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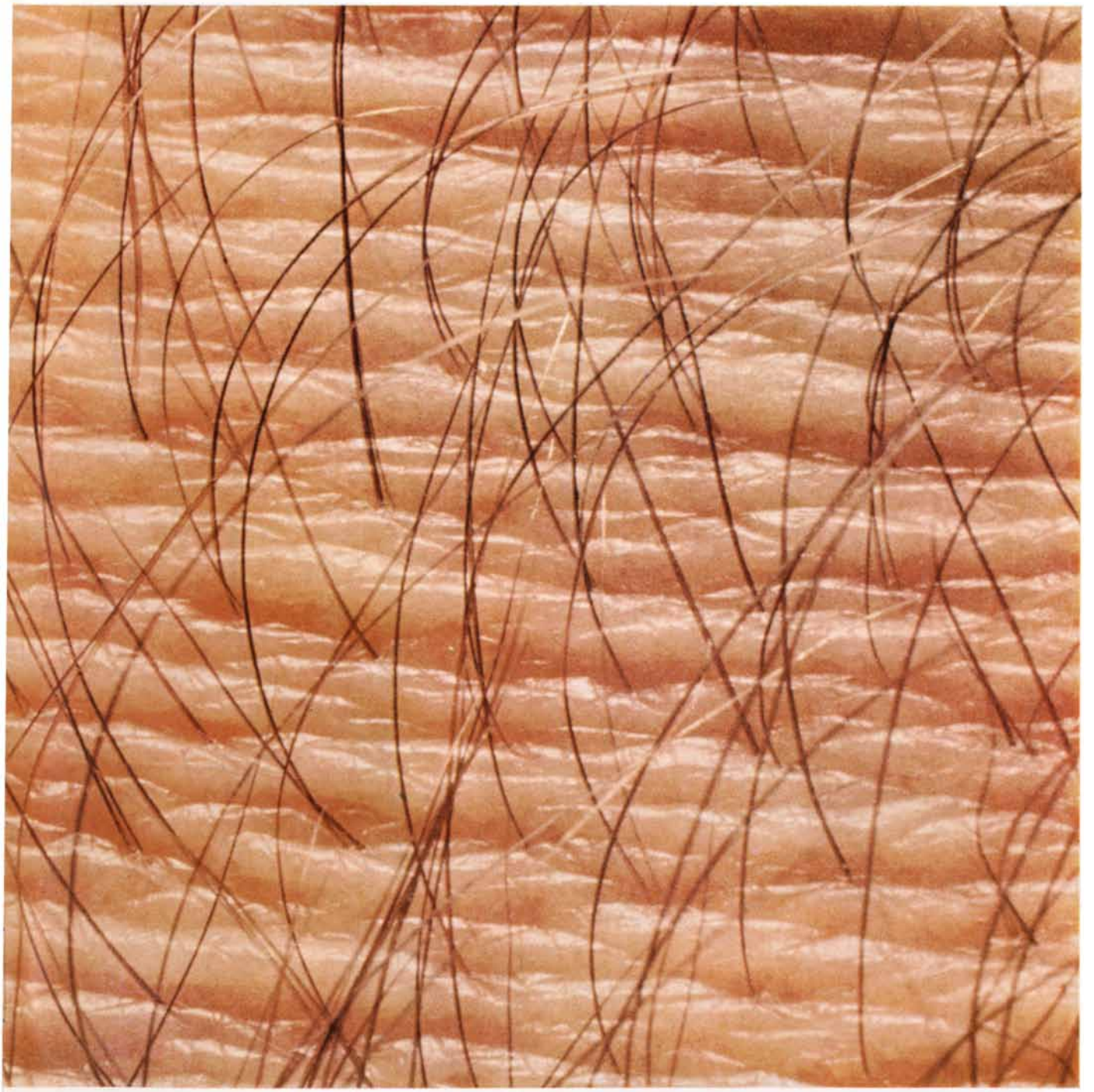

ECOLOGY OF THE SKIN

SEVENTY-FIVE CENTS

January 1969

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They have to. Construction is a hard-nosed, low-bidder-take-all business... and old-hat thinking doesn't go far in a hard-hat world.

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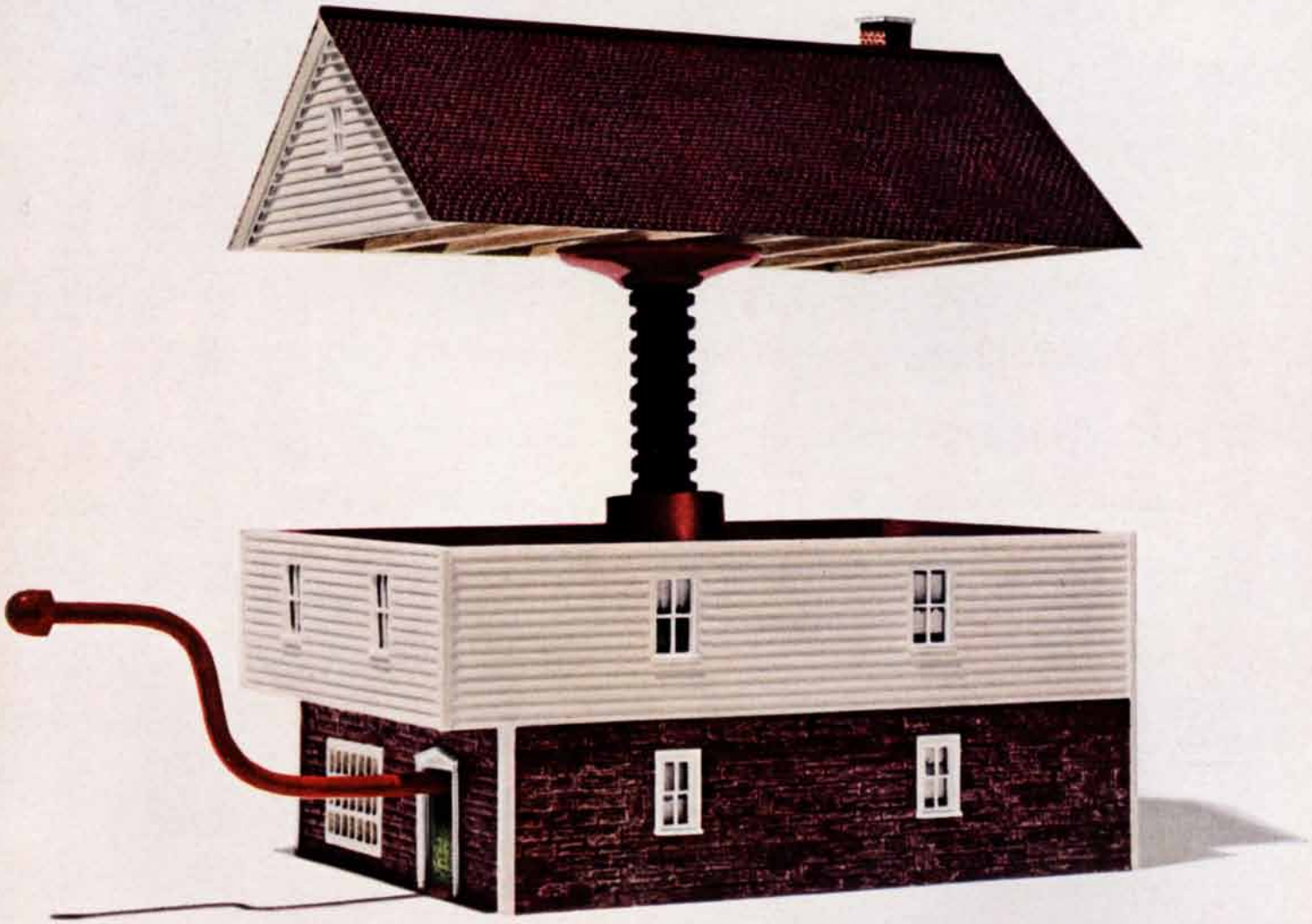

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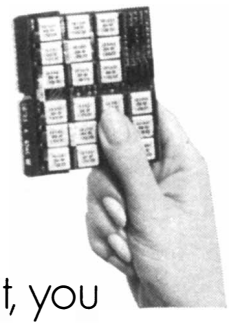

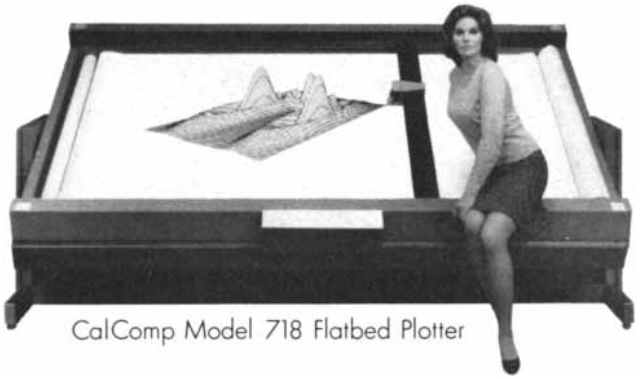

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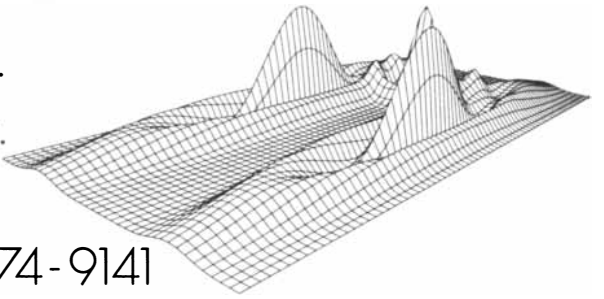

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ARTICLES

DEPARTMENTS

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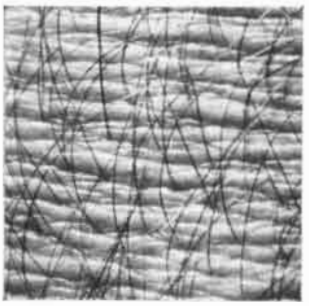

THE COVER

The photograph on the cover, which at first glance may seem to show blades of grass on a rippled sand dune, actually shows the skin on the back of the hand magnified 20 diameters. The resemblance is a relevant one: the human skin, like a sand dune, is a distinct ecosystem (see "Life on the Human Skin," page 108). It has its own flora and fauna, each species occupying its own ecological niche. The species are of course microscopic, and normally they do not harm their host. When the ecosystem is disturbed, however, some of the species (notably *Staphylococcus aureus*) can cause disease.

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Cover photograph by Sol Mednick

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LABORATORY REPORT NO. 12

How to Help Solve Viscosity Control Problems in Medium-Polar Liquid Systems with CAB-O-SIL®

Polarity in commercial liquid systems is an important factor which affects the thickening efficiency of the silica. The polarity may veer toward either polar or non-polar, depending upon the nature of the liquid or blend. Even the basic liquid can vary from batch to batch, which influences control of viscosity.

TYPICAL MEDIUM-POLAR LIQUIDS

In this category are vegetable oils, dioctyl phthalate, tricresyl phosphate, vinyls, polyesters, epoxies, alkyds, and polyurethanes. These liquids have polar groups (such as hydroxyl or amino) on the molecule, which are capable of hydrogen-bonding to the -OH groups on the CAB-O-SIL surface.

As the number of -OH or polar groups present on the liquid molecule increases, the thickening efficiency decreases. Greatest thickening efficiency with CAB-O-SIL is realized when the -OH groups on the CAB-O-SIL surface can bond to each other and form a chicken-wire type structure which increases viscosity.

How CAB-O-SIL clusters hydrogen-bond to each other for thickening and thixotropy

INCREASING THICKENING EFFICIENCY

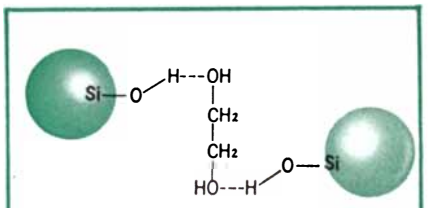
To offset the reaction of a hydrogen-bonding liquid, and to obtain highest thickening efficiency with CAB-O-SIL, additives can be introduced to the system which function to change the surface characteristics of the CAB-O-SIL.

If the liquid system demonstrates characteristics more closely associated with non-polar or non-hydrogen-bonding liquids, higher viscosity can be obtained by introducing an additive with a short carbon chain, such as ethylene glycol, glycerine, or water.

If the liquid shows polar tendencies, select additives which have a long non-hydrogen-bonding chain at one end (8 or more carbon atoms), and a hydrogen-bonding group, e.g., hydroxyl, amino, carboxylic, at the other end.

OBTAINING UNIFORM VISCOSITY

Among the additives which can be used to improve thickening efficiency and to compensate for variations in number of -OH groups, are Triton X-100, Ucon LB 1715, ethylene glycol, glycerol, and Formonyte 808. Depending upon the system, dramatic changes in viscosity can occur by adding two additives such as Triton X-100, a non-ionic surfactant and Armeen 12, a cationic type. Usually less than .5% of additive based on the weight of liquid will achieve marked increases in viscosity, together with greater stability on aging.



How terminal -OH groups of ethylene glycol hydrogen-bond to -OH groups on CAB-O-SIL surface

HOW MUCH TO ADD

Generally the weight of the additive is calculated in relation to the weight of the CAB-O-SIL — not the liquid. When the amount of the additive is calculated at 20% by weight of the CAB-O-SIL, for example, it may represent only about .5% or less by weight of the liquid.

2.5% CAB-O-SIL M-5 by weight added to medium-polar dioctyl phthalate increases viscosity only slightly.

The same amount of CAB-O-SIL in dioctyl phthalate plus 20% ethylene glycol increases viscosity substantially.

CAB-O-SIL is a fire-dry 99% pure fumed silica with a particle size of 0.015 micron, surface area of 200 m²/gm, bulk density of 2.3 lb./cu. ft.

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MEMO

SUBJECT **Fire**

TO All Personnel FROM Frank Sharpe DATE January 3, 1969

The building is on fire.
Evacuate immediately.

Xerox is for when you want to spread the word. Fast.

In the old days, if you had some hot news in an office, you could phone it...if not many people were involved. Or route it...if you had two weeks to kill.

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At Xerox we make over twenty machines. They do everything copiers and duplicators are supposed to do plus a lot they're not supposed to do—like feeding themselves, sorting, reducing and enlarging, for instance.

And every one of them has the same job—to make sure that the information your people read is news.

Not history.

XEROX

LETTERS

Sirs:

Shmuel Winograd's article on the speed of computers [SCIENTIFIC AMERICAN, October, 1968] is unfortunately based on the propagation of some popular myths within the computer industry. The author is apparently unaware of two important papers relating to this subject: Garner's "Number Systems and Arithmetic" and McNaughton's "On Nets Made Up of Badly Timed Elements."

Garner describes various methods of addition that cheat the "carry" problem (which Winograd correctly proves to be essential). The carries in a series of additions are effectively saved and all carries are accomplished in one grand conversion at the end of a string of additions. Thus if 100 numbers were added, there would be only one addition in which the carries would occur. This effectively reduces the carry propagation time to an average of $1/n$ over normal arithmetic (where n is the number of numbers being added). This has been used in the design of ILLIAC II in 1957. Since the number representations are complete and unambiguous, such conversions need only be done prior to output. Carry propagation is therefore not the limitation. These number representations, however, require carries within a group of bits.

McNaughton examines the problem of building high-speed logic circuits of elements that have delays that are only statistically determinable. The delay of an element is assumed to be described by a probability distribution. He further assumes that elements have either a fan-in of 1 and fan-out of 2, or the converse. A further assumption is that an element can only be connected to its nearest neighbor on a gridwork of such elements. Crossovers are accomplished by special crossover elements. These restrictions constitute the harshest theoretical conditions that could be imposed on a logic design. The key to McNaughton's work is the observation that the switching time of the element is not the same as its delay. Thus an element may be able to switch up and back in one nanosecond, but suffer a propagation delay of 10 nanoseconds. What McNaughton proves is that under these conditions any sequential circuit can be constructed such that its speed is limited only by the switching speed of its elements and not by the element delay. A computer constructed of such elements (called RBF elements for ready bit feedback) will have an initial delay between inputs and outputs, but thereafter results will come streaming out at a rate limited only by the switching speed of the individual elements. Thus a computer constructed of RBF elements with a switching speed of one nanosecond could accept inputs at a rate of 500 megacycles. The time lag between the first input and the first output could be of the order of milliseconds. Since there appears to be no physical limit to switching time of components, there would appear to be no mathematical limit to the processing rate of computers.

BORIS BEIZER

Data Systems Analysts, Inc.
Pennsauken, N.J.

Sirs:

Mr. Beizer seems to have missed the meaning of the results reported in my article. Let me, therefore, summarize them before commenting on the points he has raised.

The result concerning addition is: If the numbers inside a computer are represented by a one-to-one code, then the time delay between the instant the num-

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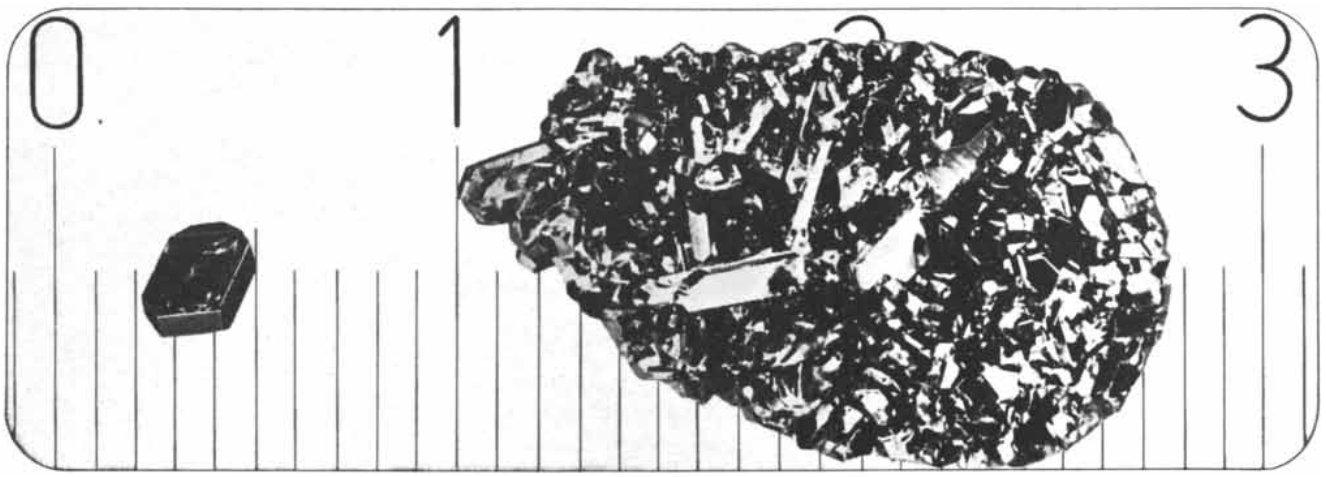
NAME

NEW ADDRESS

OLD ADDRESS



Gold diggers in the lab

Mineralogists generally agree on the way in which natural crystalline materials have been formed. Many silicates, quartz and other oxidic minerals were deposited hydrothermally. This also applies to gold. It simply means that crystallization took place in an aqueous medium at a temperature above 100° C and at high pressure. Unlike the other substances however, gold crystals could not be reproduced in the laboratory like this. So theory remained theory . . . until recently.

Last year Dr. Rabenau and Dr. Rau from Philips Zentrallaboratorium, Aachen, Germany demonstrated how to grow gold single crystals. They had studied laboratory methods of hydrothermal growth using an alkaline solvent with the oxidic materials. Quartz, the best known example, is grown in this way. An autoclave - a pressure vessel capable of withstanding high temperatures - is heated to about 400° C and a small temperature gradient is sustained for several days. Quartz is transported to the coldest area and builds up on an existing seed of quartz to form a large single crystal. Corrosivity of the solvent can be overcome by using gold capsules or liners covering the inside of the autoclave. To grow gold crystals, Rabenau and Rau reversed this principle and at the same time replaced the alkaline medium with a hydrogen halide acid as the solvent. They introduced this method primarily to grow single crystals of metal sulphides, which are of interest because of their physical properties. With these acidic solvents, quartz resists up to 500° C and 3000 atmospheres, but gold is attacked if the medium is also oxidising. So they took a quartz glass ampoule, added gold filings and filled it to 65% of its volume with a concentrated aqueous solution of hydrogen iodide, then sealed it. One practical problem was that a quartz ampoule would break at an inside pressure of some 50 atm. This was averted in an ingenious way by creating a high outside pressure, enabling the ampoule to withstand pressures in the order of thousands of atmospheres. A predetermined amount of dry ice was added to the sealed ampoule in the autoclave. Heating automatically produced a safe excess pressure of CO_2 on the outside. The lower end of the ampoule was kept at appr. 480° C and the other end a few degrees higher. This created the right condition for the gold to dissolve and be transported through the solvent to the hotter end where it crystallised. After 10 days, single crystals up to 1 cm across could be "panned". Under isothermal conditions, druses are formed (lumps of encrusted small gold crystals).

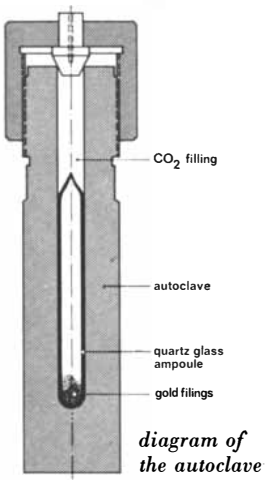


diagram of the autoclave

In further systematic experiments, Rabenau and Rau were able to show that gold could also be transported in the milder conditions, found in nature. That is, in acidic solutions of rock salt, in the presence of oxygen at temperatures below 500° C - but naturally at a slower rate. In these conditions, gold can be dissolved in appreciable amounts by the formation of so-called "ionic complexes". What does an industrial laboratory do with gold "nuggets"? Little more than describe them in scientific papers and delight in displaying this novel form of jewellery. It is only a side line of systematic investigations into hydrothermal mechanisms, which helped in this case to solve a long-standing scientific problem.

In the Research Laboratories of the Philips group of companies, scientists work together in many fields of science. Among these are: Acoustics, Chemistry, Information Processing, Mechanics, Nuclear Physics, Perception, Solid State, Telecommunications and Television.

bers to be added are presented to the adder and the instant the sum appears has to exceed the time given by the formula reported in the article. If this is the popular myth referred to by Mr. Beizer, then it is no myth, but a fact.

However, it does not imply that if the solution of a problem requires 1,000 additions, then the computer requires at least 1,000 times the time delay given by the formula. Several methods have been proposed to reduce the time required to solve the problem, and thus give the appearance of reducing the time required to perform a single addition. Various "carry-save" methods, parallelism and "pipelining" fall in this category. Since Mr. Beizer has emphasized "pipelining," I shall comment on this method in more detail.

If we could present a new pair of numbers to the adder before it finished adding the previous pair, then the rate at which the sums are obtained is increased. Note, however, that the time elapsing between the time the pair of numbers is presented and their sum appears is still governed by the formula reported in the article. The limitation of this method rests on the phrase, "If we could present a new pair of numbers." It is quite often the case that one of the summands is the result of the previous addition, and then we have to wait for this result before a new pair of numbers can be presented. To make this point more concrete, consider the problem of adding $a + b + c$. We can start by presenting a and b to the adder, and one nanosecond later (I am using the numbers given by Mr. Beizer) the adder is ready for another pair of numbers. Unfortunately the next pair of numbers is c and $(a + b)$, and therefore we have to wait milliseconds to continue the process.

It should be clear that "pipelining" is useful only for some problems, the important factor being: Is the data to be operated on available when it is needed? The answer to this question depends, as was shown in the preceding paragraph, on the time it requires to add (or multiply) numbers. Thus not only are the results reported in my article not negated by "pipelining"; they are an important tool in analyzing the suitability of a given problem to "pipelining."

SHMUEL WINOGRAD

Thomas J. Watson Research Laboratory
International Business Machines Corporation
Yorktown, N.Y.

RECENT FINDINGS

RESEARCH LABORATORIES

Ford

Research in the solidification of metals leads to methods of controlling grain structure.

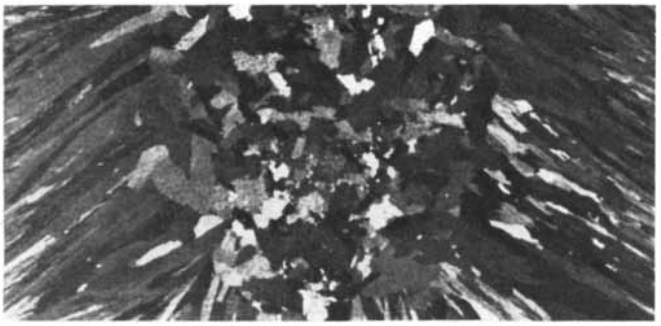
The final properties of castings are strongly influenced by the grain structure present. However, there are real difficulties which have prevented advances made in the laboratory from being scaled-up into useable products.

Many of these difficulties can be skirted by controlling local events at the solid/liquid interface. A continuing investigation of fluid flow shows that moving liquid interacts with specific growth events, and allows us to learn just how these interactions may be controlled.

Three structures are illustrated. The first shows the casting in its conventional static state. The second was solidified from a liquid made more quiescent than normal by slowly rotating to overcome natural convection. The last was solidified during abrupt changes in the fluid flow. These modifications of structure were indeed forced externally, but the changes in solidification occurred at the solid/liquid interface. It proves possible to control the grain structure in cast iron or in alloys as diverse as those for lead-acid batteries, and turbine blades.

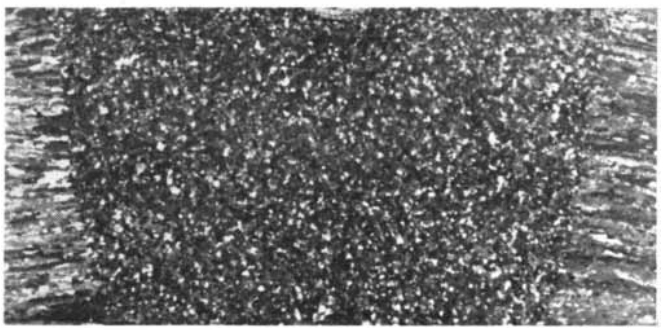
The real advantage found by this research is not this control itself but the possibility of designing structure-to-order.

The ingot sections below were cast to illustrate the effects of changing the fluid flow during solidification and thus the sequence of events at the solid/liquid interface.



Conventional static casting.

Solidified under steady rotation to dampen fluid flow.



Oscillated during solidification to increase fluid flow.

PROBING DEEPER FOR BETTER IDEAS

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General Electric is demonstrating the only 3-dimensional information system

Maybe you're already doing batch processing, remote batch, and time-sharing. But you're using several independent computers. Watch what happens when you replace them with a single GE-600, the *only* information system today that can operate in all three dimensions of information processing:

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You'll save money at satellite facilities. Compact GE-115 computers and keyboard terminals at your remote operations link up with the central GE-600. This gives your small satellite systems big system capability.

You'll put your organization on line. All your files are contained in a common data base. Every computer, every terminal, in every mode has access to it. With time-sharing, you can give your technical people fingertip access to an on-line computation capability. You can give management immediate access to the facts of the business. You can give your salesmen their order-entry system . . . your warehouses their dynamic inventory system.

You'll put your programmers on line too. They can develop their programs at time-sharing terminals. They can maintain their source program files in the system. They can initiate time-sharing or batch-mode jobs in debugging mode or for production processing.

No waiting for key punch, collation, and batch-mode turn-around.

Discover the three-dimensional world of the GE-600. Ask your General Electric Sales Representative for a demonstration. Or write Section 290-25A, General Electric, 1 River Road, Schenectady, N. Y. 12305.

GENERAL ELECTRIC

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JANUARY, 1919: "The war has been a great educator on the value of research, and well-qualified research men are in greater demand now than at any other time. Three hundred and fifty-five American manufacturing concerns maintain their own research laboratories and many more employ the facilities of commercial laboratories, consultants and educational institutions. The total is but a fraction of the number which should take full advantage of what modern science offers, and the layman has yet really to appreciate research. Hence the proposal now before Congress to establish engineering research stations throughout the country, one in each state, or to appropriate money for each state to be expended in the support of research of importance to science and industry carried on in whichever educational institution might show itself best suited to undertake the specific problem. It is proposed to grant $15,000 to each state the first year, $20,000 the next, $25,000 the third and $30,000 the fourth and subsequent years."

"The development of a hydrogen substitute that would be non-inflammable has always been considered by airship advocates as the most important progress that remained to be realized in aerostatics to make the airship really safe. Heretofore the difficulties encountered in this endeavor have appeared as an unsurmountable stumbling block. Today the great problem is solved, for American enterprise, engineering skill and ingenuity have succeeded in achieving an extraordinary *tour de force* by developing apparatus for the production of helium in large quantities and at a comparatively low cost. Helium, an inert, non-inflammable gas, the second lightest known (the lightest being hydrogen), is relatively abundant, but the operation of separating it has involved such a great expense—from $1,500 to $6,000 per cubic foot—that its use as a hydrogen substitute was never seriously considered until the war. When it is considered that by next spring helium will be produced in this country on an industrial basis and at a cost of approximately 10 cents per cubic foot, the magnitude of the achievement will be fully realized."

"The astounding proposition by Secretary of the Navy Daniels not only that the vast program of ship-construction mapped out and passed by Congress in 1916 should be completed but also that an additional program, equal in extent, should be approved by Congress, places the United States in a most inconsistent, if not ridiculous, position. Our President has gone before the Allied nations with an olive branch in one hand, a proposal for a League of Nations in the other and words of peace upon his lips; nevertheless, while our President is thus advocating disarmament and the destruction of militarism, the Secretary of the Navy is calling for an enormous increase in the size of our navy. It would seem that the heavy sums which have been handled in the course of the war have so blunted the money sense of some of our Government officials that they have forgotten that it is the individual taxpayers of the United States who must carry the burden and pay the price."

SCIENTIFIC AMERICAN

JANUARY, 1869: "Remarkable progress was made during the past year in the most mighty undertakings the world has ever witnessed. The most gigantic railroad enterprise ever attempted—our transcontinental railroad—has been pushed this year almost to completion. The Suez canal now almost joins the Mediterranean to the Red Sea, while during the year a movement has been initiated for the construction of a similar work across the Isthmus of Darien, which will unite the Atlantic and the Pacific. A new sub-Atlantic telegraph of greater length than any heretofore attempted has been made and will soon connect the two continents, to be followed, no doubt, by others of greater magnitude. It has also been the subject of serious contemplation to lay a cable between the Pacific coast and China, and we would probably hazard little in predicting that some old men will live to see that work accomplished. Never has the earth seen a period of greater enterprises; never before has civilization made such triumphant advances."

"The New York *World* has been doing the country a service by some investigations into the quality of liquors sold at the different bars in that city. A large number of samples of brandy sold at from 30 to 50 cents a glass and of whisky sold at from 20 to 30 cents a glass were examined and found to be genuine in only two instances. If such be the case with liquors sold at the best places, what must be the character of the fluids retailed at the low grog shops where whisky can be obtained for from five to 10 cents a glass? In this connection it may be remarked that some specimens of brandy pronounced by experts under oath in a recent revenue case to be genuine and worth $12 a gallon in gold were afterward found to have been manufactured in Brooklyn and to contain not one particle of genuine liquor. How shall the sale of these poisons be stopped?"

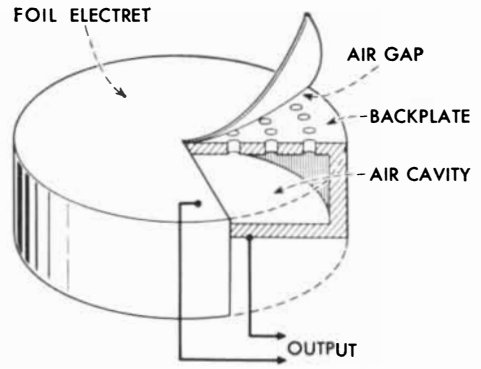
"Prof. Othniel Marsh of Yale College is said to have discovered in the Tertiary deposits of Nebraska the minutest fossil horse yet obtained. It is only two feet high, although full grown, as the character of the bones fully indicates. This makes the 17th species of fossil horse discovered on this continent."

"We read with interest the following notice in the New York *Evening Post:* 'The name of the late King of Siam was Phra-Bard Samdetch-Phra-Pharamendr-Maha-Monkut. He was 70 years of age and had some taste for civilization, having dug canals, built forts, railways, steamboats, founded a printing office at Bangkok, and paid some attention to education. These peculiarities probably came from reading the *Evening Post,* to which he was for many years a subscriber. The king leaves an extensive family of widows, said to be 2,000 in number, to mourn his loss. He spent the last years of his life chiefly in studying Siamese theology, and in photographing his wives.' Now, we have a very high respect for the *Evening Post,* and it is therefore with some hesitation that we disturb its theory respecting the progress made in civilization by Phra-Bard Monkut of Siam. His late highness was a regular reader of SCIENTIFIC AMERICAN, and it seems to us very likely that he learned more from its columns about forts, steamboats, railways, canals and photography than from the *Post;* but so far as his knowledge of theology and social science is concerned, we have no doubt that he found the *Post* an able assistant, and we hope our contemporary will forward a copy of the paper containing the notice to each of the 2,000 bereaved widows."

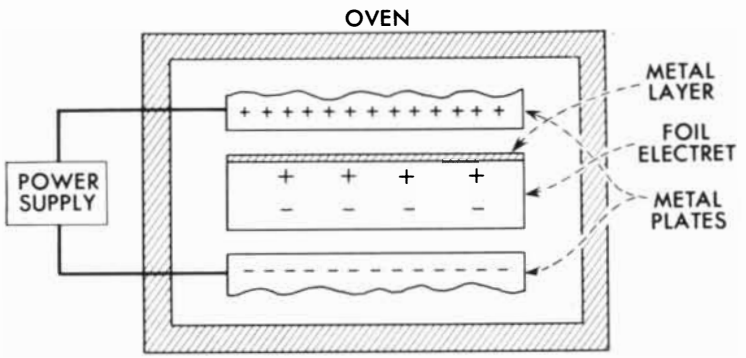
Report from

BELL LABORATORIES

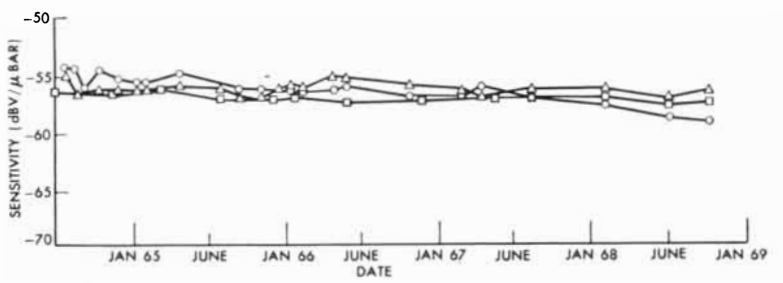
A simple, better microphone



Essentials of the new microphone: The microphone's diaphragm is a charged dielectric foil upon which a thin metal layer has been deposited; it is called a foil electret. The electret touches a metal backplate in several places and, due to surface irregularities, air pockets form between the electret and the backplate. The backplate is perforated so that the air layer can communicate with the larger cavity, increasing the vibration amplitude (and thus the sensitivity) of the system.



Simplified cross-sectional diagram showing how microphone "electrets"—permanently charged dielectric foils—are made. The metallized foil is heated to about 200°C while between a pair of charged metal plates which create an electrostatic field of between 10 and 100 kV/cm. Charges, identical in sign to the adjacent plates, migrate from the plates to the electret, where they remain after cooling. This method of foil electret preparation was announced by Bell Laboratories in 1962.



Sensitivity of electret microphones using fluorocarbon foils is nearly constant. Extrapolated lifetime is about 100 years.

A new kind of condenser microphone with several valuable features has been invented by Gerhard M. Sessler and James E. West of Bell Laboratories. It has the excellent sound fidelity of former types of condenser microphones, but does not need a d-c supply, and has much lower electrical impedance; this permits good low-frequency response without the need for special circuits.

Like previous designs, the new microphone depends on a varying capacitance—produced as sound vibrations impinge on one flexible plate of a capacitor. But there's a difference: here, the flexible plate is a "foil electret"—a thinly metallized sheet of fluorocarbon or polycarbonate. The electret contains a permanent static charge. As the electret moves, it varies the electrostatic field across the air gap (drawing). This produces a varying voltage at the output. Thus, the microphone needs no d-c supply.

In any capacitor, the thinner the dielectric, the higher the capacitance. Dielectric films can be made 0.00012 to 0.001 inch thick. So, the capacitance of the electret microphone is about triple that of conventional types of condenser microphones, and the impedance is comparably lower. This simplifies accompanying circuitry.

The microphone is inexpensive, exceptionally rugged, and immune to wide temperature fluctuations.

As the graph (left) shows, the microphone's sensitivity remains essentially constant for very long periods. This is due to an inherent compensation only possible with thin-film electrets: as the charge on the electret decays—and measurements indicate that it will take about 100 years to fall 50 percent—electrostatic attraction between electret and backplate is reduced. This diminishes the restoring force on the electret, allowing it to vibrate at greater amplitude. Electrical output remains, therefore, nearly constant.

As with all promising devices the electret microphone is being evaluated by our development and systems engineers. Because of its simple construction and low cost it may well find application in future telephones.

Bell Telephone Laboratories
Research and Development Unit of the Bell System

a measure of progress

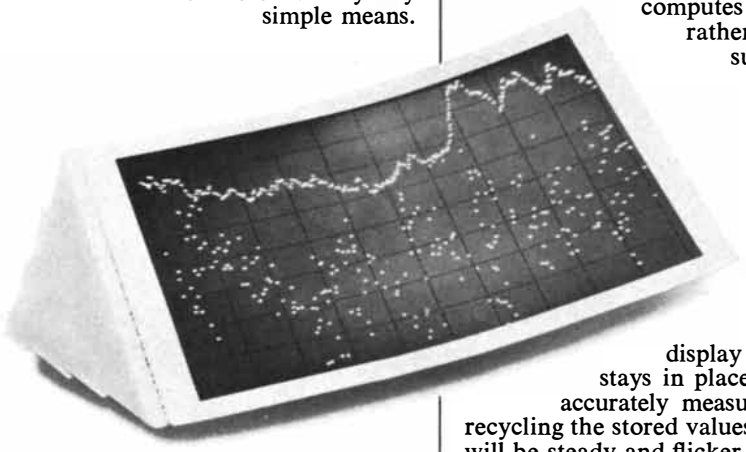
1. Signals buried in noise
2. A computing calculator
3. Hot-carrier diodes
4. Neutron activation analysis
5. Electronic patient monitoring

1. Averaging out body static

Someday your doctor or a specialist may want to know in minute detail exactly what's going on in your brain, your heart, a specific muscle or nerve. With very sensitive instruments he can tune in on the electrical signals these organs constantly generate. The problem is, your whole body generates a veritable electric cacophony that may mask the signal he wants. Noises that can't be filtered out by any simple means.

To help medical researchers, Hewlett-Packard has developed a signal analyzer which ferrets out signals buried in noise—using to advantage the random nature of noise itself. The signal is sampled repetitively by being broken up into a thousand short segments whose values are deposited into memory cells. The noise, sometimes plus and sometimes minus, tends to cancel itself out. The repetitive, information-bearing signal is progressively strengthened.

To keep a steady, calibrated display, the HP 5480A Signal Analyzer computes the average, rather than simply summing. The



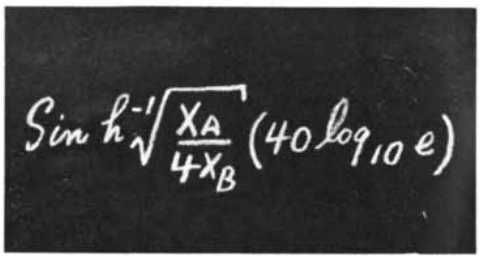
display on the scope stays in place and can be accurately measured. And by recycling the stored values, the display will be steady and flicker-free, regardless of how often the samples are taken.

Other candidates for signal averager assistance are seismology, fluorescent-decay studies, and numerous other laboratory applications. Whenever there's a repetitive signal and a synchronizing signal, an averager can improve signal-to-noise ratio by as much as 60 dB. The HP 5480A sells for $9500. The whole story is told in the April, 1968, issue of the HP JOURNAL. Write for a copy.

00803

2. Hyperbolic functions on a desk calculator

The new Hewlett-Packard computing calculator is no ordinary calculator—though it is about the size and weight of an ordinary typewriter. There's scarcely a mathematical problem you—or your son or your scientists—couldn't solve with it. In fact, it's almost like having a large computer on your desk. The difference is, it's designed from the outside in, with the user in mind. We started with the keyboard.



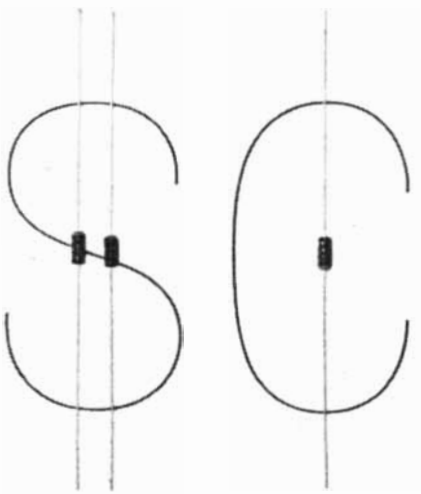
Suppose you want to solve the problem shown on the blackboard. We've locked into the machine's memory the value of *e*, the log routines, the trig routines and the necessary hyperbolic routines. All you do is push buttons which call these functions into action in the proper sequence. Once you've set up the problem, you can store the operation on a wallet-sized magnetic memory card. The next time you need the program, insert the card and key in the measured values. Each card will hold two 196-step programs. And you don't need to know any programming language.

For $4900 you can do fixed or floating-point arithmetic, coordinate conversions, regression analysis, coordinate geometry, transcendental equations, numerical integration, network analysis, differential equations, branching and looping operations, business calculations—or anything else that's in our growing program library. You can speed your work with a 1.6 microsecond memory cycle, and handle numbers as small as 10^{-98} or as large as 10^{99}, simultaneously.

To find out more about the versatile Hewlett-Packard 9100A Computing Calculator, write for our fully illustrated brochure.

3. Spreading a good diode around

One of the significant advances in recent electronics history is the hot-carrier diode—a tiny device that can switch off and on in one ten-billionth of a second. That makes it an almost perfect switch or an ideal detector. But it was priced at five dollars, which limited it to esoteric or military uses.



Before **After**

Now Hewlett-Packard is producing these instant switches by the millions—to sell at 55 cents each in quantities of 1000. At this price they might be used to speed up commercial computers or make home TV sets more reliable.

The price reduction was made possible by a combination of new design and new manufacturing techniques. First, our engineers eliminated a cat-whisker contact by using junction diode construction. This got rid of the expense of hand-probing for an active area on the diode surface. Then they developed a hybrid combination of a molybdenum metal barrier to gain speed and a graded pn junction to gain stability.

The hybrid technique isn't limited to 55 cent diodes. It could be used in integrated circuits, as well. We're already experimenting with devices that will have higher operating temperatures, higher breakdown voltages and higher forward threshold currents. If you'd like to experiment with the new HP 5082-2800 Diode, we'll sell you one for 99 cents. Or we'll send you Data Sheet 2800 for free.

4. Information from next-to-nothing

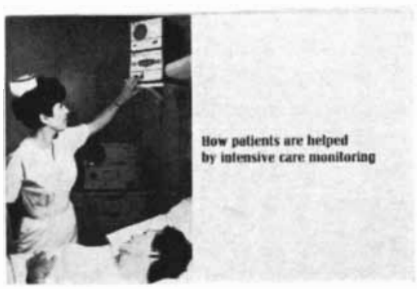
It was just a relic of hair from Napoleon's head. But could it tell if he had been slowly poisoned to death with arsenic? A technique known as neutron activation analysis led to that suspicion—without harming even the smallest hair.

The technique used pumps neutrons into the hair to activate the different elements present. Then the hair starts pouring out rays of energy. What kind of rays, how many there are, and how strong they are produce an exact signature of each element in the hair. In the case of arsenic this technique can detect 10 billionths of a gram. In some cases the traces can be as small as a millionth of a millionth of a gram—next to nothing.

The technique depends on an instrument capable of measuring and recording the radiation spectrum. First, the activated sample is placed in a detector which gives off an electrical pulse for each ray—a pulse whose strength is proportional to the strength of the ray.

A Hewlett-Packard multichannel analyzer can then separate the pulses into a thousand distinct energy levels and count the number in each. The count is displayed on a screen as a graph, and the signature of each element can be recognized. The analyzer will also measure the amount of energy given off in a specific time period—another clue to a material's identity.

The 5400A Multichannel Analyzer is one of the fastest, most accurate and versatile systems available for spectrum analysis. It sells for $9500. For a complete discussion of this instrument and this technique, write for the March, 1968, issue of the HP JOURNAL.



5. Bedside sentries

Suppose you were in a hospital recovering from major surgery or a heart attack. You wake up—and find yourself surrounded by electronic instruments, with wires of all sorts leading from them to you. It could be frightening. You could feel far worse than you are. And your family might think you've taken a turn for the worse. Not so, and here's why.

An electronic patient monitoring system is measuring, transmitting, displaying and recording heart rate, blood pressure, temperature, and respiration. Second-by-second it forms a continuous communications link between your body's vital functions and the medical staff. Even so, it could still scare you.

