permanently damages the cell.

On the other hand, every cell must be fully discharged at least once a year and fully recharged, otherwise the cells deteriorate chemically, with the result that ampere-hour capacity is permanently reduced. To discharge a battery safely, disconnect the cells from one another and connect each cell to a separate resistor load until it is fully discharged. Cells can be stored indefinitely without damage in the fully discharged state. A fully charged but idle nickel-cadmium battery will lose approximately 20 percent of its charge within two weeks at room temperature.

In this department's description in September of a quartz-crystal oscillator for a pendulum clock the two integrated COS/MOS circuits labeled CD 4020 AE in the upper right corner of the illustration on page 195 should have been labeled CD 4024 AE.

EIGHT-INCH MASK				FOUR-INCH MASK	
DISTANCE FROM EYE END (INCHES)	ANGLE OF ARC (DEGREES)	DISTANCE FROM EYE END (INCHES)	ANGLE OF ARC (DEGREES)	DISTANCE FROM EYE END (INCHES)	ANGLE OF ARC (DEGREES)
5.7	70	18.8	24.0	14.2	16.0
6.3	65	19.7	23.0	14.7	15.5
6.9	60	20.6	22.0	15.2	15.0
7.6	55	21.6	21.0	15.7	14.5
8.6	50	22.7	20.0	16.3	14.0
9.0	48	23.3	19.5	16.9	13.5
9.4	46	23.9	19.0	17.6	13.0
9.9	44	24.6	18.5	18.3	12.5
10.4	42	25.3	18.0	19.0	12.0
11.0	40	26.0	17.5	19.9	11.5
11.6	38	26.8	17.0	20.8	11.0
12.3	36	27.6	16.5	21.8	10.5
13.1	34	28.5	16.0	22.9	10.0
13.9	32	29.4	15.5	24.1	9.5
14.9	30	30.4	15.0	25.4	9.0
15.5	29	31.5	14.5	26.9	8.5
16.0	28	32.6	14.0	28.6	8.0
16.7	27	33.8	13.5	30.5	7.5
17.3	26	35.1	13.0	32.7	7.0
18.0	25	36.5	12.5	35.2	6.5

Data for calibrating a cross-staff

Western Electric Reports:

An inside look at crystal growth.

Engineers at Western Electric's Engineering Research Center have developed an improved method for controlling the growth of the crystals used in light emitting diodes (LED's). The new technique represents one more step toward low-cost, mass produced LED's.

LED's have found many uses in telecommunications equipment as illuminators, indicator lamps and numeric displays. They consume very little power and last from 10 to 100 times longer than the devices they replace.

LED's used in the Bell System are made from gallium phosphide (GaP) single crystals. Economical processing using standard-sized fixtures requires crystals of uniform diameter. But because GaP single crystals must be grown inside a high pressure vessel, monitoring and controlling crystal growth has been a problem.

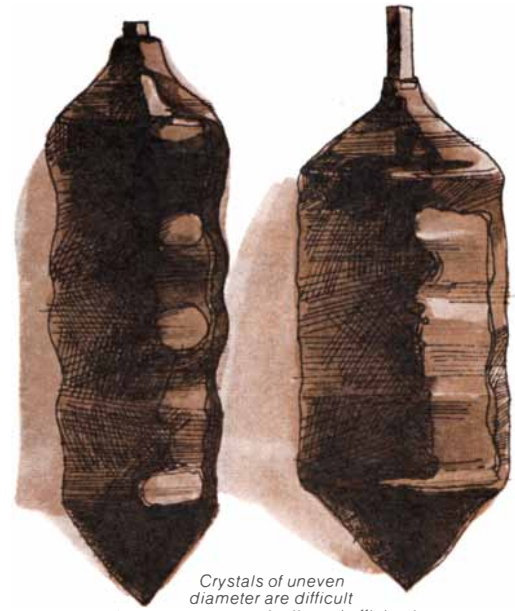
Previously, crystal growth could only be monitored visually. The halo surrounding the growing crystal was observed through closed circuit television. Since the halo would expand and contract with the diameter of the growing crystal, it provided some measure of control. But phosphorous vapors condensing on the viewing window partly obscured the halo, making precise control difficult.

The new monitoring technique is similar to the use of a fluoroscope in medicine. X-ray imaging provides an unobstructed view of the meniscus formed where the solid crystal meets the liquid melt. Western Electric engineers have correlated the height and angle of this meniscus to the crystal's growth condition. This is useful because a change in the shape of the meniscus signals a change in the temperature of the melt *before* it is manifested as a change in the crystal's diameter.

A change of just 4° in the liquid-solid contact angle can be observed, allowing adjustments to be made in either temperature or pulling rate to maintain uniform growth.

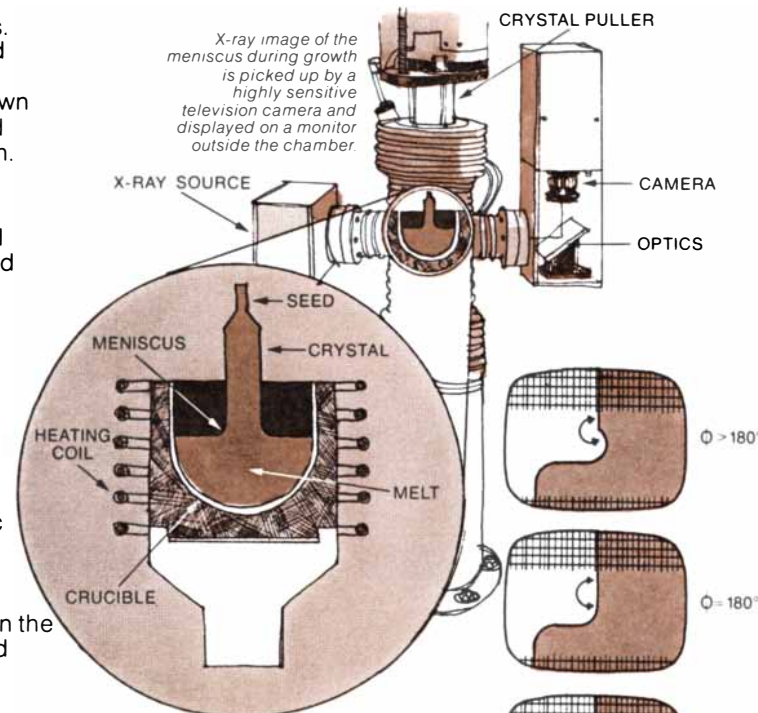
X-ray imaging is in production use at Western Electric's plant in Reading, Penn.

Benefit: X-ray imaging of the meniscus of a growing crystal has permitted a marked improvement in the monitoring and control of crystal growth. It helps insure high yields of uniform diameter crystal wafers for processing into LED's.



Crystals of uneven diameter are difficult to process economically and efficiently. X-ray imaging now yields crystals of a diameter within a tolerance of ± 1/16 inch

X-ray image of the meniscus during growth is picked up by a highly sensitive television camera and displayed on a monitor outside the chamber.



Growing crystals. seed is dipped into crucible of molten GaP, maintained just above melting temperature. It is rotated and withdrawn at controlled rate, producing cylindrical crystal

THE LIQUID-SOLID CONTACT ANGLES

X-ray image of the meniscus at various temperatures. The smaller the angle, the lower the temperature. The larger the angle, the higher the temperature. An angle of 180° indicates the desired "steady state" growth condition

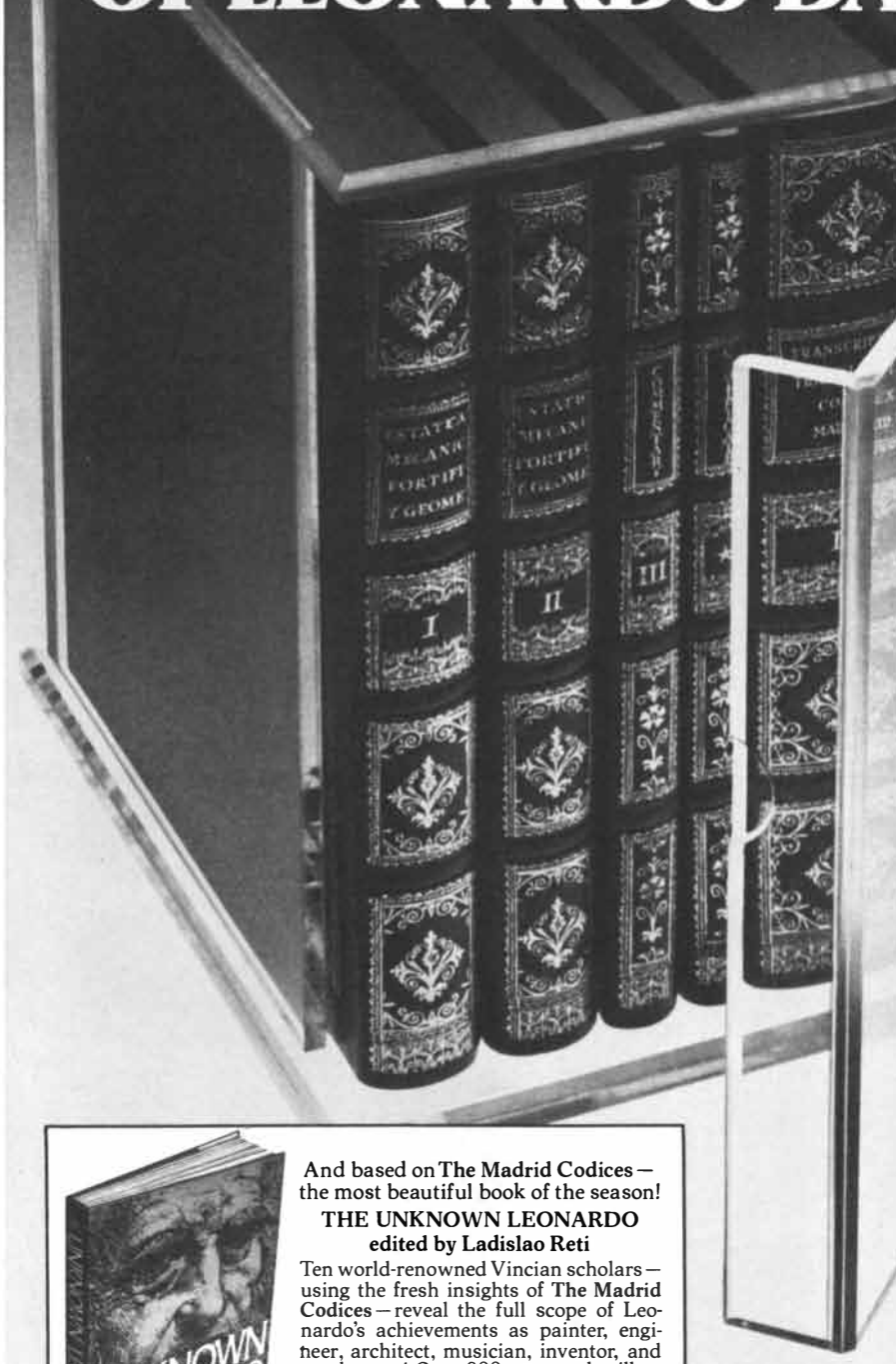
Western Electric

We make things that bring people closer.

THE FIRST PUBLICATION EVER—IN A MAGNIFICENT FACSIMILE EDITION—OF

"One of the great manuscript finds of the 20th century"*

THE MADRID CODICES OF LEONARDO DA VINCI



Deluxe Limited Edition. Five volumes and matching certificate case. Each set individually numbered. $750

In 1967, The New York Times first broke the story that two remarkable notebooks in Leonardo's own hand—The Madrid Codices—had been discovered in the National Library of Spain. The amazing writings and drawings in these manuscripts—which add about 20% to Leonardo's known literary legacy—reveal visionary ideas and inventions that were centuries ahead of their time. They throw new light on Leonardo's genius as scientist, inventor, engineer.

This momentous edition consists of Leonardo's two notebooks, meticulously reproduced in color gravure directly from the original manuscripts—along with two companion volumes of transcription and English translation and one volume of commentary, all by Professor Ladislao Reti. Luxurious red leather binding, gold tooled. Handsome transparent display case. Limited to only 1000 numbered sets—of which no more than 975 will ever be offered for sale. Authenticating certificate bearing signature and seal of the Director of the National Library of Spain, in matching case.

A triumph of scholarship. A masterpiece of bookmaking. A possession of rare beauty. Ask your bookseller for the Prospectus.

Library edition also available at $400 to scholars and institutions.

*Dr. Edward C. Moore, in The New York Times (2/14/67), pg. 1

And based on **The Madrid Codices**—the most beautiful book of the season!

THE UNKNOWN LEONARDO
edited by Ladislao Reti

Ten world-renowned Vincian scholars—using the fresh insights of **The Madrid Codices**—reveal the full scope of Leonardo's achievements as painter, engineer, architect, musician, inventor, and much more! Over 800 spectacular illustrations, hundreds in color. 10¼" x 12¾". $34.95 to December 31, 1974; $39.95 thereafter. At bookstores.

McGRAW-HILL BOOK COMPANY
1221 Avenue of the Americas
New York, N.Y. 10020

BOOKS

The Great Barrier Reef of Australia, its coral and Captain Cook, who discovered it

by Philip Morrison

THE GREAT BARRIER REEF, by Isobel Bennett. Charles Scribner's Sons ($17.50). THE LIFE OF CAPTAIN JAMES COOK, by J. C. Beaglehole. Stanford University Press ($18.50). THE EXPLORATIONS OF CAPTAIN JAMES COOK IN THE PACIFIC AS TOLD BY SELECTIONS OF HIS OWN JOURNALS 1768–1779, edited by A. Grenfell Price. Illustrated by Geoffrey C. Ingleton. Dover Publications, Inc. ($3.50). THE CORAL SEAS: WONDERS AND MYSTERIES OF UNDERWATER LIFE, by Hans W. Fricke, with an introduction by I. Eibl-Eibesfeldt. G. P. Putnam's Sons ($25). The continental shelf outlines a funnel 1,000 miles long on the east coast of tropical Australia. The deep water of the open Tasman Sea is more than 200 miles from the mainland at the southern end and only 10 or 15 miles out at the narrow stem. In May of 1770 H.M. Bark *Endeavour,* her master Mr. Cook, "a good mathematician, and very expert in his Business," sailed into the mouth of the great funnel all unaware. A radiant moon lit the calm sea, and the *Endeavour* "stole along under double-reefed topsails" until " 'before the Man at the lead could heave another cast the Ship Struck and stuck fast.' "

The *Endeavour* was the first we know of to go aground (and she got away), but 500 later shipwrecks have been documented on the shelf along the present steamer track, which is now guarded by a hundred lights, marks and radio beacons of the Queensland Coast and Torres Strait Pilot Service. The track is the longest single stretch of pilotage in the world, one pilot alone conning every ship for the entire voyage. Masters can opt instead for the open ocean east of the shelf, to which Cook gratefully escaped through a narrow passage after beaching and repairing the *Endeavour.* Back into the reefs he came a few days later, shoal water and all! He had to flee the heavy ocean swell and the beating surf, which one becalmed day threatened to throw his drifting ship "upon this Reef where the Ship must be dashed to peices in a Moment. A Reef such as is here spoke of is scarcely known in Europe, it is a wall of Coral Rock rising all most perpendicular out of the unfathomable Ocean."