But one day a nurse who knows us well suggested another way Hewlett-Packard might help hospitals and their patients. We're old hands at building and installing monitoring systems for hospitals. Why couldn't we publish a booklet telling people how these systems work? A booklet to allay the fears of patient and family alike. We did. It's pictured above. If you'd like, write for a copy.

Hewlett-Packard, 1501 Page Mill Road, Palo Alto, California 94304; Europe: 1217 Meyrin, Geneva

HEWLETT hp PACKARD
Measuring instruments for science and industry

THE AUTHORS

CHRISTOPHER TIETZE and SARAH LEWIT ("Abortion") are on the staff of the Bio-Medical Division of the Population Council in New York. Tietze, a native of Austria, holds an M.D. from the University of Vienna. Since he came to the U.S. in 1938 his professional interests have shifted to medical statistics and demography, with a special concern for human fertility and its control. Before joining the Population Council, where he is now associate director of the Bio-Medical Division, he was affiliated with the School of Hygiene at Johns Hopkins University, the Department of State and the National Committee on Maternal Health. In addition to his work with the Population Council he is serving as a member of Governor Rockefeller's Committee to Study Abortion in New York State. Sarah Lewit, who in private life is Mrs. Tietze, was graduated from Brooklyn College of the City of New York and served as a statistician in several Government agencies, including a period as acting chief of the Marriage and Divorce Section of the National Office of Vital Statistics. For the past 10 years she has been working with her husband as a research associate.

RAY J. WEYMANN ("Seyfert Galaxies") is an astronomer at Steward Observatory of the University of Arizona. He received his bachelor's degree in astronomy from the California Institute of Technology in 1956 and his Ph.D. from Princeton University in 1959. He then returned to Cal Tech as a postdoctoral fellow for two years before joining the staff of Steward Observatory, where he has remained since except for the academic year 1963–1964, when he was at the University of California at Los Angeles. Weymann's interests other than Seyfert galaxies include mass loss from stars, destruction of the element lithium in the sun, the primordial radiation field and intergalactic matter.

ALEXANDER TOMASZ ("Cellular Factors in Genetic Transformation") is associate professor of genetics and biochemistry at Rockefeller University. Born in Hungary, he received his diploma from the Pázmány Peter University of Budapest in 1953 and spent three years as a research associate in the Hungarian National Academy's institute of genetics. Moving then to the U.S., of which he is now a citizen, he obtained his Ph.D. from Columbia University in 1961 and began his association with Rockefeller University in the same year. Tomasz' interests include the biosynthesis and functioning of cell surface structures, cell-to-cell interactions, molecular genetics and the control of cell division.

ARTHUR W. JOHNSON ("Weather Satellites: II") is deputy director of the National Environmental Satellite Center of the Environmental Science Services Administration in the U.S. Department of Commerce. Soon after he was graduated from Colgate University with a degree in chemistry his interests turned to meteorology, international affairs and the conduct of research and operational projects designed to make maximum use of new sources of meteorological information. He worked in the postwar reestablishment of the German weather service and then joined the U.S. Weather Bureau in a planning capacity. He was meteorological attaché to the World Meteorological Organization in Geneva and operations manager of the National Hurricane Research Project before taking up his present work in 1961.

KARL H. PRIBRAM ("The Neurophysiology of Remembering") is research professor of psychology and psychiatry at Stanford University. He began his studies of the brain as a neurosurgeon. The advent of psychosurgery caused him to move into laboratory studies of monkeys; the premise, he writes, is that "one should know what one is about before mucking around with the human brain." The work has directed his career toward neuropsychology and experimental psychology, to the point where he was recently elected president of the Division of Physiological and Comparative Psychology of the American Psychological Association. Pribram's hobby is photography, and when holography became a practical reality, he perceived its relevance to problems of brain function that had been baffling for many years. As a result the image-forming properties of the brain have become a major focus of his current work.

C. R. TAYLOR ("The Eland and the Oryx") is a research associate in the department of zoology at Duke University. A graduate of Occidental College in 1960, he obtained his master's degree and his Ph.D. from Harvard University. He has taught at Harvard and at the University of East Africa. Taylor writes: "My competence in science, but not my interest, is limited to environmental physiology. Fortunately this allows me to look at problems as different as the viscosity of blood, the temperature regulation of antelopes and the metabolism of a snail. There are as many interesting problems as there are interesting animals. If I had time and could choose another field of specialization, it would probably be sociology or anthropology. I am fascinated by the influence of Western values on and their assimilation by other cultures. I am also interested in the economic and political problems of developing countries. My problem is to find time for the things that interest me. To break the monotony of a rather sedentary existence in the laboratory I manage to find time to run several miles a day."

THEODORE P. YIN ("The Control of Vibration and Noise") is a member of the research staff of the elastomer chemicals department of E. I. du Pont de Nemours and Company. Born in Hankow, China, he received his secondary education in Shanghai and was graduated from the University of Hong Kong in 1953. He took his master's degree in organic chemistry at the University of Alberta and, after moving to the U.S. in 1957, his Ph.D. in physical chemistry from the University of Wisconsin. His research interest is in the rheology and physical chemistry of synthetic polymers, particularly elastomers, with the aim of correlating the chemical nature and structure of elastomers with their physical properties. Aside from his work Yin enjoys reading in the modern history of China.

MARY J. MARPLES ("Life on the Human Skin") recently retired from the department of microbiology in the medical school of the University of Otago in New Zealand. She now lives in England, although she travels extensively and at the time her article was being prepared for the press was in Jamaica as a consultant to the World Health Organization. She holds a master's degree in zoology from the University of Oxford and a medical degree from the University of Otago. Her husband, Brian J. Marples, was professor of zoology at Otago for many years until his recent retirement.

JOHN UPDIKE, whose verse inspired by the special issue of SCIENTIFIC AMERICAN on "Materials" in September, 1967, is published in this issue, is the well-known American author; his most recent novel is *Couples*.

An aircraft carrier may be a very big ship but it's also a very small airport.

Over the past few years the Navy's planes have grown more and more complex. A lot more maintenance checks had to be made—and a lot more men and equipment were needed to make them.

All of which took more time and more space. The trouble is on an aircraft carrier you never have enough of either.

The advantage of UNIVAC® computer systems is they save on both.

The Navy worked with Univac engineers to develop a computer system that would check and troubleshoot equipment by zipping impulses through a plane's electronic package.

The system is called VAST—for Versatile Avionic Shop Test.

VAST will do routine aircraft maintenance in a fraction of the time taken by the equipment it replaces.

It will also take less than half the space.

It will cut down on the men needed by twenty-five percent.

VAST is easier to use so it will be easier to train men to use it.

And it can be shared by six different repair crews at the same time.

Univac systems are at work in many fields. In industry, science, education and government.

On five continents.

And the seven seas.

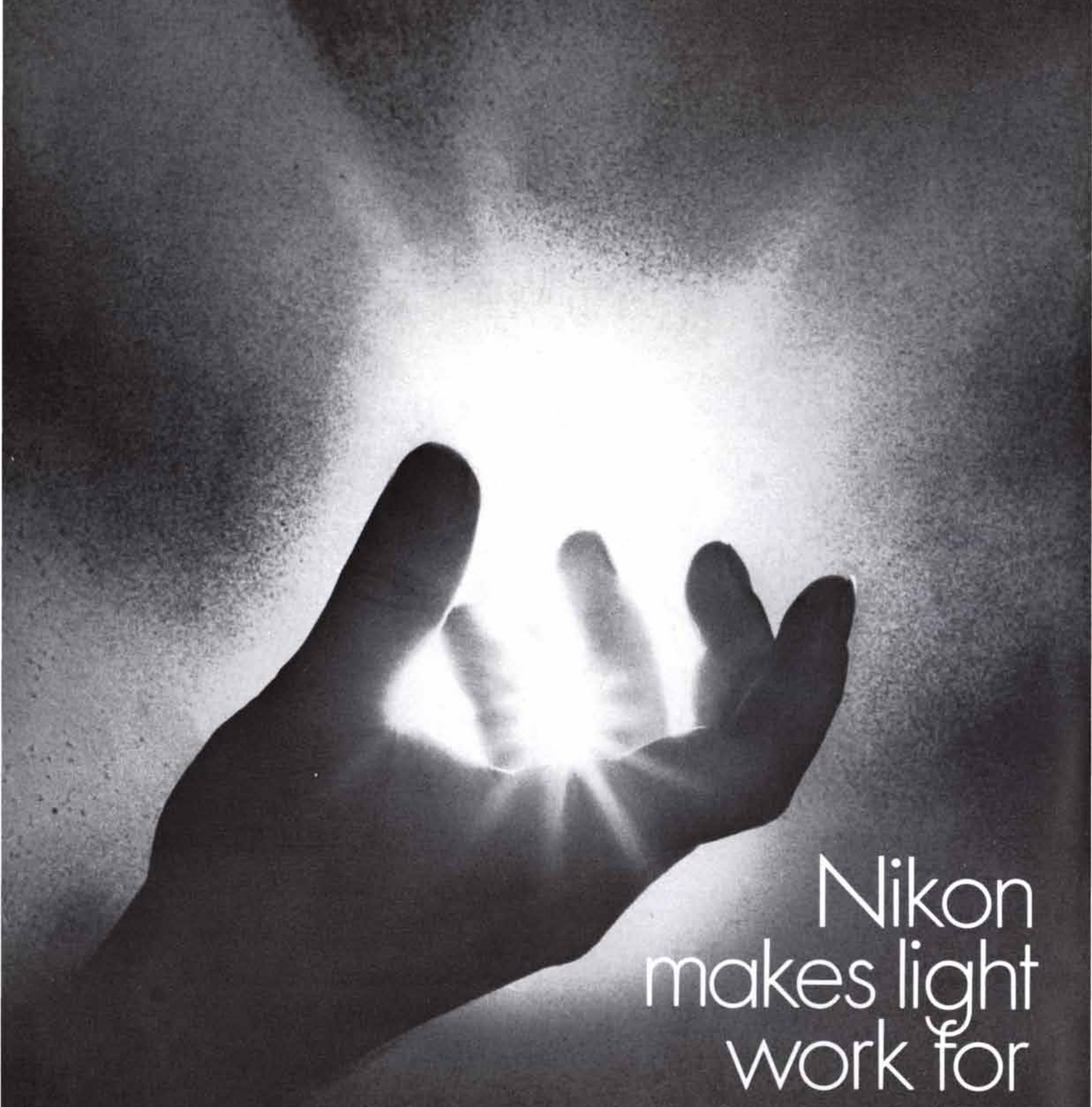
UNIVAC

Univac is saving a lot of people a lot of time.

SPERRY RAND

When it comes to expanding facilities, some airports are at a disadvantage.

So the Navy uses computer systems to keep its planes shipshape.



Nikon makes light work for you

Light illuminates and reveals. Aided by optics it is a tool, a yardstick, a language. It can perform a thousand tasks.

The name *Nikon* figures prominently in this. Nikon achievements in theoretical optics, optical glass chemistry and optical instrumentation have become something of a legend in their own time.

A photographer is poised for an exposure. His picture may chronicle a great moment in history; depict a fashion trend; show a new plant installation; record a surgical procedure; or simply capture a likeness. The camera is a Nikon.

A sportsman watches the favorite down the stretch; a yachtsman sights a channel marker. A hunter spots a buck; a birder identifies an uncommon specie. Through Nikon binoculars.

A biologist observes the miracle of mitosis; a medical student, the characteristics of cell abnormality. A metallurgist inspects a turbine blade; a pathologist readies a specimen for photo-micrography. In each case, a Nikon microscope.

A QC inspector gages an intricately shaped component with a Nikon Profile Projector. It is capable of repeat measurement accuracy to 0.0001". A maintenance man checks the flatness of a lathe bed with a Nikon Auto-Collimator. He can detect angular deviation to less than ½ second of arc. A cameraman shoots a set of process negatives, the first critical step in graphic arts color reproduction. The lens, a Nikon Apo-Nikkor.

An electronic engineer studies the drawings for an integrated circuit. They will be reduced optically to the miniscule proportions of an IC chip. Most likely with a Nikon Ultra-Micro Nikkor lens. And a Nikon Mask-Alignment microscope will probably be used for registration.

Nikon can make light work for you, too. For wherever light has a job to do, you will find Nikon optics and optical instruments in evidence and in use.

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Established 1845 SCIENTIFIC AMERICAN January 1969 Volume 220 Number 1

Abortion

Experience in a few countries where induced abortion is legal is now beginning to provide the first reliable data on this age-old, most widely used and most clandestine method of fertility control

by Christopher Tietze and Sarah Lewit

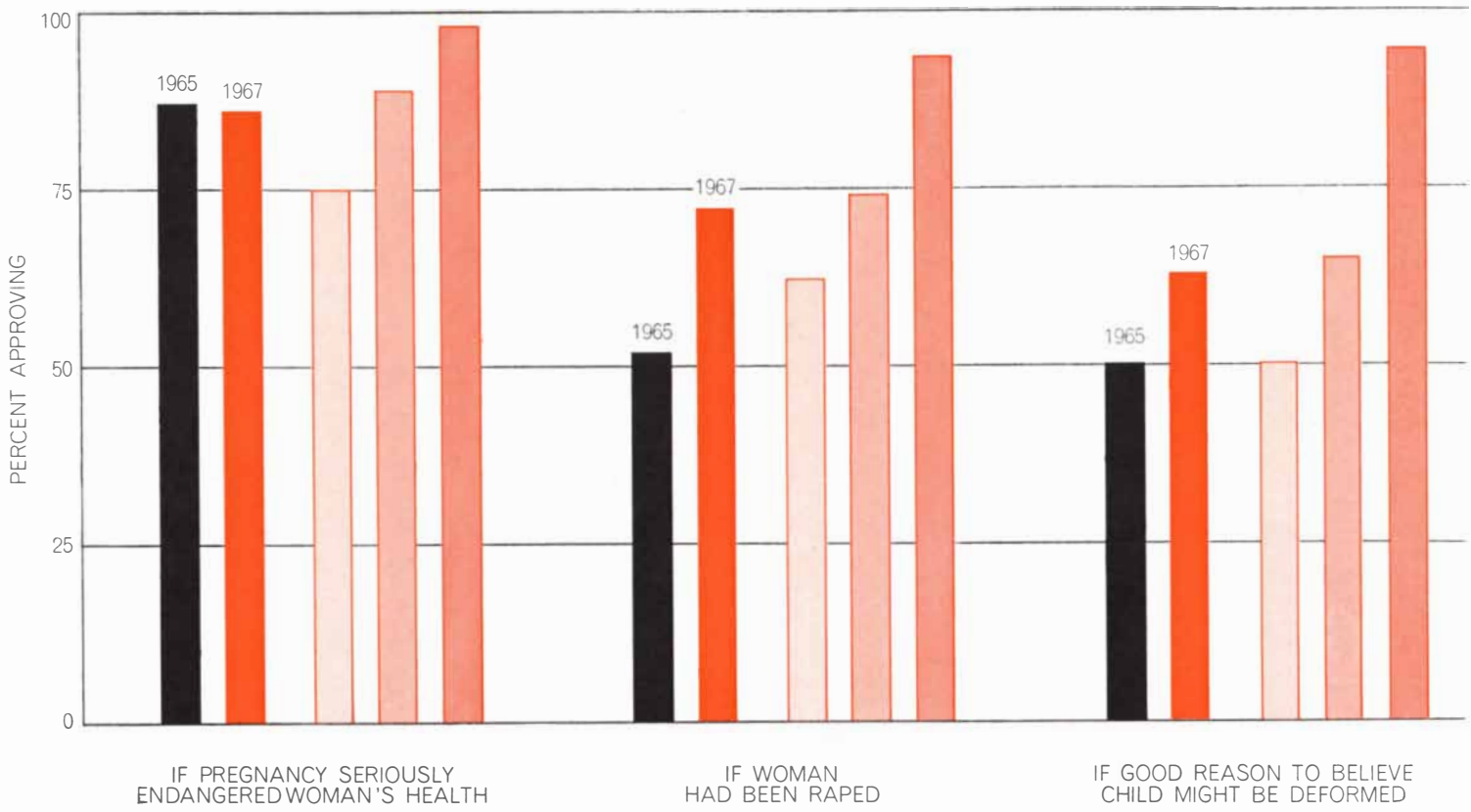
The practice of abortion goes back to human traditions far older than the earliest written history. Abortion is still the most widespread, and the most clandestine, method of fertility control in the modern world. In recent years several nations have legalized the practice, and as a consequence induced abortion is emerging from the shadows and has become a topic of worldwide discussion and controversy. The debate ranges over a wide spectrum of considerations: moral, ethical, medical, social, economic, legal, political and humanitarian. The experience of countries that have made abortion legally permissible is now beginning to provide a body of reliable data with which to evaluate the pros and cons of the practice.

That induced abortion was probably common among prehistoric peoples is suggested by anthropological studies of primitive tribes still living in isolated parts of the world today. The motivation is much the same as it is in civilized societies: the illness or extreme youth or advanced age of the pregnant woman, economic hardship, the desire of unmarried women to avoid disgrace and a variety of other biological and social considerations. The methods employed by women in primitive societies to terminate unwanted pregnancy vary from hard physical exertion to the application of heat or skin irritants to various parts of the body or the insertion of a variety of instruments into the uterus.

Techniques for abortion are mentioned in some of the oldest medical texts known to man. An ancient Chinese work, said to have been written by the Emperor Shen Nung 4,600 years ago, contains a recipe for the induction of abortion by the use of mercury. In ancient Greece, Hippocrates recommended violent exercise as the best method, and Aristotle and Plato advocated abortion to limit the size of the population and maintain an economically healthy society. With the rise of the Jewish and Christian religions abortion fell under moral condemnation. During the Renaissance, however, popular disapproval of abortion was relaxed considerably. In English common law abortion was not regarded as a punishable offense unless it was committed after "quickening," or the first felt movements of the fetus in the womb. Even then it was classed only as a misdemeanor. Abortion did not become a statutory crime in England until 1803; it did not become one in the U.S. until about 1830. Today it is still prohibited in most states of the U.S. except in cases of serious hazard to the mother's life.

The arguments for and against abortion are widely known. The moral objection is based primarily on the contention that human life begins with the union of the egg and the sperm, so that destruction of the fertilized ovum is an act of homicide, even murder. Opponents of abortion hold that it opens the door to the brutalization of society, encouraging "mercy deaths," infanticide, use of the gas chamber and other violations of the sanctity of life. Abortion is said to undermine the social structure by encouraging promiscuous sexual relations, by weakening family ties and by raising legal problems with respect to property ownership and inheritance. In the medical area many physicians find the abortion operation distasteful because of their training as guardians of human life, and some believe it may cause sterility, menstrual disorders, ectopic pregnancy (implantation of the fertilized ovum in the Fallopian tube), miscarriage, abnormal delivery or guilt feelings that may lead to neurotic or even psychotic symptoms.

The defenders of abortion take the position that the embryo does not become a human being until after a certain time, fixed variously from 12 to 28 weeks of gestation. Their arguments for the legalization of abortion are based on the premise that the overriding consideration should be the health (mental and physical) of the prospective mother and child. If there is a risk that the child may be malformed because of genetic factors, illness (for example German measles during the first three months of pregnancy) or injury (such as ingestion of thalidomide by the pregnant woman), she and her physician should be allowed to decide whether or not the pregnancy



U.S. OPINION on abortion has become somewhat more permissive in recent years. The chart shows what percentage of respondents answered yes when asked if they thought it would be all right for a woman to have a pregnancy interrupted for each of several

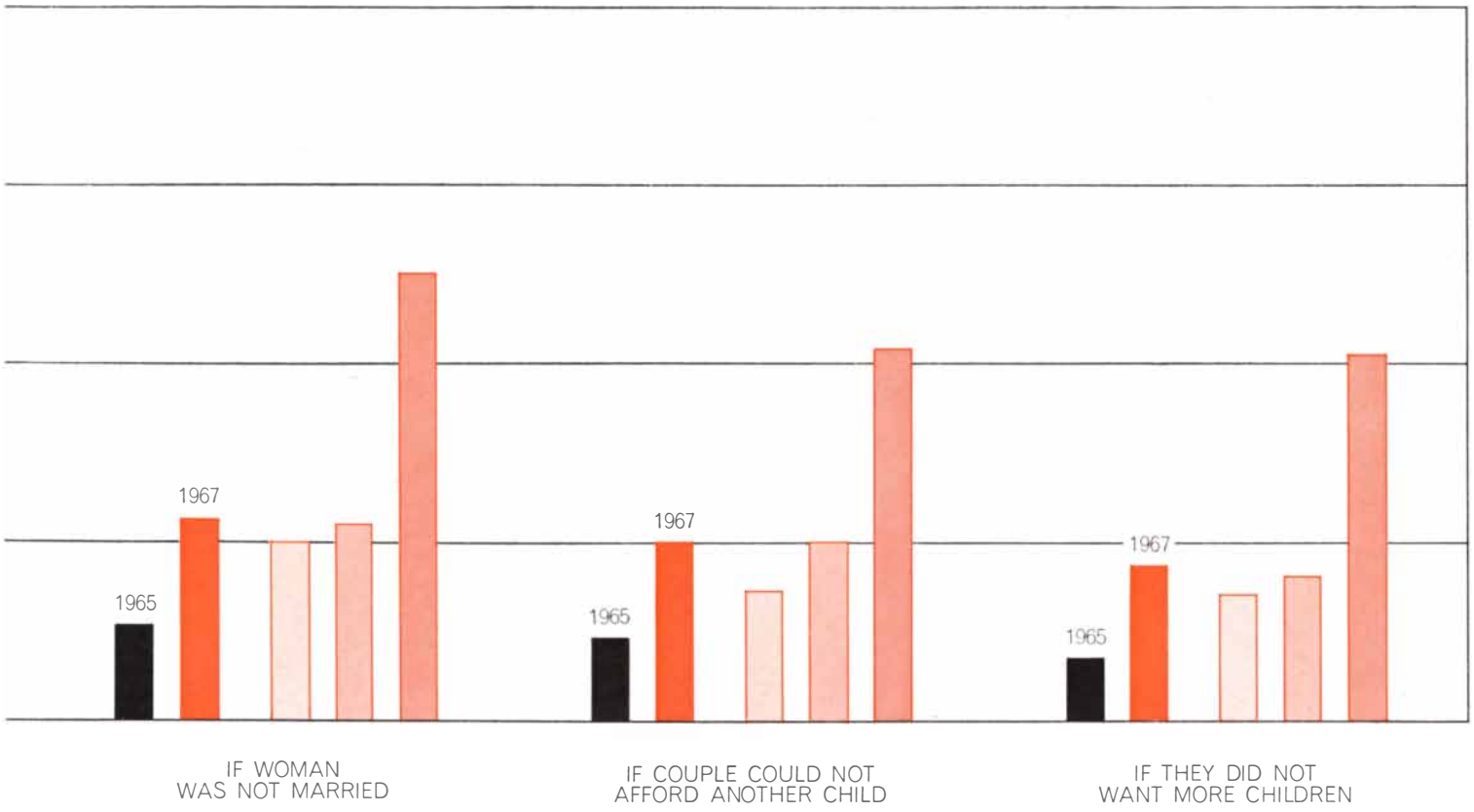
should continue. The birth and rearing of a deformed or mentally defective child may have profoundly disturbing effects on a family. It is contended further that the outlawing of abortion, with the consequent lack of medical regulation and safeguards, has made it a leading public health problem in many countries because large numbers of women are maimed or killed by unskilled or irresponsible operators. The defenders of legalized abortion point out that present techniques for the operation, when it is performed by a competent physician, are so safe that the risk to life is well below the risk of childbearing itself. To the moral objections they reply that most abortions are performed on married women with the consent of their husbands, and that a woman who has been the victim of a criminal rape should not be forced to suffer the additional indignity of having to bear the child. At the philosophical level it is argued that no woman should be forced to bear a child she does not want, and that the implied rights of every child include the right to be born wanted and loved.

Clinically we can divide induced abortions into two broad categories: those performed clandestinely by lay abortionists and those performed by physicians using techniques that minimize the health hazard. The methods employed by lay abortionists are generally either ineffective or potentially dangerous to the pregnant woman. Over the centuries many kinds of internal medication have been tried, ranging from the bush tea of preliterate tribes to white phosphorus to hormones; almost invariably these treatments fail to induce abortion. It does not seem likely that a safe and reliable "abortion pill" will be realized in the near future. The most common technique employed by lay abortionists in the U.S. is the insertion of a foreign body, usually a rubber tube, into the cervix. This procedure brings on contractions, bleeding and the expulsion of the fetus. Part of the placenta may remain in the uterus, however, so that bleeding persists and the patient must go to a physician or a hospital to have the placental fragment curetted (scraped out). In any case, the lay operation usually carries a high risk of infection, owing to the lack of aseptic precautions.

In the medical profession the favored technique for early abortion (that is, during the first 12 weeks of pregnancy) has been dilation and curettage, or "D & C." A series of metal dilators, each slightly larger than the preceding one, is inserted into the cervical canal to stretch it, and when the passage has been opened wide enough, the contents of the uterus are scraped out with a curette. The entire procedure usually takes only a few minutes. In recent years a suction method has become popular, particularly in eastern Europe. After dilation of the cervix a metal, glass or plastic tube with a lateral opening near the end is inserted into the uterus and moved about to dislodge the embryo from the uterine wall; the fragments are then drawn out by means of a vacuum pump connected to the tube. This technique is easier, quicker and less traumatic than D & C.

Abortion is seldom performed after the 12th week of pregnancy, even in countries where it is legal with few restrictions. Late abortion may, however, be necessary to save the life of the pregnant woman. The method usually employed is to remove the fetus by a Cesarean-like operation or to inject into the uterus a highly concentrated solution of salt or sugar, which ends the development of the fetus and causes it to be expelled within a few days.

In nearly two-thirds of the world (in terms of population) abortion is prohibited entirely or is allowed only for narrowly defined medical reasons. The U.S. is one of the restrictive countries.



reasons. The bars give results for 1965 (*black*) and 1967 (*solid color*) and in 1967 for Catholics (*light tint*), Protestants (*darker*) and Jews (*darkest*). Abortion is much more widely approved as an emergency measure than as an elective method of birth regulation.

In 43 states abortion is permitted only if the pregnancy threatens the mother's life. The other seven states and the District of Columbia are somewhat more permissive. In 1967 and 1968 five states —California, Colorado, Georgia, Maryland and North Carolina—adopted liberalized abortion laws based on the model code recommended by the American Law Institute. The code allows abortion in cases where there is a substantial risk that the mother's physical or mental health may be gravely impaired or that the child would be born with a serious physical or mental defect, or when the pregnancy is the result of rape or incest.

The medical profession in the U.S. has generally interpreted the abortion laws conservatively. Most of the large hospitals require a careful review by a board of physicians of each application for an abortion. It is estimated that the number of therapeutic abortions performed in U.S. hospitals from 1963 through 1965 was only about 8,000 per year, a ratio of about two abortions to 1,000 births. About two out of five abortions were performed for psychiatric reasons, about a fourth because the mother had German measles during the first three months of pregnancy and the rest for a variety of other health reasons. In New York City in 1960–1962 the abortion ratios ranged from 3.9 per 1,000 births in proprietary hospitals to only .1 per 1,000 in municipal hospitals, indicating that legal abortion was less readily available to low-income families than to those with higher incomes. There was also a marked ethnic differential: the ratio of therapeutic abortions per 1,000 deliveries was 2.6 for white women, .5 for Negro women and .1 for Puerto Rican women.

It is extremely difficult to obtain a reliable estimate of the number of illegal abortions in the U.S. In 1955 a Conference on Abortion, sponsored by the Planned Parenthood Federation and the New York Academy of Medicine, was held at Arden House; a committee of the conference could only estimate that the number of illegal abortions might be as low as 200,000 or as high as 1,200,000 per year. No information on which to base a better estimate has been obtained since that time. Nor do we have reliable data for determining the number of deaths from illegal abortions in the U.S. Some 30 years ago it was judged that such deaths might number 5,000 to 10,000 per year, but this rate, even if it was approximately correct at the time, cannot be anywhere near the true rate now. The total number of deaths from all causes among women of reproductive age in the U.S. is not more than about 50,000 per year. The National Center for Health Statistics listed 235 deaths from abortion in 1965. Total mortality from illegal abortions was undoubtedly larger than that figure, but in all likelihood it was under 1,000.

The late Alfred C. Kinsey and his associates, in their famous studies of sexual behavior more than a decade ago, found that among the women they interviewed abortions were performed in most cases (about 90 percent) by physicians, although not necessarily physicians in good standing. It is suspected that many American women seeking abortions go abroad to countries where the laws are not as restrictive or are not enforced. Among the less privileged women who do not have access to a skilled physician the abortion risk is substantial compared with other risks of pregnancy. According to a study by Edwin M. Gold of deaths of women from complications of pregnancy or childbirth in New York City in 1960–1962, abortion was the cause of death for 25 percent of the white women, 49 percent of the nonwhite women and 56 percent of the Puerto Rican women.

Since the Arden House Conference of 1955 the subject of abortion has been

discussed by many professional and civic groups. In 1967 the House of Delegates of the American Medical Association endorsed liberalization of the abortion laws, and in 1968 the American Public Health Association urged repeal of all restrictive statutes.

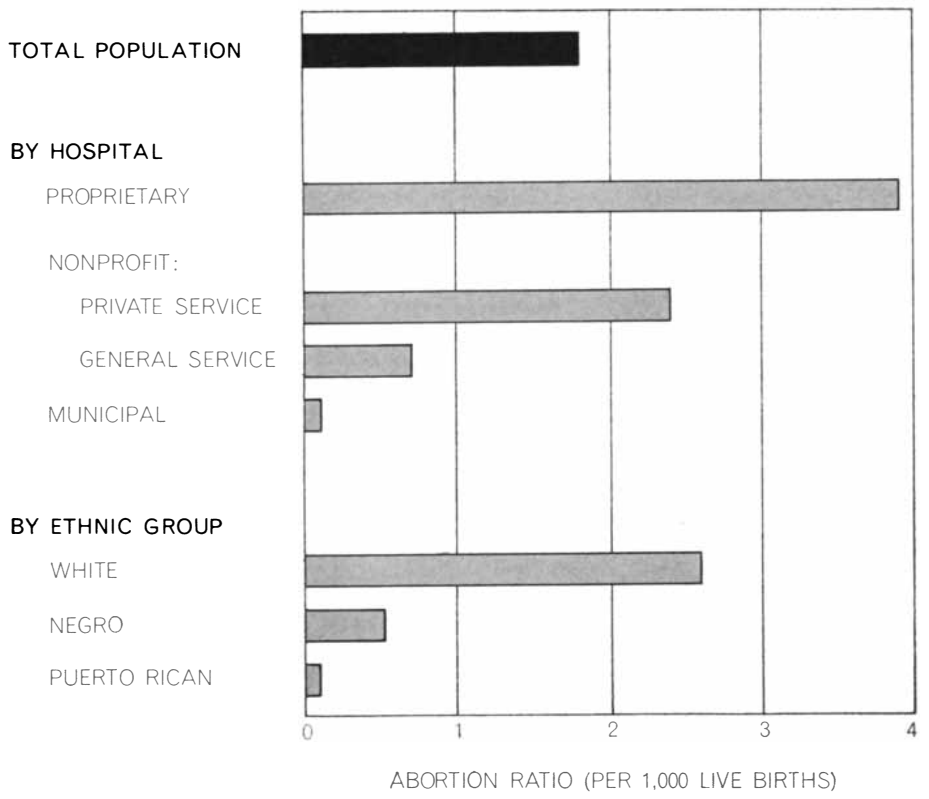
Public opinion polls also support liberalization. In the National Fertility Study conducted in the fall of 1965 a considerable majority favored legalization of abortions to protect the health of the mother, and a smaller majority approved abortion to prevent the birth of a defective child or in cases of rape. On the other hand, only 13 percent at that time approved of abortion for unmarried women and only 8 percent for any woman who wanted it. Two years later a Gallup poll conducted for the Population Council showed a "substantial liberalization of attitudes," with a rise to 28 percent approving abortions for the unmarried and 21 percent for any applicant.

The two-thirds of the world where prohibitions like those in the U.S. are in effect include countries in the Western Hemisphere, southern and western Europe, Africa and most of Asia, with the exception of Japan and China. In Britain and the Scandinavian countries, constituting 2 percent of the world population, the laws are considerably more liberal, allowing abortion on broad medical, eugenic and humanitarian indications. Japan, China and most of the countries of eastern Europe, which account for the remaining nearly one-third of the world population, have gone further in liberalization, permitting abortion at the request of the pregnant woman or on broadly interpreted social indications.

The countries with the longest uninterrupted experience are Sweden and Denmark, which began to liberalize their abortion laws in the 1930's and have gradually relaxed the conditions for abortion over the years. In both countries the criteria for permission are primarily based on the physical and mental hazards for the mother, taking into account "the conditions under which the woman will have to live." Indeed, most of the abortions have been approved on psychiatric grounds. In Sweden, where most applications originally were referred to the Royal Medical Board, a large proportion of the procedures are now performed on the recommendation of two physicians. In Denmark certification by the chief of the obstetrics and gynecology department of a hospital is sufficient authority for an abortion on purely medical considerations; in cases involving other factors the application must be approved by a committee of the Mother's Aid Institution consisting of a psychiatrist, a gynecologist and a social worker.

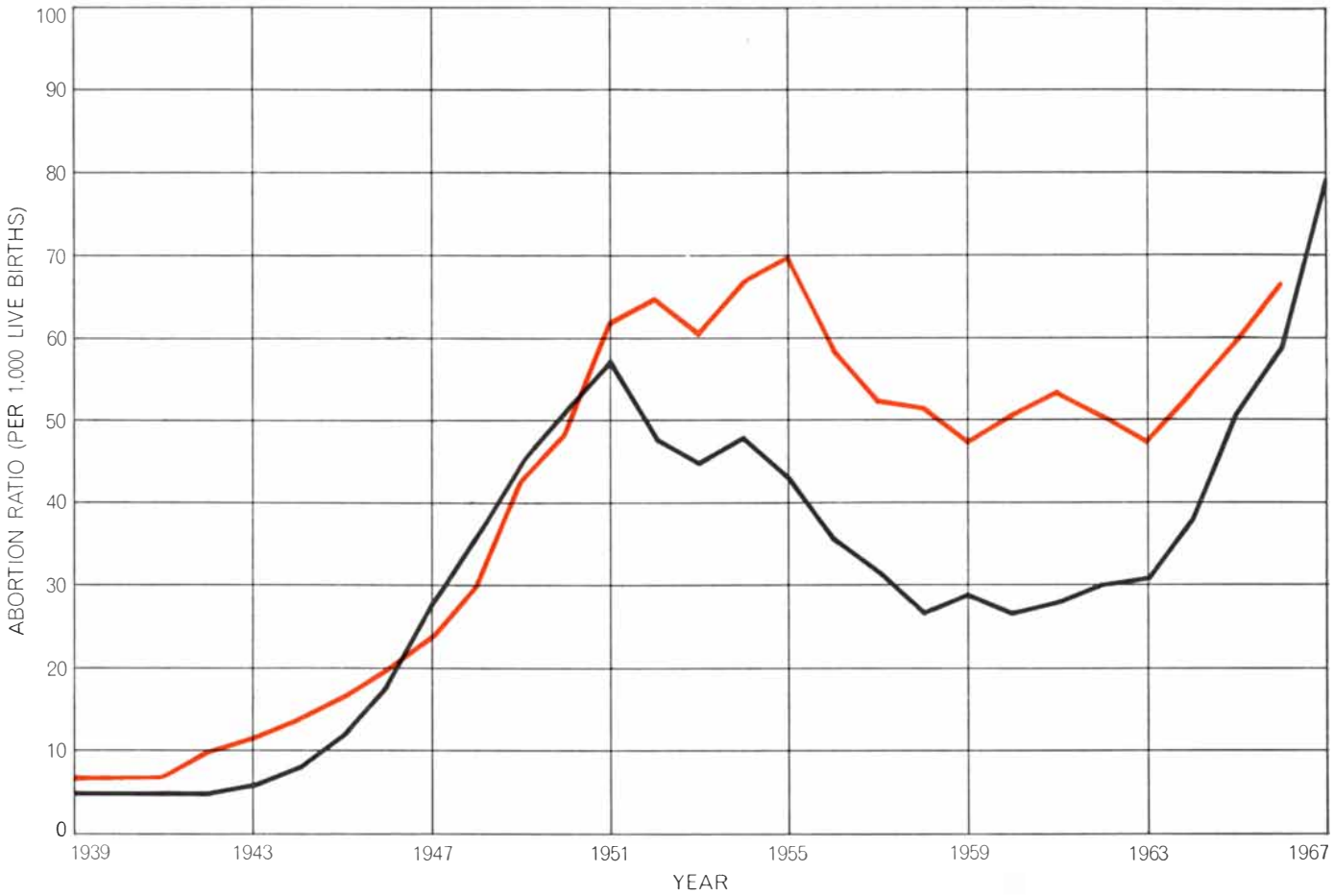
The annual number of legal abortions in Sweden rose from 400 in 1939 to more than 6,300 in 1951 and then declined, and in the past few years it has risen again to an estimated 9,600 in 1967. The ratio of abortions to live births was five per 1,000 in 1939 and 79 per 1,000 in 1967. Denmark's experience has paralleled Sweden's [*see illustration on opposite page*]. As legal abortions increased, the death rate associated with the operation declined. In Sweden, for example, mortality fell from 257 per 100,000 legal abortions in the period 1946–1948 to 39 per 100,000 in the period 1960–1966.

In Britain abortion to protect the health of the mother has been legal since a 1938 court decision in a famous rape case in which the judge held that abortion was justified "if the doctor is of the opinion . . . that the probable consequences [of the birth] will be to make the woman a physical and mental wreck." The British medical profession, however, took a conservative attitude toward making use of this ruling. In 1967, after a long and bitter legislative struggle, Parliament enacted an abortion law similar to the Scandinavian model and going beyond it in certain important respects. The new British law authorizes abortion on the certification by two physicians that continuance of the pregnancy would involve risk to the life or the physical or mental health of the pregnant woman, even if the risk is very slight: it need only be greater than that of abortion, which, if performed under the proper conditions, involves less danger to life than pregnancy and childbearing. Furthermore, the British law permits abortion if the prospective birth would imperil the physical or mental health of "existing children" of the pregnant woman's family or if there is a substantial risk that the child would be born defective. Since the new British abortion law came into force only in April, 1968, no significant information has yet become available concerning its effects.



INDUCED ABORTION is generally illegal in the U.S. but may be performed in hospitals under certain circumstances. It is more readily available to people with money, as indicated by this chart giving the abortion ratio in New York City from 1960 through 1962.

What has been the experience of the countries with the most permissive abortion laws, that is, the countries of eastern Europe and Japan and China? No information is available on China, but fairly detailed data have been re-



SCANDINAVIAN COUNTRIES have been liberalizing their abortion laws since the 1930's. The chart shows the trend of the abortion ratio in Sweden (*black*) and Denmark (*color*) since 1939. The ratios rose to peaks in the 1950's, fell and are now rising again.

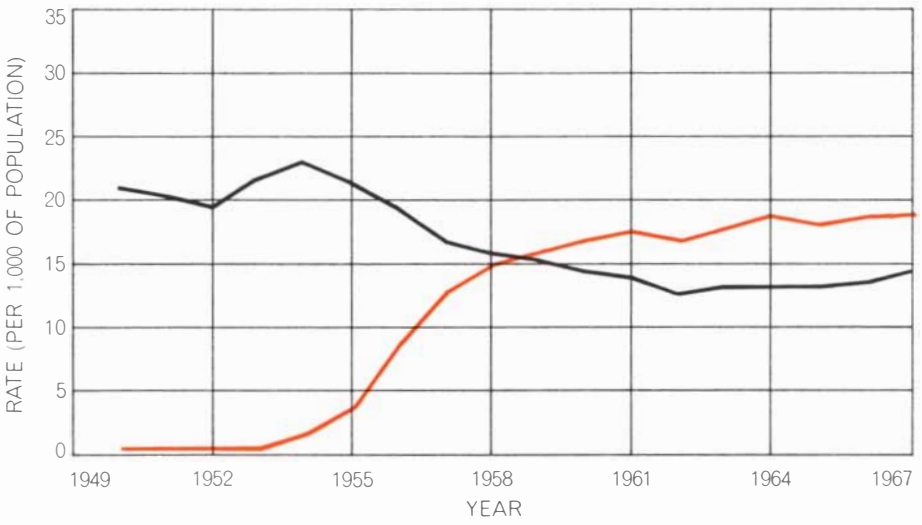
ported from such countries as Hungary and Czechoslovakia, which (along with the U.S.S.R.) enacted liberal abortion statutes in the 1950's, and from Japan, which has had a "Eugenic Protection Law" since 1948.

In most of these countries the laws permit abortion on broadly interpreted social indications, if not at the request of the pregnant woman. Poland, for example, lists any "difficult social situation" as an acceptable reason for a legal abortion. Czechoslovakia allows abortion on grounds of the woman's advanced age, the presence of three or more children in the family, the loss or disability of the husband, a broken home, a threat to the family's living standard when the woman bears the main economic responsibility, "difficult circumstances" in the case of an unmarried woman and pregnancy resulting from rape. Similarly, in Yugoslavia abortion is permissible whenever the birth of the child would unavoidably create a serious personal, familial or economic hardship for the mother. As a general rule, in the eastern European countries abortions for medical reasons are performed in hospitals without charge; in other cases the applicant pays part of the costs.

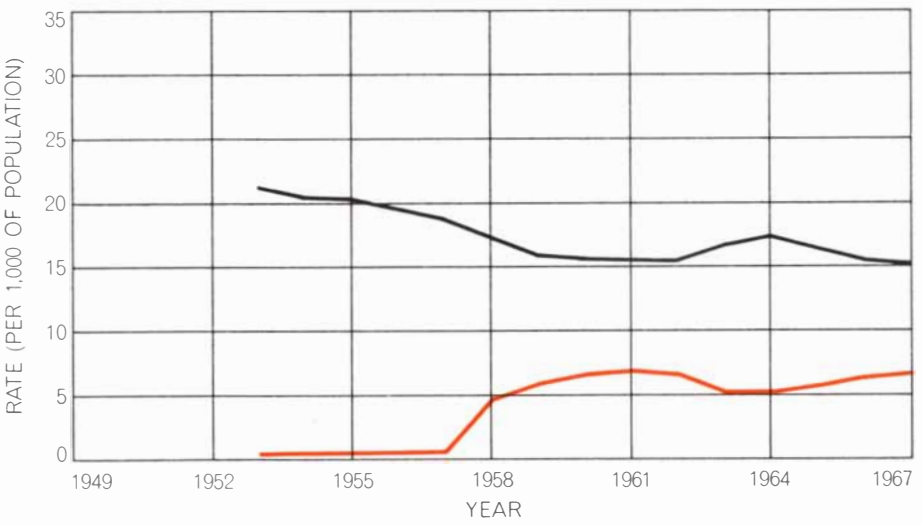
Not surprisingly, where the abortion laws are as permissive as they are in eastern Europe the number of legal abortions has risen sharply. In Hungary, for example, the increase has been so great that the number of legal abortions now exceeds the number of births. In 1967 there were 187,500 legal abortions in that country as against 148,900 live births [*see top illustration on next page*]. The contrasting curves, showing that as the abortion rate has gone up the birthrate has gone down, suggest that for many women in Hungary abortion has replaced contraception as the means of birth control. Similarly, the statistics in Czechoslovakia indicate that legalized abortion has reduced the birthrate, although it is still considerably higher than the abortion rate [*see middle illustration on next page*].

The drop in the birthrate has caused two countries of eastern Europe to revise their abortion laws. In October, 1966, Romania substituted a restrictive statute for one allowing abortion on request. Abortions on medical grounds are permitted now only if the pregnancy threatens the woman's life, and the other acceptable indications are limited to cases in which the woman is over 45 years of age, or has four or more children, or may give birth to a malformed child or has become pregnant as a result of rape or incest. Following the enactment of the new Romanian law the birthrate rose from 13.7 (per 1,000 of population) in the fourth quarter of 1966 to 38.4 in the third quarter of 1967. This rise indicates that before the repeal of the permissive law the annual rate of legal abortions in Romania had been at least 24.7 per 1,000 of population, which is considerably higher than the high rate of 18.4 that was reported for Hungary in 1967.

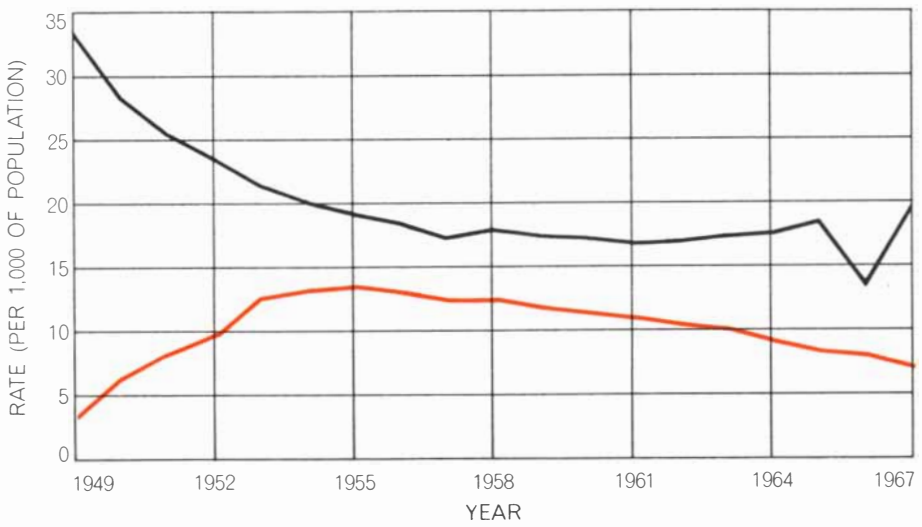
In 1968 Bulgaria also imposed restrictions—somewhat less drastic—on abortion. Women with three or more children may still have an abortion on request, but those with one or two children must apply to a board that "shall explain the harmfulness and dangers of abortion, the need to take the pregnancy to full term, the financial support that the family



IN HUNGARY, where abortion is allowed essentially on request, abortion rate (*color*) now exceeds birthrate (*black*) by one-fourth; legal abortion is a routine means of birth control.