Isobel Bennett, a marine biologist in Sydney, explains it all in her big, handsome book. There is no single great barrier reef; there are many. The entire 100,000-square-mile wedge of shelf is studded with islands high and low, both the high outcrops of the shelf rocks and the patient low fabric of the coral polyps, 2,500 reefs ranging from a few hundred acres up to 20 square miles, and uncounted smaller ones. The book, at once wide-ranging and intimate, surveys the life and geography of the region as a thoughtful field biologist sees them, at normal scale and mainly from the surface, reveling in the intricacies of that living fabric. In one of the photographs made by the author you can see from the air the surf-streaked *Endeavour* reef as it is today. A steel peg marks the spot where Cook struck and where, five years ago, they recovered six guns of half a ton each, which that prudent and decisive man had thrown overboard along with 50 tons more of stores to lighten his grounded and leaking ship. Overleaf is the richer blue of Cook's Passage. Out through it the *Endeavour* sailed freely, following the lead of the pinnace sent ahead to check the opening Cook had made out from the top of high Lizard Island, to ride at last on a "well growen Sea rowling in." Here his final Providential Channel is only marked on the maps; it would be interesting to see the place of his reentry, "not more than a quarter of a Mile broad," a break in that terrible reef wall where Cook was "happy once more to incounter those shoals which but two days ago our utmost wishes were crowned by geting clear of.... The world will hardly admit of an excuse for a man leaving a Coast unexplored.... If dangers are his excuse he is than charged with *Timorousness* and want of Perseverance...; if on the other hand he boldly incounters all the dangers... and is unfortunate enough not to succeed he is than charged with *Temerity.*" The historian comments: "This... is... hardly even... a commander justifying himself to the Lords of the Admiralty; it is a man, not unduly nervous but emerging from one of the dark places of the soul... passing judgment on himself."

This Great Barrier Reef Province, as Bennett calls it, is not merely the site of a dozen national parks and tourist resorts, a major route of shipborne trade, a theater of old heroic voyages and the target of mineral and offshore-oil concessionaires. It is all those but it is also home to a web of species: the big violet starfish, the tangled mangroves, the barnacled sea turtles, the palms, the orchids, the crested terns and many others; the faunas of the province have never been completely listed.

Coral is the dominant sea organism. A coral cay is a little like an old tree: just as the strong trunk is the fibrous product of past growth, a growth active only in the outermost layers and in this season's foliage, so is the cay a limestone structure accreted in the past. The luxuriant living coral is found not on the white limy flats or the miles of dead tracts of boulders and old coral heads but only as a thin veneer of life on the seaward edges and in deep pools or at the outer margins of a lagoon. A complex and lengthy sequence of other forms exploits the coralline gift of a limestone foundation. Coral polyps feed only on marine plankton. Their own enzymatic powers do not extend to the digestion of plant tissue, but within the inner layers of many coral animals live specialized single-cell algae, certain dinoflagellates. The photosynthesis of the algae of course requires sunlight. In nature not much coral can grow deeper than the sunlit layers where its internal algae can prosper; in the laboratory, although coral survives in the dark, the internal algae disappear. Until lately it was thought that the algae must have some useful but secondary aid to give their coral hosts, perhaps in waste removal. Now it appears that the corals are really agri-

culturists: their symbiotic algae supply much of their food energy for life. It was studies at Eniwetok, the bomb-test site, that first suggested the animal plankton were quantitatively inadequate to support the life of the coral; the algae, on the other hand, comprise a greater living mass than the animal tissue does in a typical colony of algae-supporting coral. It has been known for a long time how successful the big clams of the genus *Tridacna* (the largest forms of all occur in the Great Barrier Reef Province) have become at such internal farming. The rich-hued mantles of several such clams are exhibited in the Bennett book, with the lens spots that focus light between the lips of the heavy shell deep into the tissues of the folded mantle where the algae grow, vividly pigmented in violets, greens and blues.

The four books noted here differ greatly. The Bennett book is an engaging introduction to a region of living interest. The biography by J. C. Beaglehole is the fruit of a life's study of Pacific exploration; the noted New Zealand historian spent decades in careful editing of the journals of Cook and of his scientist-shipmate Joseph Banks, prepared a study of the discovery of New Zealand and traveled in the tracks of Cook from Nootka Sound to Dusky Bay, half a world apart. He completed this last, ripened book, but it was left to his son to take up the final task of readying it for the printer. The Price paperback is a high-grade sampling of the four volumes of the *Journals* that takes some advantage of Beaglehole's editorial work; it is a great bargain. Fricke is a daring scuba diver and a behavioral biologist; his book gives a good account of the biology of subsurface life as the scientific diver sees it and celebrates in particular the undersea photographer: his book has 150 color plates supplied by the world's masters of that demanding art. The volume is more cosmopolitan than the rest, but it does not neglect the Great Barrier Reef. Indeed, here one can see a full-face view of the largest cold-blooded fish in those or any seas: the plankton-feeding whale shark, *Rhincodon,* its crevasse of a mouth stretching across the double page, while close above floats the nonchalant diver, arms only partly spanning that great flat head. (The photographer and the diver are themselves intrepid and ingenious members of the fauna of the Great Barrier Reef Province—two filmmakers of Queensland, Ron and Valerie Taylor.)

Cook, science's classic seaman, sailed in the *Endeavour* as part of the flowering of post-Newtonian physics. His first task was not the exploration of the earth but rather concerned the universe. He was posted to observe from far Tahiti the transit of Venus in the year 1769. The injunction had been a legacy. In 1716 Edmund Halley had exhorted the Royal Society to ensure that "many observations... might be taken... at separate places... of a sight... on which depends the certain and adequate solution of a problem the most noble, and at other times not to be attained to." The astronomical world had tried hard in 1761, but the first worldwide trial was no success. There would be no chance again until 1874. A supreme effort was needed in 1769, and the Royal Society pressed for many observers, widely spread in both hemispheres, "not merely beyond the Arctic Circle but into the Pacific Ocean." Off went Cook, already known as a careful marine surveyor but in no way famous. A good judge of men in the Admiralty had seen his promise. He became the paragon of explorer-seamen: humane, cool, patient, imaginative and expert. "He had a plain heroic magnitude of mind." Cook sailed amid ironies. He dealt fairly and even nobly with all manner of men, yet weariness and bad judgment in one moment brought him to a violent end, and warrior Hawaiian chieftains who had venerated him fed on his roasted flesh. He proved the new chronometer, measured the parallax of the sun, found the means to end scurvy and left a track on the world's great ocean as fair as any that violent Europe can claim. Beaglehole's own insight and devotion fashioned these eloquent final words to the biography: "There are statues and inscriptions; but Geography and Navigation are his memorials.... Geography and Navigation; if we wish for more, an ocean is enough, where the waves fall on innumerable reefs, and a great wind blows from the south-east with the revolving world."

SCHISTOSOMIASIS: THE EVOLUTION OF A MEDICAL LITERATURE, SELECTED ABSTRACTS AND CITATIONS, 1852–1972, by Kenneth S. Warren. The MIT Press ($35). The size and heft of a hardbound Manhattan telephone book but with thicker paper, this volume was photo-offset from a manuscript typewritten in two neat columns by a meticulous and heroic woman, Dorothy Linick. The organizer-compiler-abstractor is an experimental parasitologist who himself made contributions to the literature.

The story of this book is all but unique. A two-volume computer printout issued in 1967 was its bibliographic precursor. It presented an indexed list

of citations on schistosomiasis covering the entire world literature from 1852 to 1962, citing about 10,000 papers in 27 languages by some 6,000 authors in nearly 1,800 journals—60,000 entries in all! The list was daunting, and the material was inaccessible to most people. The author decided to select the best of it for a more practical presentation. How could that be done?

"Obviously, the best approach" was to ask the help of people working in the field, since merely counting citations to evaluate the papers was impractical. On hand was a volume to serve not only as a source of citations but also as a "means of bribing the people" to perform such an arduous task. Leading experts at the World Health Organization and the Pan American Health Organization picked a worldwide list of some 60 people with about half "overlap" of expertise; the subject is by no means narrow. The disease, dependent on a half-inch worm, a blood fluke with a complex life cycle, infects more human beings than any other; perhaps 180 million people are chronically ill with the debilitating condition, which is sometimes acute and can be fatal. Its mastery requires the help of parasitology (both in the field and in laboratory animals), of medicine itself, of the entire biology of the intermediate snail host, of epidemiology and of public-health control. In the end, after several rounds of give-and-take, 47 final selectors from 14 countries chose about 400 books and papers as the core of the literature "of lasting importance." Nearly all these entries had five or six supporters or more and no strong representations for deletion. Only one paper was selected by 25 readers, and only 10 had more than 20 citations. The field is indeed a wide one. About a seventh of the papers turned out to be in languages other than English, and they were translated. The author then took on himself the task of writing an abstract of each paper, reducing some 7,500 pages to this single bulky volume. (Some figures and photographs survive, although not very many.) The abstracts are deliberately written to emphasize materials and methods and results; the hope is that "the reader has been provided with the tools to judge the quality of the work for himself." There are subject and author indexes, and the abstracts are arranged in order of their date within each field. A chapter-length up-to-date overall review of schistosomiasis and a brief history, both by the abstractor, begin the text.

By 1972 the literature had grown to include another 5,000 papers, half of

the total up to 1962. This newer literature is not abstracted, but some 650 citations are given for that decade, each nominated by one of 28 experts asked to select not more than 20 papers in his field. The presence of these powerful-sounding recent papers by title only is the chief complaint of a general reader. One longs to know more about catalytic models in epidemiology and how the fly set to control the snails worked out.

A review of sifted abstracts is somehow inappropriate. Suffice it to describe a few disparate ones to transmit the flavor of an entire literature. It was the young pathologist Theodor Bilharz (his name did not quite stick to the worm and to the disease owing to a technicality) who found, in autopsies in Cairo in 1852, "many excrescences which are unfamiliar in Europe," the size of a pea, on the inner wall of the urinary bladder. These held a white thread that remained on the knife; it was a trematode worm with a split gut. Not for nothing do the old medical papyri mention bloody urine 50 times; later the eggs were found in ancient mummies. The cycle was first worked out by Japanese physicians in the years just before World War I. The eggs were plain in patients' feces, the eggs and the worms in tissues at autopsy. (The Japanese species frequents the liver, not the bladder.) The rice farmers recognized the origin of their own fever and jaundice (which was not unlike a disease of their calves, dogs and cats) in the itchy rash that followed planting in certain paddies. It was known that most trematode worms had small intermediate molluscan hosts, but the German worm expert in Cairo in the 1890's had never found any. "His great authority . . . and his skill in dialectics" misdirected research for 20 years.

Drs. Miyairi and Suzuki found the tiny snails that release the infant worms in a village where the infectious eggs were common, "after a careful search . . . in a little ditch by a rice field in the village. . . . As amateurs we couldn't tell the exact name of the snail." They nurtured the entire cycle—egg, hatching, snail, larva, human, worm, egg—in the laboratory, reporting their work to a medical society in Yamanashi: " 'This is it, this is it,' we shouted, and our joy knew no bounds." Europeans learned of the find first from an abstracting journal on tropical medicine and then from medical officers on visiting Japanese warships. In Egypt, it developed, there were several worm species with different intermediate hosts. Since the disease was found among children in Cairo who used only filtered water, the idea of a mollusk had been ruled out early. Their gardens, however, were watered by a separate supply, piped directly from the Nile. The vituperative savant had not noticed that, just as he had never found the right snails. "I have personally experimented with all the species occurring in the Nile Valley, but in vain," he wrote authoritatively. Yet the snails were there in plenty, it turned out, "within half an hour's journey by tram and train from Cairo."

This compilation is not only an entree to study of the disease but also a source for an investigation of "the dynamics of a literature," its development in time and across nations. This second level of study will be worth making even after we have beaten back the white threads and their hungry larvae.

PLANETS, STARS AND NEBULAE STUDIED WITH PHOTOPOLARIMETRY, edited by T. Gehrels. The University of Arizona Press ($27.50). Our actively scanning eyes sharply record intensity and color differences in the visual field. These properties depend ultimately on two properties of the photon swarms that enter the eye: the number of photons at a given time and direction translates in a complicated but plausible way into intensity, and the energy per photon in the end fixes color. (This is not to minimize the heavy internal computing we perform on the raw signals.) Now, photons carry one more physical quantity: their spin. Our eyes cannot detect that at all well; only one or two subtle effects like the one named after Wilhelm Haidinger give our eyes any clue to the spin relations of the incoming photons, which determine polarization. Thermal equilibrium of course can favor no spin direction, so that black-body radiation is intrinsically unpolarized, impartial. Sunlight, firelight, candle flame, the glow of the television screen approximate that blandness. The world at large is not fully thermal, however, and hence not fully symmetrical. Polarization marks the blue sky, the light underwater, moonlight, the planets, the zodiacal light, the glows of the Great Nebula in Orion and of the supernova remnant we call the Crab and the invisible radio emission of mysterious sources far across space.

It was the crystalline state, transparent matter with built-in symmetries, whose interaction with light first revealed the phenomena. Those doubled images viewed through calcite made manifest to the 17th century that light has some properties our eyes cannot resolve. Reflection and scattering quite generally impose some asymmetry on

light beams and everywhere on the earth in part polarize the light of the sun. Magnetic fields polarize atomic spins and therefore the light of atoms that emit within such fields; George Ellery Hale first showed the Zeeman effect in sunspots back in 1908. In 1928 the young Edwin Land found a way to make inexpensive sheet polarizer, which has taken the experience of polarization from the darkened optics laboratory out to the beach. The wonderful effect has become as unjustified a commonplace as Keats's awful rainbow.

In the subtle relationships of phase and spin direction we call polarization (there is no need to distinguish the various kinds here) we have come to read a great deal, however. This splendidly edited volume, with 74 papers ranging from two pages with a couple of striking composite photographs to a tough chapter on integral-equation techniques, is a general source book on the entire topic. Its title and design are astronomical in the wide sense, but it felicitously includes accounts of the daylight sky, of the beetle's wings and the crab's eyes and a good deal more, far from observatory dome or radio dish. The photographs alone would repay any browser; technical libraries will need the book. It is not a mere conference report. It reports a conference all right, but it includes as well a dozen papers prepared beforehand as reviews of major topics and an overview done afterward, and the papers were carefully edited.