IN CZECHOSLOVAKIA grounds for abortion recognize social and economic, as well as medical, factors. In recent years the abortion rate (*color*) is up, birthrate (*black*) down.



IN JAPAN, where abortion is freely available, abortion rate (*color*) may be understated. This is indicated by its failure to rise when the birthrate (*black*) dropped sharply in 1966.

will receive after the birth of a child and, in general, shall make every effort to dissuade every woman who expresses the desire to have her pregnancy interrupted from doing so. If, nevertheless, the woman concerned persists in asking for her pregnancy to be interrupted, the board shall give its approval to this effect." Childless women may be aborted on medical grounds only.

In Japan the Eugenic Protection Law authorizes abortion if the pregnancy will seriously affect the woman's health "from the physical or economic viewpoint." This provision has been interpreted so broadly that any Japanese woman can have a legal abortion on request. The number of legal abortions reported in Japan rose from 246,000 in 1949, the year after passage of the law, to 1,170,000 in 1955. After that year the reported number declined, and by 1967 it had fallen to 748,000 [*see bottom illustration at left*]. There are reasons to believe, however, that the reports may understate the actual number of legal abortions by several hundred thousand. It is said that many Japanese physicians, in order to minimize their income taxes, do not report all the abortions they perform. Curiously, the number of reported abortions continued to decline instead of rising when the birthrate dropped precipitately in 1966, the "Year of the Fiery Horse." (According to tradition, girls born during such a year grow up to be bad-natured and hence difficult to marry off.) Since it is doubtful that the sharp drop in births can be attributed mainly to a surge in the effective use of contraception by the most tradition-bound segment of Japanese society, one can surmise that the number of abortions must actually have risen, rather than declining, in 1966.

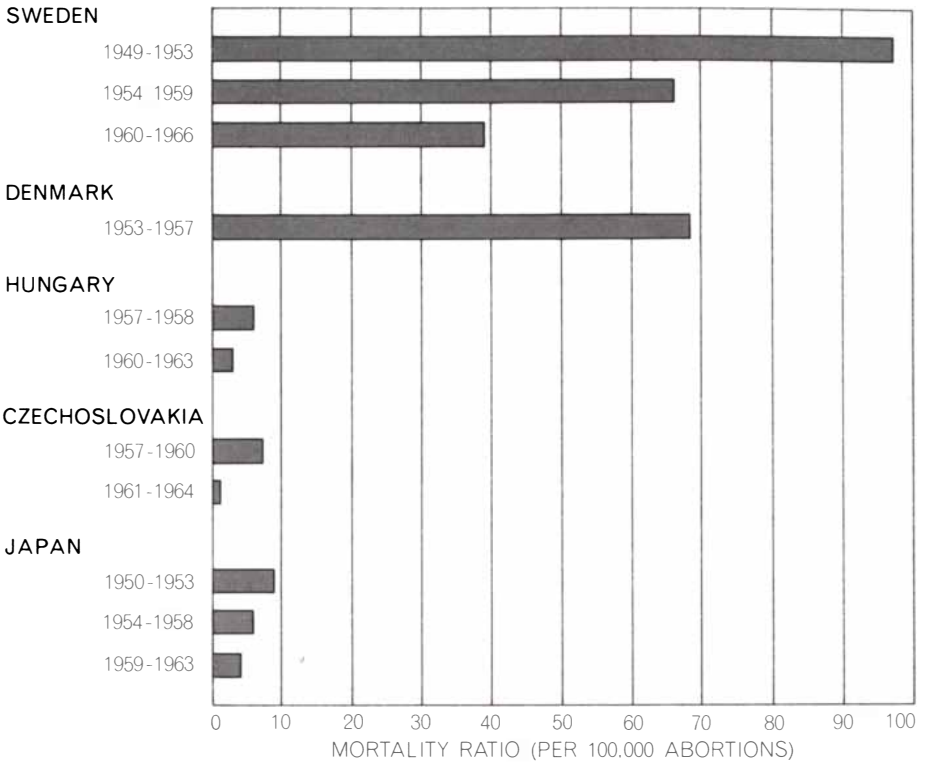
A noteworthy fact about the legalized practice of abortion in the socialist countries of eastern Europe and in Japan is the remarkably low mortality. The mortality rates from abortion in these countries in recent years have been only one to four deaths per 100,000 legal abortions, far lower than the rates in the Scandinavian countries [*see top illustration on opposite page*]. One of the main reasons for the lower mortality is that Japan and the eastern European countries prohibit abortion after the third month of pregnancy except for medical reasons, whereas Sweden, for example, permits it up to the fifth month and Denmark up to the fourth month. Another reason is that the women applying for abortions in the Scandinavian countries

are in a poorer state of health than the women undergoing abortion on request in the countries of eastern Europe and in Japan.

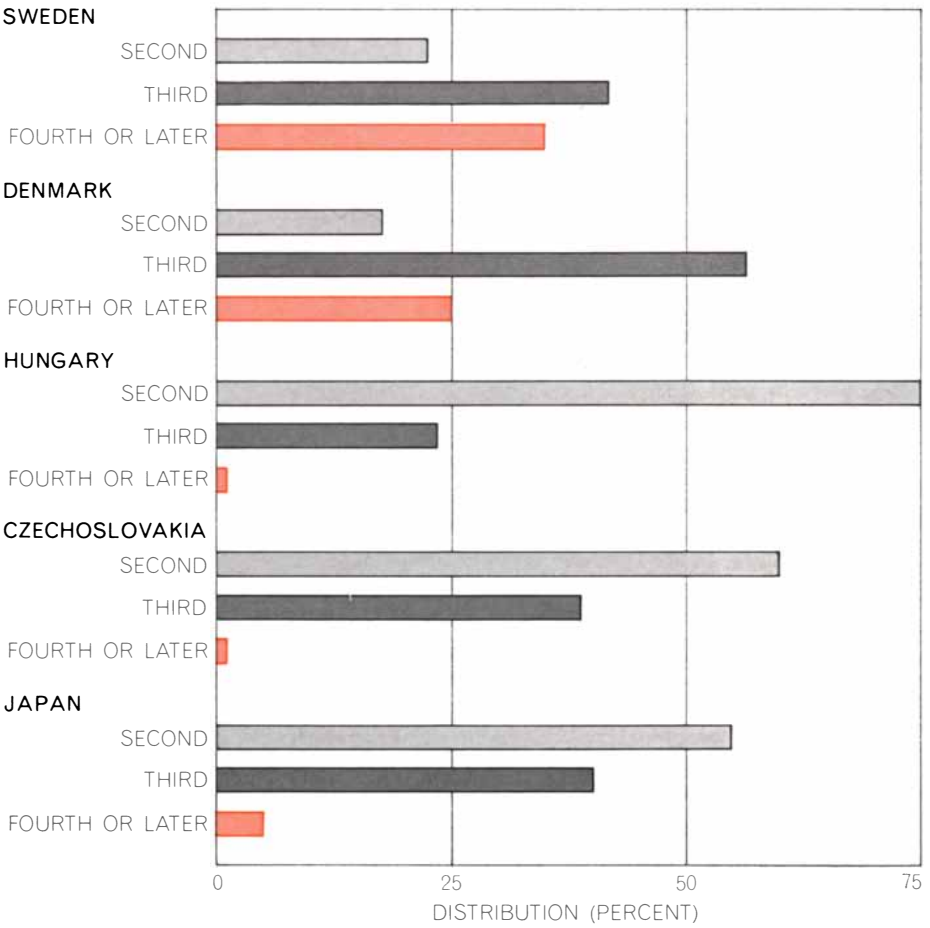
It is hard to determine the extent to which the legalization of abortion in these countries has reduced the incidence of criminal, or clandestine, abortions. Certainly illegal abortions have not been eliminated entirely, as is evidenced by the fact that a number of women with difficulties arising from such abortions turn up at hospitals for treatment. This stubborn survival of illegal abortion can probably be attributed to the fact that, for one reason or another, women sometimes want to conceal their pregnancy and therefore avoid the procedure of formal application and official approval. Be that as it may, there is little doubt that in the countries that permit abortion on request the practice of illegal abortion has declined greatly.

Little is known about the situation in the rest of the world. We have already noted that the number of illegal abortions in the U.S. is estimated to be in the hundreds of thousands a year. In most of the countries of western Europe illegal abortion is believed to be more common than in the U.S., and it has been said, although not verified, that in some of those countries the abortion rate exceeds the birthrate. Illegal abortion appears to be most prevalent in Latin America, particularly among the urban poor. In Chile, whose abortion laws are similar to those in the U.S., Rolando Armijo and Tegualda Monreal of the University of Chile School of Public Health estimated after a study of vital statistics that in a single year there were 20,000 illegal abortions, compared with 77,440 births, in Santiago, the capital city. A similar situation has been reported on the other side of the world. In Korea, which has a restrictive abortion law similar to those in most U.S. states, Sung-bong Hong estimated that Seoul, the capital city, had 55,000 illegal abortions in 1963—more than half as many abortions as births, 108,700.

The problem of illegal abortion is one that every nation must eventually deal with in some way. In a number of countries it is so serious that the medical profession and the government have joined forces to organize programs for family planning. It seems only reasonable that the U.S., particularly the state legislatures, should draw on the experiences now available from countries that are trying new approaches in the search for a rational solution to the problem.



MORTALITY RATIO (deaths per 100,000 abortions) is known only where abortions are legal. It is much lower in permissive eastern Europe and Japan than in Sweden and Denmark.



LOW DEATH RATES in eastern Europe and Japan are attributed to the discouragement there of abortions late in pregnancy and to the fact that many abortion patients in Scandinavia are already in poor health. In the chart abortions are distributed by month of gestation.

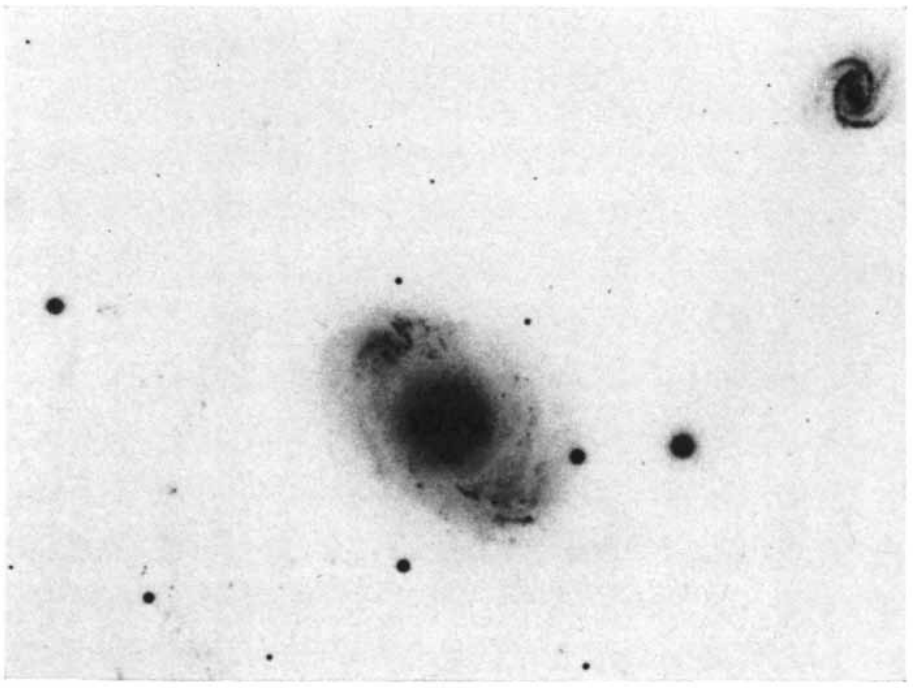
SEYFERT GALAXIES

They superficially resemble normal spiral galaxies, but something violent is going on in their central regions. They seem to have much in common with the most powerful radio sources known, the quasars

by Ray J. Weymann

During the second quarter of this century astronomers gradually came to realize that many of the faint nebulas that populate the sky are really great islands of stars far outside our own galaxy. On the basis of their appearance Edwin P. Hubble of the Mount Wilson and Palomar Observatories divided these objects into two broad classes: spiral galaxies, whose general shape resembles a flat pinwheel, and elliptical galaxies, smooth, featureless structures that range in shape from elliptical to spherical. A typical large galaxy, such as our own spiral galaxy, contains about 100 billion stars. In the universe visible to the largest telescopes there are billions of galaxies.

In 1943 Carl K. Seyfert, then working as a postdoctoral student at the Mount Wilson Observatory, described a small class of spiral galaxies that seemed notably different from the hundreds of other spirals they superficially resembled. The most distinctive feature of the Seyfert galaxies (as they are now called) is that they have very small, intensely bright nuclei whose broad emission lines, as recorded in spectrograms, indicate that the atoms present are in a high state of excitation. The spectra of normal galaxies show few, if any, strong emission lines, and those they do show are rather narrow and typical of the emission lines found in the nebulas within our own galaxy.



SEYFERT GALAXY NGC 4151, shown here in a negative print, appears to be a fairly typical spiral galaxy. When viewed directly through a telescope, however, it presents a starlike appearance because most of its light emission originates in a dense, central nucleus (*see illustration on opposite page*). Such "Seyfert" nuclei have now been identified in about a dozen galaxies. The picture was taken with the 200-inch telescope on Palomar Mountain.

In addition to their puzzling spectra, the Seyfert galaxies now confront astronomers with a number of other peculiar properties. The light emitted by at least two of the Seyfert galaxies has varied strongly over a period measured in months. Two of them are now known to be powerful emitters of radio energy, and this emission has been changing violently in intensity. Several of the Seyfert galaxies emit an enormous amount of energy in the infrared region of the spectrum by a mechanism as yet unknown. All Seyfert galaxies emit more ultraviolet radiation than can be explained in terms of starlight, and in some instances this radiation is polarized.

Many readers will recognize that these are some of the characteristics that make the quasi-stellar radio sources (quasars) so fascinating. These starlike objects are among the most powerful radio sources in the sky [see "The Problem of the Quasi-stellar Objects," by Geoffrey Burbidge and Fred Hoyle; SCIENTIFIC AMERICAN, December, 1966]. There are, however, two striking differences between the nuclei of Seyfert galaxies and quasars. First, the emission lines in the spectra of quasars are enormously shifted from their normal wavelengths to the red end of the spectrum, whereas the emission lines in the Seyfert nuclei have only the very modest red shifts observed in normal, nearby galaxies. Second, the quasars appear as mere points of light with no indication of a surrounding galaxy, whereas the Seyfert nuclei are clearly embedded in the center of apparently normal spiral galaxies.

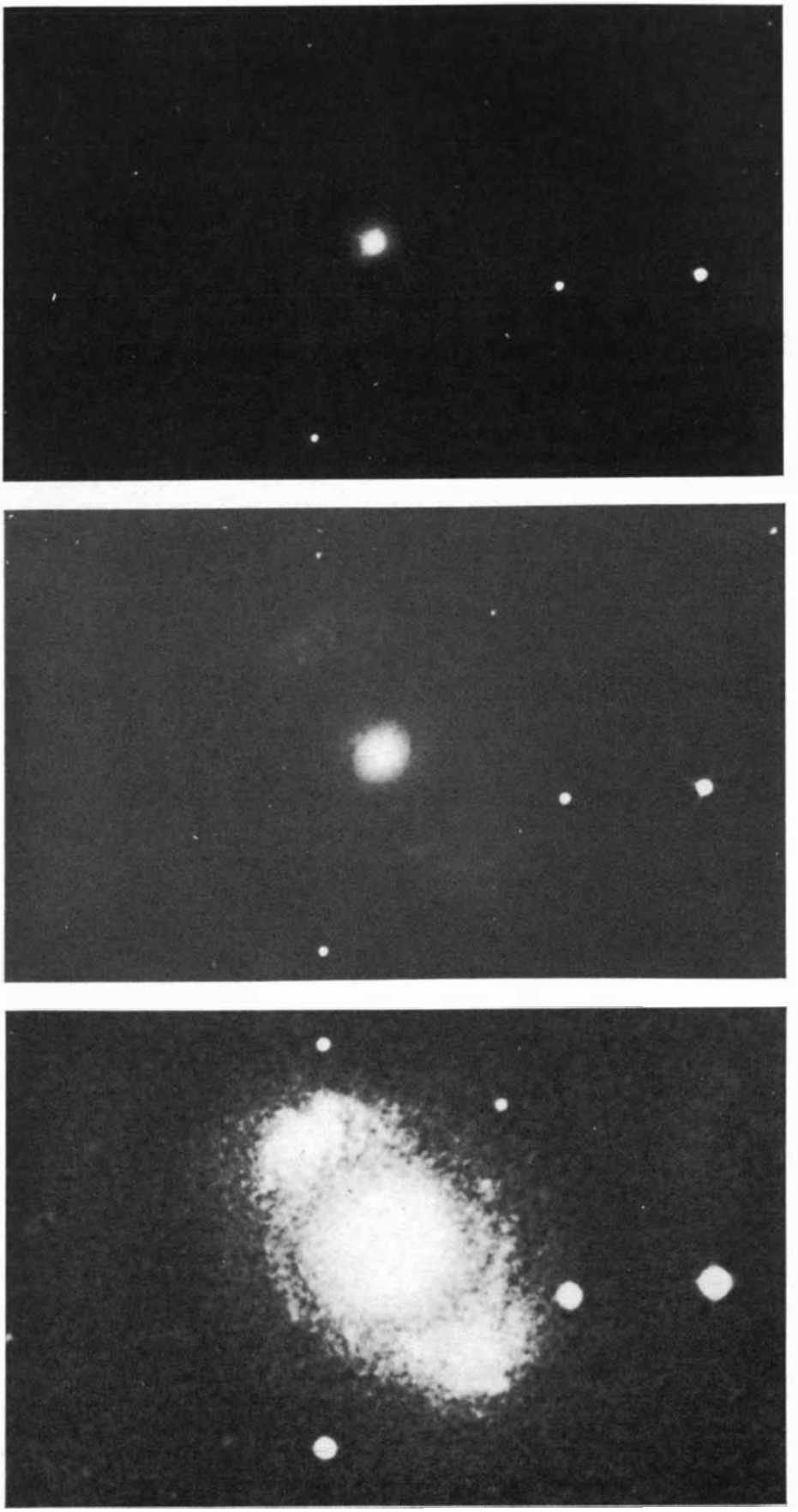
Thus, in addition to the challenging questions posed by the Seyfert phenome-

non itself, there are the larger questions of the relation between the Seyfert nuclei and the quasars and the nature of a whole range of violent activity found in the nuclei of galaxies. At the present time no one knows whether the quasars are "local" (nearby objects having distances comparable to the Seyfert galaxies) or "cosmological" (that is, having the distances implied by assuming the validity of the relation between red shift and distance found for ordinary galaxies), so that their intrinsic luminosities are highly uncertain. The distance to the Seyfert galaxies, however, is known with reasonable precision; thus they offer the astronomer the significant advantage that their distances are not in dispute by a factor of 100 nor their true luminosities by a factor of 10,000.

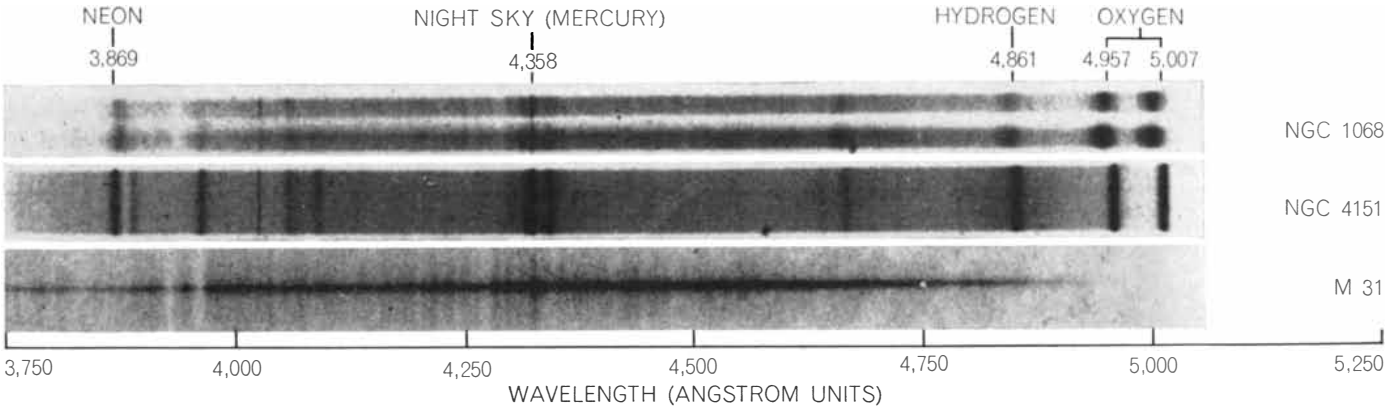
The number of objects generally recognized as Seyfert galaxies is still only about a dozen; a few that were in Seyfert's original group have now been dropped and a few new ones have been added. Two of the best-studied are NGC (for New General Catalogue) 1068 and NGC 4151. The three photographs of NGC 4151 at the right represent the appearance of the galaxy at three different exposures. The two shortest exposures reveal the presence of the brilliant small nucleus at the center of the galaxy, almost starlike in appearance. Such nuclei are characteristic of Seyfert galaxies and account for most of the remarkable properties of these objects.

It is the spectra, however, that provide the richest source of information about conditions inside the nucleus of Seyfert galaxies [*see illustration on next page*]. In most instances the emission lines are the same as those seen in several "high excitation" planetary nebulas, which are shells of gas surrounding a small, very hot star. The chief difference is that the emission lines are much broader in the Seyfert spectra. The width of the lines provides the first clue to conditions inside the Seyfert nucleus.

In the spectrum of a typical Seyfert galaxy the lines attributable to oxygen ions (oxygen atoms stripped of one or more electrons) and the lines attributable to hydrogen present a puzzle. A curve tracing the intensity of the hydrogen line from one side to the other is a peak flanked by broad "wings"; in curves tracing the intensity of the oxygen lines the wings are usually missing. When astronomers see a broad line in a spectrum, they immediately assume that the emitting gas is in motion, so that some of the gas is moving toward the observer (shift-



STARLIKE NUCLEUS OF NGC 4151 is revealed by short-exposure photographs (*top and middle*). In the top picture, made at Mount Wilson, the nucleus resembles a slightly fuzzy star. In the middle picture, also from Mount Wilson, the spiral structure has become faintly visible. In the long-exposure photograph at the bottom, made with the 48-inch Schmidt telescope on Palomar Mountain, the spiral structure is fully developed. The negative print on the opposite page, however, shows considerably more detail than any of the positive prints. The series of three photographs was assembled by W. W. Morgan of the Yerkes Observatory.



EXCITED NUCLEI OF SEYFERT GALAXIES produce spectra with prominent emission lines, such as those visible in the spectra of NGC 1068 and NGC 4151. In the spectrum of a normal spiral galaxy, for example M 31 in Andromeda (*bottom*), there are no emission lines but there are a number of strong absorption lines, characteristic of the spectra produced by fairly cool, ordinary stars like the sun. Of the two Seyfert spectra shown here, that of NGC 4151 is the more typical in that the beta hydrogen line at 4,861 angstrom units has very broad "wings," whereas wings are lacking on the "forbidden" oxygen lines at 4,957 and 5,007 angstroms. The Seyfert spectra were made by J. Beverly Oke and Wallace L. W. Sargent of the California Institute of Technology; the spectrum of M 31 is by Ivan R. King of the University of California at Berkeley. The line at 4,358 angstroms is produced by the glow of city lights.

ing the line toward the blue) and some of it is receding (shifting it toward the red). These are the well-known Doppler shifts. If the widths of the oxygen and hydrogen lines in the Seyfert spectra are interpreted in this way, one deduces velocities of several hundred kilometers per second for the oxygen and velocities of several thousand kilometers per second for the hydrogen.

Are these true velocity effects? If so, is the motion chaotic and disorganized, or is it orderly and perhaps organized in a manner that might be associated with rotation? If the motion is chaotic, would not the material soon leave the nucleus and eventually the entire galaxy? What mechanism can continuously replace the matter being ejected and accelerate it to such high velocities? Why, in the majority of these objects, should there be such a striking difference between the profiles of the oxygen and hydrogen lines?

Let us consider the last question first. In planetary nebulas the oxygen and hydrogen lines are produced in the same region of space but by quite different processes [*see illustration on page 32*]. Both the hydrogen and the oxygen are kept in a state of nearly complete ionization by the intense flux of high-energy (ultraviolet) photons emitted by the central star of the planetary nebula. Occasionally a bare proton, that is, a hydrogen nucleus, will recombine with a free electron to form a hydrogen atom; the process is called radiative recombination. If the newly formed hydrogen atom is in a high-energy state when it is created, the electron will rapidly jump to the "ground" state, either directly (producing an ultraviolet photon that is invisible to observers on the earth) or cascading downward in smaller jumps, some of which give rise to the observed hydrogen line. Soon after reaching the ground state the hydrogen atom is reionized by the radiation from the central star and the process is repeated.

For oxygen the process is a different one: collisional excitation. The flux of high-energy photons from the star readily strips one or two electrons from each oxygen atom, and it is these ions that give rise to the observed radiation. They usually have electrons in low-energy levels that can be excited to higher levels by free electrons in the immediate vicinity. When the excited ions subsequently return to the ground state, they emit the observed radiation.

In addition to this difference in the way the hydrogen and oxygen emission lines are generated there is a further important distinction. The cascades producing the hydrogen lines take place very rapidly: a hydrogen atom typically spends only 10^{-8} second in one of the excited states. The lifetimes of the excited oxygen ions, on the other hand, are far longer: up to 1,000 seconds. (Because these downward transitions occur so infrequently they are never observed in the laboratory and are thus called forbidden lines.)

This long life in the excited state can be cut short, however, by collisions with other electrons, and if the density of electrons is high enough, the excited oxygen ions will be collisionally de-excited before they have had a chance to radiate.

With this background one can speculate about the conditions that give rise to the contrasting widths of the hydrogen and oxygen lines in the spectra of Seyfert galaxies. If the density of particles is very low, the intensity of forbidden oxygen lines should roughly equal the intensity of hydrogen lines. As the particle density increases one can expect to see a decrease in the intensity of forbidden lines, relative to the intensity of the hydrogen lines, as more and more oxygen ions are collisionally de-excited before they can radiate. What this suggests is that the region responsible for the wings on the hydrogen lines is a rather small, dense core where hydrogen is traveling chaotically at high speed (5,000 kilometers per second) and generating smeared-out emission lines. If oxygen ions are also present and are moving at comparable speeds, they are being de-excited before they can radiate, and hence there are no comparable wings on the oxygen lines.

It has been estimated that the amount of material needed to produce the observed emission lines is only about five solar masses of gas confined to a region perhaps as small as .06 light-year (roughly three light-weeks) in diameter. Hydrogen atoms moving at a speed of 5,000 kilometers per second would traverse such a core and escape in only about four years. To hold this relatively small amount of high-speed gas inside the core indefinitely by gravitational forces would require that some 20 million stars of solar mass also be packed within the core. Because such a density of stellar matter is difficult (although not impossible) to conceive, it has been assumed either that the high-velocity gas must escape or that there are other ways in which the hydrogen lines might be broadened. In any event, it seems likely that the excited oxygen atoms emit their forbidden lines not in the core but in a much less dense re-

gion around the core. The gas velocities there are much lower, with the result that the lines produced in that region (by hydrogen as well as oxygen) are much narrower. Indeed, the profile of the hydrogen lines shows a narrow central peak that closely matches the wingless profile of the oxygen lines.

If we accept the fact that the gas inside the tiny core of a Seyfert galaxy is moving at the high apparent velocity indicated by the spectra, and if we assume that the gas is not held within the core by gravitation, we must explain how it is replaced or conclude that the violent activity observed in the core is a rare transient event caused by some explosive outburst. The difficulty with this point of view is that although only a dozen Seyfert galaxies are known, they cannot be considered particularly rare. The Seyfert phenomenon has been observed only in large spiral galaxies, of which between 500 and 1,000 are close enough and sufficiently well classified to be candidates. Thus between 1 and 2 percent of large spiral galaxies are Seyfert galaxies.

Let us assume, for purposes of simple computation, that all spiral galaxies, including our own, have spent 1 percent of their lifetime in the Seyfert condition. One can readily calculate how many times a typical spiral galaxy has experienced a Seyfert outburst during the estimated 10 billion years the galaxies have been in existence. If the duration of the outburst is as brief as 10 years, 10 million outbursts would be needed. This implies that in a 10-billion-year lifetime a spiral galaxy has experienced an outburst on the average of once every 1,000 years.

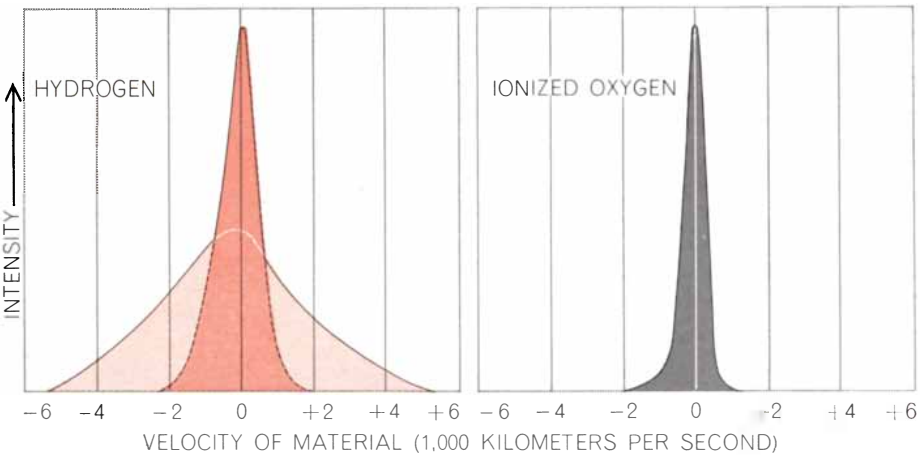
It would be remarkable indeed if an astronomer in his own lifetime could follow all or a substantial part of a Seyfert outburst, but such may be the case. Recently the French astronomers Y. Andrillat and S. Souffrin remeasured the spectrum of NGC 3516, one of the galaxies Seyfert had studied, and found that marked changes have taken place in the relative strengths of the hydrogen and forbidden oxygen lines. To explain these changes they proposed a model, quite similar to the one described above, that assumes an explosive outburst of gas from the nucleus of NGC 3516.

The problem of confining the gas would be eased somewhat if some mechanism other than high-velocity motions could be found to explain the broad wings on the hydrogen lines. One mechanism that seems attractive is the scattering of photons by electrons. When a gas containing both electrons and protons is in equilibrium, both kinds of particles have about the same amount of thermal kinetic energy, equal to one-half the mass of the particle multiplied by the square of its velocity. Since an electron has only about 1/1,800th the mass of a proton, its velocity must be greater by a factor of about 40 (the square root of 1,800). Thus the protons responsible for the hydrogen lines need not be traveling at 5,000 kilometers per second but could be moving at the much lower speeds associated with a gas whose temperature is about 20,000 degrees. Although the probability of a photon's being scattered by a free electron is low, if there are enough electrons blocking the escape of a photon, each photon will undergo several scatterings, whose net effect would be to smear out a hydrogen line that was intrinsically narrow.

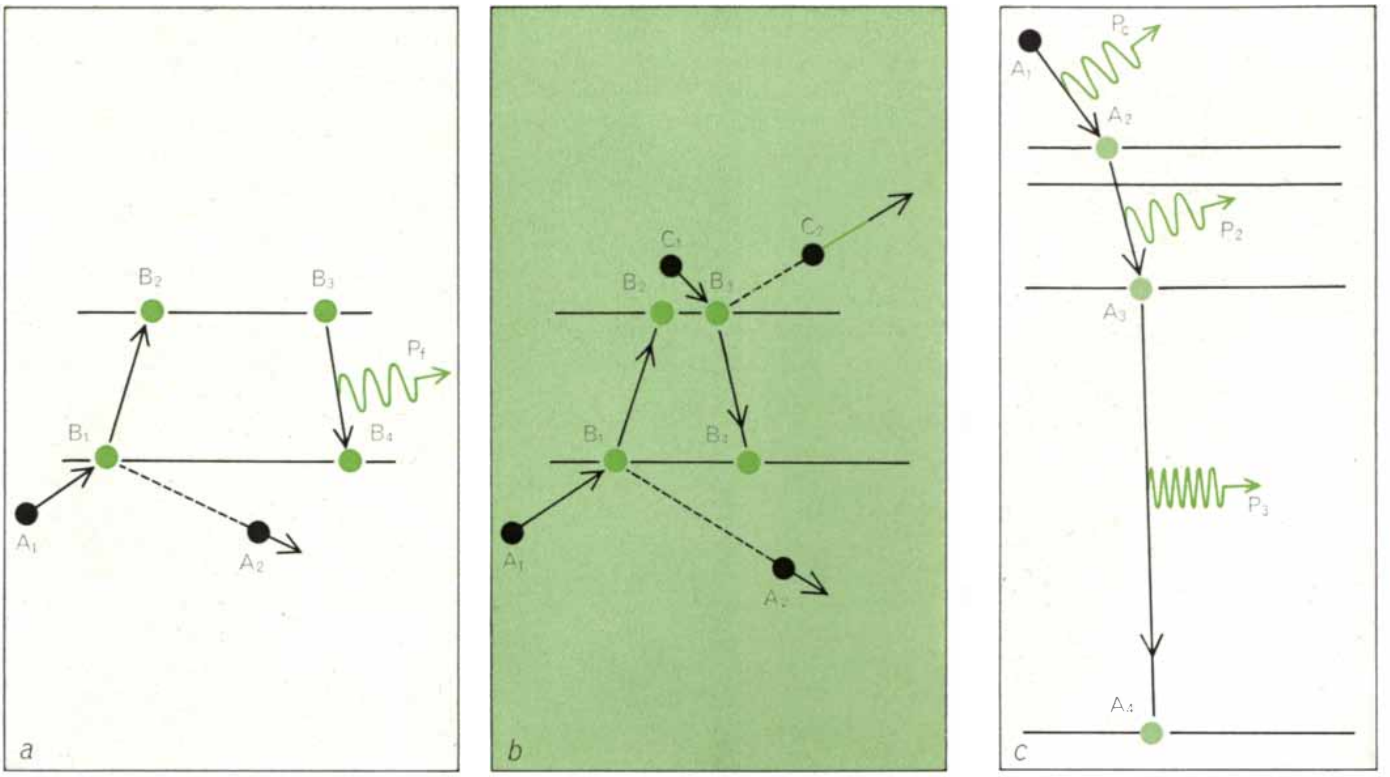
An additional remarkable feature has been observed in the spectrum of the Seyfert galaxy NGC 4151: lines produced by very highly ionized iron atoms. These same lines are found in spectra of the corona of the sun, where the temperature is several million degrees. The energy needed to produce such lines is nearly 30 times greater than the energy needed to produce the hydrogen lines. J. Beverly Oke and Wallace L. W. Sargent of the California Institute of Technology have suggested that the "coronal" iron lines may be produced by a very hot, tenuous gas filling the nucleus of NGC 4151. They further suggest that embedded in this hot gas are cooler, denser clouds moving at high velocity that account for the more familiar lines of hydrogen and oxygen. Occasional collisions between these clouds might produce and replenish the tenuous gas. An alternative hypothesis suggests that a powerful source of X rays is ionizing the iron atoms responsible for the coronal lines. Detection of such X-ray sources by rockets equipped with sensitive detectors now appears feasible and should provide a decision between these hypotheses.

Direct evidence for the existence of the cloudy structure envisaged in Oke and Sargent's model has been found by Merle F. Walker of the Lick Observatory, who observed NGC 1068 and NGC 4151 with an electronic image-amplifier attached to the spectrograph on the 120-inch Lick telescope. Working with the velocity data obtained from many separate observations, Walker plotted a two-dimensional map of the nucleus of NGC 1068 and found what appear to be four clouds moving at different velocities [*see illustration on page 33*].

Let us turn now from the emission lines seen in the spectra of Seyfert galaxies to the way continuous radiation, as distinct from line radiation, is distributed among various wavelengths. A rough index to the character of continuous radiation from an astronomical object is obtained by comparing the amount of energy received through filters passing one of three bands of wavelengths: ultraviolet (U), blue (B) and yellow, or "visual" (V). When ordinary stars and ordinary galaxies are observed through such filters, one finds that the U intensity is less than the B and the B intensity less than the V. In other words,



COMPARISON OF INTENSITY PROFILES for hydrogen lines (*left*) and the forbidden lines of oxygen (*right*) in NGC 5548 demonstrates the difference usually seen in Seyfert spectra. If the line-widening is attributed to the motion of gas particles, the hydrogen velocity is four or five times the velocity of oxygen. Negative velocity values indicate motion of gas toward the earth, positive values motion away from the earth. The hydrogen lines could be smeared out, however, by the scattering of photons off rapidly moving electrons. The curves are based on the work of Kurt Anderson of the California Institute of Technology.



EMISSION LINES OF OXYGEN AND HYDROGEN arise by different processes in Seyfert nuclei. Moreover, the forbidden lines of oxygen appear only when the gas is at low density (*a*). In that case a free electron (A_1) collides with an oxygen ion and excites one of its electrons that is in the lowest level (B_1), raising it to a higher level (B_2). The free electron leaves with reduced energy (A_2). After about 100 seconds the excited electron makes a forbidden transition (B_3 *to* B_4), emitting a photon (P_f). When the gas is at high density (*b*), the electron that has been excited to the higher level (B_2) is de-excited (B_3, B_4) by another free electron (C_1) before it has a chance to emit a photon. The energy the photon would have carried away is acquired by the colliding electron (C_2). Hydrogen-line emission arises differently (*c*). A free electron (A_1) is captured by a proton, forming a hydrogen atom whose electron is in an excited level (A_2). A photon emitted in the process (P_c) is said to be a continuum photon because it can have various wavelengths. Within about 10^{-8} second the electron cascades to a lower level (A_3), emitting an observable Balmer-line photon (P_2), and immediately drops to the ground state (A_4), emitting a Lyman-line photon (P_3), which being in the far ultraviolet cannot be observed.

ordinary stars (such as our sun) emit more yellow light than blue light. This is also the case if one observes a Seyfert galaxy through an aperture that admits most of the light from the galaxy. As the aperture is reduced to accept light only from the central region, however, the ultraviolet and blue part of the spectrum begins to predominate. Conceivably this could be due to a concentration of ordinary hot young blue stars in the nucleus. On the other hand, such stars have spectra with certain characteristic absorption lines, and these lines do not appear in the spectra of Seyfert nuclei. If one subtracts from the spectrum of Seyfert nuclei the yellowish radiation from cool stars, and also the radiation from gaseous hydrogen, one is left with a smooth blue spectrum similar to the one produced by quasars and, within our own galaxy, by the Crab nebula.

The Crab nebula is the remnant of a supernova explosion observed on the earth in A.D. 1054. It is now generally accepted that both the radio and optical radiation emitted by the nebula is produced by synchrotron radiation: radiation from electrons spiraling at virtually the speed of light in a magnetic field. A characteristic of such radiation is that it is polarized. A significant amount of the radiation from the Crab nebula is polarized, and a modest amount has now been detected in some of the Seyfert nuclei and in quasars.

An additional striking similarity between Seyfert nuclei and quasars is their variability in light output. This was first shown for the quasar 3*C* 273 by Harlan J. Smith of the University of Texas and E. Dorrit Hoffleit of Yale University, who reported variations in the image intensity of 3*C* 273 in photographs that had been made over a period of several decades.

By this time attention had been called to the similarities between the nuclei of Seyfert galaxies and quasi-stellar sources by a number of astronomers. Consequently a search began for light variations in the nucleus of Seyfert galaxies. Such variations were detected in NGC 4151 by photoelectric measurements at the University of Arizona [*see illustration on page 34*]. Simultaneously Oke reported finding variations in an "N-galaxy," one of a class of objects that have many of the properties of Seyfert nuclei. Subsequently T. D. Kinman of the Lick Observatory found that 3*C* 120, a radio galaxy that is now classed as a Seyfert galaxy, had varied in light output.

The history of our knowledge of the quasi-stellar sources has been one surprise after another. Indeed, almost without exception, every new line of observational investigation has disclosed something unexpected. Infrared measurements of the quasi-stellar sources were no exception. Observations of 3*C* 273 at wavelengths from one micron to 20 microns made by Frank J. Low and Harold L. Johnson of the University of Arizona revealed that at the longer wavelengths the amount of energy radiated increases sharply. Its peak cannot be observed because long infrared wavelengths are absorbed by the earth's atmosphere, but it must lie somewhere between a wavelength of 20 and 1,000 microns (one millimeter). In fact, the bulk of the energy is radiated in the infrared. This discovery implies a severalfold increase in the already incredible luminosity of this quasi-stellar source,

if its distance is indeed cosmological.

It was logical to search for strong infrared radiation in Seyfert galaxies. In fact, this search was carried out by A. G. Pacholczyk and W. Wisnewski at the University of Arizona before the search for optical variability was made. They found a very steep increase in the infrared radiation of NGC 1068, a phenomenon that has now been found in most of the remaining Seyfert galaxies [*see illustration on page 35*]. Three possible mechanisms have been proposed to account for the infrared output: synchrotron radiation, a process involving high-velocity streams of plasma (free electrons and protons) and thermal radiation from dust. Convincing models of the first two processes are difficult to construct, and the fact that no well-substantiated variations in the infrared light have been detected argues against their correctness. There is, however, some observational support for the dust hypothesis.

If a dust particle is exposed to a distant, intense source of radiation, the temperature of the particle will rise until its own rate of radiation just equals the rate at which it is absorbing energy. For example, a small blackened sphere placed at the earth's distance from the sun will be warmed to a temperature of about 300 degrees Kelvin (about room temperature) by the sun's rays. Such a body will radiate primarily in the infrared with a peak output at a wavelength of about 10 microns. The precise wavelength distribution of the radiated energy will depend on the composition and size of the dust particle.

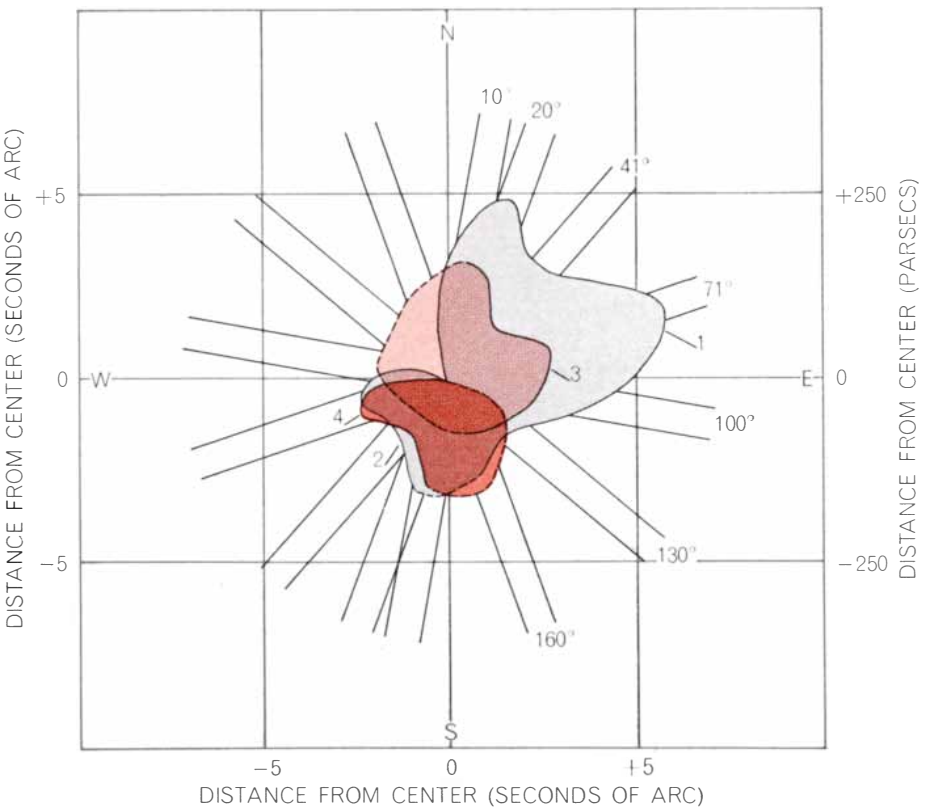
If there are large concentrations of dust in Seyfert nuclei, and if the dust particles are anything like those with which we are familiar in our own galaxy, they should absorb far more readily in the ultraviolet and blue parts of the spectrum than in the yellow or red. This is merely to say that dust usually "reddens" light passing through it. There is no way to check for this reddening of the continuum radiation in Seyfert nuclei because we have no way of knowing what the intrinsic radiation is like. One can calculate, however, the relative intrinsic intensity in the red and blue of certain sets of emission lines, since we do know the probability of the atomic transitions responsible for the lines. E. Joseph Wampler of the Lick Observatory measured these lines in the Seyfert nuclei and found that the blue lines were very much weakened relative to the red ones. Reddening by dust is the only known explanation. What is disturbing about the dust hypothesis is that it implies that the intrinsic continuous radiation of Seyfert nuclei is far bluer than anything previously encountered.

One additional bit of evidence in favor of the dust hypothesis is the case of the planetary nebula NGC 7027. There is no evidence at all for anything like synchrotron radiation in this object, but it too has intense radiation in the infrared strikingly similar to that in NGC 1068. A quite plausible explanation is that ultraviolet radiation trapped in the nebula is converted into infrared radiation by dust grains.

The final property that some Seyfert galaxies share with quasars is intense radio emission. Here, on first consideration, the differences seem more striking than the similarities. The quasars are powerful radio emitters by definition, whereas the radio emission of several of the Seyfert galaxies either is not detectable or is quite weak. On the other hand, the Seyfert galaxies NGC 1068, NGC 1275 and 3*C* 120 are strong radio sources; moreover, the last two objects are variable, and at wavelengths around one centimeter they very much resemble quasars. The recent quasar-like variations in 3*C* 120 are particularly spectacular [*see illustration on page 36*].

It now seems likely that quasars are actually a subclass of a much larger group of objects now known as quasi-stellar galaxies (as distinct from quasi-stellar objects), which emit no detectable radio signal. Similarly, the three Seyfert galaxies that are strong radio sources may simply be a subclass within a larger group of objects most of which do not now have (or perhaps never had) the extended halo of high-energy electrons in a weak magnetic field that seems to be necessary for generating strong radio emission at long wavelength.

Let me summarize briefly the observed properties of the Seyfert galaxies and indicate their points of similarity with some of the quasi-stellar sources. The Seyfert galaxies have compact nuclei, whose emission spectra indicate that the gases in them are in a high state of excitation and are traveling at high speed in clouds or filaments. Outbursts probably occur from time to time, producing new high-velocity material. The continuous spectrum of a Seyfert nucleus, perhaps produced by the synchrotron mechanism, is very blue and may also vary in intensity with strong outbursts. The comparatively short duration of these outbursts requires that the energy be released within a remarkably small volume—not more than a third of a light-year across. There are also outbursts that can trigger strong fluctuations in the radio emission. Much of the energy emitted by Seyfert nuclei is in



MAP OF CLOUDS IN NGC 1068 was made by Merle F. Walker of the Lick Observatory, who analyzed high-dispersion spectra produced by a spectrograph whose entrance slit was positioned across the nucleus of the galaxy at the seven different positions shown. From his analysis Walker identified four distinct cloud masses, each moving at a different velocity.

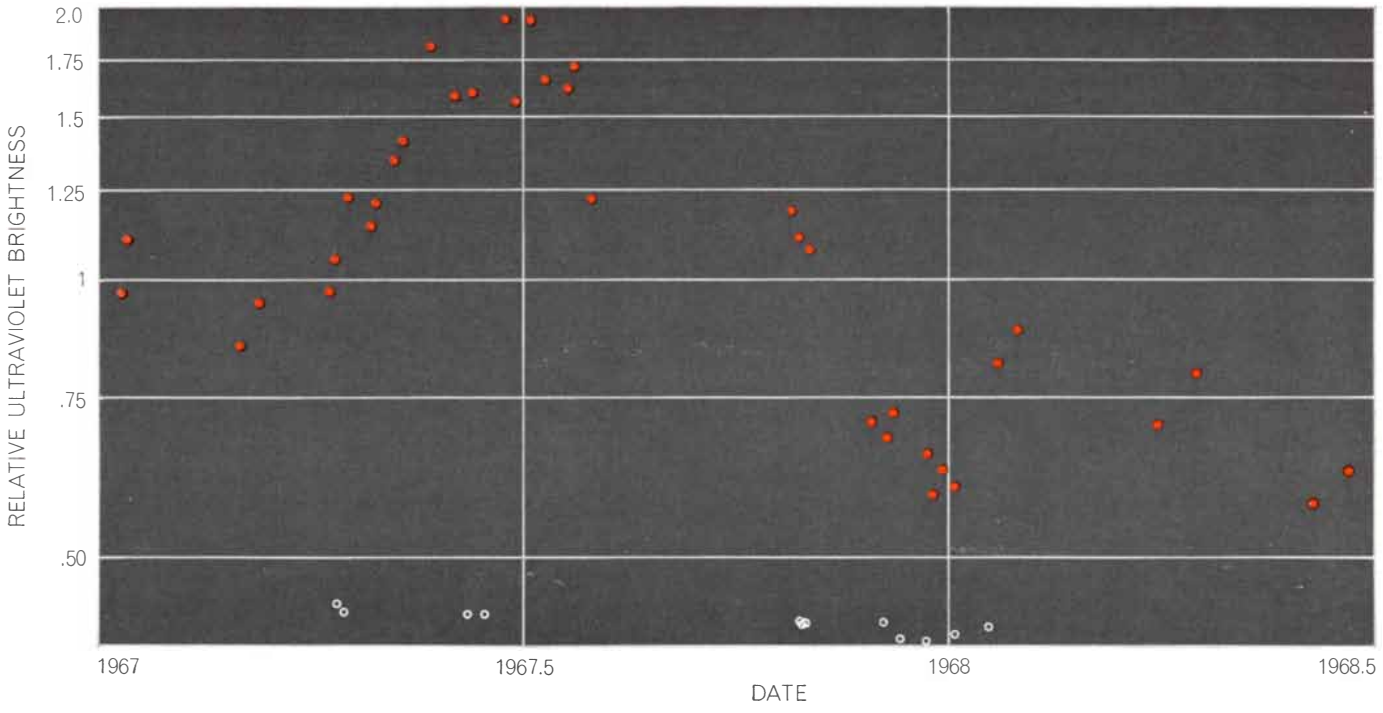
the far infrared, possibly because the intrinsic radiation is absorbed by dust and reradiated. Most of the foregoing characteristics are shared by the quasi-stellar radio sources. The most striking difference between the two kinds of object is that the spectra of quasars show a strong red shift, implying that the quasars are receding at high velocity, and hence that, according to the cosmological interpretation of red shifts, they are enormously distant. If they are indeed cosmologically distant, quasars must be extraordinarily luminous to appear as bright as they do.

Therefore, except for an apparent difference in luminosity, Seyfert galaxies and quasars may represent essentially similar phenomena. Astronomers inclined to this view have looked for objects that might bridge the "luminosity gap" between the two. In fact, the gap is nearly bridged by the radio-bright Seyfert galaxy 3*C* 120, if one takes into account its great infrared emission. 3*C* 120 is then only about 20 times less luminous than the most luminous quasar, 3*C* 273, and it approaches the luminosity of some of the dimmer quasars. Nevertheless, the average luminosity of Seyfert galaxies at light wavelengths alone is several hundred times less than the average optical luminosity of the quasars.

Efforts to find objects resembling Seyfert nuclei and quasars—some of which might turn out to be the missing links between the two—have led to the investigation of a bewildering variety of objects with somewhat confusing *ad hoc* designations: N-type galaxies, "blue interlopers," Braccesi objects, Markarian objects, "blue stellar objects," Haro objects, Zwicky compact galaxies and others. Because these objects were discovered by different observers using different techniques no one knows how many distinct species they represent. The most pertinent generalization emerging from a study of these objects is that when they are very blue in color, very compact and essentially stellar in appearance, they often exhibit the kind of optical spectrum we have been discussing. Some are radio sources, some are not. Their starlike nuclei may or may not be embedded in a fuzzy nebulosity, which in turn may or may not represent an ordinary—but very distant—spiral galaxy. Two of the Zwicky compact galaxies recently studied by Sargent have pronounced red shifts and thus seem to be as luminous optically as some quasars.

It should perhaps be emphasized that astronomers have only two ways of estimating the distance to other galaxies. If the galaxies are close enough for individual stars to be visible, one can look for certain stars (for example Cepheid variables) whose intrinsic luminosity is known because they occur in our own galaxy at distances that have been measured directly by triangulation, with the earth's orbit serving as a base line. Knowing the absolute luminosity of individual stars enables one to compute the distance to galaxies that lie within about 30 million light-years. Beyond that individual stars cannot be observed. One must then use the second method, which assumes that the brightest galaxies in a remote cluster of galaxies are as intrinsically bright as the very bright elliptical galaxies whose distance has been determined by the first method. It has also been found that the light from remote galaxies is red-shifted in direct proportion to their distance as estimated by the second method. This relation is named Hubble's law.

One would like to know, therefore, if the various blue, compact objects, ranging from the Seyfert nuclei to the quasars, follow Hubble's law. To answer this question Halton C. Arp of Mount Wilson and Palomar plotted apparent brightness (since intrinsic brightness is unknown) against red shift for a smooth sequence of Seyfert-like objects and quasars. He then compared the slope of the resulting curve with the slope of a similar curve for the bright elliptical galaxies on which the Hubble law is based. Arp found that for his collection of objects the red shift increased more rapidly as magnitude decreased than it did for normal galaxies; Hubble's law was seemingly violated [*see illustration on page 37*].

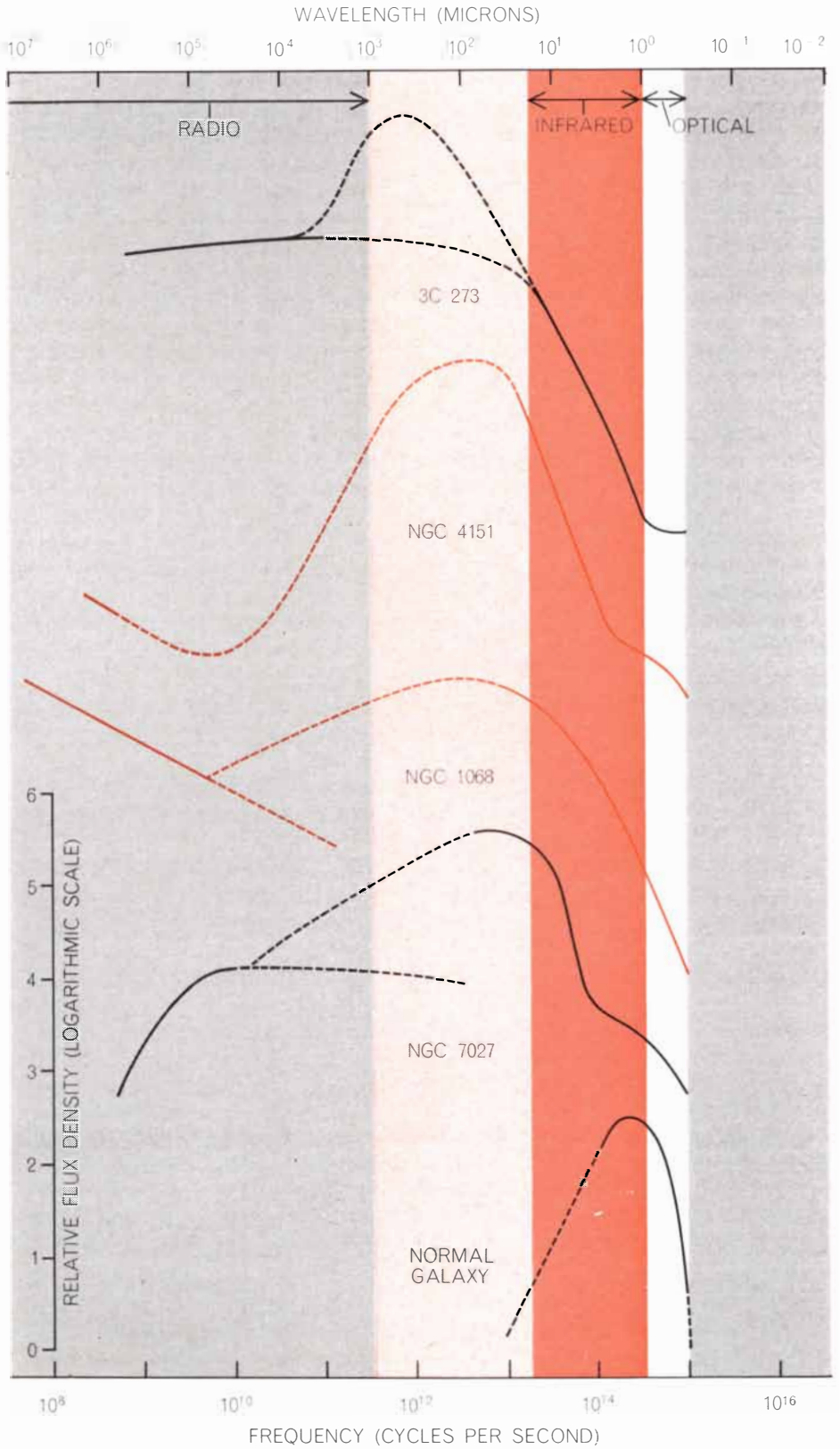


BRIGHTNESS VARIATIONS IN NUCLEUS OF NGC 4151, measured in the near ultraviolet (*color*), covered a range of nearly four to one during a recent 18-month period. The open circles show the brightness of a nearby reference star. Because the aperture used in the study let in starlight from outside the nucleus of NGC 4151, the actual variability must be greater than shown.

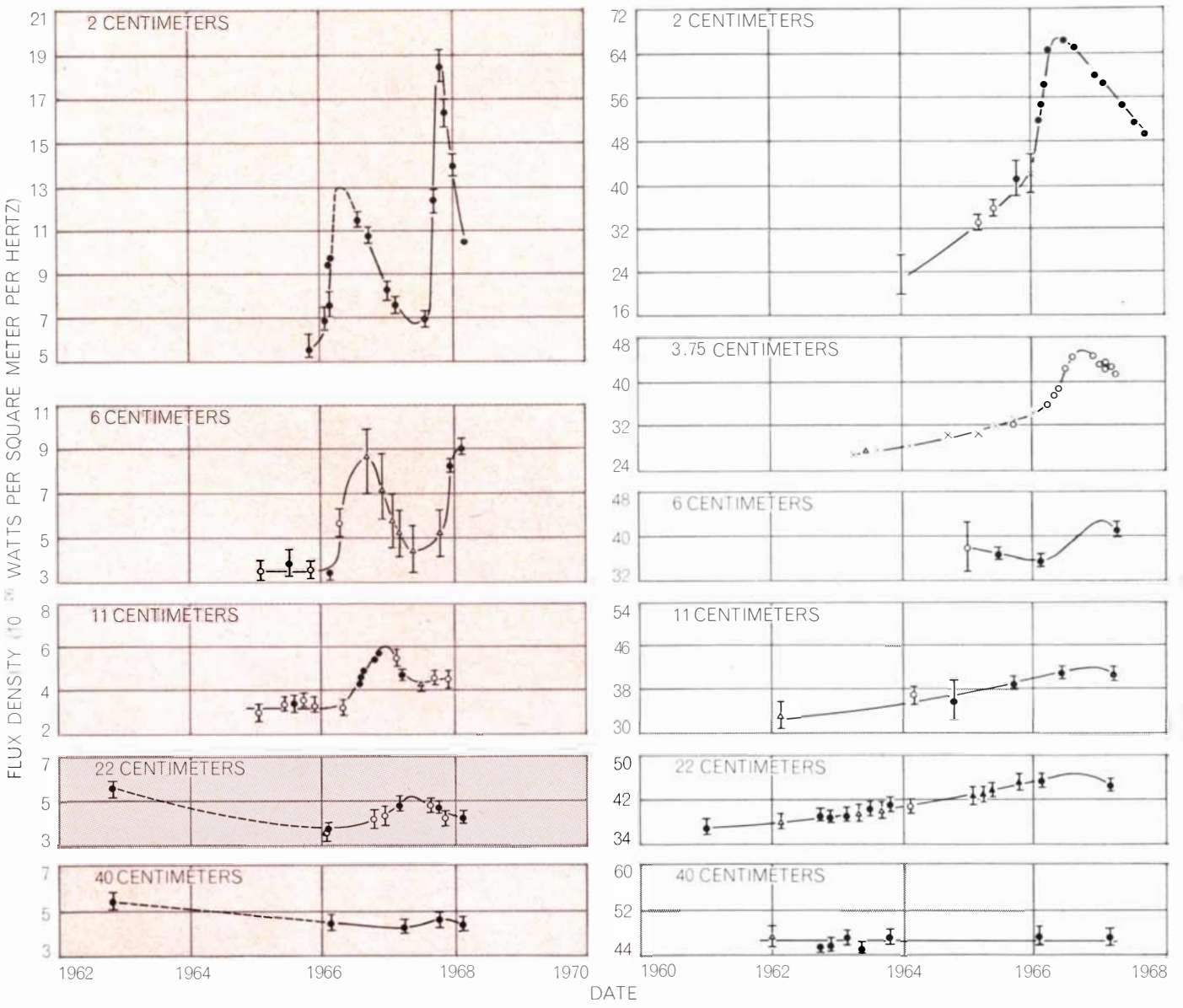
Is this violation real or only apparent? One possible explanation is the following. The Arp objects may have a wide range of intrinsic luminosities, with the less luminous objects being the more common; if one selects objects down to a given apparent brightness (knowing nothing, of course, about their distance), then any random selection will be skewed by including too many nearby objects that are below average in luminosity and too many very distant ones that are above average. Even though Hubble's law may actually hold for these objects, it will seem to be violated because the most distant (and thus more red-shifted) objects will tend to be intrinsically much more luminous than the nearby objects.

Another possible explanation for the apparent failure of Hubble's law is that a significant portion of the red shift in high red-shift objects is not cosmological (that is, due to the expansion of the universe) but is due to something else. What this other red-shift-producing mechanism might be has been the subject of intense speculation. The two alternatives most commonly invoked are a "local" Doppler shift, which would be observed if local objects were moving away at extremely high velocity (produced perhaps by gigantic explosions either in our own galaxy or ones nearby) and a gravitational red shift. The latter explanation demands the presence of a very strong gravitational field at the emitting source, produced by a compact, enormously massive object. A few years ago the gravitational explanation was in disfavor, but the total absence of any blue shifts—which one might expect to find if high-velocity objects had been ejected by nearby galaxies and were moving in random directions—has reopened the question of whether satisfactory models involving large gravitational fields might be constructed. If and when blue shifts are found, the whole outlook will of course be drastically changed.

A decisive observation that would rule out the cosmological origin of the red shift would be the discovery of a high red-shift object that is clearly associated physically with other material in space (perhaps a cluster of galaxies) that does not have the same high red shift. Alternatively, the cosmological nature of the red shift would be confirmed if it could be shown that the spectra of quasi-stellar sources exhibit effects of some kind that could be attributed unambiguously to the presence of intervening matter, associated perhaps with an ordinary galaxy at moderate distance.



WAVELENGTH DISTRIBUTION OF ENERGY EMITTED by Seyfert galaxies (*colored curves*) closely resembles the distribution characteristic of the powerful quasi-stellar radio sources (quasars), represented here by 3*C* 273. Seyfert emission, which is totally unlike that of a normal galaxy, also resembles that of the planetary nebula NGC 7027, a cloud of gas raised to incandescence by a hot central star. Quasar 3*C* 273 and the two Seyfert galaxies exhibit a greater energy output at infrared than at optical wavelengths and strong emission at radio wavelengths as far out as the emission has been measured. The broken lines indicate estimates where measurements are lacking or uncertain, or where atmospheric absorption precludes observations. The placement of curves does not signify absolute differences in emission; it simply ranks the quasar, the Seyfert galaxies and the planetary nebula from most energetic (*top*) to least energetic (*bottom*); the radiation curve of a normal galaxy is shown for reference. The scale of relative flux density applies to each curve individually.



CHANGES IN RADIO EMISSION from Seyfert galaxy 3*C* 120 over the past few years (*curves at left*) are remarkably like those displayed by quasar 3*C* 273 (*curves at right*). In both objects the changes are much more abrupt and steeper at shorter wavelengths, for example at two and six centimeters, than at longer wavelengths. On the basis of the red shift observed in its spectrum, 3*C* 273 may be as remote as two billion light-years and thus among the most distant objects known. Its intrinsic radio luminosity is therefore assumed to be much greater than that of 3*C* 120 or other Seyfert galaxies, which all lie within about 100 million light-years. The emission curves are from a paper published by I. I. K. Pauliny-Toth and K. I. Kellermann of the National Radio Astronomy Observatory.

Because the various strange objects plotted on Arp's diagram have many properties in common, it is tempting to believe we are presented with a whole sequence of blue, compact, intensely bright objects culminating in the quasars and representing various degrees of violent activity in the center of galaxies. Beyond a certain distance the underlying galaxy could not be discerned; only the optically bright nucleus would remain. If this view is correct, then the objects with large red shifts must be quite distant. We still know too little about the so-called compact galaxies to say if it is possible to have an alternative sequence of compact galaxies culminating in the quasars, whose character is wholly different from that of either ordinary spiral or elliptical galaxies.

If there is some kind of sequence of violent activity in galactic nuclei, we should not be surprised to find "baby" Seyfert nuclei. The strong activity we recognize in Seyfert nuclei may well occur in other galaxies on a more modest scale. For example, radio observations indicate that something quite unusual is going on in the center of our own galaxy. Recently strong infrared emission has been found in the direction of the galactic center. Unfortunately the amount of dust in the direction of the galactic center is so great that we are prevented from inspecting the nucleus of our galaxy at optical wavelengths.

Recent observations by Campbell M. Wade of the National Radio Astronomy Observatory have detected small but intense sources of radio emission in the nuclei of a number of ordinary spiral galaxies as well as in several Seyfert galaxies. For example, in M81, one of the nearest spirals, Wade has found a radio source at the center less than 100 light-years across whose intensity is far stronger than the small source at the center of our own galaxy. It appears certain that this source is not just ordinary radio emission from ionized gas.

We turn finally to the question of the cause of this violent nuclear activity. Any model of a Seyfert nucleus must

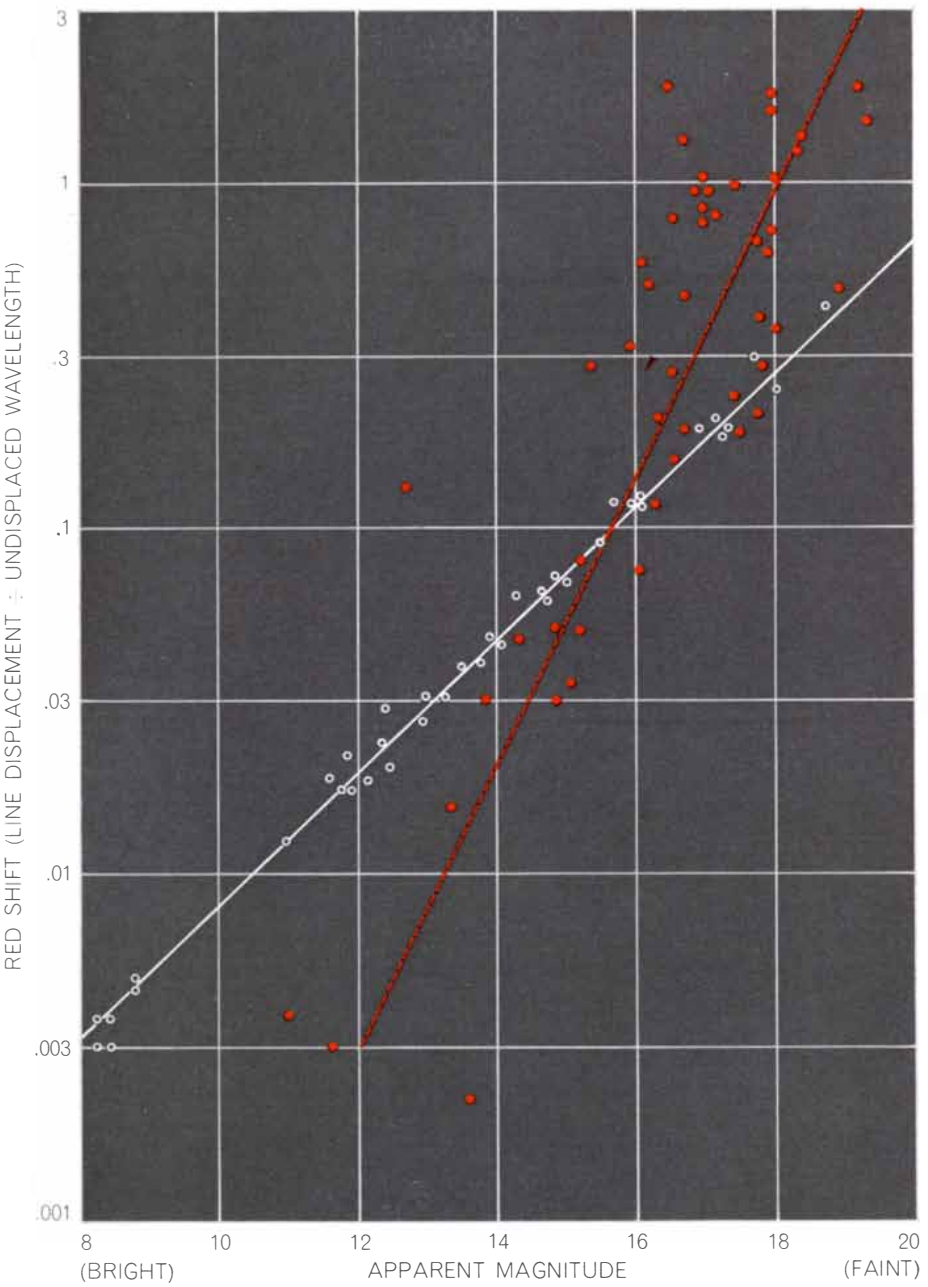
be based on some estimate of how much energy is released; the model must then provide a source for this energy and a mechanism for its release. For 3C 120 the energy release is estimated to approach 2×10^{46} ergs per second; for a more typical Seyfert nucleus the rate is about 100 times less: 2×10^{44} ergs per second. Therefore over the 10-billion-year lifetime of a galaxy the Seyfert process, if it is operating about 1 percent of the time, will have expended about 10^{60} ergs.

This amount of energy could be released by the thermonuclear conversion of 5×10^{8} solar masses of hydrogen to helium. In ordinary stars, however, this is a sedate, well-regulated process, not the violent, explosive kind of event that is needed. The kind of objects able to provide such events are supernovas and extremely massive objects, which yield their energy primarily through gravitational collapse rather than through nuclear reactions.

To produce 10^{60} ergs through conversion of gravitational potential energy would require the collapse of an object with a mass of at least 10^{6} solar masses. The problem here is to find some way to stretch the energy release over a long period of time; single massive objects would tend to collapse in one short, convulsive event. Although such events would not meet the energy needs of Seyfert nuclei, they might provide the energy for quasars, which are far rarer and more luminous and seem to need great bursts of energy at frequent intervals. It may be that the Seyfert nuclei are fueled by the repeated formation and collapse of somewhat less massive objects.

An alternative process visualizes the agglomeration and collapse of considerably smaller objects (on the order of 10 to 100 solar masses) in a restricted volume of space. Such a hypothesis has been presented by Stirling A. Colgate of the New Mexico Institute of Mining and Technology in his stellar-coalescence model. A high-density star cloud in the nucleus of a galaxy evolves to the point where stars begin to collide. At first they collide with such low velocity that they stick together. Eventually some of the agglomerates evolve to the supernova stage, whereupon they collapse with a violent release of energy. Assuming that such supernovas form at random in a reasonable volume of space, say 100 light-years across, it should be possible to ascertain by observation that the center of activity moves about from time to time. Alternatively, one might be able to show that the center of activity remains fixed, which would be a strong argument in favor of a model in which energy is released by single massive objects.

The reader will by now have formed the entirely correct impression that we are still groping for some unifying rational picture of all this activity. Astronomers working today on processes in the nuclei of galaxies are continually startled by the many unexpected observations being secured with both conventional and new techniques. Some very recent observations are even casting doubt on our traditional ideas about the origin of the galaxies. The present situation might be compared to the one in stellar evolution about half a century ago. At that time empirical trends and relations were being revealed through calculations of the mass, luminosity and radius of stars, but a fundamental theory of stellar evolution had to await the key provided by the development of nuclear physics. We are still looking for the key to a real understanding of the violent activity taking place on the fantastic scale of galactic nuclei.



COMPARISON OF "COMPACT" OBJECTS AND NORMAL GALAXIES suggests that the former (*colored dots*) do not follow Hubble's law, which defines the relation between the apparent brightness, or magnitude, of an object and the red shift of its spectrum. The law is based on measurements made on giant elliptical galaxies (*open circles*), which fall along the flatter curve. Data on these giant objects were assembled by Allan R. Sandage of the Mount Wilson and Palomar Observatories. The compact objects represent a smooth sequence of Seyfert-like objects and quasars selected by Halton C. Arp of the same institution. Most of the objects are very blue and have spectra with broad emission lines. They either may have an excess red shift that is not "cosmological" (that is, not related to velocity of recession) or they may represent anomalously luminous objects that do obey Hubble's law.

Cellular Factors in Genetic Transformation

In transformation certain bacteria change their hereditary makeup by absorbing DNA molecules from their environment. The ability to do this is induced by a giant-molecule factor synthesized by the cell

by Alexander Tomasz

The phenomenon of transformation in bacteria was first observed in 1928, led to the identification of DNA as the genetic material in 1944 and has since been recognized as a significant form of genetic intervention: a means whereby bacterial cells can acquire new genes (and thus new traits) with a frequency many orders of magnitude higher than if such changes occurred only through random mutation. Transformation is easy to demonstrate, as is now done routinely in college and high school laboratories, and yet its actual mechanism has not been well understood. The importance of learning more about the mechanism is obvious, since the invasion of cells by extraneous genetic material is not restricted to the world of bacteria. Such events are the essence of all viral infections and may be responsible for the induction of some forms of cancer.

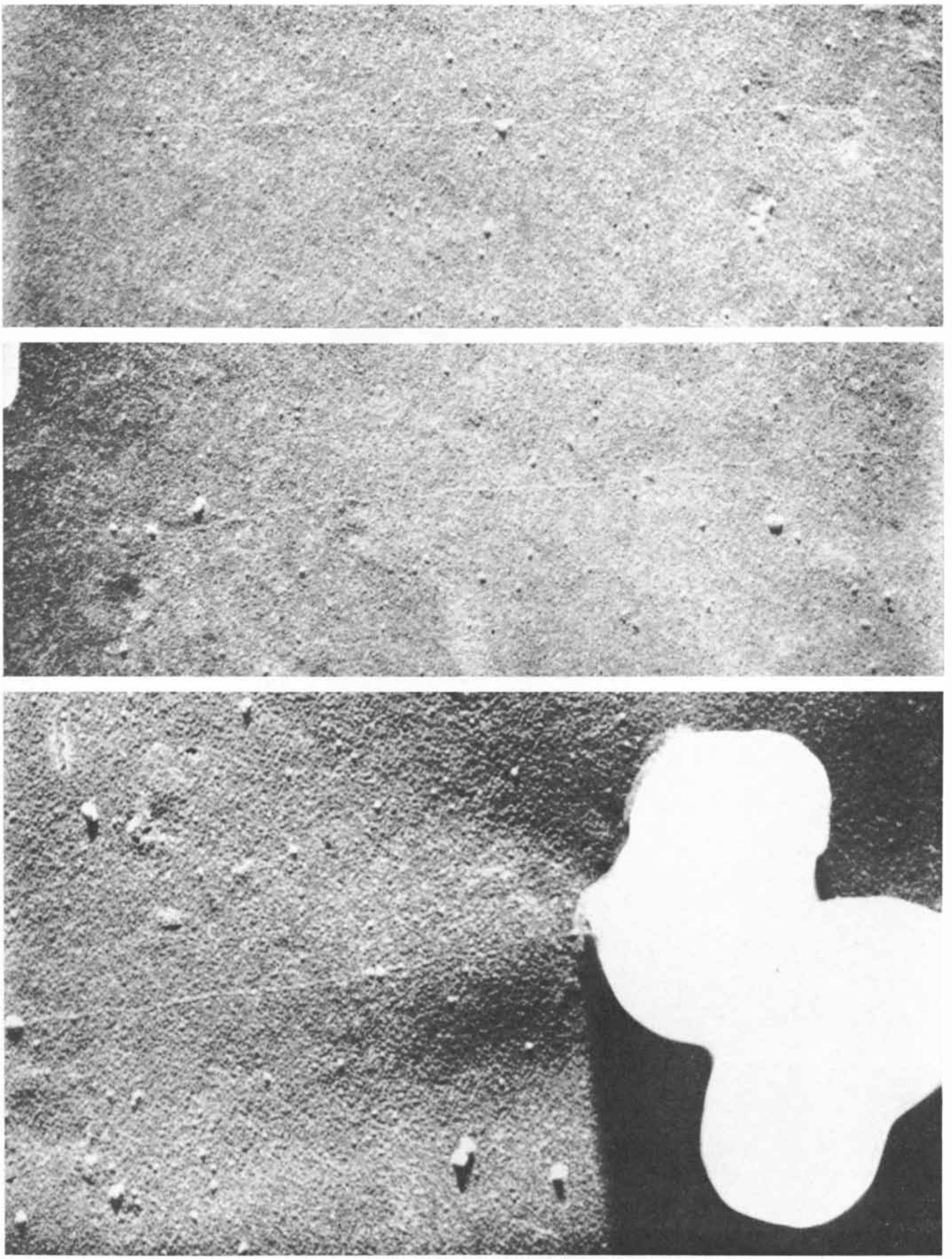
In bacterial transformation a bit of DNA penetrates the boundary of a bacterial cell and becomes incorporated into the cell's genetic apparatus. How does it get in? In particular, why are only certain species of bacteria transformable, and then only under certain conditions and at certain times? Our group at Rockefeller University has been investigating such questions for several years, and we are beginning to learn something about a mechanism by which the cell apparently controls its own transformability.

Transformation was first noted as a bizarre phenomenon peculiar to the pneumonia bacterium *Diplococcus pneumoniae*. In 1928 the British bacteriologist Fred Griffith found that if heat-killed pneumococci of a virulent strain were injected into mice along with live pneumococci of a normally nonvirulent strain, the mice died. Moreover, large numbers of live, virulent bacteria could be isolated from their bodies. It was not that the heat-killed virulent bacteria had come to life; rather, Griffith showed, some substance from the killed bacteria had "transformed" the normally harmless nonvirulent cells into virulent ones. It was not until 1944 that Oswald T. Avery, Colin M. MacLeod and Maclyn McCarty of the Rockefeller Institute for Medical Research identified that substance as deoxyribonucleic acid, which by that time was known to be associated with chromosomes in the cells of higher organisms.

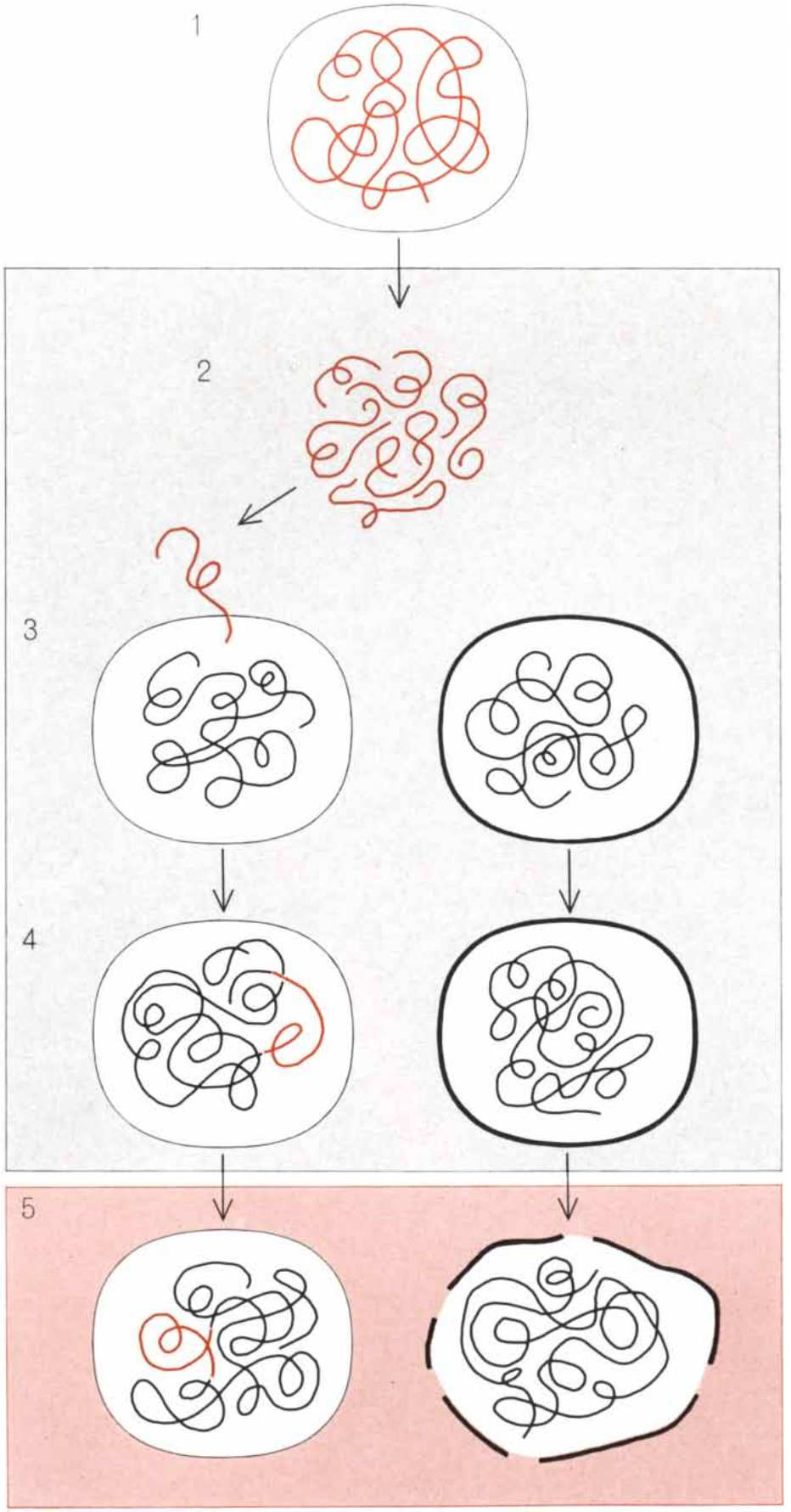
Avery and his colleagues utilized transformation to develop experimental techniques with which to investigate the role of DNA in heredity [see "Transformed Bacteria," by Rollin D. Hotchkiss and Esther Weiss; SCIENTIFIC AMERICAN, November, 1956]. For example, one can extract the DNA from disrupted cells of a mutant pneumococcus strain that can survive and multiply in the presence of streptomycin and then add the DNA to a culture of a more typical strain that is susceptible to the antibiotic. Sometimes nothing happens. Sometimes, however, a piece of the giant DNA molecule makes its way into the cells of the streptomycin-sensitive strain [*see illustration on opposite page*]. Within five minutes after the contact is established a segment of DNA has become an integral part of the recipient cell's chromosome. If the segment includes the sequence of DNA units that encodes the property of resistance to streptomycin, the recipient cell is soon able to survive and multiply in the presence of streptomycin [*see illustration on page 40*]. Even more important, the blueprint for streptomycin resistance becomes a permanent, heritable property of the cell, which replicates it and eventually passes it on to its progeny.

Through this process new, heritable properties can be introduced into pneumococcus populations with startling frequency. By treating about a million cells of a streptomycin-sensitive strain for 20 minutes with a few billionths of a gram of DNA from resistant cells, one can render several hundred thousand cells permanently and heritably resistant to the antibiotic; without the added DNA one could not expect to find even a single resistant cell among a million such pneumococci. Clearly transformation is a powerful method of introducing changes into the hereditary makeup of a living bacterial cell. It appears that bacteria may practice this kind of genetic engineering on their own. If one allows cultures of two pneumococcal strains that differ in a number of properties to grow in a common medium, the bacteria engage spontaneously in bilateral exchanges of genes: cells of one strain are transformed by DNA liberated into the medium by the other strain. (Whether this DNA is excreted by living cells or originates only from the hulks of a few dead cells we still do not know.)

Of the many species of bacteria that have been tested, only about half a dozen have been found that can absorb DNA and undergo genetic transformation. What special properties make them susceptible? These properties must somehow account for the ability of DNA to penetrate the tough multilayered bacterial surface, which is not normally permeable to a molecule of even moderate size. Yet DNA segments with molecular weights on the order of a million to 100 million are rapidly absorbed in transformation. Moreover, this DNA is a bare molecule. In the other known forms of genetic transfer in bacteria the transfer is mediated by outside agents. In conjugation, or sexual mating, it is the "male" bacterium that actively mediates



DNA MOLECULE entering a pneumonia bacterium (*Diplococcus pneumoniae*) is seen in electron micrographs made by the author and arranged here vertically to present the full length of the DNA. The enlargement is about 70,000 diameters. The bacterium, one of two, is at the bottom right, shadowed with uranium, which visualizes the DNA as a fine line extending to the left and across the upper micrographs. The DNA, about seven microns long, encompasses about 21,000 base pairs, or enough to code for 10 to 14 proteins.



TRANSFORMATION EXPERIMENT begins with the extraction of DNA from a strain of pneumococci resistant to streptomycin (*1*). Placed in a medium with a strain susceptible to streptomycin (*2*), some of the DNA is absorbed by "competent" cells (*left*), but it cannot be absorbed by incompetent cells (*right*). The absorbed DNA is integrated into the chromosome of competent cells (*4*), transforming them so they (and their progeny) survive and can multiply in a streptomycin environment (*color*), whereas incompetent cells cannot (*5*).

the transfer of DNA into a "female" of the same species; in transduction by a phage, or bacterial virus, the contractile injection mechanism of the virus helps to introduce a small amount of DNA from one bacterial cell into another cell along with its own viral genetic material. In transformation, on the other hand, a sizable segment of DNA enters a cell without any outside help, and so the entire apparatus for the uptake must reside in the recipient cell. One of the most interesting aspects of genetic transformation is therefore the cellular one: how do the bacteria transport the giant DNA molecules through the multiple layers of their surface?

There is evidence that the ability to absorb DNA is correlated with the chemical composition of the bacterial surface. Frank Young of the Scripps Clinic and Research Foundation in La Jolla, Calif., has noted that the cell wall of transformable strains of the bacterium *Bacillus subtilis* is richer in the amino sugar galactosamine than the wall of strains that cannot absorb DNA. In our laboratory we were able to affect the transformability of pneumococci by changing the composition of the cell wall. One of the components of the cell surface is a giant molecule of which one building block is choline. When, by suitable means, we forced the bacteria to replace the choline with such close structural analogues as ethanolamine or monomethyl-amino ethanolamine, the ability to absorb DNA was completely inhibited, although the cells survived and multiplied.

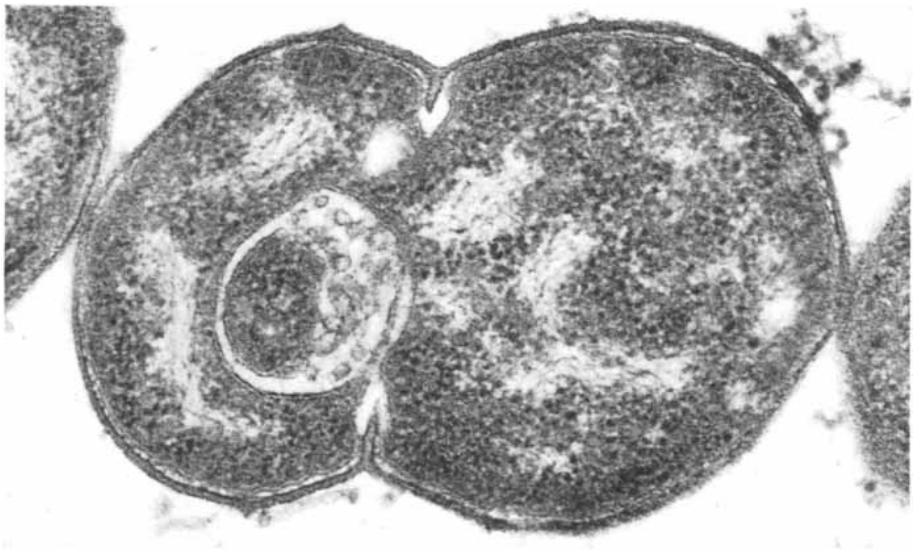
I mentioned earlier that even potentially transformable cells are "competent" to participate in transformation only at a certain time, and our major line of investigation has been directed toward clarifying this observation. If one allows a culture to multiply from a relatively small concentration—say 10,000 or 100,000 cells per cubic centimeter of growth medium—practically none of the cells are capable of undergoing transformation for a long period during which they grow and divide normally. Then, as the concentration reaches a million or 10 million cells per cubic centimeter, the property of competence appears abruptly and spreads with explosive speed to practically all the bacteria. With 10 million bacteria per cubic centimeter present, the number of competent cells can increase more than a millionfold in 10 minutes. (Under the same conditions a single division, or doubling, of pneumococci would require more than an hour.) We found that it was specifically the degree of concentra-

tion that governs the appearance of competence, not the rate of growth and not the fact that a culture may be nearing the stationary phase of growth during which the concentration levels off.