The sky is blue with scattered—and hence polarized—sunlight. We have known since Rayleigh how small scatterers such as air molecules polarize. Indeed, careful quantitative skylight polarimetry (the heart of the subject is our new ability to measure what the eye cannot see) is now a good measure of Los Angeles smog and of Sahara dust as well as of distant planetary atmospheres. Reflecting surfaces polarize too. In general (they speak of the "Umov effect") the less the reflection, the greater the fractional polarization. Polarization occurs at the very surface, as in the familiar case of the wet road, and any internal beam that can eventually emerge comes out mainly as unpolarized light. And so we analyze the solid surfaces of the satellites. Polarization demonstrates that the asteroids and satellites, like the moon, are dusty places. The Great Red Spot of Jupiter? Alas, it shows no polarization different from its planetary background, down to the level of parts in a thousand.

Yet polarization has not always disappointed us. James E. Felten reminds us

that the polarized optical light of the Crab Nebula was predicted by Russian theorists and was discerned in 1953 by Russian observers. That success "can be said to mark the birth of 'high-energy astrophysics,'" because it made plain that the strange light—1,000 times the sun's—was emitted by electrons moving at velocities near the speed of light in paths controlled by a magnetic field; the glow had nothing to do with atoms and their thermal motion. Such electrons had been known to dominate the emission of the strong radio sources but the finding that even visible synchrotron light was not newborn in laboratory accelerators brought awe to physicists. There are excellent accounts here of radio emission and its unsolved problems, of the infrared sources, of star dust and its complex nature, all owing much to our new interest in polarimetry.

The arthropods and the cephalopods have not waited until their physicists learned about polarized light. They regard the sky and the surfaces they move on with polarimetric eyes. An electron micrograph of a section of the absorbing layers of the retinal cells within one facet of the compound eye of a crayfish shows two layers of sensitive pigmented detector rods, nearly crossing each other at a careful right angle. This is a two-channel analyzer, which works apparently too well for easy explanation.

Examine the sky reflection in a pool of still water. The clouds, which polarize little, stand out in higher contrast in the image than in the real blue sky. It takes insight to see this view no less than eyes; such insight was absent even among astronomers until some 50 years ago. If our eyes had evolved more of the crayfish's abilities, "this first general source book would not have been published in 1973." The book is welcome, and it will not be the last.

INSECTS IN FLIGHT: A GLIMPSE BEHIND THE SCENES IN BIOPHYSICAL RESEARCH, by Werner Nachtigall. Translated by Harold Oldroyd, Roger H. Abbott and Marguerite Biederman-Thorson. McGraw-Hill Book Company ($13.95). "A bluebottle irritates us with its buzzing and we squash it. What have we destroyed?... [A] diminutive, incredibly complex, wonderful nuisance." So begins and ends the first brief chapter of this personal, uniquely illustrated, detailed but easily read story of a modern field of biological research. A leader in the science, a biophysicist at the University of Saarland in West Germany, takes the reader behind the scenes, alternating meticulous accounts of experiments with broad, chatty generalizations and giving us some sense not only of how the wonderful fly works but also of how the investigator works.

Fly flight, like airplane flight, is best studied in the wind tunnel. The technique must be made subtle, miniaturized, appropriate. The fly faces the breeze—two meters per second—on a fine wire glued to the tip of its abdomen. Yet its flight is mechanically free because it is attached by the lightest of restraints to three delicate balances, one for each of the three forces: turning moment, lift and thrust. "Each component... is set on knife edges, has its own oil damping and ... adjustable... weights." Fly forces are measured in tens of milligrams. The airflow is servoed by a contact system that in effect allows the fly to choose the air speed. Once started, the fly is comfortable, and often the lift-weight balance remains at zero "for a quarter of an hour, as though frozen." You can, of course, just stick a fly to a piece of wood, lift its legs off the ground and photograph the beating wings. Filmmakers have done it. But what does it mean? The entire condition is artificial. "If you watch it flying there seems to be no difference, but the one is a game and the other science."

What that science has unfolded is remarkable. The fly wing beats intricately: a couple of hundred times per second its tip describes a curve rather like a lazy letter *U*. Fifty-six points on that track are mapped, and with each the angle of the plane of the wing. The flat wing can generate lift on both the upstroke and the downstroke; even a backward tip motion is mainly useful. Only during one small interval must the fly produce downward forces as it brings its wing back to the main downstroke configuration. "There is no magic.... The bluebottle has to fly according to the laws of physics."

The fly wing is not willed up and down; rather it swings as we swing our arms in walking. The thorax and the muscles that move the wings in fact oscillate on their own; the muscles contract not in response to nerve impulses but when they are given a sharp pull. A snapping-disk click mechanism like a microswitch forms extremely low-loss wing hinges. The entire system is then pulsed to release chemical energy from ATP once every 10 or 20 beats, as a clock is wound while it runs, with no need for synchrony. No muscle in nature uses oxygen or fuel faster or develops more power per gram than insect flight muscle. Its ultrafine structure conforms: the cells are packed with mitochondria and

the tissue is infiltrated with "huge trunks" of trachea to transport the oxygen.

Like the beautiful jet people, the flying insect is a luxury model. It lives fast too: the reaction time of a fly is under five milliseconds. That is enough for the insect to move forward one body length, so that such response is utilitarian. "To a fly . . . a cine film must look like a lantern lecture, with long, dark pauses in between the slides!"

One fly flew tethered for six days straight, tanked up with sugar solution every five or six hours. It cruised more than 320 kilometers and stopped only because its wings were tattered, after some 88 million swings; the "motor," air supply and hinges survived this test to destruction. Here too, confirmed by high-speed photography, is the authentic maneuver that enables a fly to land upside down on the ceiling. There is 1.0 half-roll or loop. The fly flies up and in at about one foot per second, front feet first. The forefeet are held stiff and as they touch and stick the wings stop beating and the body rotates about the planted legs, the momentum of flight carrying it belly up until the other feet can grasp the ceiling. Upside down without any upside-down flight!

Graphs, photographs, diagrams, tables—it is all here for a serious reader, anyone who is interested in biology or the engineering of flight, whether by man or by the rest of nature. The thinnish, large-page book extends well beyond flies to butterflies, locust migration, mosquito "song," the technical war between the bat's sonar and the night moth's evasive action. The core of the volume is nevertheless Nachtigall's own revealing work and his reflective delight in it. We can share a little of his open pleasure as we read of his laboratory, and we can almost hear his buzzing flies and the film shooting through the high-speed camera "with a deafening siren-like howl."

BRIDGES: THE SPANS OF NORTH AMERICA, by David Plowden. A Studio Book. The Viking Press ($27.50). Close to 200 black-and-white photographs made by the author in six years of wandering over the U.S. and Canada show quite beautifully across these large pages what bridges look like, old and new, as distant webs of steel or as close-up hand-forged links. But the itinerant photographer was delightfully entrapped. His book is no album with captions or even a photo-essay adding continuity to a fine set of pictures; the detailed text approaches twice the space given over to

visual material. He has written a serious and fresh account of the how, when, where and who of "some of the most important" bridges in North America, and his understanding and pleasure carry to the reader and viewer. Without mathematics or many engineering words he fixes a thoughtful and knowing gaze on structures whose form honestly reveals the insight and the ignorance, the purpose, the choices and the experiences of the men who designed and built them, in their hopes for utility and beauty. They span our history from the Erie Canal to the 1973 tied-arch concrete bridge in Portland, Ore. (There the city fathers rejected a much cheaper workable cantilever design as "an absolute atrocity, a multiplicity of steelwork.")