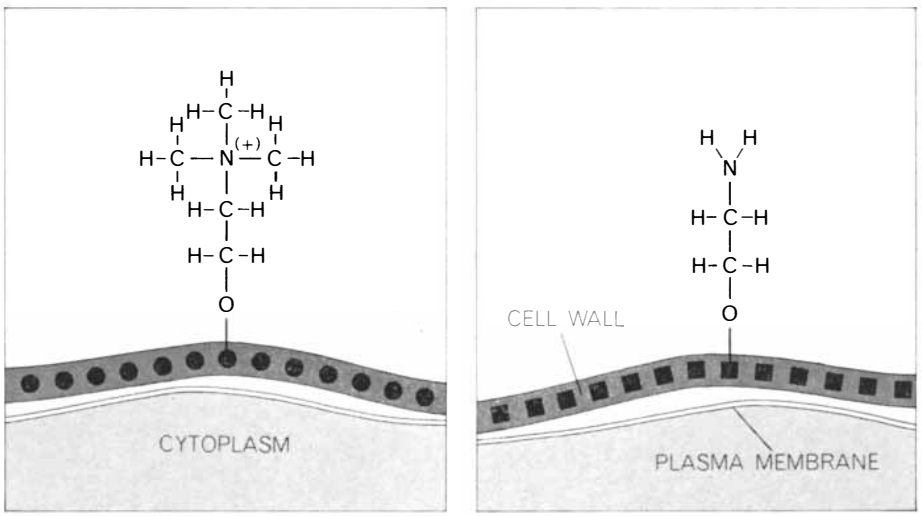
After the competence of the culture has reached its peak, we found, it soon starts to decline, and eventually it falls to an undetectable level. In short, it seemed that for some mysterious reason the ability to undergo transformation is expressed only during a brief phase of the culture cycle—and then it is expressed in a synchronous manner in practically all the cells present. This sudden and synchronous emergence of competence suggested that some kind of induction process might be operating to bring it on. Could it be that competent cells have a way of forcing incompetent ones to become competent ahead of time? Such a process might be demonstrated if incompetent cells were put into a common environment with bacteria that had already reached the competent state.

In designing an experiment we took advantage of the fact that the fewer cells one inoculates into a culture medium, the longer it will take for the culture to reach the competent phase. Indeed, given the original concentration and controlled conditions, one can predict the time of maximum competence fairly accurately. We took two strains of pneumococcus, distinguishable from each other because each was resistant to a different antibiotic, and inoculated them as follows. We put a high concentration of the first strain into one test tube and a low concentration of the second into another test tube; these were the controls. We also mixed the two strains in a single test tube, each at the same initial cell concentration as in the control tubes [*see illustration on page 43*]. Since the time of peak competence depends on initial concentration, we could predict that of the two control cultures the first strain, with the high concentration, would arrive at its peak of competence much earlier than the low-concentration second strain. The question was: What would happen in the mixed culture? Would the early development of competence in the first strain of cells influence the time-course of competence in the second strain?

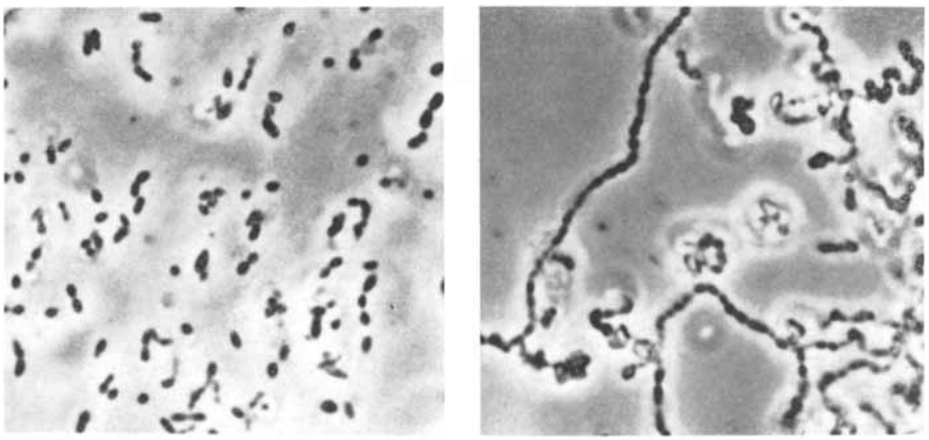
We incubated the cultures and allowed them to grow. From time to time we monitored the ability of cells of each strain to react with a transforming DNA carrying genes for resistance to a third antibiotic, streptomycin. Because of their different double-resistance patterns on mediums containing streptomycin



DIVIDING PNEUMOCOCCUS in thin section is enlarged 125,000 diameters in an electron micrograph made by James D. Jamieson of Rockefeller University (from a paper by the author, Jamieson and Elena Ottolenghi, *Journal of Cell Biology*, Vol. 22, page 453, 1964).



CELL WALL of pneumococcus is a network of macromolecules: glycopeptides, polysaccharides, proteins. Their exact structure is not known but one important component is the amino alcohol choline (*left*). The cells can be led to synthesize a wall in which these choline molecules are replaced by molecules of a structural analogue, ethanolamine (*right*). This modifies the cell wall so that the cell cannot become competent for transformation.



GROWTH PATTERN of pneumococci is altered by the surface change that occurs with substitution of ethanolamine. In the mediums used here, pneumococci usually grow alone, in pairs or in short chains (*left*). After substitution they tend to grow in long chains (*right*).

and one of the other antibiotics, we could selectively count the transformed cells of both test strains even when they came from the mixed culture.

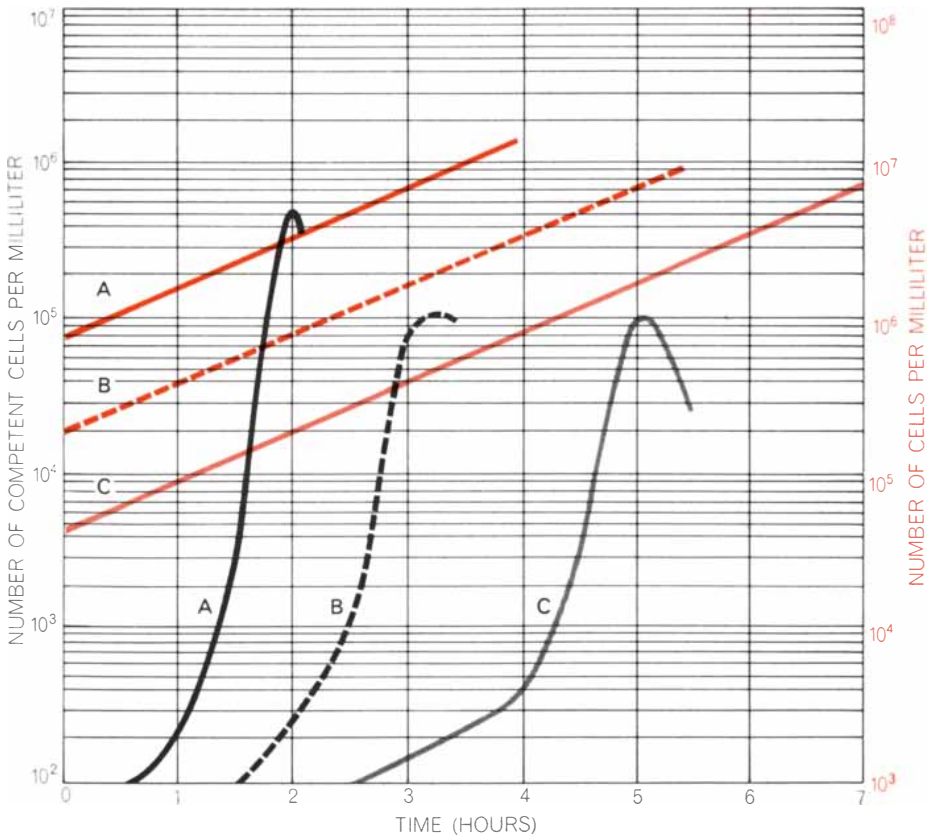
The results were striking. The time-course of the appearance of competence was as predicted for the two strains grown separately. It was the same for the high-concentration first strain whether it was grown separately or in mixed culture. Although the low-concentration second strain became competent at the predicted slow rate in the control tube, however, the same strain grown at the same concentration in a mixed culture became competent quickly; it precisely copied the time-course of the first strain! The answer to our experimental question was therefore affirmative: Pneumococci in the competent state are apparently capable of transferring competence to cells that are as yet incompetent.

The problem now was to identify the agent responsible for this induction effect. First we considered the possibility that a competent cell had to come into physical contact with an incompetent one in order to induce competence. To test this possibility we repeated the experiment in a modified form. We used a U-shaped tube separated into two compartments by a filter membrane that had pores too small to pass cells but that was quite permeable to the growth medium. We put a culture that was already competent in the left arm of the U-tube and an incompetent culture in the right arm [*see top illustration on page 44*]. We then immersed the tube in a warm bath and pumped the medium slowly back and forth between the two chambers, at intervals analyzing the two separated strains for competence in the same manner as before. Once again the result was positive: the competent state was induced rapidly in spite of the fact that physical contact between the two strains of cells was precluded. Apparently, then, we were dealing with an inducer substance that was produced and secreted into the medium by the competent cells and was able to move through the filter.

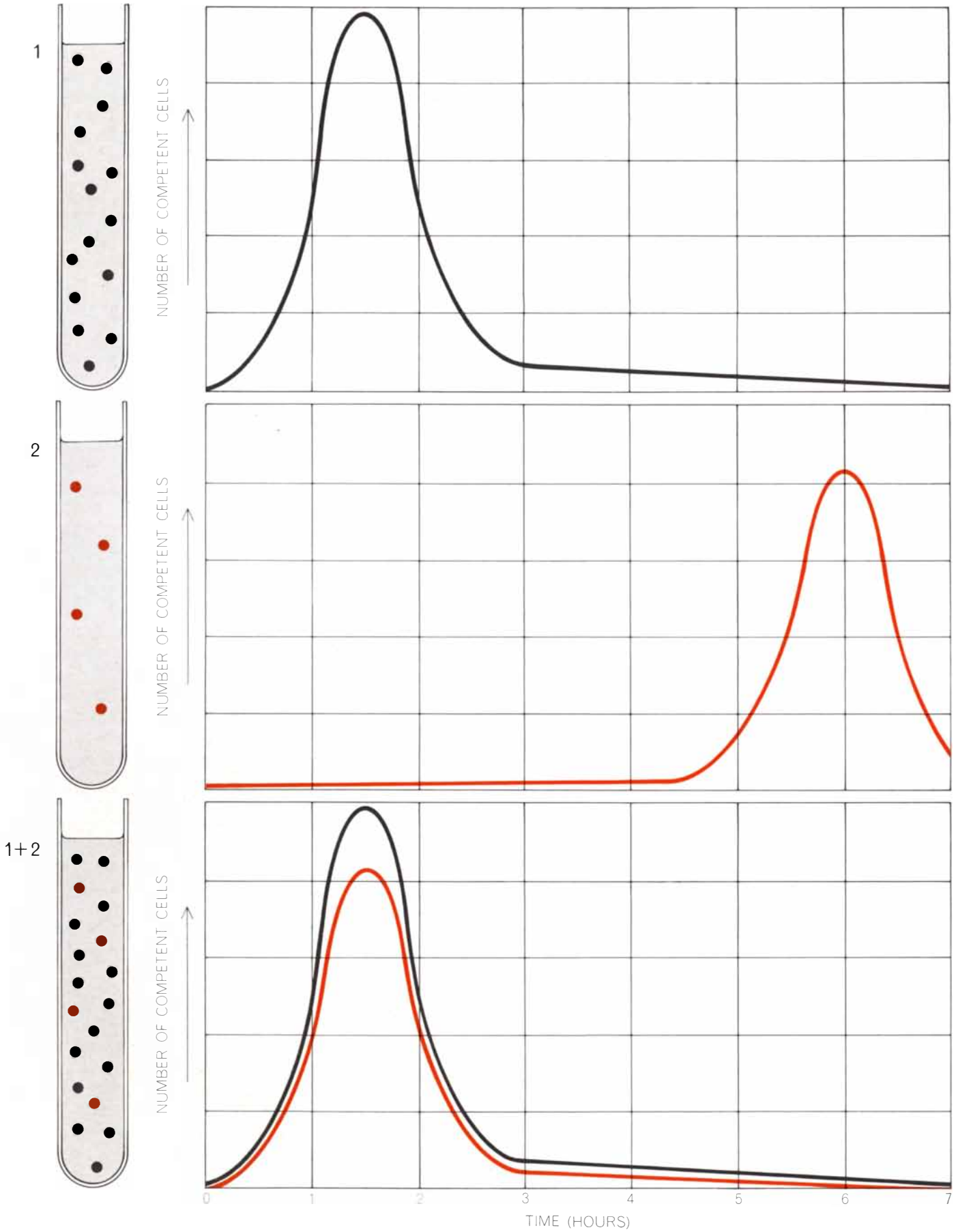
The next problem was to isolate this inducer substance, which we have provisionally called "activator." Setting about this task, we removed competent pneumococci from their culture medium by centrifugation. Somewhat to our surprise we found that very little, if any, activator remained behind in the cell-free medium, indicating that most of the activator was bound to the competent bacteria. This seemed to be in conflict with the result of the U-tube experiment, in which some of the activator had clearly been free in the medium. The two findings could be reconciled if the activator were loosely bound to the surface of the cells and could be detached rather easily, perhaps by rubbing against the filter membrane in the U-tube. Apparently that is the case. When we stirred the cells or exposed them to a few seconds of ultrasonic irradiation, substantial quantities of activator were detached and appeared in the medium. These experiments indicated that the activator was a surface component of competent cells and should not be hard to purify. We found that this could best be done by washing competent cells free of growth medium in a centrifuge, resuspending them in a salt solution and then heating the suspension to detach the activator from the cell debris and kill the cells. Repeated extraction of heat-killed cells with salt solution finally yielded highly purified preparations of the activator, which we then set out to characterize.

Chromatography revealed that the activator is a large molecule (molecular weight about 10,000) with a positive charge. It must be a protein or at least contain protein that is essential to its activity, since it is completely inactivated by small amounts of protein-digesting enzymes; treatment with enzymes that attack nucleic acids, polysaccharides, glycopeptides and phospholipids have no effect on it. We are still working toward a fuller biochemical description of the molecule.

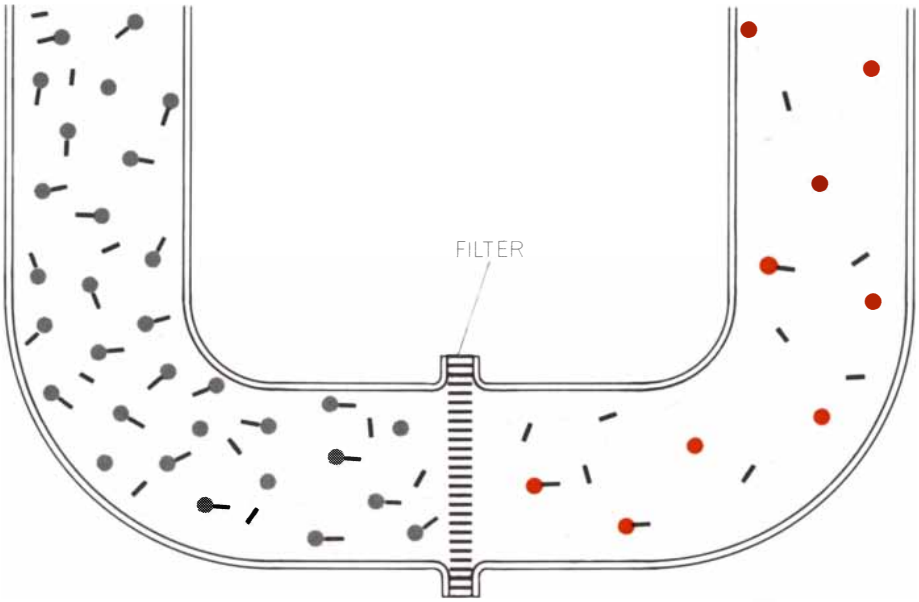
These procedures have required the development of a more precise test for the presence and potency of activator than we had used to determine peak competence. The cells exposed to an activator preparation must be completely incompetent and not in the process of developing spontaneous competence, and yet be sensitive to activator. We accomplish this by growing pneumococci in a slightly acid medium (*p*H 6.8), in which activator does not function, and then transferring them at the desired concentration into a more alkaline medium (*p*H 7.6), where they immediately respond to any activator present. Next the length of the activation process must be accurately established in each experiment. We do this by transferring the cells being tested, after the desired exposure, to test tubes containing both transforming DNA and a proteolytic en-



RELATION of competence to cell concentration is illustrated. Three cultures of pneumococci (*A, B, C*) differ in their initial cell concentrations. The time required to reach peak competence (*black curves, scale at left*) varies approximately inversely with concentration (*colored curves, scale at right*): the lower the concentration, the later the peak.



INDUCTION OF COMPETENCE was demonstrated by growing two strains of pneumococci at different concentrations in control cultures (*top and middle*) and in a mixed culture (*bottom*). The graphs show, for each strain, the number of cells that were found to be competent for transformation. In the high-concentration culture (*1*) the degree of competence increases rapidly to a peak (*top*). The low-concentration culture (*2*), grown alone, takes a longer time to reach its peak of competence (*middle*). Yet when the two strains are grown in the same tube, cells of the second strain "copy" the competence curve of the first strain (*bottom*).



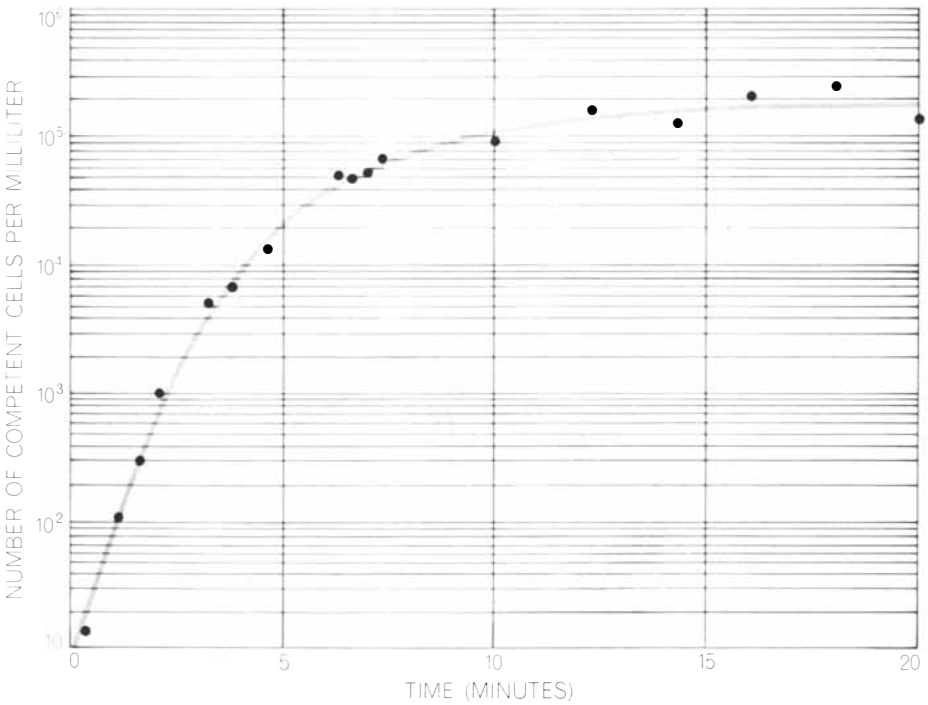
EXTRACELLULAR NATURE of the inducing agent was demonstrated by separating a competent culture (*left*) from an incompetent one (*right*) by a filter that was impermeable to the cells. When medium was pumped through the filter, competence was induced in the incompetent cells, indicating that "activator" molecules (*rods*) were crossing the filter.

zyme that destroys any activator. Finally we add the enzyme DNA-ase, which destroys any DNA remaining free in the medium and thus ends the process of transformation. All of this makes for a procedure in which clear beginning and end points are established for the two phases of our assay procedure, first a "reaction" of bacteria with activator and then a "reaction" of activated cells with transforming DNA: (1) incompetent cells + activator → competent cells; (2) competent cells + transforming DNA → transformed cells. And so the induction of competence, which we originally discovered as a property of live competent cells, can now be more accurately studied as a reaction between bacterial cells and molecules of a purified activator substance. A few hundredths of a microgram of the activator can induce competence in several hundred thousand incompetent pneumococci in 10 minutes.

The existence of an activator explains how and why pneumococci express their competence in synchrony. Competence is apparently "contagious": it is a physiological state that can be provoked in the rest of the culture through the mediation of the activator. What controls the production of the activator in the first place? It is clear that the lack of competence in dilute cultures is caused by the lack of sufficient quantities of activator supplied by the cells themselves; when we supply activator, even a dilute culture becomes competent. In other words, the production (or accumulation) of this substance by the cells themselves seems to be a function of their concentration, but just how the production is triggered at a certain cell concentration we still do not know. Nor do we know what the actual change is that the activator causes in bacteria to enable them to absorb DNA molecules from the environment. At this point we can only say that the change probably involves some modification of the cell surface. This is indicated by the fact that the activator molecules seem to be located on the surface and by the importance of the choline-containing surface macromolecule, which I mentioned earlier. In addition, Sam M. Beiser and his colleagues at the Columbia University College of Physicians and Surgeons have by immunological methods detected some change in the surface of pneumococci while they are in their competent state.

The existence of an activator for transformation is not uniquely a property of the pneumococcus. Working at the University of Warsaw, Roman Pakula, now of the University of Toronto, independently isolated a similar competence-inducing substance that is apparently released into the growth medium by streptococci. The pneumococcal and the streptococcal activators are species-specific: neither induces competence in cells of the other species.

Work is now in progress in a number of laboratories, in Canada, Czechoslovakia and France as well as in the U.S. and Poland, aimed at learning more about the mechanisms that somehow open and close the gates of cells to the entry of foreign genetic material. This work could eventually lead to better understanding of viral infection and could even contribute to the possibility of deliberate genetic intervention in higher organisms. The hope is that once again, as so many times in the past, the bacteria can provide important clues to understanding how our own cells function.



PURIFIED ACTIVATOR has the same inducing effect as competent cells have. Incompetent bacteria exposed to a small amount of activator develop competence rapidly, as shown here. In the absence of activator the same cells would remain incompetent for several hours.

In hope of doing each other some good

Ceratocystis' beautiful host

A certain American elm we have long admired looked like this in early September. Come April, tender green shoots will clothe its elegant form. Come May, we fear, great masses of conidial spores of the ascomycetous fungus *Ceratocystis ulmi* will invade the vessels within those shoots, and day by day, hour by hour, they will crowd into the leaf petioles and the leaf veins. There the membranes of the host cells will probably swell so that the conducting sieve tubes are blocked, nourishment is cut off, and the magnificent *Ulmus americana* is on its way to the hearth. Why the tetraploid *U. americana* must die while lesser diploid elms better resist *C. ulmi,* René Pomerleau doesn't know.

Dr. Pomerleau does know from autoradiography on KODAK ROYAL BLUE X-ray Film with wildly proliferating P^{32}-tagged inocula of the *C. ulmi* organism that the fatal blow is delivered in the green shoots, that hyphae or conidia have to get there to do the damage, that they can move through the tree's vascular system with amazing speed, that no action at a distance by a toxin need be postulated.

It's a sad tale with no cheerful ending in sight. Perhaps our product will have played a small part in brightening the hope for a cure.

Pomerieau's work on the dynamics of the Dutch elm disease crowns his career as a phytopathologist of Canada's Department of Forestry. Some long-forgotten urgency of World War I calling for ingenuity in finding wood for crates and furniture brought *C. ulmi* conidia to North America, possibly on the bristles of elm-bark beetles. The beetles brush against the conidiophores in walking through their galleries. It now appears that *C. ulmi* doesn't need the beetles for transportation as long as the elm root systems interlock.

Cercospora's sweet host

This plant, the sugar beet, now furnishes much of the sugar for America's coffee and its apple pie and many other comforts of this sweet land. It has a dangerous fungal enemy that belongs to *Cercospora* (a form-genus of the Fungi Imperfecti recently shown to include at least one species that can be cultured from lesions in a human patient and experimentally passed on to attack seedlings of lettuce, tomato, and potato).

Cercospora leaf spot of sugar beets can be fought off before appreciable damage with timely application of suitable fungicides. But nobody—least of all the grower who has to foot the bill—wants fungicides sprayed around unless necessary. Some years there isn't much *Cercospora* present. To see whether it is or it isn't, in the Minnesota-North Dakota growing area field inspectors are sent out—if funds and manpower are available. Two men can check about 100 fields in a week. They can check only a small part of each of those fields, of course.

Now there is a better way. Drs. Merle Meyer and Lucas Calpouzos at the University of Minnesota Institute of Agriculture believe that "false color" aerial photography with EKTACHROME Infrared AERO Film should eventually make it possible to check out that same sugar-beet area with several hundred complete fields in a day or two.

Look up their paper in Photogrammetric Engineering 34, *554 (June '68) or write them for a copy.*

Modern manual arts

Half a dozen "manual arts" teachers here and there have written in recent months to Earl Dudney requesting information on subjects like fluidized-bed coatings and rotational mouldings. They seem dedicated men trained to teach woodworking and auto repair and concerned about the economic timeliness of these traditional subjects in the manual arts curriculum. They may be misguided. Certainly many a householder would so consider them when faced with long waits and high prices to get a kitchen rebuilt or a mysterious knock in the transmission investigated.

Nevertheless Earl Dudney, a householder who occasionally faces such exasperations himself, is also a plastics industry marketing man. He therefore replies as helpfully as he possibly can to teachers who want to give to boys bound to earn a living with their hands some knowledge of the most up-to-date techniques in the up-to-date plastics industry. The boys should learn not only today's up-to-date techniques but also to keep themselves open for the day when these methods in turn will begin to show their age. That would be best for them and best for Mr. Dudney's business, which, specifically, is cellulosics and currently finds its largest single outlet in packaging for today's styles in merchandising.

Mr. Dudney's address is Eastman Chemical Products, Inc., Kingsport, Tenn. 37662.

We also employ a Mr. Bill Flack. For him counsel to industrial arts teachers is no extra labor of devotion; it's his whole job. His way of improving business is to go through the land upgrading the old school print shops into centers where young people can learn the many modern manual arts that enter into visual communications *while they learn also how these processes fit into the social structure.* Along with litho plates and process cameras, it is suggested that student attention be directed to the social consequences of technological change.

Educators are invited to write to Mr. William F. Flack at Department 942, Eastman Kodak Company, Rochester, N.Y. 14650.

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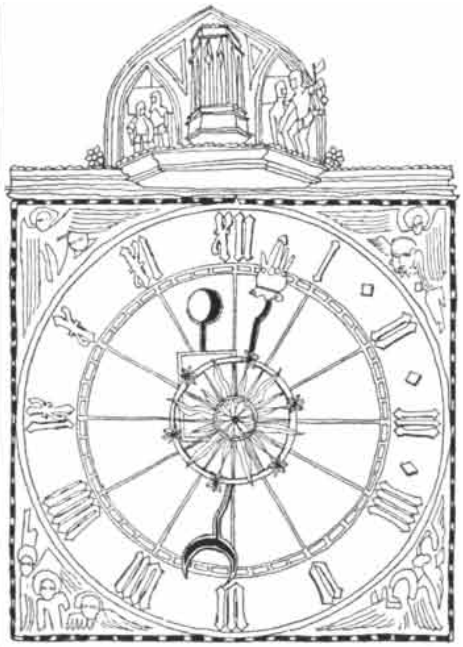


Pulsars and Supernovas (Cont.)

The notion that the stellar remnant of a supernova may survive as a pulsar has received new support with the discovery of a pulsar that appears to lie close to the center of the Crab nebula, the cloud of expanding gas believed to have been formed by a supernova observed in A.D. 1054. A few weeks earlier Australian radio astronomers had reported finding a pulsar within the boundaries of a radio source thought to be the remnant of another supernova. The Australian pulsar, PSR 0833–45, emits more than 11 pulses per second, which was the highest rate then known. The new Crab nebula object (designated NP 0532) has a pulse rate nearly three times faster. Even more noteworthy, its pulse frequency seems to be slowing down by about one part in 2,400 per year.

Originally a variable radio source in the Crab nebula had been detected at the National Radio Astronomy Observatory in Green Bank, W.Va. Subsequently the source was discovered to be a pulsar by John E. Sutton, Richard L. Lovelace, Harold D. Craft and David W. Richards of Cornell University, who worked with the 1,000-foot dish at Arecibo in Puerto Rico. By examining records made at Arecibo as early as October 20, before the pulsar had been recognized, they determined that its period on that date was .03309014 second. An observation on November 15 indicated that the period had lengthened to .03309114 second, and by November 22 it had increased to .03309140 second. In these figures allowance has been made for the movement of the earth in its orbit, which can slightly shift the period of a pulsar depending on whether the earth is moving toward the source or away from it. Further measurements should establish whether the pulsar period is really slowing down or the source itself is traveling in an orbit.

If the slowdown is genuine, it will support a hypothesis presented about a year ago by Thomas Gold, director of the Cornell Center for Radiophysics and Space Research (see "Pulsars," by Antony Hewish; SCIENTIFIC AMERICAN, October, 1968). Gold suggested that pulsars were rapidly rotating neutron stars, objects as massive as the sun but only five to 10 miles in diameter. Under such hypothetical conditions matter would be so dense that electrons should recombine with protons to form neutrons. Gold calculates that a neutron star could spin as fast as 200 times a second without tearing itself apart. In his hypothesis the radio emissions are created by a plasma (a gas of free electrons and protons) that is bound to the neutron star by an intense magnetic field and therefore forced to whirl around with the star at high velocity. Electrons moving at nearly the speed of light would generate a beam-like radio signal. Gold has calculated that if the pulsar in the Crab nebula were formed when the supernova was observed in A.D. 1054, its initial pulse rate, equivalent to its rotation speed, may have been about 50 times a second.

Interferon Stimulated

Ever since 1957, when interferon was discovered by Alick Isaacs in England, there has been the hope that this natural antiviral substance produced by cells might provide an effective treatment for a broad range of virus diseases that are not subject to control by antibiotics. Now for the first time firm evidence has been presented that an animal's body can be stimulated to produce enough interferon to cure an acute infection. John H. Park of the New York Medical College and Samuel Baron of the National Institute of Allergy and Infectious Diseases treated an eye disease in rabbits by administering an agent that raised the animals' interferon level and

THE CITIZEN

cleared up the infection. Their work is reported in *Science*.

Interferon is a protein, produced by cells under virus attack, that in turn apparently gives rise to a factor that limits the spread of the virus. The interferon system has been demonstrated in the laboratory and in human beings, but the body's own system often does not produce enough interferon to overcome an established infection. Treatment with prepared interferon can prevent many viral infections and has some protective effect when it is given after inoculation with a virus and before the onset of disease, but it is hard to accumulate enough prepared interferon to treat an established infection. This is largely because interferon is species-specific, effective only in the same species that produced it. Some years ago, however, it was discovered that a number of agents would stimulate the body to produce more than the normal quantities of interferon. The most promising of these agents is ribonucleic acid (RNA), a normal component of the cell's protein-synthesizing apparatus.

Park and Baron inoculated rabbits' eyes with herpes simplex virus, producing a serious infection of the cornea and mucous membrane called keratoconjunctivitis. Then they administered a synthetic double-strand RNA called polyinosinic-polycytidilic acid. Whether the RNA was applied topically to the cornea, injected behind the cornea or injected into the bloodstream, it promoted recovery from severe and fully established infections whenever it was administered by the third day after virus inoculation. Most of the untreated control animals, on the other hand, were blinded and about a third of them died. As evidence that the therapeutic effect of the RNA was attributable to interferon stimulation the authors cite a sharp increase in interferon levels in the blood of rabbits given the RNA intravenously.

The findings should be extended to other virus infections to establish the therapeutic role of interferon firmly, the investigators suggest. Such tests should be successful, since many viruses are more susceptible to interferon in laboratory cultures than herpes simplex. The synthetic RNA has proved to be effective in inducing resistance to viruses in human tissue cultures, they point out,

and so it may provide an effective treatment for herpes infections in man.

Up the Down Tube?

A series of laboratory experiments that may have far-reaching cosmological implications is under way at Stanford University. The experiments, which are designed to measure the force of gravity on individual electrons and positrons falling freely through vertical metal tubes, are described in a recent issue of *Nature* by Fred C. Witteborn and William M. Fairbank.

The motivation for the present experiments goes back to a speculation made about 10 years ago by Philip Morrison and Thomas Gold. They reasoned that the obvious lack of symmetry in the abundance of matter over antimatter in our immediate vicinity in space could mean that a gravitational repulsion exists between matter and antimatter. If their speculation is correct, it follows that particles and antiparticles would fall in opposite directions in a gravitational field. One could then distinguish between a gravitational field and an accelerating frame of reference, in violation of the equivalence principle of general relativity.

The experimental approach employed by Witteborn and Fairbank is based on a theoretical analysis that predicts that the electric force produced by the electrons in the wall of a metal tube would be just strong enough to cancel the effect of gravity on a free-falling electron inside the tube. According to this analysis the same force would cause the electron's antiparticle—the positron—to fall at a rate twice that expected from the force of gravity alone.

The Stanford group has devised three methods to test these predictions. Two of the techniques are designed to measure the extremely small forces exerted on electrons falling through long vertical metal tubes at low temperatures. In both cases the electrons are emitted by a hot cathode and are constrained to move along the axis of the tube by a coaxial magnetic field. The results of these experiments so far have agreed with the theoretical prediction; the gravitational potential gradient associated with a falling electron is canceled by an electric field associated with the tube wall to within less than 10^{-11} electron volt per meter of tube length. Nonetheless, the experimenters feel that the question in the case of the electron is still unresolved and that additional confirming results are required.

The third method worked out by the Stanford group is designed to measure the gravitational properties of low-energy positrons in a similar free-fall situation. No results have yet been reported. Although most physicists believe the positron will fall down in a gravitational field, the possibility remains that it will fall up.

In discussing the possible consequences of their experiments, Witteborn and Fairbank point out that "if positrons have the same gravitational properties as electrons, there would be very little change in physics except that future cosmological arguments will be unable to associate antigravity with antimatter. But if positrons have even slightly different gravitational properties (neglecting radiation reaction effects), very serious and far-reaching consequences would result. First, general relativity would have to be modified. Second, we would know that the Milky Way galaxy is composed chiefly of matter [as opposed to antimatter], for the stars in it appear to revolve around its center. Third, we would have strong reason to believe that somewhere outside our galaxy, perhaps beyond our limits of observation, there is an accumulation of antimatter." Finally, they add, "if positrons or electrons or both were to display unexpected gravitational properties, some clues about the nature of gravity itself might be uncovered."

Mid-Ocean Insects

Most people have seen one or another of the 200-odd species of insects that stride on the surface of ponds or streams, living as aquatic scavengers. Almost no one, however, has seen any of the 39 species of the oceanic waterstrider *Halobates*. These insects inhabit the tropical and semitropical waters of the Atlantic, Pacific and Indian oceans, where one generation of striders succeeds another in isolation hundreds of miles from land. R. S. Scheltema of the Woods Hole Oceanographic Institution has summarized current information about these insect occupants of an implausible ecological niche in the institution's periodical *Oceanus*. Although the first species of *Halobates* was discovered some 150 years ago in the course of the Russian explorer Kotzebue's 1815–1817 circumnavigation of the world, Scheltema notes that the task of collecting specimens has only recently been made easier with the perfection of a fine-meshed net that skims the ocean surface on floats. Since 1960 six new species

of *Halobates* have been taken in Pacific waters alone.

Like their freshwater relatives, the oceanic striders have bodies covered with fine water-repellent hairs. The middle pair of their three pairs of legs are greatly elongated and serve as oars. Less than half an inch long from tip of antenna to end of outstretched leg, the insects prey on marine life at or near the surface of the water. With their piercing mouthparts they puncture the outer membrane of jellyfish and other organisms and feed on their body fluids.

The insects often gather in large numbers near flotsam such as driftwood or the feathers of oceanic birds, and the females glue their eggs to these objects. In the only species whose life cycle has been studied, the development of *Halobates* from egg to adult takes two months. Scheltema reports that it is extremely difficult to study the mid-ocean insects in captivity: the adults move so swiftly they collide continuously with aquarium walls and soon die.

Trigonometric Outfielding

How does an outfielder judge a fly ball? He solves (unwittingly) a problem in trigonometry so that he moves at a constant rate of speed determined in such a way as to keep the tangent of the ball's angle of elevation increasing at a constant rate. This conclusion is presented in the *American Journal of Physics* by Seville Chapman, director of the physics division at the Cornell Aeronautical Laboratory.

Chapman considers first a fly ball that an outfielder can catch without moving. All the changes he can see in the position of the ball are in one vertical plane. What he sees is that the tangent of the angle of elevation of the ball (the angle between the ball and the horizontal as measured from the fielder's eyes) increases uniformly with time until the ball is caught. If, however, what the outfielder is watching is a pop fly to the infield, the tangent of the angle of elevation as he sees it will increase at a decreasing rate. If the ball is on its way out of the park, the tangent will be seen by the outfielder to increase at an increasing rate.

Suppose the outfielder has to run 50 feet forward or backward to catch the ball. Ordinarily he does not, writes Chapman, run the 50 feet at top speed and then stop and wait for the ball; instead he runs at the constant speed that will maintain a constant rate of increase in the tangent of the angle of elevation

to the ball. Things are easier for the outfielder when the ball is hit somewhat to his side. "In addition to information about elevation angle and its rate of change," Chapman writes, "there is now information about azimuth angle and its rate of change.... If the player runs so as to maintain the bearing of the ball constant... and the rate of change of [the tangent of the elevation angle] constant, he is in the right place to catch the ball at the right time.... What I have tried to show here is that an astonishingly simple amount of information... tells him that he is running at the right speed in the right direction for the catch."

Discourse with an Ape

In an experiment that is now in progress a chimpanzee is learning a language and beginning to use it successfully to communicate with man. Although chimpanzees excel at imitating certain aspects of human behavior, they have proved virtually incapable of imitating human speech. Now the animal is being taught a sign language.

The experimenters, R. A. Gardner and B. T. Gardner of the University of Nevada, are teaching their chimpanzee a system in which a movement of the hand or arm represents an entire word, phrase or sentence (the American Sign Language, used by many deaf people). The young female animal, named Washoe, they are training is housed in a furnished trailer with access to toys and play areas. In her presence the Gardners speak only in sign language, using conditioning methods for reinforcement.

After 16 months of training Washoe had mastered 19 signs. She was on the way to learning five others and understood many signs she could not yet make herself. On occasions when she was apologizing for mischief and when someone was hurt (not necessarily by Washoe) she would make the gesture meaning "Sorry." She frequently combined the sign for "Go" or the sign for "Out" with the gesture signifying "Hurry" or the one meaning "Please."

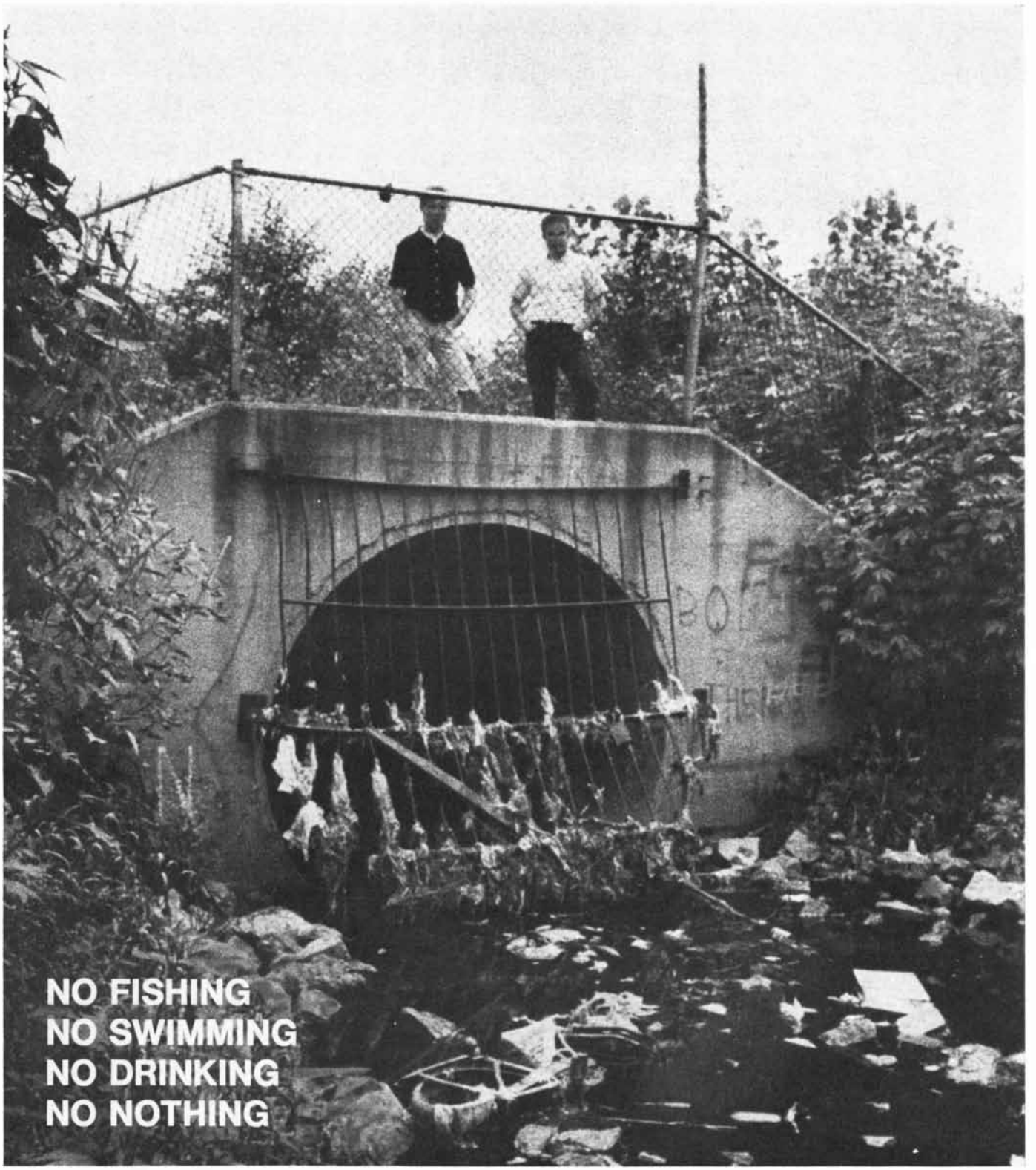
In a recent issue of *Science* Winthrop N. Kellogg, formerly of Florida State University, discusses the Gardners' experiment and five others (including one of his own with L. A. Kellogg) in which chimpanzees were reared in a household, sometimes with a human child. Whereas in most respects the animal performed as well as the child (up to the age of three) and surpassed the child in many physical feats, it did not prattle or babble as a child does. The most successful attempt to train the animal in human speech was made by Keith J. Hayes and Cathy Hayes at the Yerkes Laboratories of Primate Biology. After a very extended training period their chimpanzee could mouth four words: "Mama," "Papa," "Cup" and "Up." The words were uttered in a hoarse whisper and frequently misapplied.

Suffering Catfish!

An air-breathing "walking" catfish that comes from Asia has apparently established itself in Florida. Although the state normally cherishes visitors, the catfish are unwelcome: they are well adapted to the climate and to both fresh and brackish waterways, and they are multiplying fast; they are aggressive and voracious; they can move overland, searching out new bodies of water and thus extending their habitat with exceptional facility and speed. Such visitors clearly create ecological problems, and for a time the Florida Game and Fresh Water Fish Commission hoped to find ways to eliminate the catfish. Now, the Associated Press reports, officials of the commission have given up. "They will be with us now as one of our fish," John W. Woods of the commission conceded. "How bad they will be is hard to say."

The fish were first reported about a year and a half ago in Palm Beach and Broward counties, moving south through the Everglades toward Miami. They looked like catfish but they could obviously survive for long periods out of water; they propelled themselves by their fins on land, even climbing uphill; there was a story that one had attacked a dog. The fish were soon identified as belonging to the genus *Clarias,* various species of which are natives of South Asia and Africa. In *Clarias* the gills are modified; air chambers extend up into the skull, each occupied by a "respiratory tree" that is richly vascularized for the exchange of oxygen and carbon dioxide between the air and the fish's blood. The auxiliary breathing organ enables the fish to stay out of water for 12 hours or more.

Commission investigators decided that a few specimens had simply walked away from some tropical-fish dealer's pond. At first they worried that the wandering catfish might be *Clarias lazera,* an African species that can reach a length of four or five feet. It has since been classified as *Clarias batrachus,* a native of India no more than two feet long. According to Woods, it is not known to attack dogs or people.



Many wastes can injure a water source. One major problem is organic pollution that is turning our lakes and streams into fishless and beachless swamps.

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Weather Satellites: II

In the seven years since they were first described in these pages they have made major contributions to meteorology. Now a satellite system surveys each day the weather patterns over the entire earth

by Arthur W. Johnson

Seven and a half years ago (in July, 1961) *Scientific American* presented an article by Morris Neiburger and the late Harry Wexler titled "Weather Satellites." The article was based on preliminary results from the first two satellites in a series developed and operated by the National Aeronautics and Space Administration under the name Tiros (Television Infrared Observational Satellite). The authors predicted, among other things, the establishment of a national weather-satellite system that would eventually provide daily photographic observations of the entire earth, together with other kinds of information useful in understanding patterns of weather and in making weather forecasts.