The driver on limited-access roads today passes under scores of bridges, nearly all of them cylindrical concrete columns holding up flat slabs strengthened by parallel steel girders. Steel has been cheap here in the U.S. and design comes too dear, particularly where the span is short and the bridges are many. An air of stereotype afflicts the form of the standard highway bridge; it lacks character. Yet it is simple, unobtrusive and safe—better designed, perhaps, than it appears to be. What it lacks is translation from workaday success into visual activity. That is the magic this volume seeks, not the "word made flesh" but forces made form.

Ride the clicking rails of the New Haven northward out of Pennsylvania Station. You cross the East River on the great Hell Gate steel arch, still one of the longest and heaviest steel bridges in the world. Its designer, Gustav Lindenthal (who built the Queensboro and the Manhattan bridges as well), worked boldly on the biggest scale. Some of the bridges' steel members were the largest ever made: 185 tons. Had not the south cantilever arm of the Quebec bridge just collapsed during construction? Its members were criticized by Lindenthal himself as being "absurdly light." The Hell Gate masonry end towers receive the stiffening top chord in a slight reverse—structurally excellent, providing train clearance and improving the form. The bigger Bayonne steel arch, the longest such span in the world (two feet longer than the Sydney Harbor bridge, which was begun a little earlier), is an engineering tour de force. Its designer, O. H. Amman, had been the assistant at Hell Gate. The Bayonne bridge's arch form is justified by the flat bedrock along the shore of Staten Island. The Kill van Kull is so busy a waterway that it could tolerate no piers, and so the choices were

cantilever, suspension or arch. The first demanded too much steel, the second too much excavation to bury the cable ends safely in the hard rock. The arch could spring up securely from that solid base, its great thrust safely anchored. Plowden says, however, that the end towers of naked steel are "visually too weak." They do not actually support the arch, which is set on masonry foundations; the weakness is only a question of appearance. The Bayonne bridge lacks the huge pylons of Sydney Harbor, which contain the thrust visually as well as in Newtonian fact. Sydney's bridge is a worldwide symbol whereas the other is not widely known even in its own city.

"In the spring of 1969, the author came across a single-span Fink truss" across the south branch of the Raritan. This may be the oldest iron-truss bridge in America, the remaining pioneer of the myriad of such complex angular patent trusses that flung roads and rails across stream and valley in 19th-century America. It is about 100 feet in overall span. The design, called "No. 1 Fink's patent," was executed in prefabricated form in 1857 by one of the scores of companies that carried out such work. The design was worked out by one of a few men whose career began in the design office of the Baltimore and Ohio Railroad, where the first rational design methods in this country evolved before 1850. One good look at the bridge's patent vertical columns, its main compressive members and its ribbony diagonal tie bars, the tension members, reveals the abstract basis of the physical design to the least mechanical person.

The bridges here begin with stone and end with prestressed concrete; they range from New York to Sciotoville, Ohio, from British Columbia to Florida. It is an absorbing story and a feast for the eye. Error and tragedy are not forgotten; here is the full story of Tacoma's "Galloping Gertie," handsomely slender but vulnerable. And here too is the jumbled wreckage of the Quebec bridge of 1907 and its tale of heedless acts and bad judgment—based, however, on a lack of knowledge of compression members. Wrote *Scientific American* then: "The significance of this disaster lies in the suspicion, which is staring every engineer coldly in the face, that there is something wrong with our theories of bridge design, at least as applied to a structure the size of the Quebec bridge." We know much more today. We have computers, we understand metals, but gravity never sleeps, and our best approximations and longest iterations will sometimes nod.

BIBLIOGRAPHY

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

THE ETHICS OF GIVING PLACEBOS

ETHICS AND PRACTICE OF PLACEBO THERAPY. A. Leslie in *The American Journal of Medicine,* Vol. 16, pages 854–862; June, 1954.

ETHICS AND CLINICAL RESEARCH. H. K. Beecher in *The New England Journal of Medicine,* Vol. 274, pages 1354–1360; June 16, 1966.

CLINICAL PHARMACOLOGY: BASIC PRINCIPLES IN THERAPEUTICS. Kenneth L. Melmon and Howard F. Morrelli. Macmillan, Inc., 1971.

A PATIENT'S BILL OF RIGHTS. American Hospital Association, Chicago, 1973.

GRAVITATION THEORY

EINSTEIN ON THE FIRING LINE. Clifford M. Will in *Physics Today,* Vol. 25, No. 10, pages 23–29; October, 1972.

GRAVITATION. Charles W. Misner, Kip S. Thorne and John A. Wheeler. W. H. Freeman and Company, 1973.

COMPUTER CONTROL OF ELECTRIC-POWER SYSTEMS

COMPUTER METHODS IN POWER SYSTEM ANALYSIS. Glenn W. Stagg and Ahmed H. El-Abiad. McGraw-Hill Publishing Co., 1968.

ELECTRIC ENERGY SYSTEMS THEORY: AN INTRODUCTION. O. I. Elgerd. McGraw-Hill Book Co., 1971.

REAL-TIME CONTROL OF ELECTRIC POWER SYSTEMS: PROCEEDINGS OF THE BROWN, BOVERI AND COMPANY, LTD., SYMPOSIUM, 1971. Edited by Edmund Handschin. Elsevier Publishing Company, 1972.

PROCEEDINGS OF THE IEEE POWER INDUSTRY COMPUTER APPLICATION CONFERENCE, 1971 AND 1973. Institute of Electrical and Electronics Engineers.

THE DEVELOPMENT OF THE IMMUNE SYSTEM

THE FUNCTIONS OF THE THYMUS SYSTEM AND THE BURSA SYSTEM IN THE CHICKEN. Max D. Cooper, Raymond D. A. Peterson, Mary Ann South and Robert A. Good in *Journal of Experimental Medicine,* Vol. 123, No. 1, pages 75–102; 1966.

THE IMMUNE SYSTEM: A MODEL FOR DIFFERENTIATION IN HIGHER ORGANISMS. L. Hood and J. Prahl in *Advances in Immunology,* Vol. 14, page 291; 1971.

T AND B LYMPHOCYTES IN HUMANS. Edited by G. Möller. *Transplantation Reviews,* Vol. 16; 1973.

MODIFICATION OF B LYMPHOCYTE DIFFERENTIATION BY ANTI-IMMUNOGLOBULINS. A. R. Lawton and M. D. Cooper in *Contemporary Topics in Immunobiology: Vol. 3.* Edited by Max D. Cooper and Noel L. Warner. Plenum Press, 1974.

T AND B LYMPHOCYTES: ORIGINS, PROPERTIES AND ROLES IN IMMUNE RESPONSES. M. F. Greaves, J. J. T. Owen and M. C. Raff. American Elsevier, 1974.

MUSICAL DYNAMICS

AN EQUAL DISCRIMINABILITY SCALE FOR LOUDNESS JUDGMENTS. W. R. Garner in *Journal of Experimental Psychology,* Vol. 43, pages 232–238; 1952.

INTENSITIES OF ORCHESTRAL INSTRUMENT SCALES PLAYED AT PRESCRIBED DYNAMIC MARKINGS. Melville Clark and David Luce in *Journal of the Audio Engineering Society,* Vol. 13, No. 2, pages 151–157; April, 1965.