Here I shall briefly recount what has happened since then. I shall also describe plans for improving weather satellites to make them still more useful than they have already proved to be. Finally, like Neiburger and Wexler, I shall venture a few predictions about the future of weather observation by satellite.

Evolution of the System

It did not take long after the launching of the first Tiros in April, 1960, for it to become plain that the kind of information that could be gathered by satellites hundreds of miles above the earth would be highly useful in the daily observation of the weather. Several agencies of the U.S. Government—NASA, the Department of Commerce (which includes the Weather Bureau) and the Department of Defense—worked out plans for a system of satellites that would provide worldwide weather data for all interested users. By the end of 1961 Congress had passed at President Kennedy's request an act directing the Department of Commerce "to establish and operate a meteorological satellite system for the continuous observation of worldwide meteorological conditions from space satellites and for the reporting and processing of the data obtained for use in weather forecasting." The system is called the National Operational Meteorological Satellite System.

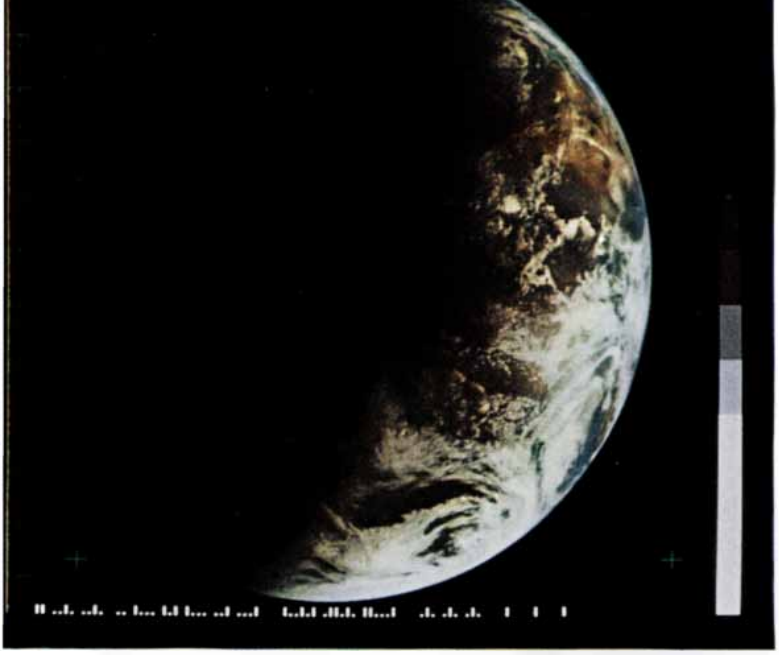
The three agencies that devised the system also drew up a list of objectives to be achieved during the first decade or so of operation. One objective was round-the-clock observation that by the end of each 24-hour period would have covered the entire surface of the earth; this objective incorporated the development of an automatic picture-transmission system that would enable photographs made by the weather satellites to be received at a number of stations on the ground. A second objective was continuous viewing of the atmosphere from satellites in synchronous orbit, that is, orbiting the earth at an altitude calculated to keep the satellite constantly above the same geographical area. The color photographs on the opposite page and on page 54 were made by such a satellite, which had an orbital position above the mouth of the Amazon River. A third objective was the making of quantitative measurements of such weather factors as temperature, pressure, humidity, wind direction and wind speed; the measurements would be used in computer-generated mathematical models of the atmosphere for highly sophisticated weather forecasting. As the reader will see, the first of the three broad objectives set for the National Operational Meteorological Satellite System has been largely attained, and much progress has been made toward the second one. A great deal must be done to realize the third.

During the early phase of the satellite system weather information was obtained from the Tiros vehicles, although they were intended as research satellites rather than as parts of an operational system. (From the beginning research and development satellites have been designed and operated by NASA, and the operational satellites resulting from the research and development programs have been the responsibility of the Environmental Science Services Administration in the Department of Commerce.) Useful as the early Tiros vehicles were, they left much to be desired from an operational standpoint. The reason was that satellite technology at the time fell far short of the requirements of the weather-satellite system.

For example, the first Tiros vehicles had their sensing equipment in the base and were so oriented in space that they occupied a fixed position with respect to the plane of their orbit. As a result the satellite could observe only about 20 percent of the earth's surface on any given day. Even when the sensors could acquire useful information, they were seldom pointing straight down at the earth, so that much painstaking geographic orientation and rectification of data were necessary to make the photographs and telemetric material from the satellites useful. Further difficulties arose from the fact that the orbits of the first Tiros vehicles were similar to the orbits of the man-in-space programs: they were inclined at 48 degrees to the Equator, so that the amount of surface they could observe was limited in terms of latitude. Later the inclination was increased to 58 degrees, allowing observation as far north and south of the Equator as about 65 degrees of latitude, but the observations were still made from an inconvenient angle and included considerable distortion.

Toward the end of the Tiros series, which continued until the launching of

COLOR PHOTOGRAPH OF THE EARTH from an altitude of 22,300 miles above the mouth of the Amazon River was made on November 18, 1967, by a weather satellite. South America is near the center of the photograph; the western bulge of Africa can be seen near the right edge of the photograph, and the southern part of the U.S. is at top left. The Applications Technology Satellite, a research spacecraft developed by the National Aeronautics and Space Administration, was in a synchronous orbit, meaning that it stayed above the mouth of the Amazon. Six photographs made by the satellite at various times of the same day are on the next page.

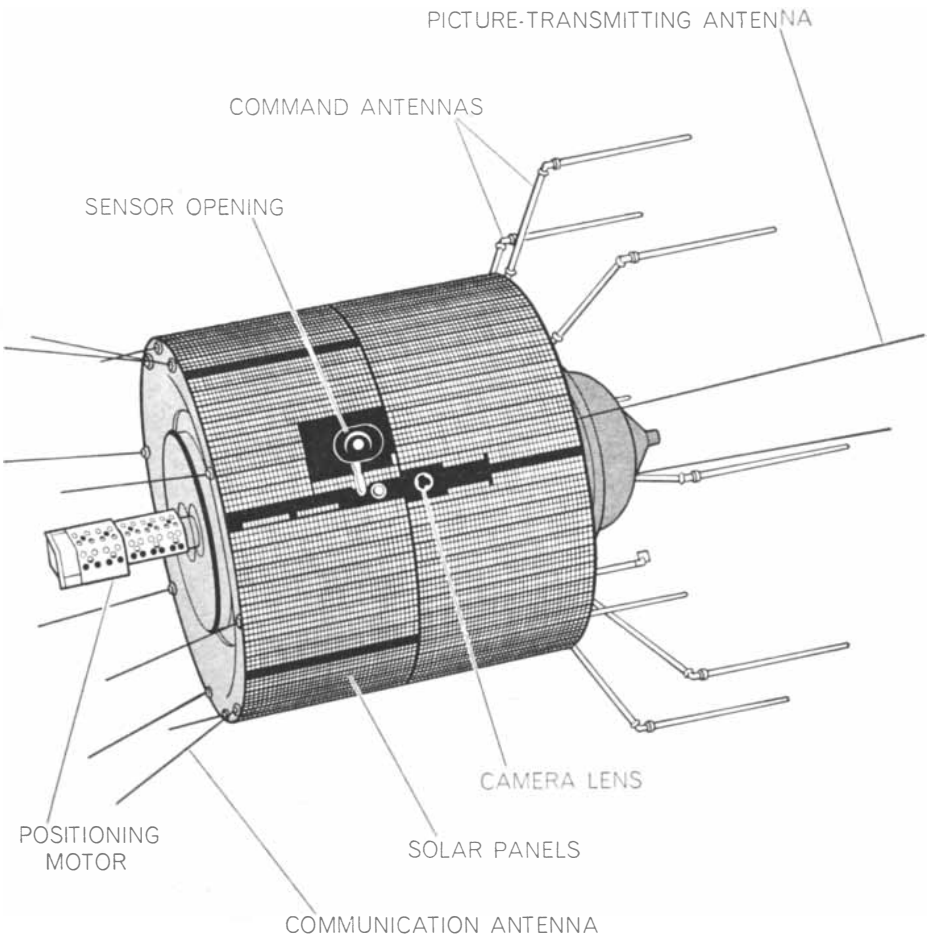


Tiros X in the summer of 1965, the satellite was redesigned to put the sensing equipment on the side of the vehicle. Thereafter, as the satellite rolled along its orbit in an orientation to the earth like that of a wheel to a road, the data were acquired only when the sensors pointed directly at the earth. Advances in technology also made it possible to launch the satellites into orbits that were nearly polar and nearly synchronous with the apparent movement of the sun; hence observations were made over a given area at the same sun time each day. The optical system was designed so that observations overlapped from orbit to orbit, making it possible to attain the objective of daily global coverage.

An Operational System

With the gradual evolution of the satellites, the Tiros Operational System was established as the first national weather-satellite system. To achieve the first stated objective—global coverage—a minimum of two satellites must be in operation at all times. Part of the reason is that the satellites have separate functions, a matter to which I shall return below. Moreover, each satellite is designed to provide redundancy: if a component fails, a corresponding component can be substituted. Limitations in space, weight and power have so far made it impossible to include all these features in a single satellite. A two-satellite operational system has now been in continuous service since the launching in February, 1966, of the successors to the Tiros series, the satellites that go by the name of Essa, which applies to both their function (Environmental Survey Satellites) and their operating agency (the Environmental Science Services Administration). When it becomes apparent that a satellite in the system is nearing the end of its usefulness, another one is launched; so far eight Essa vehicles have been put into operation.

When a two-satellite system is operating normally, each satellite has a somewhat specialized function. One of the satellites provides an advanced Vidicon camera system; in response to commands from the ground the system records on magnetic tape data over the entire earth for readout at appropriate times to either of two ground stations. From the ground stations the data are relayed to the National Environmental Satellite Center near Washington for processing. The other satellite is the automatic picture-transmission satellite; in most latitudes it can transmit photographs from three successive orbits to rather simply equipped ground stations. If satisfactory communication systems exist, ground stations that are widely separated but at approximately the same latitude (such as San Francisco and Washington) can be connected so that the coverage at both of them is extended to include data from as many as six or seven orbits. More than 400 ground stations for receiving weather-satellite photographs are now operated by national meteorological services, television stations and private users in more than 40 countries. The system has also become an important part of the American contribution to the World Weather Watch system being developed by the World Meteorological Organization, an agency of the United Nations.



APPLICATIONS TECHNOLOGY SATELLITE of the type that made the color photographs from a fixed orbital position above the mouth of the Amazon River includes an antenna array in dome at right. Positioning motor is jettisoned when satellite begins operation.

SINGLE DAY'S cloud patterns as photographed by the satellite over the Amazon appear on the opposite page. Reference marks on the photographs include a color bar, a time code (*bottom*) and a line counter (*left*) for the scanning technique by which the pictures were transmitted to the ground. The camera used three photomultiplier tubes sensitive respectively to red, green and blue light; signals they sent to the ground provided basis for the color photographs.

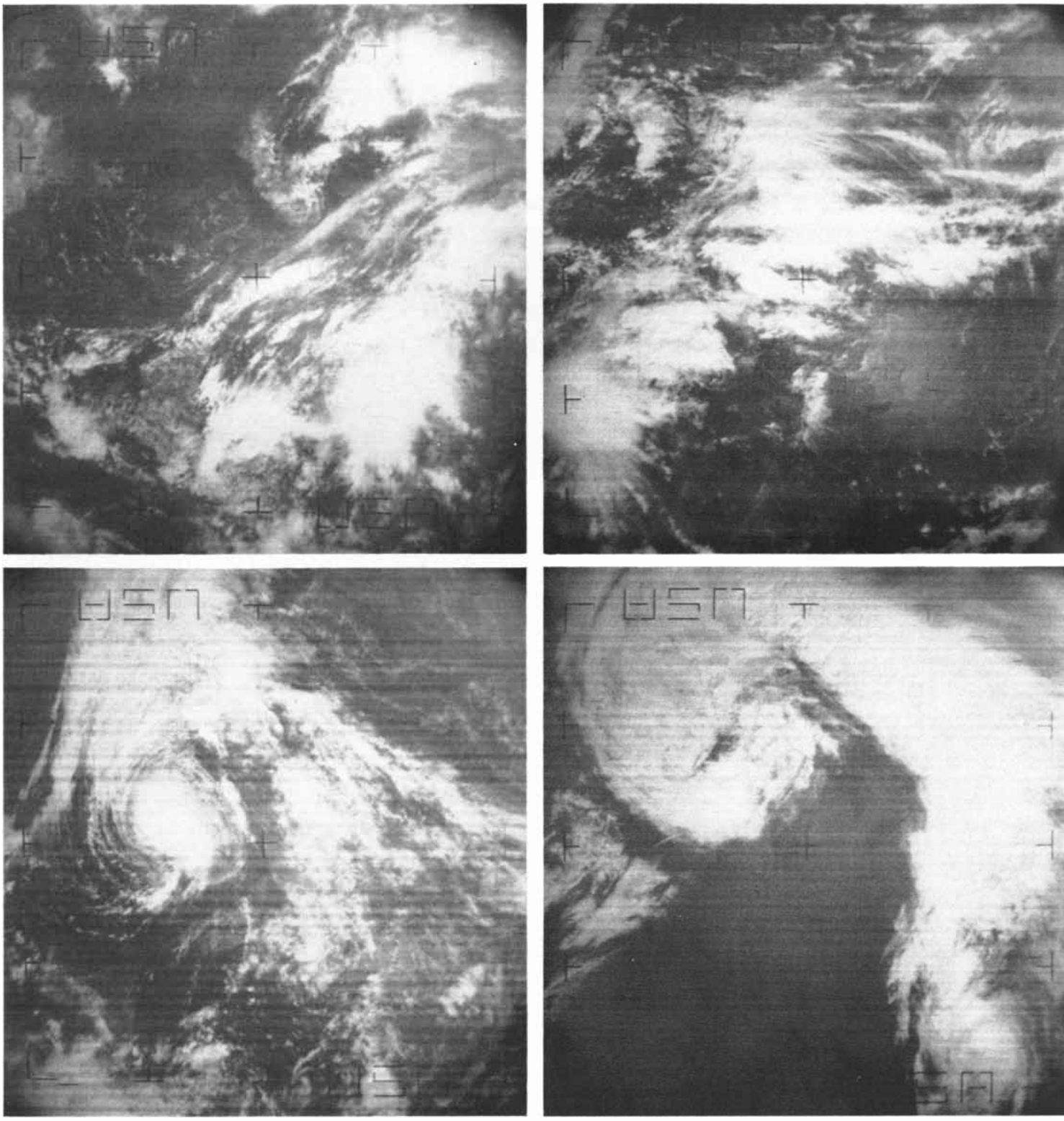
Needs and Capabilities

The preparation of a weather forecast requires an adequate description of the state of the atmosphere over the entire earth, or at least over the hemisphere of particular interest, at a given time. A major ingredient in any forecast, therefore, is enough observations. Unfortunately the earth and its atmosphere cannot be observed adequately by what are now called conventional means: weather stations on the ground, ships at sea and aircraft in flight. They cover no more than 20 percent of the earth, leaving great gaps over large areas of water and remote land masses.

Satellites provide total coverage of the surface, although they cannot yet match the conventional means in obtaining such information as wind speed and direction, atmospheric pressure, temperature, humidity and precipitation. A

considerable effort is now under way to improve the capabilities of satellites in obtaining such information. To say this, however, is not to detract from the substantial contributions the satellites have already made to meteorology.

A case in point is the capability satellites have provided for analyzing and following tropical storms. The top photograph on page 63, made by *Essa 3* on September 6, 1967, shows Typhoon Opal, which was at the time about 1,000 miles southeast of Japan. The eye of the storm is clearly discernible. Bands of cloudiness spiral inward to the eye, where the lowest atmospheric pressure in the storm is found. Such spiral bands are known to be characteristic of tropical storms. The form and definition of the bands can be used to estimate the location of a storm's center even when the position of the eye is not apparent. On the basis of considerable experience in interpreting satellite photographs of tropical storms it is now possible to look at photographs and make reasonable estimates of the maximum wind speeds being generated by a storm. For these reasons photographs from satellites have proved valuable in detecting storms in

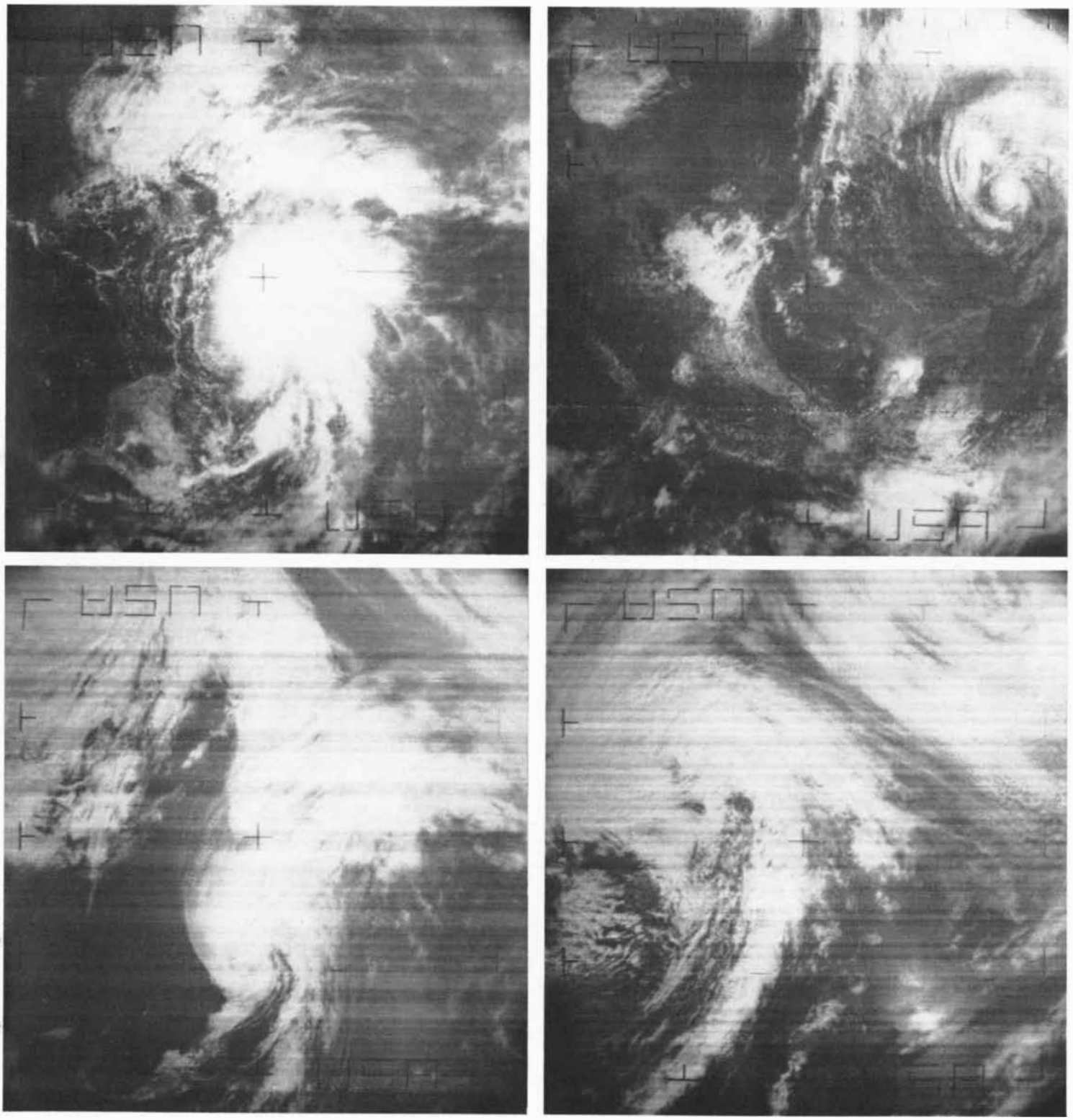


HURRICANE GLADYS, which caused severe damage in Florida and along the Gulf Coast last October, was tracked by the two satellites the Environmental Science Services Administration keeps in polar orbit for obtaining photographs of weather patterns over the

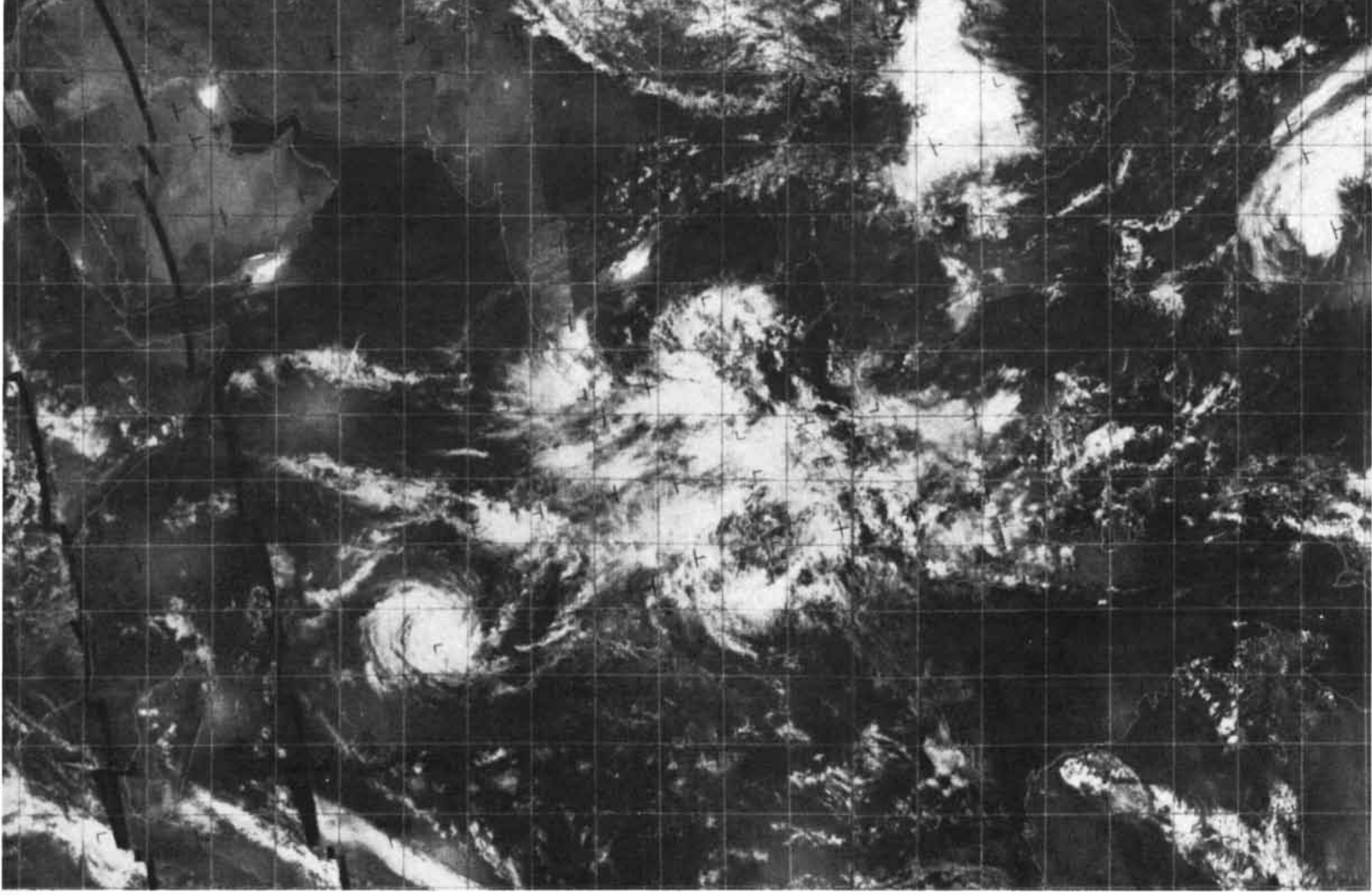
remote areas, planning aerial reconnaissance of such storms and issuing warnings to aviation and shipping firms and the public. A series of satellite photographs made it possible to keep a close watch on Hurricane Gladys, which struck Florida severely three months ago [*see illustrations on these two pages*].

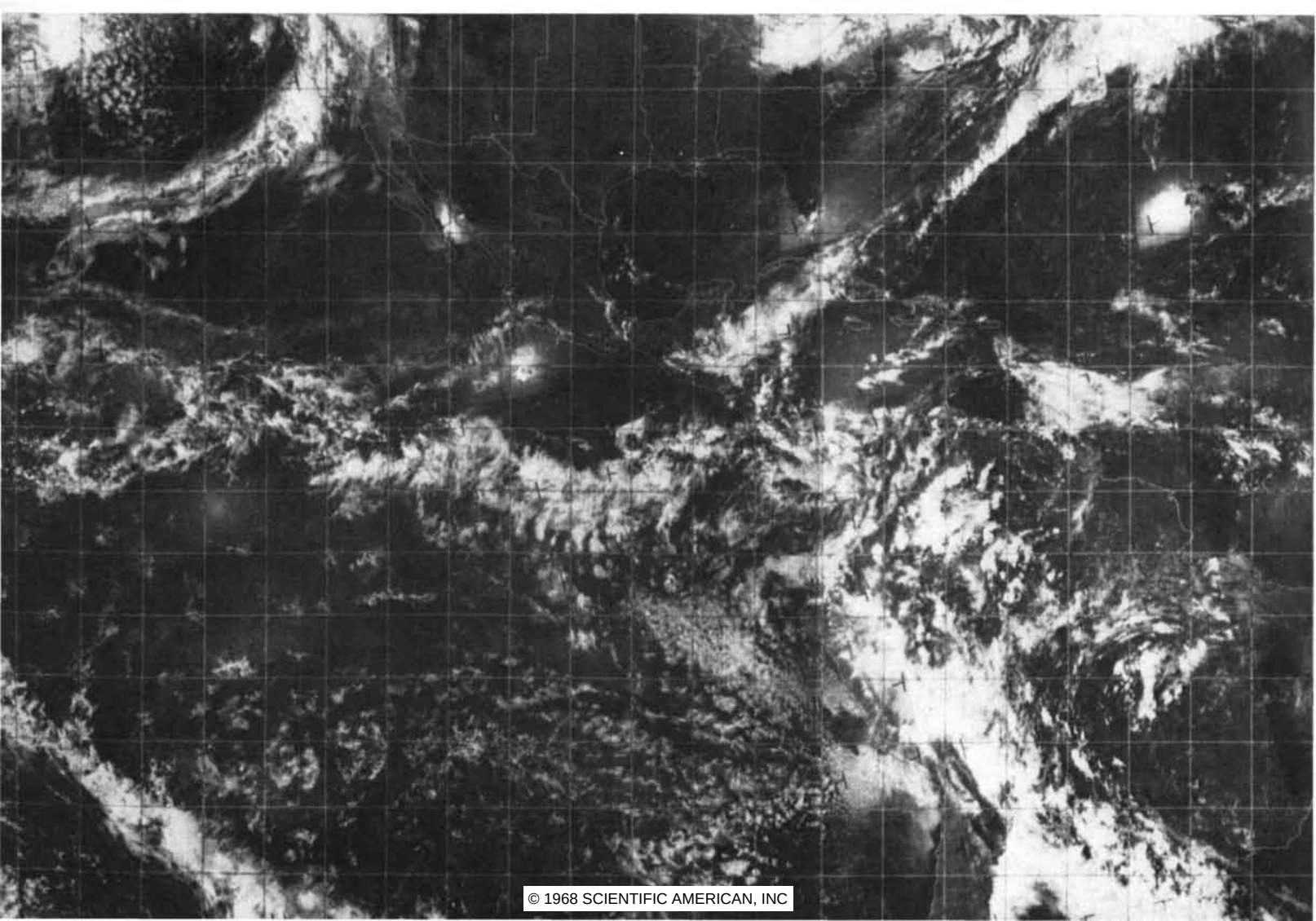
From satellite photographs it has also become possible to detect the jet streams visually: the zones of strong and highly turbulent winds that are of major concern to the aviation industry [*see bottom illustration on page 63*]. High cirrus clouds terminate at the edges of a jet stream. When sunlight falls on these clouds at a certain angle, they cast a strong shadow on the clouds below. The shadow reveals the location and course of the jet stream.

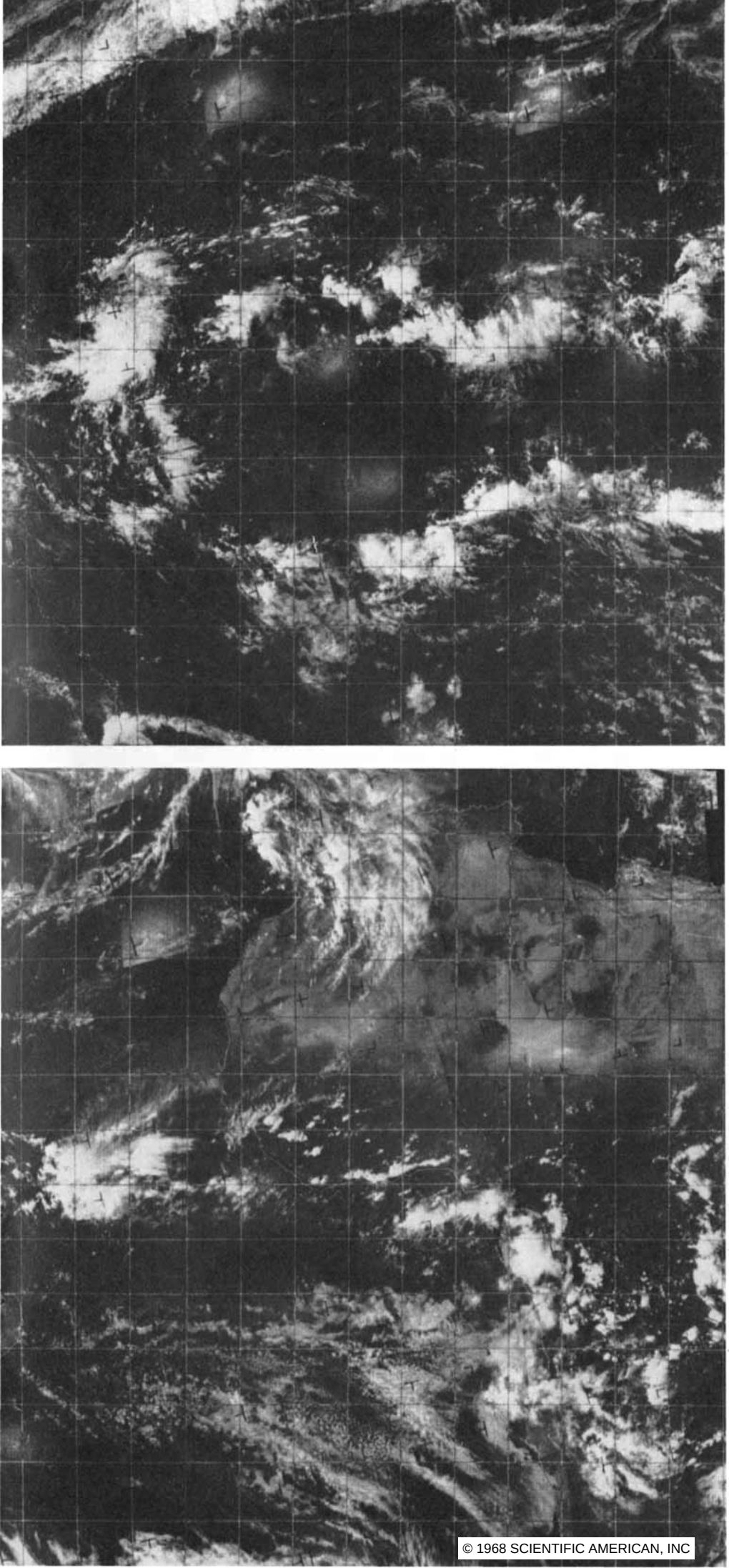
Snow cover and sea ice can be readily identified in satellite photographs [*see top illustration on page 67*]. The appearance of snow cover varies with the nature of the terrain, the extent of forests and the depth of the snow. It is now possible to prepare from satellite photographs charts of snow and ice distribution for both the Arctic and the Antarctic regions. The charts are made



entire earth during the course of a day. At top left the hurricane is shown as it appeared on October 14; it was then over the Caribbean Sea near Cuba. The remaining photographs, reading from left to right, show the daily development of the storm through October 21.







available to shipping interests in the U.S. and other countries. Icebreakers that encounter difficulties in moving can modify their course on the basis of advice provided by analysts in Washington. Another benefit of the photographs in polar regions is in planning for detailed aerial mapping. Potentially costly airplane flights have been avoided when satellite photographs revealed unfavorable weather conditions; the savings have exceeded $100,000 in a single season of Antarctic mapping.

Although the automatic picture-transmission system was originally designed for local weather forecasting, the area covered in the photographs received by a single ground station is so extensive that the information can be put to broader use. One such use is in the preparation of the weather charts required for international flights over water. Until recently such charts were based on observations made from aircraft and surface stations; a chart showed the weather at the surface and provided a "best guess" of the vertical and horizontal distribution of clouds. Now photographs from weather satellites can provide chart-makers with up-to-date information on clouds. The crews on international flights have reacted enthusiastically to the charts thus prepared.

Technological Considerations

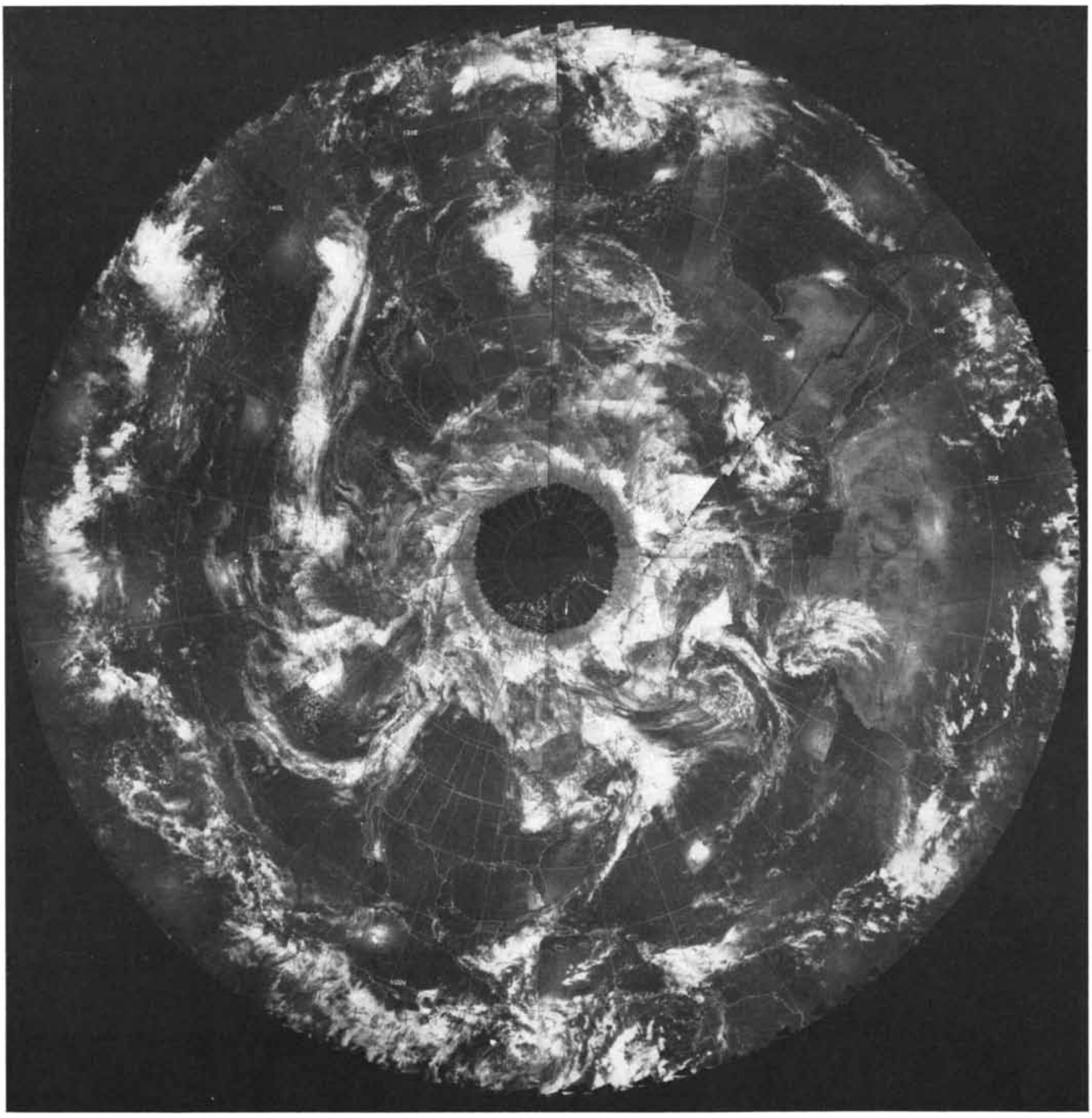
Photographs made by a satellite are transmitted to the ground by means of a scanning procedure. On the ground the photographs from satellites equipped for automatic picture-transmission are printed line by line at the local stations within range of the transmission. Photographic data reaching the ground from a satellite equipped with an advanced Vidicon camera system are recorded on magnetic tape at sophisticated command and data acquisition stations and sent by wire to the satellite center near Washington. There the picture signals are displayed on a kinescope a line at a time

GLOBAL WEATHER PATTERNS for a single day are obtained by computer processing of photographs made by polar-orbiting satellites in the U.S. operational-satellite system. These photographs encompass the region along the Equator from 35 degrees south latitude to 35 degrees north latitude. The day was October 29, 1968. Of particular meteorological interest was the circular cyclonic disturbance over the Indian Ocean southeast of the Arabian Peninsula, which is at upper left in the upper photograph.

and recorded on 35-millimeter film. When the recording of a single photograph on a frame of 35-millimeter film has been completed, precomputed latitude and longitude lines and other geographical information pertinent to the area of coverage are superposed on the film, together with a legend giving the date and time of the photograph and other relevant information.

Every day the data for the entire earth are processed by high-speed computer into three projections that show the day's weather pattern over the globe [*see illustrations below, on opposite page and on preceding two pages*]. Two polar stereographic projections show respectively the Northern and Southern hemispheres. A Mercator projection shows the tropical region from 35 degrees north latitude to 35 degrees south latitude. The processing techniques employed to achieve this kind of presentation require the most powerful and sophisticated computer facilities currently available.

The camera system that produced the color photographs, which were made only from a satellite in the development series known as Applications Technology Satellites, incorporated three light detectors of the photomultiplier type. They were respectively sensitive to wavelengths characteristic of the colors red, green and blue. On the ground the output of the three tubes was recorded on color film. The resulting photographs are beautiful and fascinating to study, but from a meteorological standpoint it is not certain that they provide enough in-



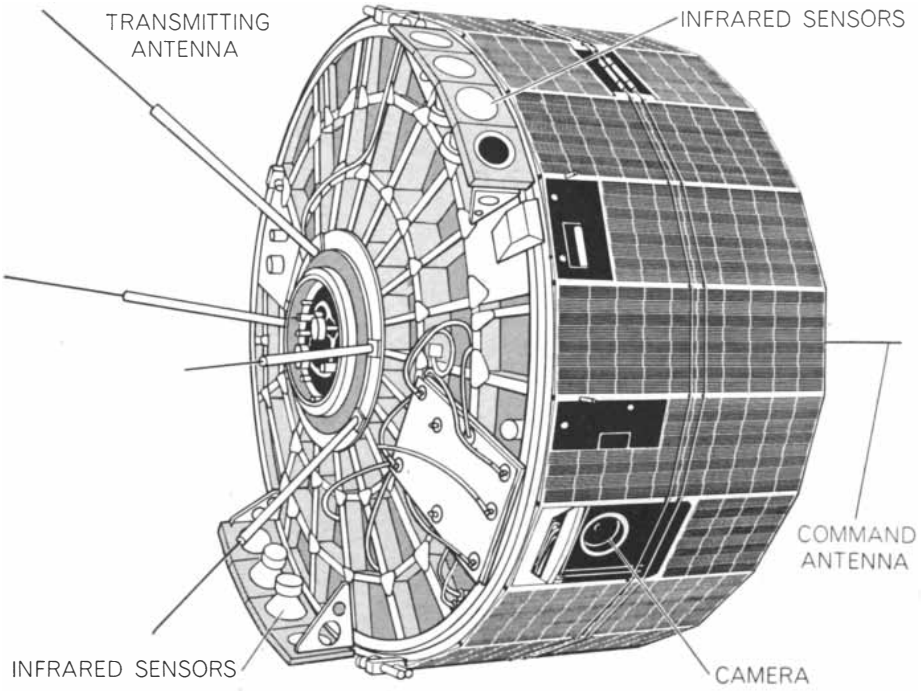
NORTHERN HEMISPHERE on October 29, 1968, appears in computer-produced mosaics of photographs made during the day by a satellite in polar orbit. Circular pattern of clouds at left center, off U.S. West Coast, is type that generates jet streams.

formation beyond what can be obtained from black-and-white photographs to warrant the extra cost of the color technique for routine use. No decision has been made to include a color capability in any future operational weather satellite.

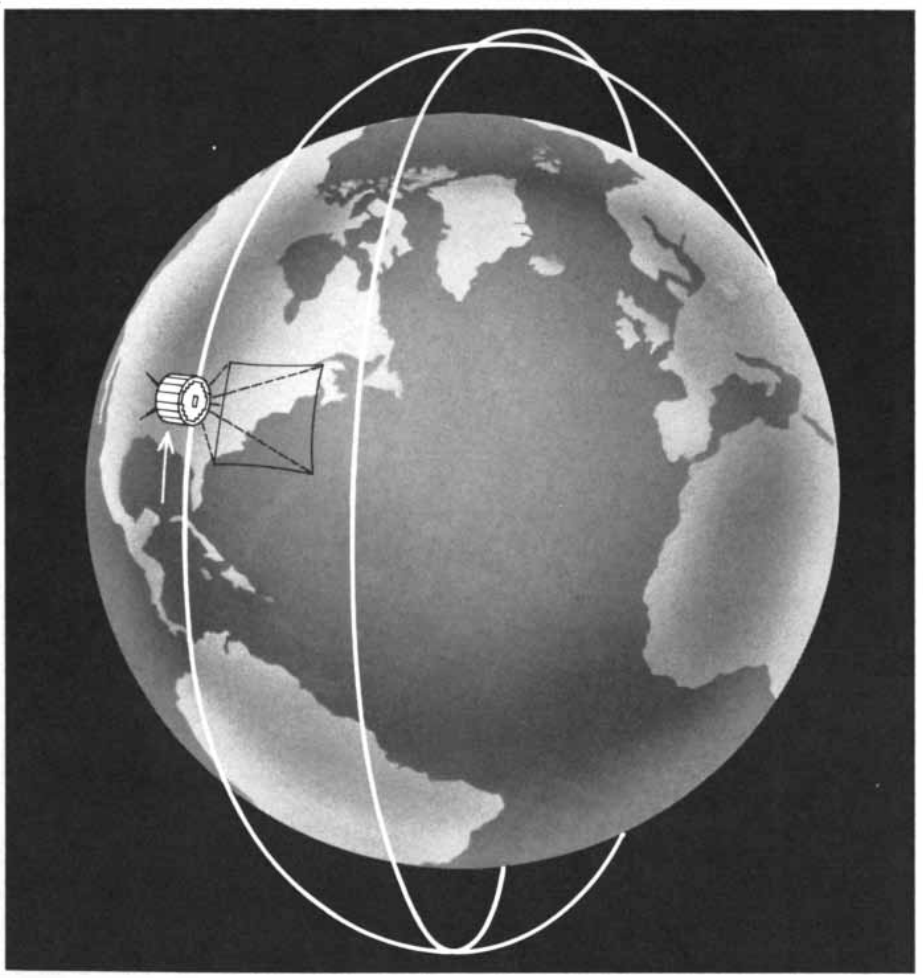
Early in the era of weather satellites it became necessary to devise a simplified, schematic means of presenting the observed data, because adequate communication networks for the distribution of photographs did not exist in many parts of the world and could be established only at prohibitive cost. The schematic presentation that was worked out is called nephanalysis (from the Greek word *nephelē*, meaning cloud). A nephanalysis looks rather like a weather map published in a newspaper, except that it contains a number of additional symbols to incorporate the kind of data that can be provided only by satellites. This type of analysis has been made available to weather stations connected to the U.S. facsimile network and can be transmitted internationally by U.S. Government broadcasts from New York and San Francisco. Techniques of data presentation currently being developed will soon replace the nephanalysis as it is now known with a system that displays more of the actual pictorial data.

In the Neiburger-Wexler article considerable emphasis was placed on the acquisition of certain types of information about radiation for use in calculations of the earth's heat budget. Since the ultimate source of energy for the

SOUTHERN HEMISPHERE on the same day showed conspicuous mantle of snow and ice overlying Antarctica (*center*) and cyclonic disturbance at lower right. The computer added the grid lines and outlines of the continents in assembling the mosaic.