INTENSITY PERCEPTION, I: PRELIMINARY THEORY OF INTENSITY RESOLUTION. N. I. Durlach and L. D. Braida in *The Journal of the Acoustical Society of America,* Vol. 46, No. 2, Part 2, pages 372–383; August, 1969.

PERCEIVED LEVEL OF NOISE BY MARK VII AND DECIBELS (*E*). S. S. Stevens in *The Journal of the Acoustical Society of America,* Vol. 51, No. 2, Part 2, page 575; February, 1972.

THE PHYSIOLOGY OF THE GIRAFFE

CIRCULATION OF THE GIRAFFE. Robert H. Goetz, James V. Warren, Otto H. Gauer, John L. Patterson, Jr., Joseph T. Doyle, E. N. Keen and Maurice McGregor in *Circulation Research,* Vol. 8, No. 5, pages 1049–1058; September, 1960.

CARDIORESPIRATORY DYNAMICS IN THE OX AND GIRAFFE, WITH COMPARATIVE OBSERVATIONS ON MAN AND OTHER MAMMALS. John L. Patterson, Jr., et al. in *Annals of the New York Academy of Sciences,* Vol. 127, Article 1, pages 393–413; September 8, 1965.

BLOOD PRESSURE RESPONSES OF WILD GIRAFFES STUDIED BY RADIO TELEMETRY. Robert L. Van Citters, William S. Kemper and Dean L. Franklin in *Science,* Vol. 152, No. 3720, pages 384–386; April 15, 1966.

CEREBRAL HEMODYNAMICS IN THE GIRAFFE. Robert L. Van Citters, Dean L. Franklin, Stephen F. Vatner, Thomas Patrick and James V. Warren in *Transactions of the Association of American Physicians,* Vol. 82, pages 293–303; 1969.

CONTRAST AND SPATIAL FREQUENCY

ELECTROPHYSIOLOGICAL EVIDENCE FOR THE EXISTENCE OF ORIENTATION AND SIZE DETECTORS IN THE HUMAN VISUAL SYSTEM. F. W. Campbell and L. Maffei in *The Journal of Physiology,* Vol. 207, No. 3, pages 635–652; May, 1970.

THE CONTRAST SENSITIVITY OF THE CAT. F. W. Campbell, L. Maffei and M. Piccolino in *The Journal of Physiology,* Vol. 229, No. 3, pages 719–731; March, 1973.

BEHAVIOURAL CONTRAST SENSITIVITY OF THE CAT IN VARIOUS VISUAL MERIDIANS. S. Bisti and L. Maffei in *The Journal of Physiology,* Vol. 241, No. 1, pages 201–210; August, 1974.

TIME SPENT IN HOUSEWORK

THE FEMALE LABOR FORCE IN THE UNITED STATES. Valerie Kincade Oppenheimer. Institute of International Studies, University of California, Berkeley, 1970.

SEX IN THE MARKETPLACE: AMERICAN WOMEN AT WORK. Juanita Kreps. Johns Hopkins University Press, 1971.

OCCUPATION: HOUSEWIFE. Helena Z. Lopata. Oxford University Press, 1972.

MATHEMATICAL GAMES

GENERATION OF PERMUTATIONS BY ADJACENT TRANSPOSITION. Selmer M. Johnson in *Mathematics of Computation,* Vol. 17, No. 83, pages 282–285; July, 1963.

PERMUTATION BY ADJACENT INTERCHANGES. D. H. Lehmer in *The American Mathematical Monthly,* Vol. 72, No. 2, Part 2, pages 36–46; February, 1965.

THE AMATEUR SCIENTIST

AMERICAN PRACTICAL NAVIGATOR. Nathaniel Bowditch. U.S. Navy Hydrographic Office, U.S. Government Printing Office, 1966.

FLUID MECHANICS. Victor L. Streeter. McGraw-Hill Book Co., 1971.

LIVE IN THE WORLD OF TOMORROW... TODAY!

And our FREE 164 PAGE CATALOG is packed with exciting and unusual values in ecological and physical science items — plus 4,500 finds for fun, study or profit... for every member of the family.

A BETTER LIFE STARTS HERE

ACTUAL WORKING SOLAR HOME PLANS

Learn all about the most fascinating possible home of the future. It can be your "now" answer to today's energy crisis in housing. Expert Dr. Harry E. Thomason tells advantages, problems, savings, and more in this important 20-pg fact-filled booklet. Also includes 8-page oversize insert of basic, actual solar home plans, a valuable guideline to you and your architect in fitting space requirements, design ideas, and local area building codes.

No. 9440S (Solar House Plans) ..... $10.00 Ppd.

METRIC CONVERTING CALCULATOR!

Amazing 5-oz. electronic machine not only has 36 instant conversion capabilities at touch of 1 button, it's a high quality 5-function calculator with a memory—worth the price alone. Add, subtract, directly figure percentages, multiply, divide—carry on U.S.-metric conversions during any function! Conversions: gal./1, miles/km, qts./1, yds./m, in./cm, °F/°C, etc. Special keys for square & cubic measurement. Rechargeable ni-cad batteries, recharger.

No. 71,982S (4¾ x 2½ x 1½") ..... $109.95 Ppd.

MYSTERY OF ENERGY AND AGING

Science fact or farce? Can our Great Pyramid unlock the mysteries of energy & aging — show that the ancient Egyptians contradicted nature? Did someone really get 85 shaves from a blade kept in a pyramid? Test claims like meat not rotting, things not rusting! Users of exact scale models of Cheop's pyramid oriented to true North claim all sorts of strange phenomena based on resonating energy. Ours is already assembled, ⅛" see-thru acrylic, 6 x 9¼ x 9¼".

Stock No. 71,817S ..... $20.00 Ppd.

ELECTRONIC DIGITAL STOPWATCH

Most precise, error-free timer ever! Obsoletes mechanical stopwatches. Not only clocks to 1/100 sec. w/inst. big bright readout, but times unlimited no. of intervals while clocking overall event. Time 2 or more participants simultaneously! Solid state; unchangeable accuracy (±0.001%) w/6 running digits always shown clearly under any conditions; quartz crystal gives lifetime reliability. Incls 4 "C" batts.

No. 1653S (16 OZ; 2-YR. WTY.) ..... $120.00 Ppd.
No. 42,174S (LEATHER CASE FOR AB.) ..... $12.50 Ppd.

3" ASTRONOMICAL REFLECTING TELESCOPE

See stars, moon, planets close-up! 30 to 90X. Famous Mt. Palomar Type. Aluminized & overcoated 3" diameter f/10 primary mirror, ventilated cell. Fork type equatorial mount. Durable PVC tube. Includes 1" F.L. 30X Ramsden, Barlow lens to triple power, 3X finder telescope, hardwood tripod. FREE: "STAR CHART", "HOW TO USE" book.

Stock No. 85,240S ..... $ 49.95 Ppd.
DELUXE 3" REFLECTOR TELESCOPE #80,162S ..... $ 79.95 Ppd.
4¼" REFLECTOR (45X to 135X) #85,105S ..... $149.50 FOB
6" REFLECTOR (48X to 360X) #85,187S ..... $249.50 FOB

KNOW YOUR ALPHA FROM THETA!

For greater relaxation, concentration, listen to your Alpha-Theta brainwaves. Ultra-sensitive electrode headband slips on/off in seconds—eliminates need for messy creams, etc. Atch'd to amplifier, filters brainwaves, signals beep for ea. Alpha or Theta wave passed. Monitoring button simulates Alpha sound; audio & visual (L.E.D.) feedback. Reliable, easy-to-use unit comparable to costlier models. Completely safe. Comprehensive instruction booklet.

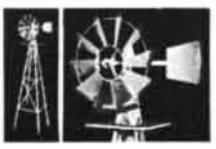
No. 1635S (8x3x4"; 24 oz.) ..... $128.00 Ppd.
LOW COST "Starter" UNIT,
No. 71,809S ..... $ 49.95 Ppd.

ERECT A "PRO" WEATHER STATION

Match your forecasting skill with **anyone!** Set up permanent meteorology sta. for reliable readings: windspeed, precipitation, barometric pressure, temp., humidity; get wind-chill, cloud types. Top qual. equipt.: rooftop remote reading pneumatic windspeed ind.; 11" rain gauge; holosteric barometer (inches, etc.); hi-lo self register thermometer; wet-dry bulb hygrometer. More!

No. 80,216S (w/372 Pg. LOG) ..... $69.50 Ppd.
BEGINNER'S KIT: COMPL., LOW COST
Stock No. 71,022S ..... $18.95 Ppd.

AUTHENTIC SCALED WINDMILLS



Real-thing replicas show wind direction, wheel silently revolves on ball bearings. Give your grounds unique rural charm! Great centerpiece for planter, flowers. Use to hold yard light, house number, sign or as mailbox. For school, a fine "energy crisis" science project — does everything but pump water. Heavy gauge steel, durable outdoor finish; aluminum color w/red trim.

17" DESK MODEL ..... No. 71,923S ..... $10.95 Ppd.
4½ FOOT—14 LB. ..... No. 71,924S ..... $32.50 Ppd.
8 FOOT — 46 LB. ..... No. 85,229S ..... $44.95 FOB

PRO ELECTRONIC SOUND CATCHER

Parabolic mike w/18¾" reflecting shield & 2 I.C.'s in amplifier magnifies signals 100X that of omni-directional mikes. Catch a songbird ½ mile off; QB's huddle strategy; sounds never before heard. Super directivity gives highest signal to noise ratio poss. Safe: auto. cuts off ear damaging noises. Earphones, tape recorder output, tripod socket. Req. two 9v trans. batt. (not incl).

No. 1649S (5½ LB.) ..... $299.00 Ppd.
BIG EAR "TOY" MODEL #80,176S ..... $32.25 Ppd.

MAIL COUPON FOR GIANT FREE CATALOG!

164 PAGES • MORE THAN 4500 UNUSUAL BARGAINS

Completely new Catalog. Packed with huge selection of telescopes, microscopes, binoculars, magnets, magnifiers, prisms, photo components, ecology and Unique Lighting items, parts, kits, accessories — many hard-to-get surplus bargains. 100's of charts, illustrations. For hobbyists, experimenters, schools, industry.

EDMUND SCIENTIFIC CO.
300 Edscorp Building, Barrington, N. J. 08007
Please rush Free Giant Catalog "S"

Name _____

Address _____

City _____ State _____ Zip _____

☐ PLEASE SEND GIANT FREE CATALOG "S"

30 DAY MONEY-BACK GUARANTEE
YOU MUST BE SATISFIED OR RETURN ANY PURCHASE IN 30 DAYS FOR FULL REFUND

COMPLETE & MAIL WITH CHECK OR M.O.

EDMUND SCIENTIFIC CO. 300 Edscorp Building, Barrington, N.J. 08007

How Many	Stock No.	Description	Price Each	Total

Add Handling Chg.: $1.00, Orders Under $5.00, 50¢, Orders Over $5.00

TOTAL $ _____

I enclose ☐ check ☐ money order for $ _____

NAME _____

ADDRESS _____

CITY _____ STATE _____ ZIP _____

Getting offshore

It takes time. The Exxon gasoline you're filling up with today may have come from an oil field we started looking for 8 years ago.

Geological survey. Eight years ago, Exxon began to explore a piece of acreage 75 miles out in the Gulf of Mexico.

Our geologists examined rocks from the bottom of the Gulf and along the shoreline. They used special devices to locate possible oil-bearing rock thousands of feet below the seafloor.

From this information, they created a vertical "picture" of the rock layers to find strata that looked promising.

These studies can take very little time, or up to six years. This one took four.

In 1970, convinced that the chances of finding oil were good, Exxon bought the rights to drill exploratory wells. This was the only way we'd find out for sure if there really was oil there.

Exploratory drilling. We started drilling for oil in mid-1971. To do it, we used a mobile drilling rig. The cost of leasing and operating this rig was $24,500 a day.

Working round the clock, it took us 25 days to drill the first well. It was 8,500 feet deep—and we discovered gas, but no oil.

We then drilled a second hole. Fortunately, we hit oil. To find out how big the field was, we drilled several more wells. They outlined the size of the field and confirmed that oil was down there in commercial quantities.

Exploratory drilling can often take as long as five years. We were lucky. It had taken us just two.

The next step was to design and construct the oil-producing platforms which would replace the mobile rig. These huge platforms would be anchored to the seafloor directly over the field.

Platform construction and installation. We started building the twin drilling and production platforms in 1972. Construction took 16 months.

Each offshore platform has to be built specifically for the area it will work in. You have to take into account water depths, wind and wave action, earthquake possibilities, and other factors. This is why a platform built for the relatively calm Gulf will be different from one built for the fierce North Sea.

Our next step was to tow the steel structures out into the Gulf. We then sank them in place in 235 feet of water, and anchored them with pilings driven into the seafloor.

Then we added the platform decks. These included the crew's quarters as well as facilities for producing the oil.

oil to you.

Production drilling. When everything was shipshape on the platform in early 1973, we began to drill the first production well that would actually bring the oil to the surface. We drilled four wells in 1973, and seven more in 1974.

The wells are drilled straight down for a few hundred feet, then slanted away from the platform base. This greatly increases the area that can be tapped from one platform.

Frequently, we use several platforms in developing an oil field. These platforms, like the individual wells, must be placed carefully to insure that the oil is recovered as efficiently as possible.

Underwater pipelaying. While the platform crew was drilling the production wells, bargemen and welders were busy laying the underwater pipeline that would take the oil from the platform to shore.

Aboard a pipelaying barge, coated sections of pipe move along a track and are welded together. Then the welds are inspected by X ray. The joints are also given a protective coating and the continuous pipe is slipped down onto the seafloor.

To get the oil to shore from our new producing platform, we simply had to lay a section of pipeline that linked our platform with a main pipeline nearby. If this main artery had not existed, and we had to lay one, then the entire pipelaying job might have taken several months. As it was, we did it in one month.

Refining and delivering to you. The crude oil that started coming to shore this year from our production platform in the Gulfwas carried by another pipeline to a nearby Exxon refinery.

Gasoline made from this crude was shipped to Exxon service stations through product pipelines and by tank trucks.

And the gasoline you're filling up with today may have come from that field we started looking for eight years ago.

U.S. offshore oil now supplies 11% of America's needs. Within ten years it will have to supply considerably more.

This is why Exxon is looking today for the oil you'll be needing in the 1980's.

EXXON

"I've got the idea, and you've got the $8,000,000. We'll merge."

More good things have been decided over Grand Marnier than any other drink in the world.

For free recipe booklet, write Carillon Importers, Ltd., 745 Fifth Ave., NYC 10022. Product of France, made with fine cognac brandy. 80 proof.