WEATHER SATELLITE of the kind now in service in the National Operational Meteorological Satellite System is called Essa for Environmental Survey Satellite and for the operating agency, the Environmental Science Services Administration. The camera lens is on the side because the satellite orbits in a wheellike orientation to the earth. Photographs are made when camera points directly toward ground. The solar cells provide power.



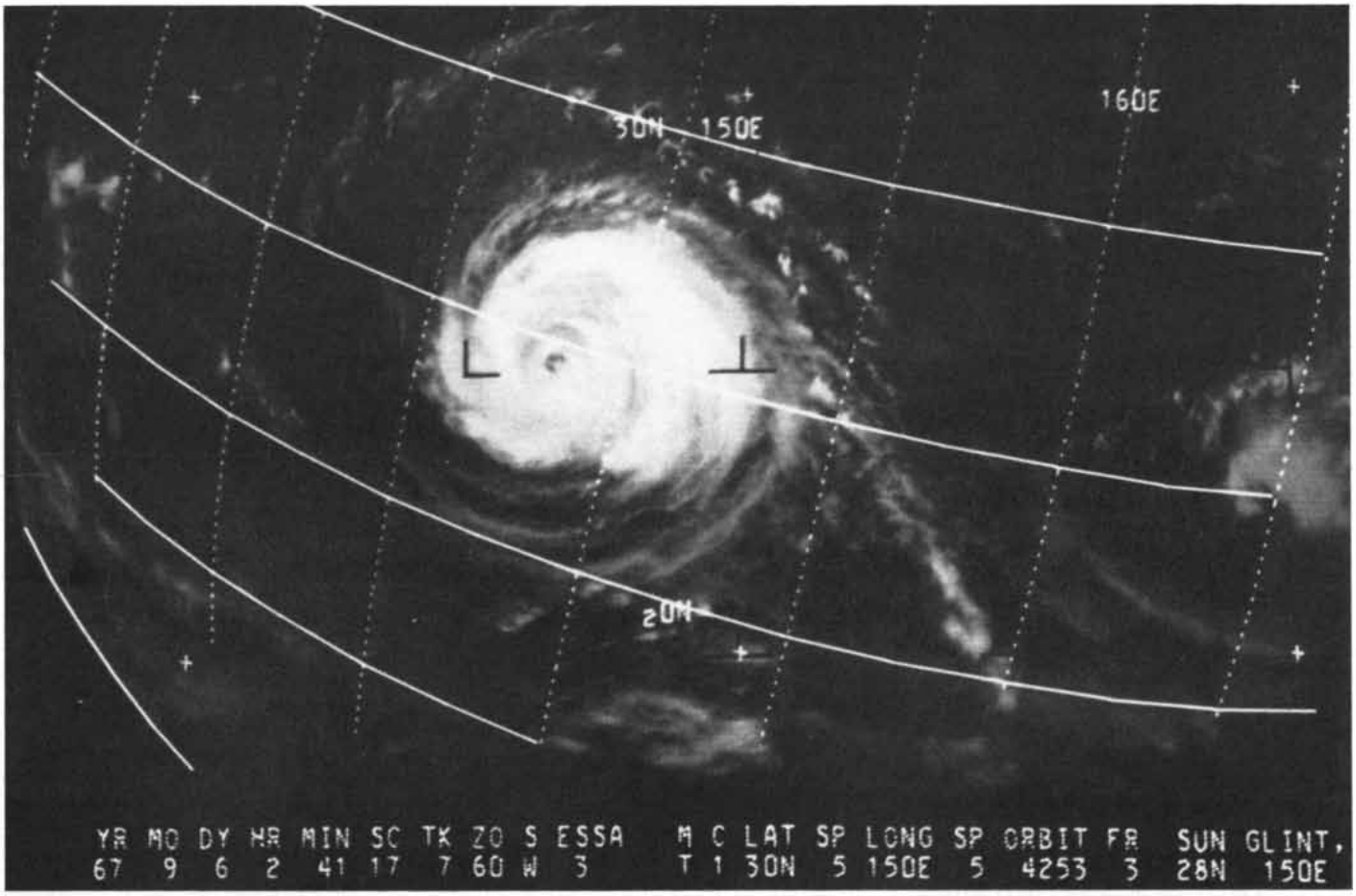
ORBITAL PATH of the Essa satellite is arranged so that the spacecraft is synchronous with the apparent movement of the sun. If the time at the Equator on a given orbit (*right*) is 3:00 P.M. when the satellite passes over the Equator, the time below the satellite when it completes a full orbit (*left*) and again crosses the Equator will once again be 3:00 P.M.

earth is the sun, it is necessary to know the amount of incoming and outgoing radiation in order to determine the effect of the radiation on the large-scale circulation processes of the atmosphere. Radiometers of several types have been carried on 10 weather satellites. Unfortunately the radiometers have varied considerably in their reaction to the space environment, so that they have not yet provided a basis for completely reliable computation of heat exchange. It has been possible, however, to relate information from the radiometers to large-scale cloud features and to employ it in calculations of albedo, or reflectivity. The calculations have indicated values of albedo quite different from those that had been derived from other computations. Not enough information has been obtained so far to resolve the discrepancy.

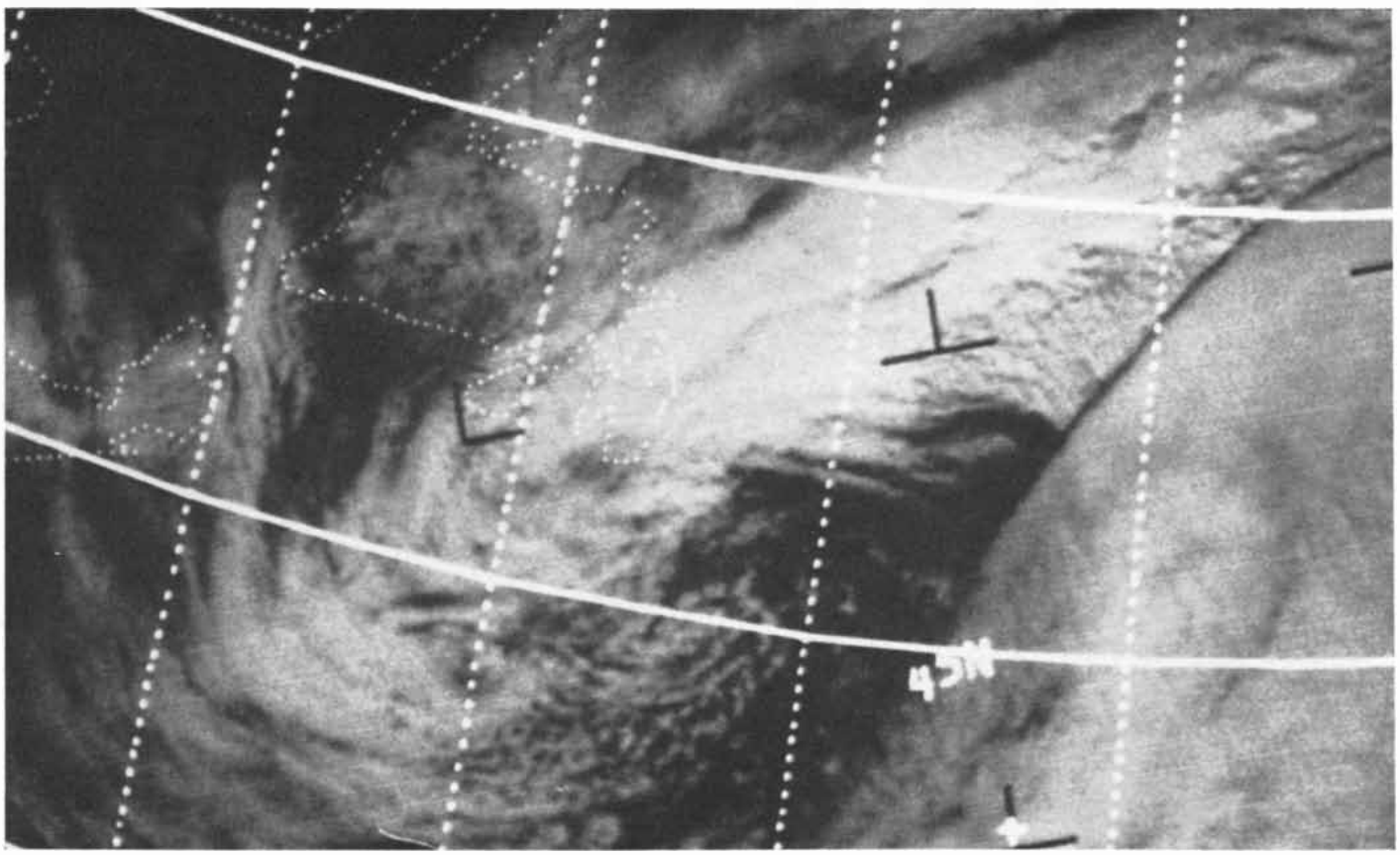
Areas of Research

The operational-satellite system as it now exists goes a long way toward meeting the first objective of the satellite system—daily global coverage—but it provides no capability for meeting the objectives of continuous viewing of the atmosphere from earth-synchronous satellites and measurement of weather factors other than cloud distribution. As a result NASA is at work on the development and testing of the next generation of weather satellites. The first satellite of the new generation will be launched this spring or summer. It will be known as *Tiros M* and will be the prototype for the Improved Tiros Operational Satellite System. *Tiros M* will be larger than the operational satellites now in service, will carry additional sensors such as one to measure the flux of protons from the sun and will have room for still more sensors that may be devised as a result of research now in progress.

A particularly valuable series of satellites in NASA's program of research and development has been the Nimbus series. Among other things, the Nimbus satellites have proved the capabilities of the camera systems now in operational use and the technique of automatic picture-transmission. Perhaps even more important in the long run will be the demonstration by Nimbus of the value of sensing in the infrared region of the electromagnetic spectrum. The demonstration showed that with infrared techniques observation at night is as feasible as observation in daylight [*see illustration on page 68*]. As a result the satellites in the Tiros M series will carry high-



TYPHOON OPAL was photographed by *Essa 3* on September 6, 1967. The storm was over the Pacific Ocean about 1,000 miles southeast of Japan. It shows a cloud pattern characteristic of tropical storms. In this case the eye of the typhoon is unusually distinct.

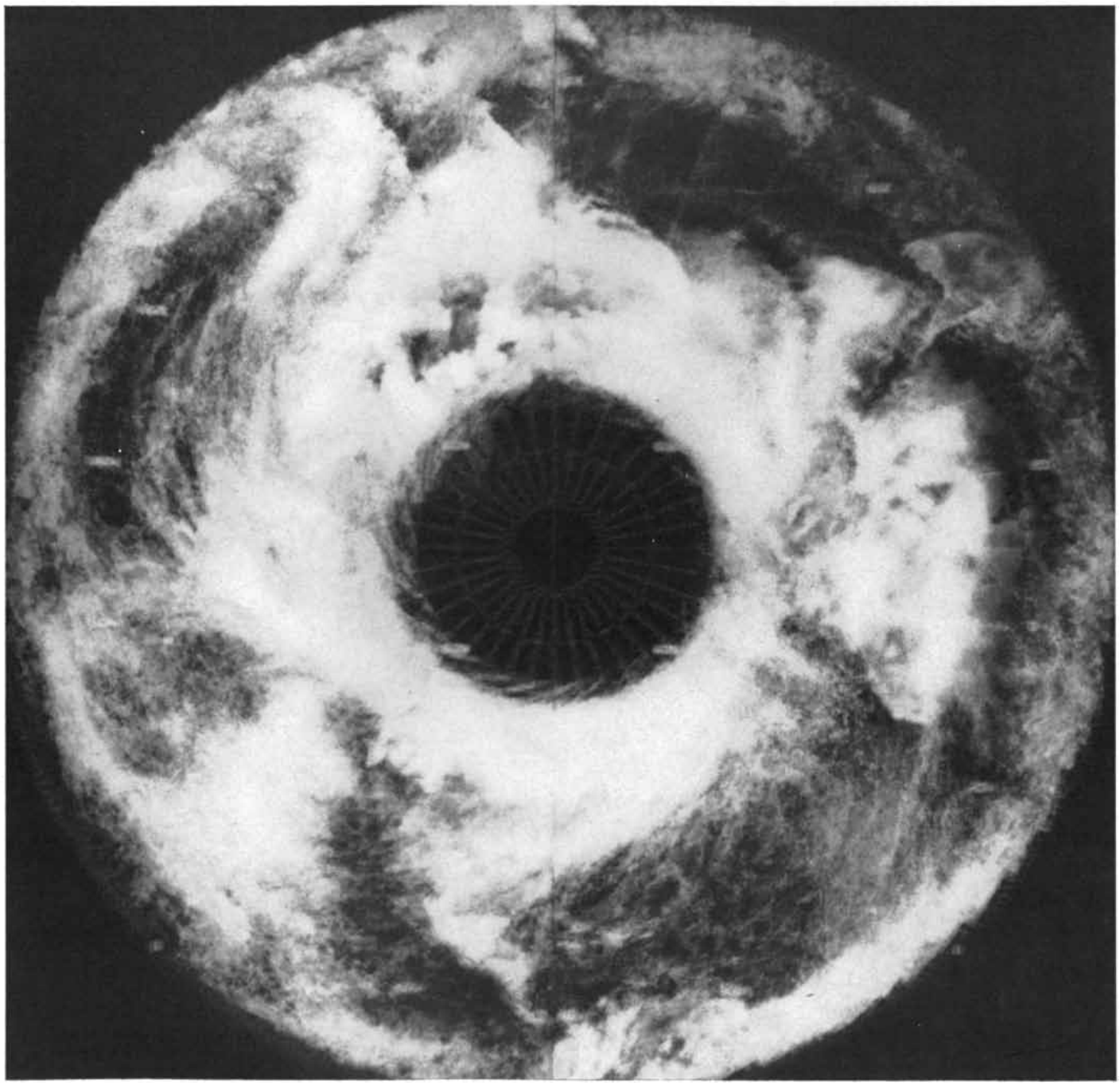


JET STREAM of strong and turbulent winds is indicated by the thin dark line curving along the right side of the photograph. The stream is made visible because high cirrus clouds terminate at its edges, and when sunlight strikes the clouds at a certain angle, a shadow falls on the clouds below, delineating the boundary of the stream. This jet stream was photographed near Newfoundland.

resolution infrared sensors, which will provide the nighttime observation required by the first objective of the weather-satellite program but not available from the present operational system.

Data obtained with high-resolution infrared sensors can be interpreted in terms of temperature, because the intensity of the energy received at the sensor, and later relayed to the ground, increases with the temperature of the object being viewed. With this kind of data the subjectivity that is now inescapable in the determination of cloud types by interpretation of satellite photographs will be decreased somewhat, since knowledge of the temperature of a radiating surface such as the top of a cloud makes it possible to infer the height of the cloud tops accurately. Such information is valuable not only for the determination of cloud types but also for analyzing the kind of weather system shown in the satellite pictures.

Studies of the uses of infrared sensing are continuing. One of the newer and more promising applications is in oceanography. Infrared sensing makes it possible to determine the location of ocean currents; more important, through analysis of data from successive days it provides information on the direction of the currents. On the basis of infrared data from satellites the Environmental Science Services Administration has prepared colored, maplike charts of ocean temperatures. By incorporating high-resolution infrared radiometers in the Tiros M series it will be possible to provide such charts several times weekly—even daily if such frequency should prove desirable and the ocean area of interest is largely free of clouds. It is also possible to determine by satellite the in-

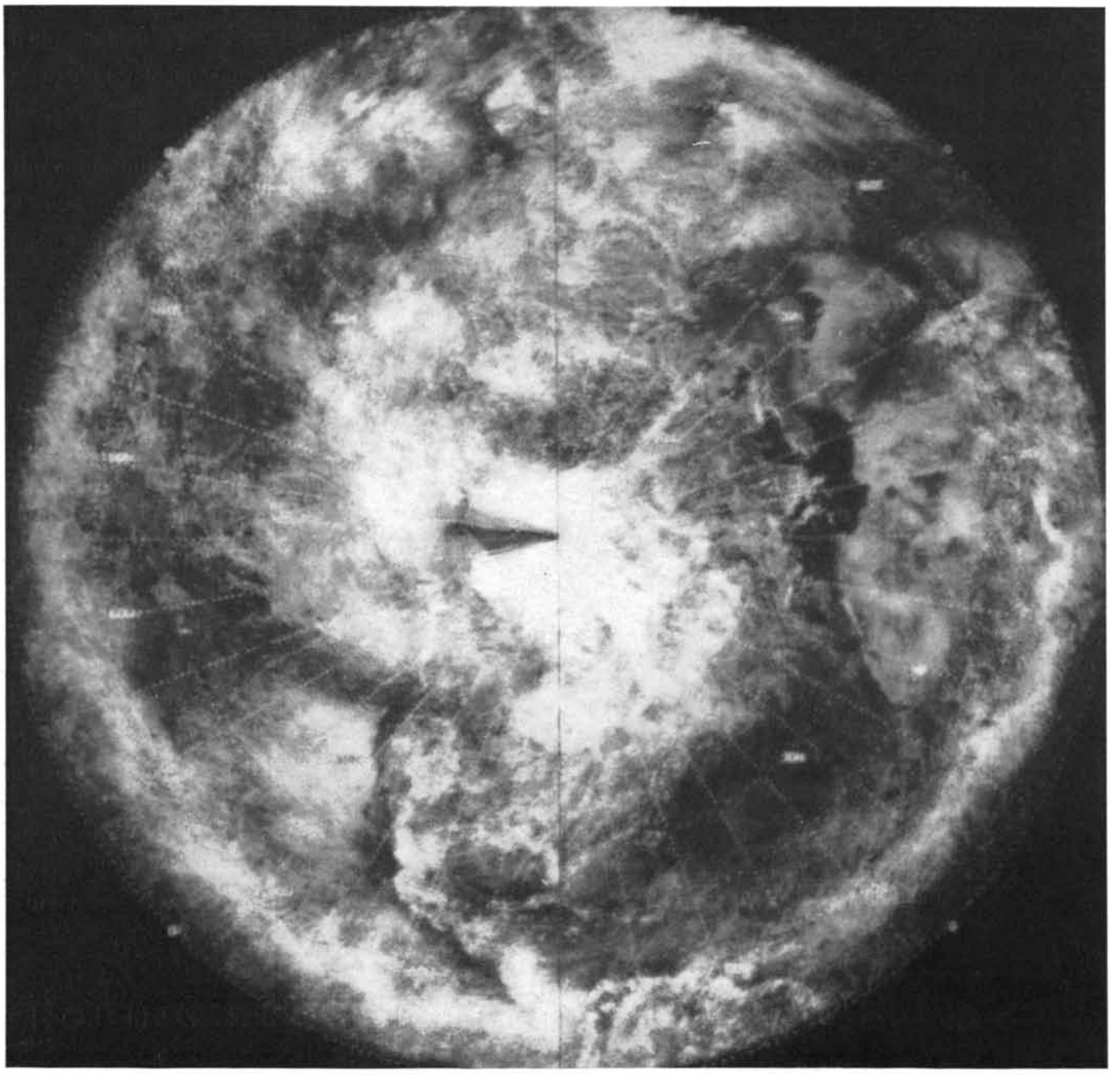


WINTER PATTERN of clouds over the Northern Hemisphere during a two-week period in February, 1967, was obtained by making multiple exposures of daily mosaics of photographs from Essa satellites. North America is at bottom center. Region around the North Pole is dark because the sun does not shine there in February and there is no reflected light to be photographically recorded.

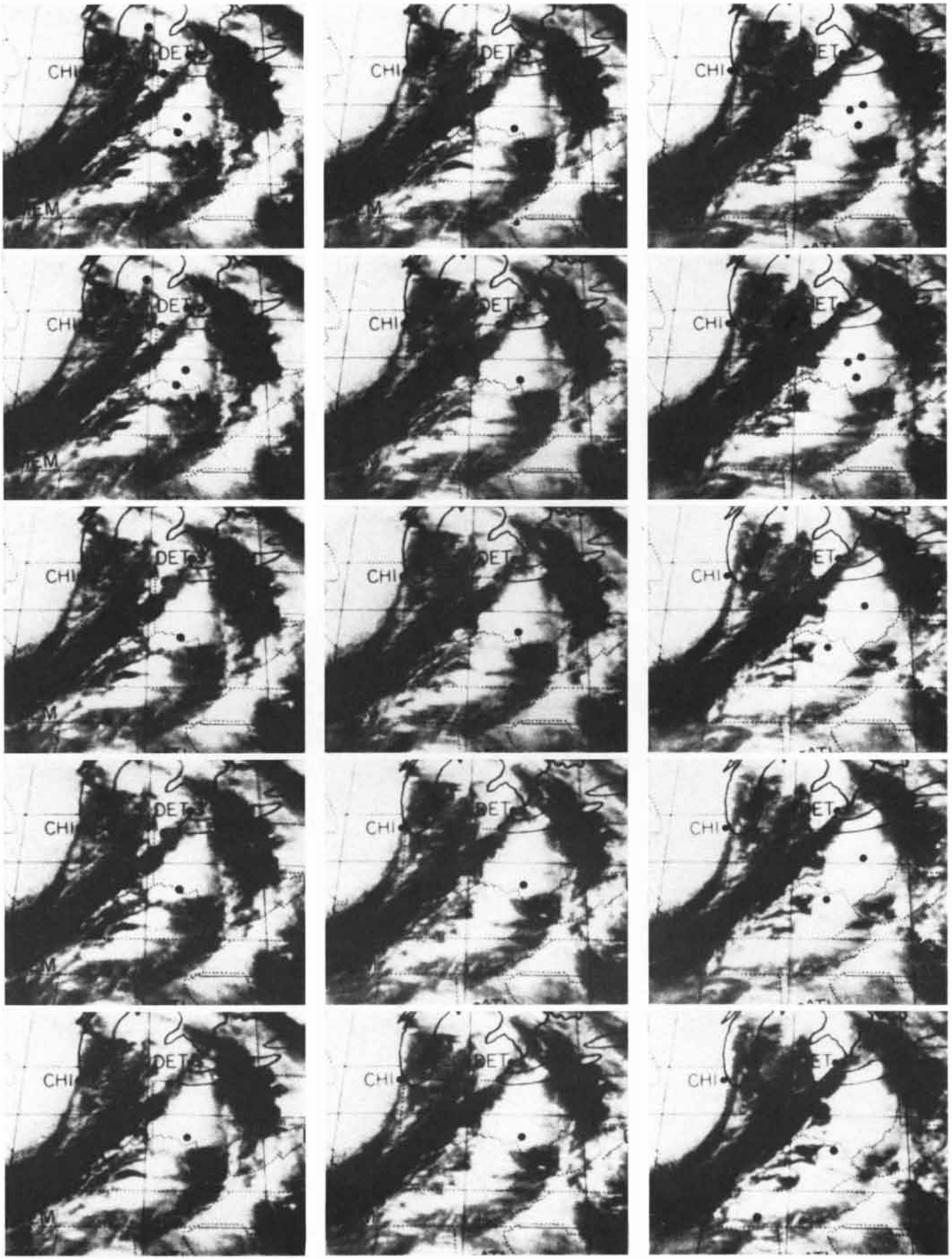
frared temperature of land surfaces. It is expected that in many instances the temperature pattern thus obtained will make it possible to distinguish clouds from snow and ice—a discrimination that is sometimes difficult in the interpretation of satellite photographs made at visible wavelengths. Knowledge of the distribution of snow would clearly be valuable for forecasts of water supply and floods.

One of the purposes of the Nimbus system is to test new sensors designed to measure the vertical distribution of temperature in the atmosphere. Present methods of weather prediction include the highly involved processing of equations of motion by computer. The equations require information based on the densest possible coverage of many weather factors, including not only spot temperature readings but also the vertical distribution of temperature. Techniques developed by the National Environmental Satellite Center and other groups provide for the measurement of temperature by spectrometer in the band of wavelengths centered on 15 microns and in the region between eight and 12 microns. Mathematical work on the measurements yields average temperatures for distinct layers of the atmosphere about 3,000 feet thick.

The spectrometer capability has been demonstrated in flights of high-altitude, constant-level balloons. The first spectrometer in a weather satellite was aboard the vehicle that would have become *Nimbus III* if it had not had to be destroyed during launch last May. A Nimbus spacecraft scheduled for launch early this year will also carry a spectrometer. We expect that the use of spectrometer data in mathematical models of the atmosphere will make possible the



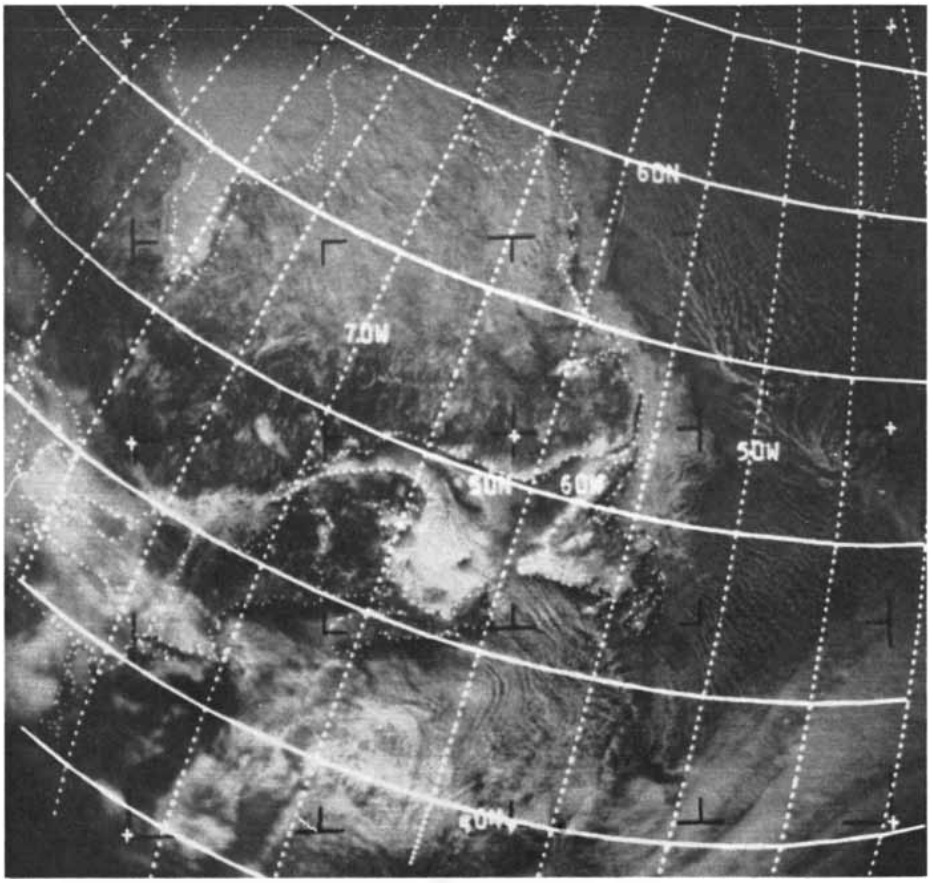
SUMMER PATTERN of clouds over the Northern Hemisphere is shown for a two-week period in July, 1967. Greenland is at right center; India, much more covered with clouds than in winter because of monsoons, is at top center. Multiple-exposure averaging technique was worked out by Jack Kornfield, A. F. Hasler and V. E. Suomi of the University of Wisconsin and K. J. Hanson of ESSA.



THUNDERSTORM AREA over the central part of the U.S. was photographed last April 23 by an Applications Technology Satellite. A number of photographs were marked with grids, abbreviated names of cities such as Chicago and dots to indicate where tornadoes appeared. The photographs were then assembled on a time-lapse motion-picture film so that the movement of the storms could be observed. These photographs are from the film. Aim of techniques is to see if conditions producing tornadoes can be identified.

improvement of weather forecasting to the extent that reasonably accurate predictions of large-scale weather patterns can be made as much as two weeks in advance.

Weather research is of course not limited to the U.S. Programs designed to increase knowledge of the atmosphere and to lengthen the period of time over which weather forecasts will be reliable are being organized jointly on a worldwide basis by the International Council of Scientific Unions and the World Meteorological Organization. Highly concentrated observation programs for certain areas are being planned for the next few years. Another international program is the bilateral space agreement between the U.S. and the U.S.S.R., which calls for an exchange of data from weather satellites over a direct communication circuit that now exists between Washington and Moscow. The U.S.S.R. has been sending television and radiation data over the circuit to Washington, with some interruptions, since 1966. Comparable U.S. data are provided over the circuit to Moscow on a daily basis. Here is a potential connection of the meteorological services of the two major powers and an example of the peaceful use of outer space on an international basis.

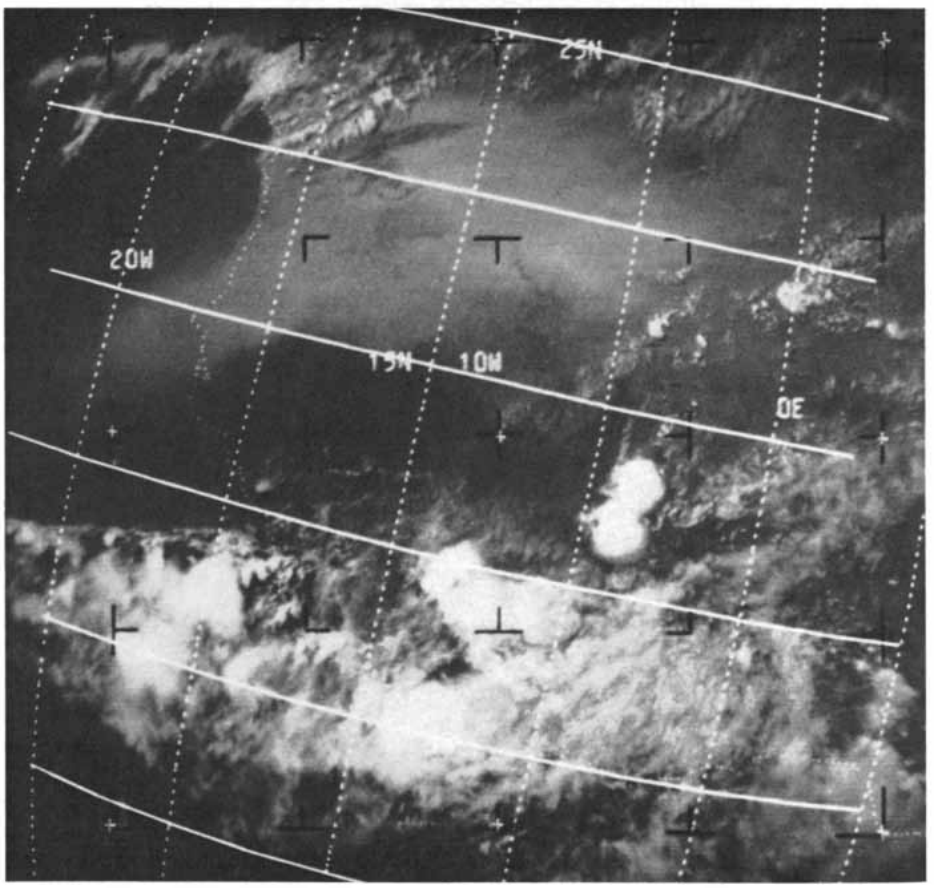


SNOW AND ICE cover of Newfoundland and Quebec is visible in a photograph made by *Essa 3* on February 19, 1967. The light area below and to the left of the notation "50N" is the ice in the Gulf of St. Lawrence and the St. Lawrence River. Hudson Bay is at upper left.

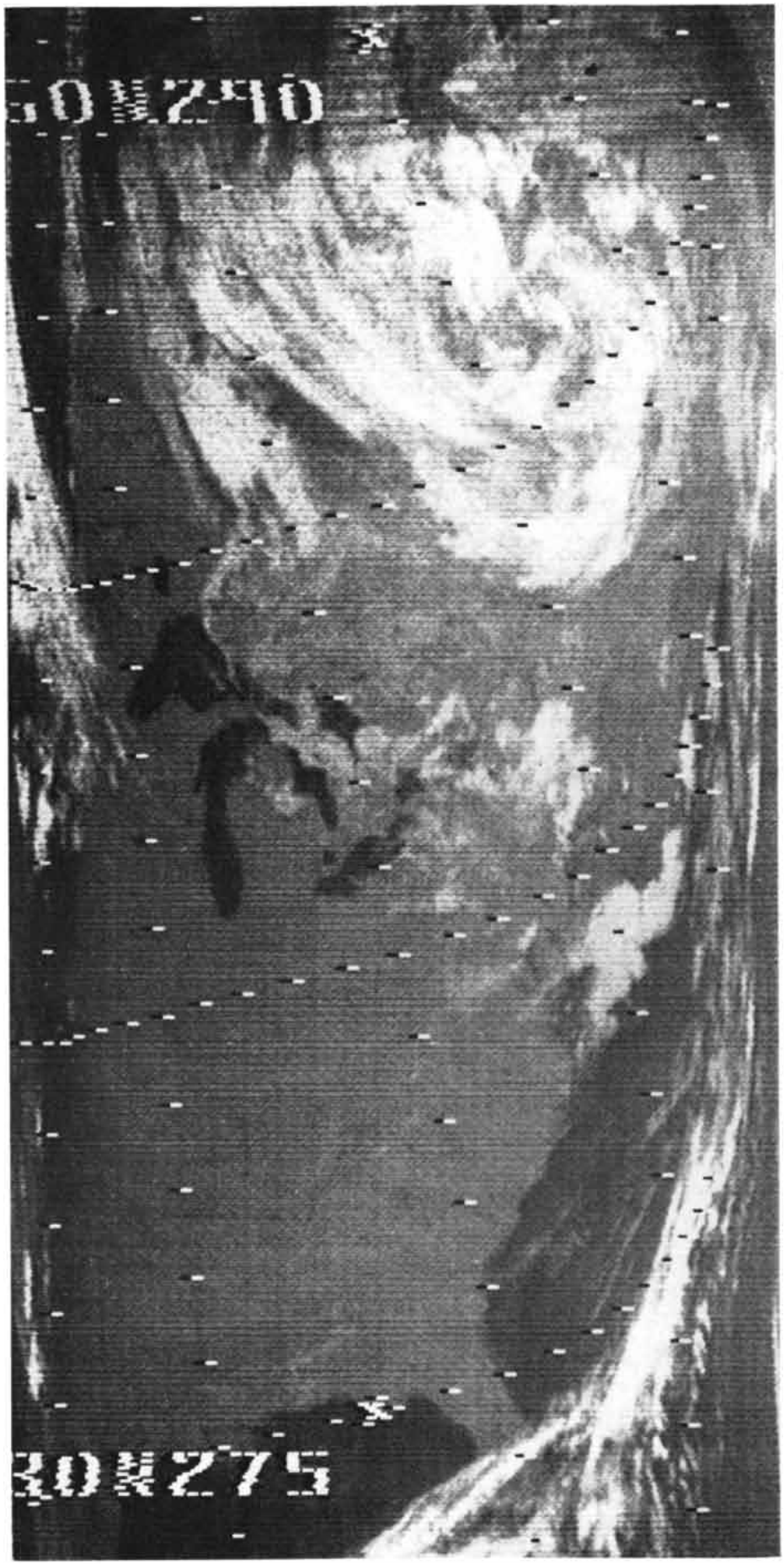
Prospective Developments

The Applications Technology Satellites, two of which are now operating, represent a particularly promising achievement in the weather-satellite enterprise. They are flown at an altitude of 22,300 miles, which means that their orbital period is 24 hours and synchronous with the earth's rotation. This type of spacecraft is a big step toward the fulfillment, at least during daylight hours, of the objective of nearly continuous viewing of the atmosphere. We hope that the resources will become available to establish an operational system of such satellites so that at least two of them can be kept in orbit at all times. With one of them stationed over the Atlantic and the other one over the Pacific, both could be operated by a single ground station in the U.S. Such a system is entirely feasible, and its design has been started.

Studies are in progress on the uses of the information that synchronous satellites can provide. We have prepared motion pictures in which data for an entire day, as received from a synchronous satellite, are shown in a brief sequence. Our hope is that it will be possible by means of such films to study the displacement of storm systems and cloud formations and thereby to determine wind speed



SANDSTORM over the Sahara was photographed by *Essa 5* on June 7, 1967. Storm can be seen over the Atlantic Ocean near "20W" and "15N" and extends some 3,000 miles eastward.



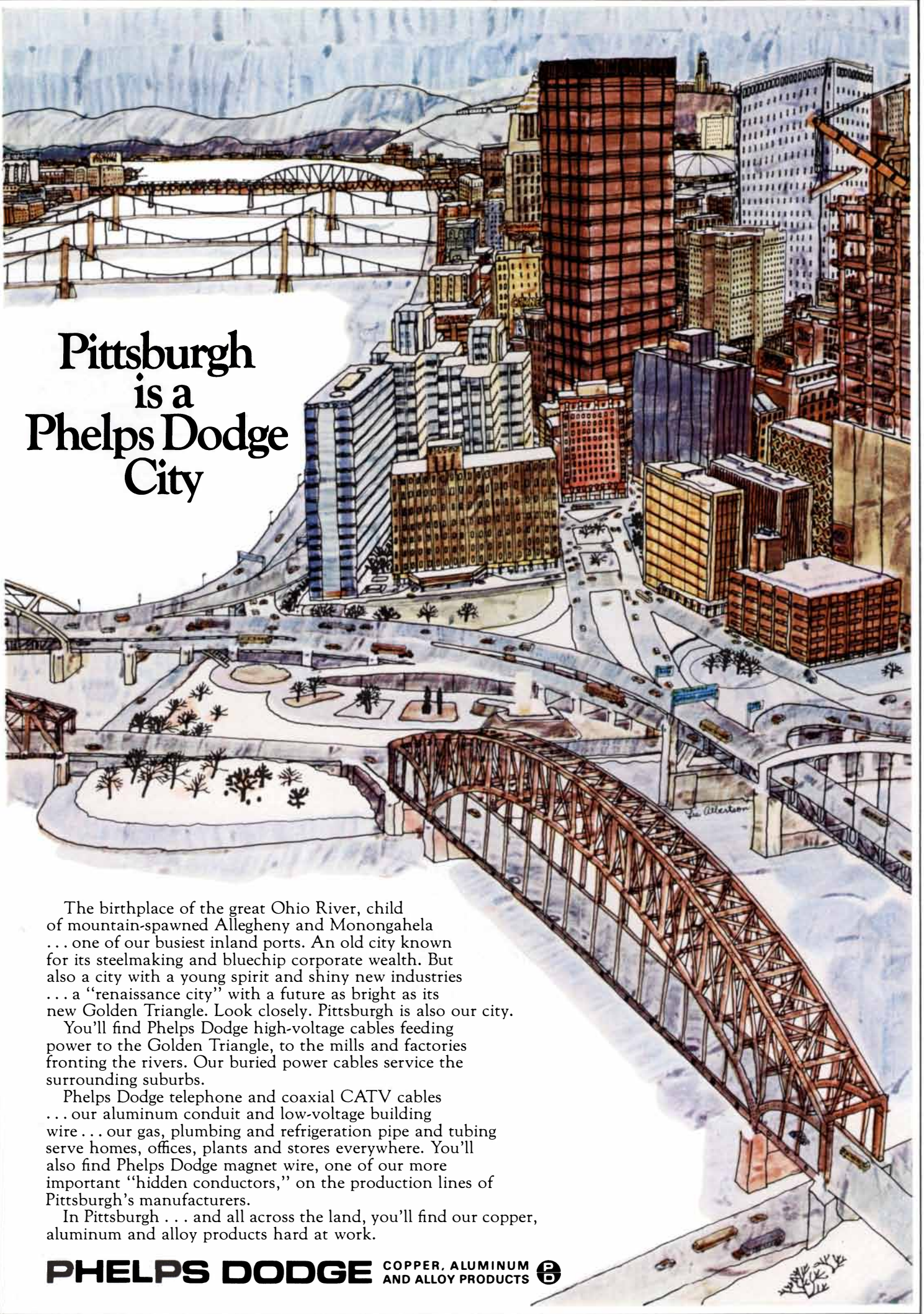
INFRARED VIEW of eastern U.S. was obtained on September 24, 1966, by the research satellite *Nimbus II*. In processing, the usual arrangement of infrared photographs, in which the warmest areas are the lightest, has been reversed, so that the warm waters of the Great Lakes appear dark and the cold ice-crystal cirrus clouds over Florida (*lower right*) are light.

and direction, storm motion and rates of cloud development and decay. The availability of more or less continuous observation of tropical storms far beyond the reach of normal reconnaissance, and of nontropical storms with their attendant warm and cold fronts, jet streams and cloud patterns, presents exciting opportunities to meteorologists. More important is the fact that this nearly continuous surveillance of the atmosphere will enable meteorologists to provide complete descriptions of the distribution and variation of weather systems—a capability that could be expected to lead to improvements in the service rendered to all users of weather information.

The information on the flux of solar protons that will come from the Tiros M series will go to the Institute for Telecommuni-Sciences in the Environmental Science Services Administration. Within the institute is the Space Disturbances Laboratory, which prepares forecasts of solar disturbances that affect communications and manned space flights and that can be expected to affect the operation of the supersonic transports the aviation industry intends to put into service. It can be hoped that the laboratory's forecasts will benefit conspicuously from the proton-flux measurements made by weather satellites.

Among the capabilities under consideration for incorporation in future satellites is a very-high-resolution observation technique. It could find and evaluate geologic resources and could keep track of the characteristics of soil and vegetation [see "Remote Sensing of Natural Resources," by Robert N. Colwell; SCIENTIFIC AMERICAN, January, 1968]. Modifications to provide for geodetic mapping, navigation services and communication with fixed and moving platforms (buoys and balloons) are clearly within reach of operational satellite systems.

In the past decade weather satellites have steadily added to the flow of information man has about his atmospheric environment, and they have materially improved the quality of that information. Such advances have stimulated meteorologists to look beyond describing the atmosphere and predicting its behavior toward the possibility of precisely modifying the weather for the benefit of man. It is clear that far more investigation is needed before weather modification is undertaken on any substantial scale. In such investigations weather satellites will certainly play a central role.



Pittsburgh is a Phelps Dodge City

The birthplace of the great Ohio River, child of mountain-spawned Allegheny and Monongahela . . . one of our busiest inland ports. An old city known for its steelmaking and bluechip corporate wealth. But also a city with a young spirit and shiny new industries . . . a "renaissance city" with a future as bright as its new Golden Triangle. Look closely. Pittsburgh is also our city.

You'll find Phelps Dodge high-voltage cables feeding power to the Golden Triangle, to the mills and factories fronting the rivers. Our buried power cables service the surrounding suburbs.

Phelps Dodge telephone and coaxial CATV cables . . . our aluminum conduit and low-voltage building wire . . . our gas, plumbing and refrigeration pipe and tubing serve homes, offices, plants and stores everywhere. You'll also find Phelps Dodge magnet wire, one of our more important "hidden conductors," on the production lines of Pittsburgh's manufacturers.

In Pittsburgh . . . and all across the land, you'll find our copper, aluminum and alloy products hard at work.

PHELPS DODGE COPPER, ALUMINUM AND ALLOY PRODUCTS

Cosindas on Cosindas on Polaroid Land Film

Marie Cosindas has had one-man shows of her Polaroid photography in many of the world's major art museums. One of her recent commissions has been a series of portraits for Helena Rubinstein.

"I started out as a painter. And a painter I remain.

Only now I use Polaroid Land color film and a camera instead of oils and brushes. Somehow it seems right to me that the artist today should use the materials that technology has given us.

Of course, just being contemporary doesn't make something good. To me Polacolor film is good. Primarily because of its extraordinary color.

But it's just as important not to have to depend on a laboratory; to be able to see the results right away; and to be able to develop and continuously build upon an idea.

The portrait on the opposite page, for example, is one of a series commissioned by Helena Rubinstein, the cosmetics manufacturer, to be used for advertising. They wanted the unusual effect I get with Polaroid film.

When I began photographing this model, she saw the results immediately and became involved with what I was working towards. She reacted with feeling. In short, we established a relationship.

That's the beauty of Polaroid Land film. The instant pictures help form an instant relationship. Which, I believe, adds that special quality that can turn photographs into art."

■ No proving ground can duplicate the elements which make competition the final test of a car's performance. The rivalry of premier drivers, the unexpected moments, the constant stress on the entire machine, and the incentive to win are present only in racing.

Research, not publicity, has been the prime objective of Porsche's competition program since the firm's founding. Win or lose, Porsche races to prove out engineering and design concepts under the toughest of all possible conditions.

Take one example. The Sportomatic semi-automatic transmission was installed in a Porsche 911 and raced in the Marathon de la Route, 84 hours over the demanding Nurburgring course. It met the test. The car won.

Porsche prototype racers, last year, won the Daytona 24-hour; Sebring 12-hour; Targa Florio; Nurburgring 1,000 kilometer and other major races. The earlier developments perfected in these unique cars brought victory to virtually stock Porsche sedans in the Trans-American championship and to hundreds of amateur owner-drivers who race their own Porsches.

Not all Porsches are raced, of course. But the Porsche you drive is raceworthy; able to take the punishment of high speed racing. Engine, brakes, suspension, electrical system—the total design—are based on race-bred research and built to racing standards.

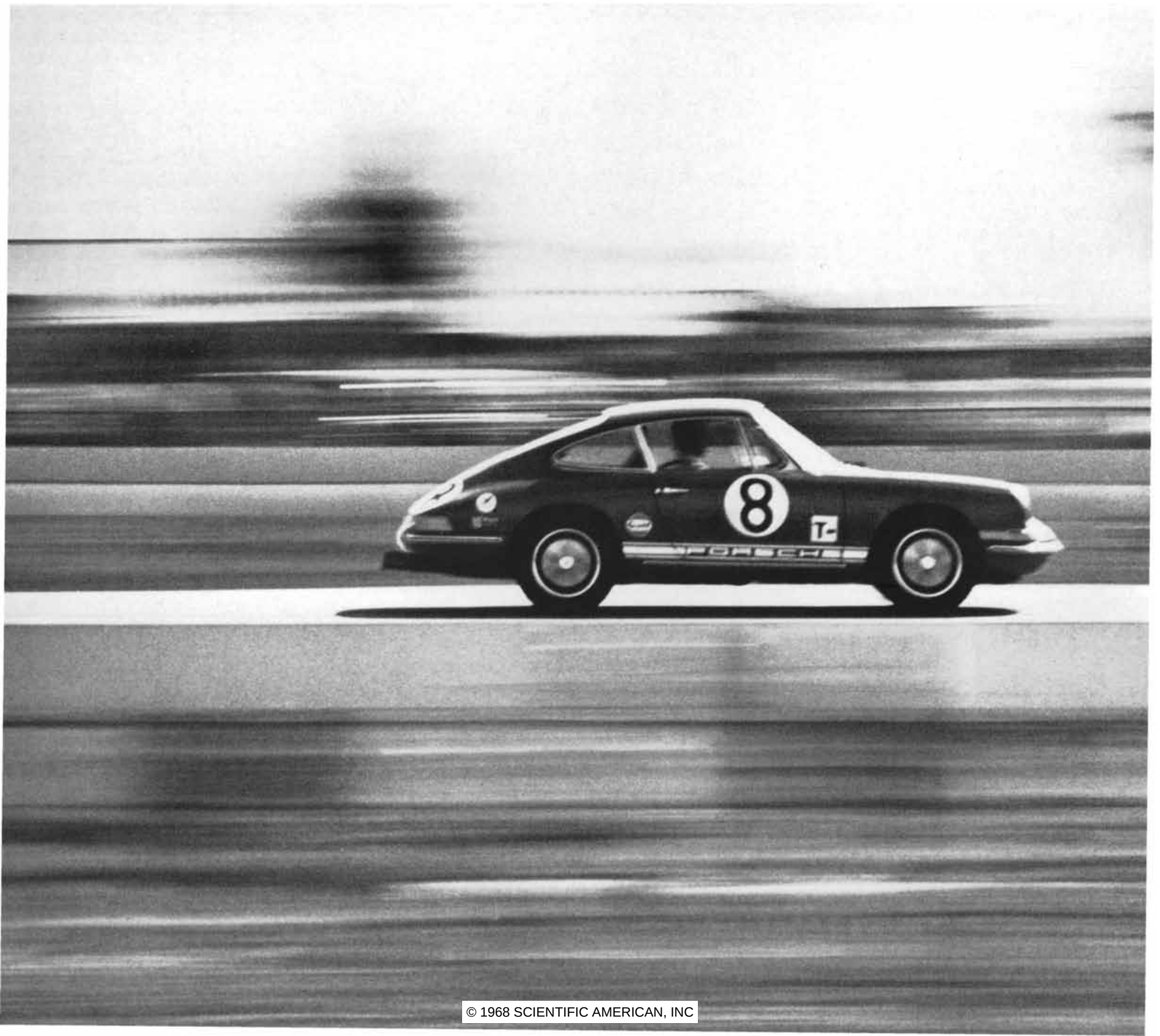
Can a car be built too good for everyday use? Porsche doesn't think so.

If you're serious about your driving, you can have a lot of fun driving a Porsche, the car that's good enough to race.

Prices start at about $5,100, East Coast P.O.E. See your Porsche dealer or write to the Porsche of America Corporation, 100 Galway Place, Teaneck, N.J. 07666.

PORSCHE

Racing—the ultimate proof



The Neurophysiology of Remembering

Experiments with monkeys have identified the brain areas involved in the recall of various learned tasks. Memory may take the form of interference patterns that resemble laser-produced holograms

by Karl H. Pribram

In 1950, toward the end of a busy life devoted to investigating the neurophysiology of memory, Karl S. Lashley wrote: "I sometimes feel, in reviewing the evidence on the localization of the memory trace, that the necessary conclusion is that learning just is not possible at all. Nevertheless, in spite of such evidence against it, learning does sometimes occur." That same year Edwin G. Boring, a leading psychologist of Lashley's generation, pointed out the deep impact that this failure to find physiological evidence for the memory trace had had on psychology. "Where or how," he asked, "does the brain store its memories? That is the great mystery. How can learning persist unreproduced, being affected by other learning while it waits? On the proper occasion what was learned reappears somewhat modified. Where was it in the meantime?... The physiology of memory has been so baffling a problem that most psychologists in facing it have gone positivistic, being content with hypothesized intervening variables or with empty correlations."

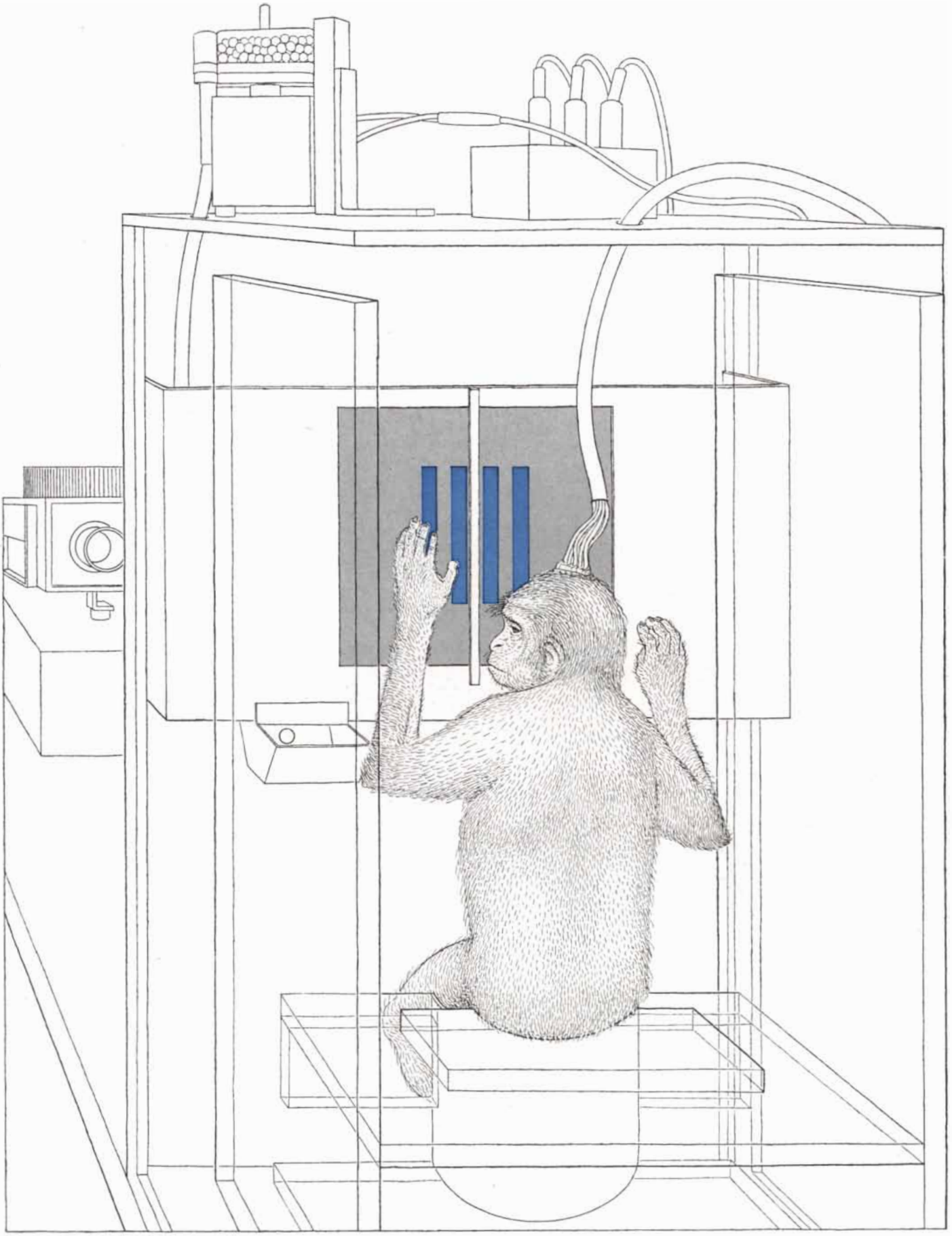
Hardly were these bleak observations in print before new research tools became available and were promptly applied in experiments on the neurophysiology of memory. As in all research that produces results important to workers in more than one discipline, however, dissemination across traditional boundaries is slowed by differences in vocabulary, in research technique and in the way a problem is subtly influenced by the subjects and materials employed by workers in different disciplines. As a result one finds even today that many psychologists (even those kindly disposed toward physiology) have the impression that little or no progress has been made in the effort to establish the neurophysiological basis of memory. This stems from the fact that psychologists have addressed themselves primarily to questions about *process*, whereas neurophysiologists and neurochemists have addressed themselves primarily to the question of how the brain achieves short-term and long-term *storage*.

My own research has sought to answer more directly the questions posed by psychologists: What kinds of memory process must exist in the brain to allow remembering to take place? The results of this research have cast doubt on at least some of the assumptions about brain mechanisms (explicit and implicit) that are held by both psychologists and physiologists and that in my view have impeded any coming to grips with the problem of process.

Neurophysiologists had over several decades extensively mapped the brain with electrical recording devices and with weak electric currents to trace nerve pathways. As a result of such experiments on cats, monkeys and even men (performed during neurosurgery) physiologists could speak with some confidence of visual, auditory and somesthetic and motor areas in the cerebral cortex. Although they remained baffled by the "memory trace," they still felt they could describe the nerve pathways from a stimulus input (say the flash of a light) to a muscular response. The success of these studies often blinded the investigators to the fact that many of these presumed pathways could hardly be reconciled with Lashley's experiments dating back to the 1920's, which showed that rats could remember and could perform complex activities even after major nerve pathways in the brain had been cut and after as much as 90 percent of the primary visual cortex had been surgically removed.

As a neurosurgeon I had no reason to challenge the prevailing views of physiologists until I met Lashley and was convinced that we knew less than we thought. I soon resolved to continue his general line of investigation, working with monkeys rather than with rats, and in addition to make an effort to follow recordable changes of the electrical activity of the brain as the animals were trained to perform various tasks. Although this work has gone slowly at times (one experiment I shall describe took seven years), my co-workers and I have now gathered neurophysiological data from more than 950 monkeys. The results of these experiments are forcing many revisions in traditional concepts of how the brain works when tasks are learned and later remembered.

Beyond this I believe there is now available a hypothesis about the nature of the memory trace that satisfies the known physiological requirements and that can be tested by experiment. It is perhaps not surprising that the brain may exploit, among other things, the most sophisticated principle of information storage yet known: the principle of the hologram. In a hologram the information in a scene is recorded on a photographic plate in the form of a complex interference, or diffraction, pattern that appears meaningless. When the pattern is illuminated by coherent light, however, the original image is reconstructed. What makes the hologram unique as a storage device is that every element in the original image is distributed over the entire photographic plate. The hypothesis is attractive because remembering or recollecting literally implies a reconstructive process—the assembly of dismembered mnemic events. In what follows, therefore, I shall give first the evidence for believing that

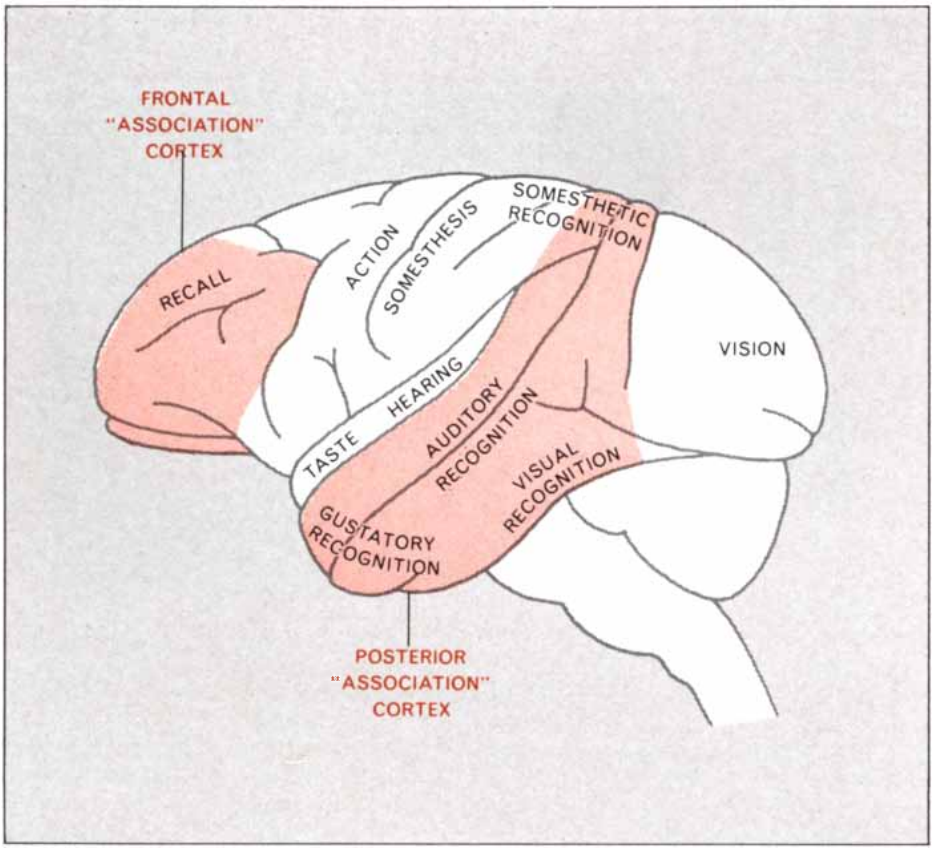


VISUAL-DISCRIMINATION TASK developed in the author's laboratory at Stanford University School of Medicine is depicted in this illustration. On the translucent panel in front of him the monkey sees either a circle or a series of vertical stripes, which have been projected from the rear. He is rewarded with a peanut, which drops into the receptacle at his left elbow, if he presses the right half of the panel when he sees the circle or the left half when he sees the stripes. Electrodes record the wave forms that appear in the monkey's visual cortex as he develops skill at this task. Early in the experiments the wave forms show whether the monkey sees the circle or stripes. Eventually they reveal in advance which half of the panel the monkey will press (*see illustration on page 76*).

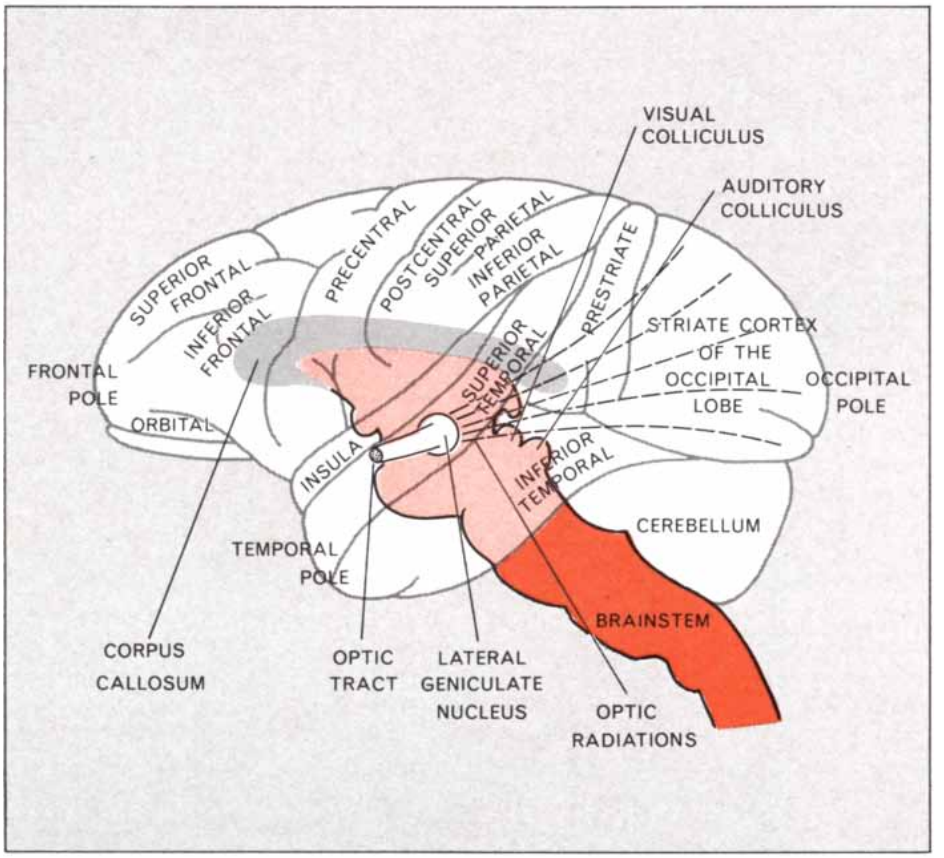
mnemic events are distributed in the brain and then describe experiments that tell us something about the way these mnemic events become re-collected into useful memory processes.

The abuses that the brain can survive and still function successfully have been documented many times since Lashley's pioneering experiments. Human testimony is provided daily in the neurological clinic of every large hospital when diseased or damaged brain tissue has to be removed. In the laboratory the brain seems to mock the ingenuity of the experimenter. Robert Galambos of the University of California at San Diego has severed up to 98 percent of the optic tract of cats without seriously impairing the cats' ability to perform skillfully on tests requiring them to differentiate between highly similar figures. Roger W. Sperry of the California Institute of Technology has surgically crosshatched sensory receiving areas in the cortex of monkeys without disturbing the presumed organization of the input system. In other experiments the system continued to function even when Sperry inserted strips of mica in the crosshatched troughs in an effort to electrically insulate small squares of tissue from one another. Conversely, Lashley, Kao Liang Chow and Josephine Semmes tried, without success, to short-circuit the electrical activity of the brain by placing strips of gold foil over the receiving areas. To accomplish a similar end I injected a minute amount of aluminum hydroxide cream at a number of points within a receiving area of an animal's cerebral cortex to produce electrical discharges resembling those seen in electroencephalograms during an epileptic seizure. Although these multiple discharging foci sharply retarded the animal's ability to learn a task of pattern discrimination, they did not interfere with recognition of these patterns when the multiple lesions were produced after learning.

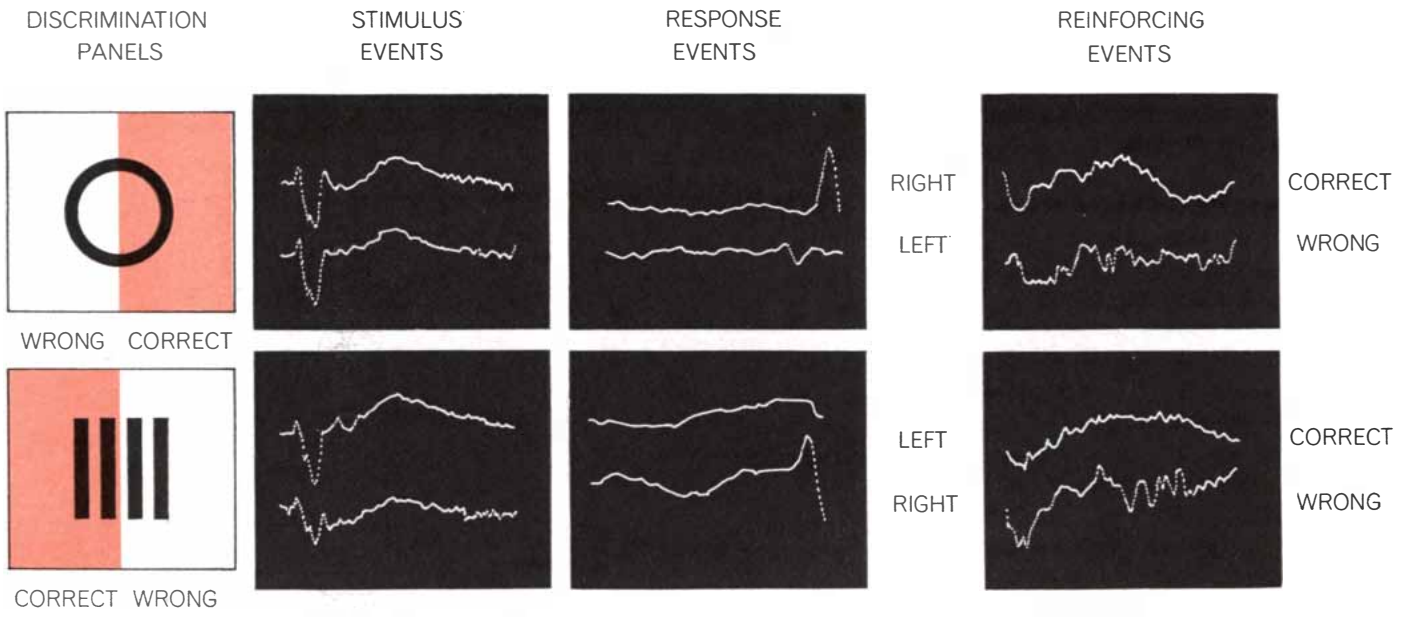
Such experiments have been interpreted as showing that each sensory system has considerable reserve capacity. Since it seems to make little difference in terms of performance which parts of the system are destroyed, it has been suggested that this reserve is distributed throughout the system, that the information needed to discriminate patterns is duplicated in many locations. According to this hypothesis, the discharging foci produced by injections of aluminum hydroxide cream interfere in some way with the reduplication that normally



LOCALIZATIONS OF FUNCTION in the cerebral cortex of monkeys have been known in general for many years. The evidence has been supplied in part by anatomical tracing of nerve pathways and more recently by electrical recording of wave forms, both through the intact skull and by use of implanted electrodes. Somesthesis refers to the sense of touch.



STRUCTURES IN CEREBRAL CORTEX AND BRAINSTEM mentioned in the text can be identified with the help of this illustration. Most of the cortical areas are labeled in adjectival form, the word "cortex" being omitted. The brainstem and its structures are shown in color. The corpus callosum is a bundle of nerve fibers that connects the two hemispheres of the brain. The lateral geniculate nucleus is the major relay station in the visual input system.



RESULTS OF VISUAL-DISCRIMINATION EXPERIMENT are shown in the wave forms recorded from the striate (visual) cortex of a monkey. The waves are those recorded after he has learned the task illustrated on page 74. The records under "Stimulus events" are wave forms that appear immediately after the monkey has been shown a circle or stripes. The records under "Response events" were generated just prior to the moment when the monkey actually responded by pressing either the left or the right half of the panel. The records under "Reinforcing events" were produced when the monkey was rewarded with a peanut if he was correct or not rewarded if he was wrong. The correct response was to press the right half of the panel on seeing a circle, the left half on seeing stripes. A slight difference in the "stimulus" wave forms indicates whether the monkey has seen stripes or a circle. After he has learned his task well sharp differences appear in the response and reinforcing panels. The response wave forms, which are actually "intention" waves, show one pattern (the one with the sharp peak) whenever the monkey is about to press the right half of the panel, regardless of whether he has seen a circle or stripes. If he has actually seen stripes, of course, pressing the right half of the panel is the wrong response. Thus the wave forms reflect his intention to press a particular half of the panel. They could hardly reveal whether his response is going to be right or wrong because at this point he still "thinks" he is about to make the correct response.

takes place when information is being stored, but once storage is complete and the information is distributed all parts of the system are more or less "equipotent."

The correctness of this view has now been put to direct test. Over the past few years Nico Spinelli and I have shown that electrical activity recorded from widely distributed points in the striate, or visual, cortex of monkeys shows distinctive responses to different stimuli. Moreover, other widely distributed points within the cortex and brainstem give evidence that they have participated in storing information linked to the animal's response to particular stimuli. Let me describe the experiment more fully. (This is the one that took seven years to complete.)

Monkeys were placed in front of a translucent panel on which we could project either a circle or four vertical stripes [*see illustration on page 74*]. If, when the monkey saw the circle, he pressed the right half of the panel, he would be rewarded with a peanut. He would be similarly rewarded if he pressed the left side of the panel when the stripes appeared. Before the training begins we painlessly implant a number of tiny electrodes in the monkey's visual cortex. We then compare the electrical wave forms produced by the cortex during training with the wave forms produced after a high level of skill has been attained. We had expected that the wave forms would be different, and they were.

What we did not expect was that we would be able to tell from the wave-form records whether the monkey saw a circle or vertical stripes, whether he responded correctly or made a mistake and, most surprising of all, whether he *intended* to press the right half or the left half of the panel once he was presented with the problem and *before* he initiated an overt response [*see illustration above*]. All these differing electrical responses arose in the visual cortex—the part of the brain that receives the visual input. We are forced to conclude that signals representing experience converge with and modify the input to the visual-input systems. We also found, however, that within the visual cortex different electrodes recorded different events.

Thus we now have direct evidence that signals become distributed within the input system. What we see (or at least what the monkey sees) is not a pure and simple coding of the light patterns that are focused on the retina. Somewhere between the retina and the visual cortex the inflowing signals are modified to provide information that is already linked to a learned response, for example the monkey's intention to press one panel or another. Evidently what reaches the visual cortex is evoked by the external world but is hardly a direct or simple replica of it. Further, the information inherent in the input becomes distributed over wide regions of the visual cortex.

How might such a distribution of information occur? A possible clue to the puzzle came from an optical artifact, the hologram, which was then being made for the first time with the help of coherent laser light [see "Photography by Laser," by Emmett N. Leith and Juris Upatnieks; SCIENTIFIC AMERICAN, June, 1965]. The interference pattern of the hologram is created when a beam of coherent light is split so that a "reference" portion of the beam can interact with a portion reflected from a scene or an object. I reasoned (much as Lashley had) that neuronal events might interact in some way to produce complex patterns within the brain; the hologram now provided an explicit model.

Evidence for some such patterning of neuronal events, at least in the visual channels, has been provided by the work of R. W. Rodieck of the University of Sydney. He has shown that the initiating events in the visual channel that express the relations between the excitation of one receptor in the retina and the activity of neighboring points can be described mathematically through the use of "convolutional integrals," expressions somewhat similar to the familiar Fourier transformations. For example, the shape of the visual receptive field of a single retinal ganglion cell represents the convolution of a derivative of the shape of the retinal image produced at that point [*see illustration on this page*]. Convolutional integrals and Fourier transformations provide the mathematical basis on which holography was founded. Thus at least a first step has been taken to show that interference effects may operate in the central nervous system.

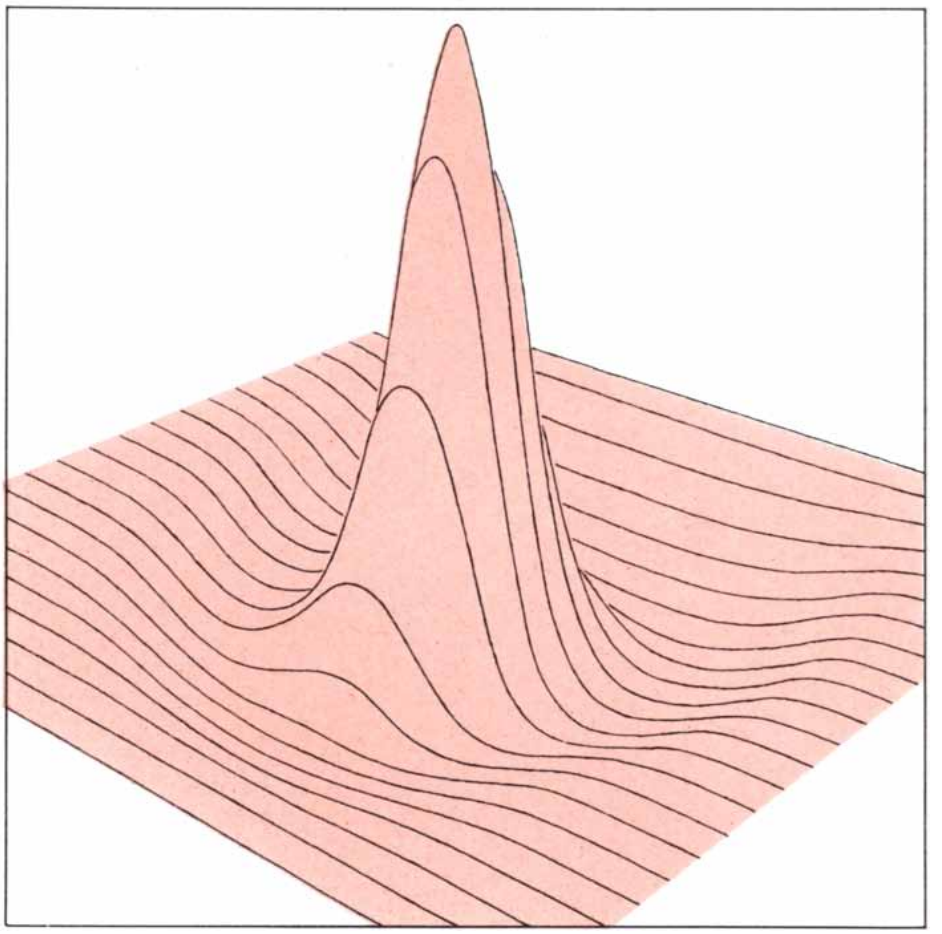
The question remains: How can interference effects be produced in the brain? One can imagine that when nerve impulses arrive at synapses (the junction between two nerve cells), they produce electrical events on the other side of the synapse that take the form of momentary standing wave fronts. Typically the junctions made by a nerve fiber number in the dozens, if not hundreds. The patterns set up by arriving nerve impulses presumably form a microstructure of wave forms that can interact with similar microstructures arising in overlapping junctional contacts. These other microstructures are derived from the spontaneous changes in electrical potential that ceaselessly occur in nerve tissue, and from other sources within the brain. Immediate cross-correlations result, and these can add in turn to produce new patterns of nerve impulses.

The hypothesis presented here is that the totality of this process has a more or less lasting effect on protein molecules and perhaps other macromolecules at the synaptic junctions and can serve as a neural hologram from which, given the appropriate input, an image can be reconstructed. The attractive feature of the hypothesis is that the information is distributed throughout the stored hologram and is thus resistant to insult. If even a small corner of a hologram is illuminated by the appropriate input, the entire original scene reappears. Moreover, holograms can be layered one on top of the other and yet be separately reconstructed.

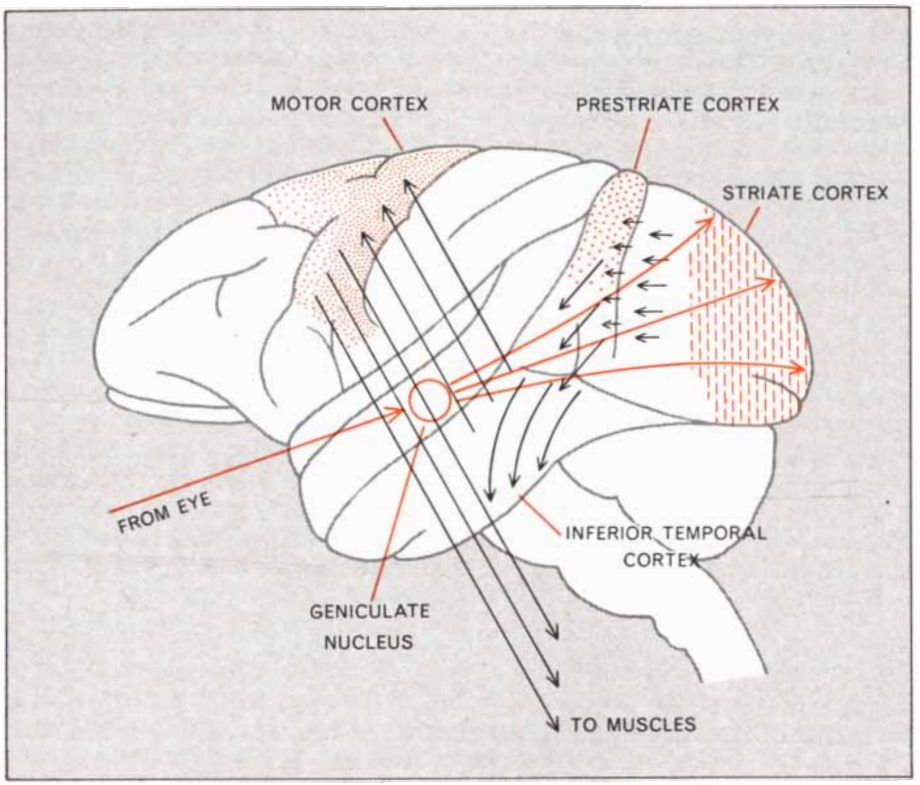
The holographic hypothesis immediately raises many questions. Do the mathematical expressions that interpret the shape of visual receptive fields at the ganglion-cell layer of the retina yield equally useful interpretations at more central stations in the visual system? What kind of neural reference mechanism plays the role of the coherent light source needed to make and display holograms? Perhaps a kind of coherence results from the anatomical fact that the retina and the visual cortex are linked by many thousands of fibers arranged in parallel pathways. Or it could be that the nerve cells in the visual channel achieve coherence by rhythmic firing. Still another possibility is that coherence results from the operation of the variety of detectors that respond to such simple aspects of stimuli as the tilt of a line and movement that have recently received so much attention [see "The Visual Cortex of the Brain," by David H. Hubel; SCIENTIFIC AMERICAN, November, 1963].

Other questions that flow from the holographic hypothesis are concerned with the storage of the memory trace. Two alternatives come to mind. The first involves a "tuning" of cell assemblies by changing synaptic characteristics so that a particular circuit will somehow resonate when it receives a familiar "note"; the second is some form of molecular storage, perhaps involving a change in structure at the synapses. Of course circuit-tuning may be secondary to just such structural changes, or the job may be done by a mechanism as yet unimagined. Such questions can be and are being investigated in the laboratory with techniques available today.

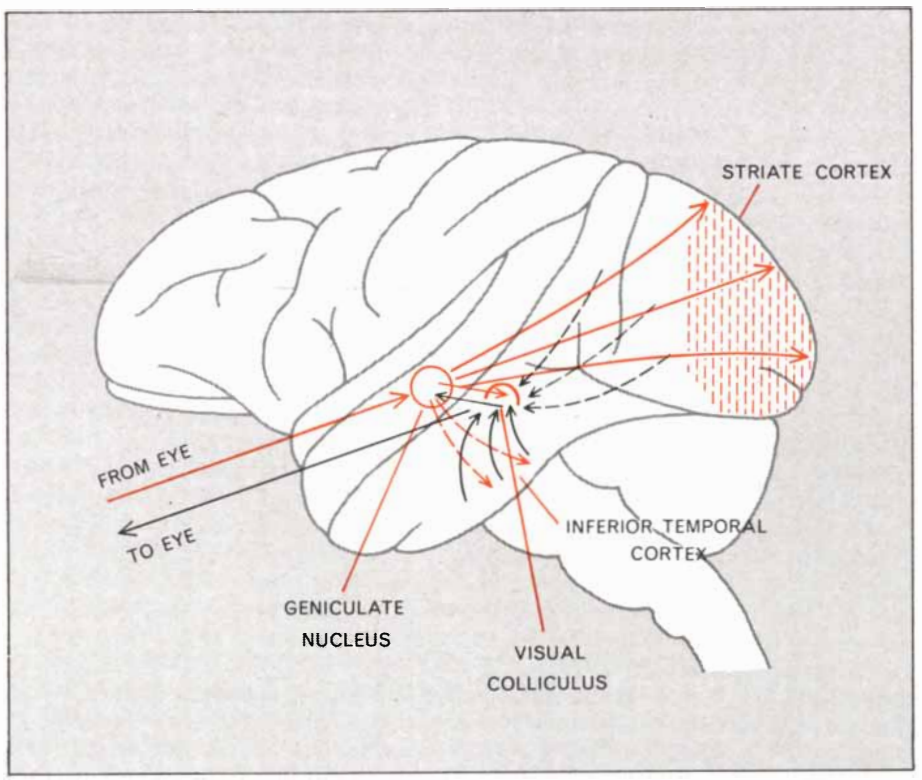
There is another line of investigation demonstrating that representations of



IDEALIZED MAP OF VISUAL RECEPTIVE FIELD represents recordings made from a single ganglion cell in the retina of the eye when a point source of light is presented in various parts of the visual field. The map contains smooth contour lines because the ganglion cell integrates the response of its neighbors, with which it is interconnected. The height of the contour at any point represents the number of times the individual nerve cell fires when the location of the point light source corresponds to that position on the map. Maximum firing occurs when the position of the light corresponds to that of the central peak. In mathematical terms, each contour line represents the "convolutional integral" of the first derivative of the shape of the stimulus figure. The interaction of many such convolutional integrals may produce hologram-like interference patterns within the visual system and elsewhere in the brain. Storage of such patterns could provide the basis of memory.



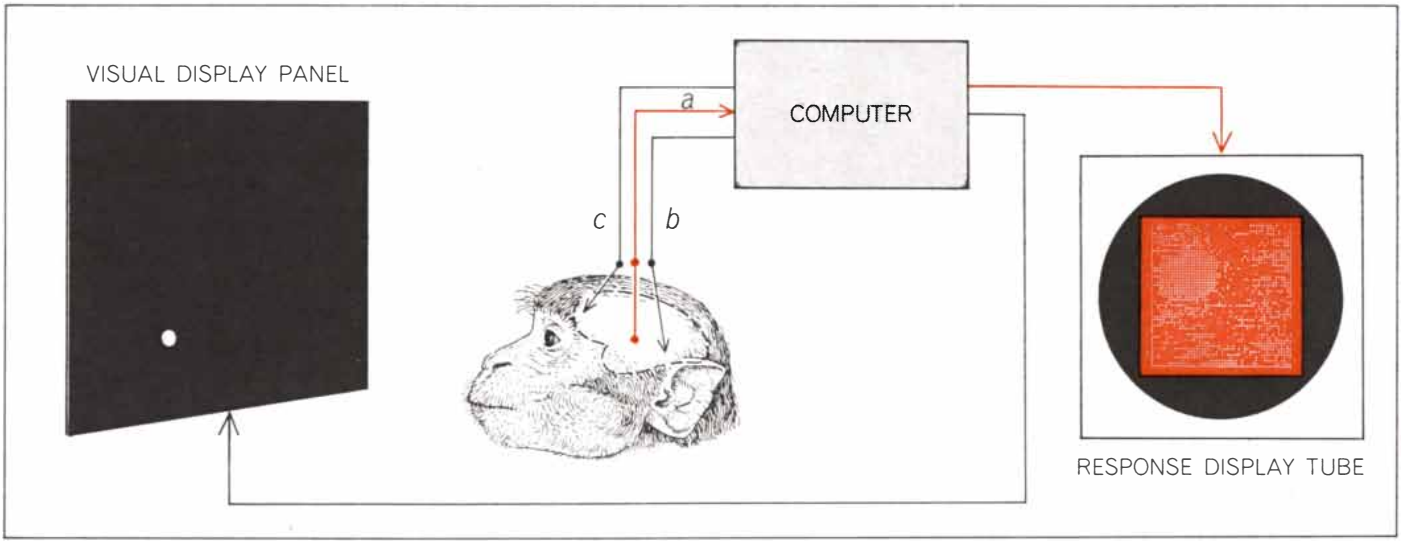
OLD VIEW OF VISUAL-RECOGNITION MECHANISM assumed that after visual information reached the striate cortex it was transferred to the prestriate cortex in two steps and from there to the inferior temporal cortex. Muscular response, according to the old view, then required that a message travel from the inferior temporal cortex to the precentral cortex (the motor cortex), which responded by sending signals down the brainstem to the muscles.



NEW VIEW OF VISUAL-RECOGNITION MECHANISM emphasizes the recent evidence that impulses from the inferior temporal cortex directly modify the visual input *before* it reaches the striate cortex (*see illustration on page 80*). This modification takes place subcortically through tracts leading to the visual colliculus and through interactions between that part of the brainstem and the lateral geniculate nucleus. There is also some evidence for an indirect pathway from the retina to the inferior temporal cortex. Visual information also seems to flow from the visual cortex to the visual colliculus. In the new view the body's muscle responses are relatively independent of the visual-recognition mechanism.

experience are distributed after entering the brain. The experiments I have described thus far demonstrated a distribution in space. There is also distribution in time; there are mechanisms in the brain for temporally distributing, or holding, events long enough so that they can be firmly registered. The evidence comes from an important group of experiments showing how animals (including man) gradually become habituated to a novel stimulus. Until recently habituation was thought to be due to a fatiguing of the nervous system. Eugene Sokolov of the University of Moscow showed, however, that when one is habituated, one can be dishabituated, that is, "oriented" anew, by a lowering in the intensity of the stimulus or even by complete silence when stimuli are expected. I like to call it the "Bowery-el phenomenon." For many years there was an elevated railway line (the "el") on Third Avenue in New York that made a fearful racket; when it was torn down, people who had been living in apartments along the line awakened periodically out of a sound sleep to call the police about some strange occurrence they could not properly define. Many such calls came at the times the trains had formerly rumbled past. The strange occurrences were of course the deafening silence that had replaced the expected noise.

In laboratory studies of this phenomenon the physiological concomitants of the orienting reaction are recorded and their reduction allows habituation to be investigated. The orienting reaction includes, among other things, changes in the conductivity of the skin (the galvanic skin response), changes in heart rate and respiratory rate, and changes in the electroencephalogram. Muriel H. Bagshaw and I found that we had to separate these physiological indicators of the orienting reaction into two classes. This was necessary because after we had surgically removed the frontal lobes of a monkey's brain, or the brainstem region known as the amygdala, the orienting stimulus no longer evoked the galvanic skin response or changes in heart rate and respiratory rate. (The responses themselves were not destroyed, because they could be evoked under other conditions.) On the other hand, surgery did not eliminate certain changes in the electroencephalogram and certain behavioral changes that also occur as a part of the orienting reaction. Surgery also interfered with habituation: a monkey lacking his frontal lobes or his amygdala continued much longer to show the behavioral and electroencephalographic orienting reactions. These results suggested that the loss of



INVESTIGATION OF VISUAL RECEPTIVE FIELDS is carried out by presenting a monkey with a small source of light that is systematically moved from point to point in a raster-like pattern. At each point the response of a single cell in the lateral geniculate nucleus is recorded by a microelectrode (*a*). During this mapping a weak electrical stimulus can be delivered to other parts of the brain, such as the inferior temporal cortex (*b*) or the frontal cortex (*c*), to see if there is any effect. Some typical results are illustrated on the next page. The technique, which relies heavily on the computer, was developed by the author's colleague Nico Spinelli.

galvanic skin responses and heart and respiratory changes precluded habituation; when these indicators of orienting were not present, the stimulus, although perceived, failed to be registered in memory.

We have all had the experience of being preoccupied while a friend is recounting his experiences to us. Finally in exasperation he may say, "You aren't listening." Caught unaware, you may still be able quickly to repeat your friend's last sentence and from this even reconstruct what the "conversation" was about. If, however, your reverie is allowed to continue, much of what reached your ears will have been irretrievably lost; things just did not register. Thus there are two classes of indicators of orienting: the one concerned with just "sampling" the input, the other with its "registration," or storage.

E. D. Homskaya in the laboratory of A. R. Luria in Moscow and Mrs. Bagshaw in our laboratory at the Stanford University School of Medicine have also demonstrated that removal of the frontal lobes or the amygdala interferes with the indicators of registration when they appear in classical conditioning experiments. In normal animals the conditioning cue (such as a bell or a light) evokes changes in the galvanic skin response, in heart rate and in respiratory rate, as well as in the electroencephalogram. As the conditioning trials continue, these changes take place earlier and earlier until they actually precede the conditioning cue. It is as if the subject of the experiment were rehearsing the situation, anticipating what is coming next. After removal of the frontal lobes or the amygdala, however, this rehearsal apparently ceases. Thus one can demonstrate that both anticipation and registration—a temporal distribution of mnemic events—take place in a normal subject, and that these processes are impaired by surgery in certain parts of the brain. There is as yet little evidence to indicate how these parts of the brain bring about this temporal distribution of mnemic events.

Given the fact that mnemic events become distributed in the brain, what happens during remembering? Some kind of organizing process is clearly required. Experimental data make it likely that this process involves the "association cortex" of primates such as monkeys and man [*see top illustration on page 75*]. These regions are not to be confused with the "polysensory association cortex" that immediately surrounds the sensory projection areas and that has been studied so intensively in cats. The primate association areas consist of two general classes: the frontal and the posterior. The posterior association areas are located among the various primary sensory areas and consist of subareas that are specific for each of the senses.

In operations on several hundred monkeys my colleagues and I have made many kinds of lesion in this posterior system; the type, the size and the location of the lesions were based on a variety of anatomical and physiological criteria. These monkeys have been tested for their ability to learn and to retain discrimination tasks involving four senses. Vision is studied with a variety of patterns, colors and brightnesses; touch, with unseen objects of different shapes and textures; taste, with samples differing in bitterness or sweetness; hearing, with different sound patterns. From the results of such experiments we are able to subdivide the posterior association cortex into areas, each serving a particular sense. These investigations show that the parieto-occipital area is concerned with touch, the anterior temporal cortex with taste, the middle temporal region with hearing. The inferior temporal cortex is important to visual discrimination [*see illustrations on page 75*].

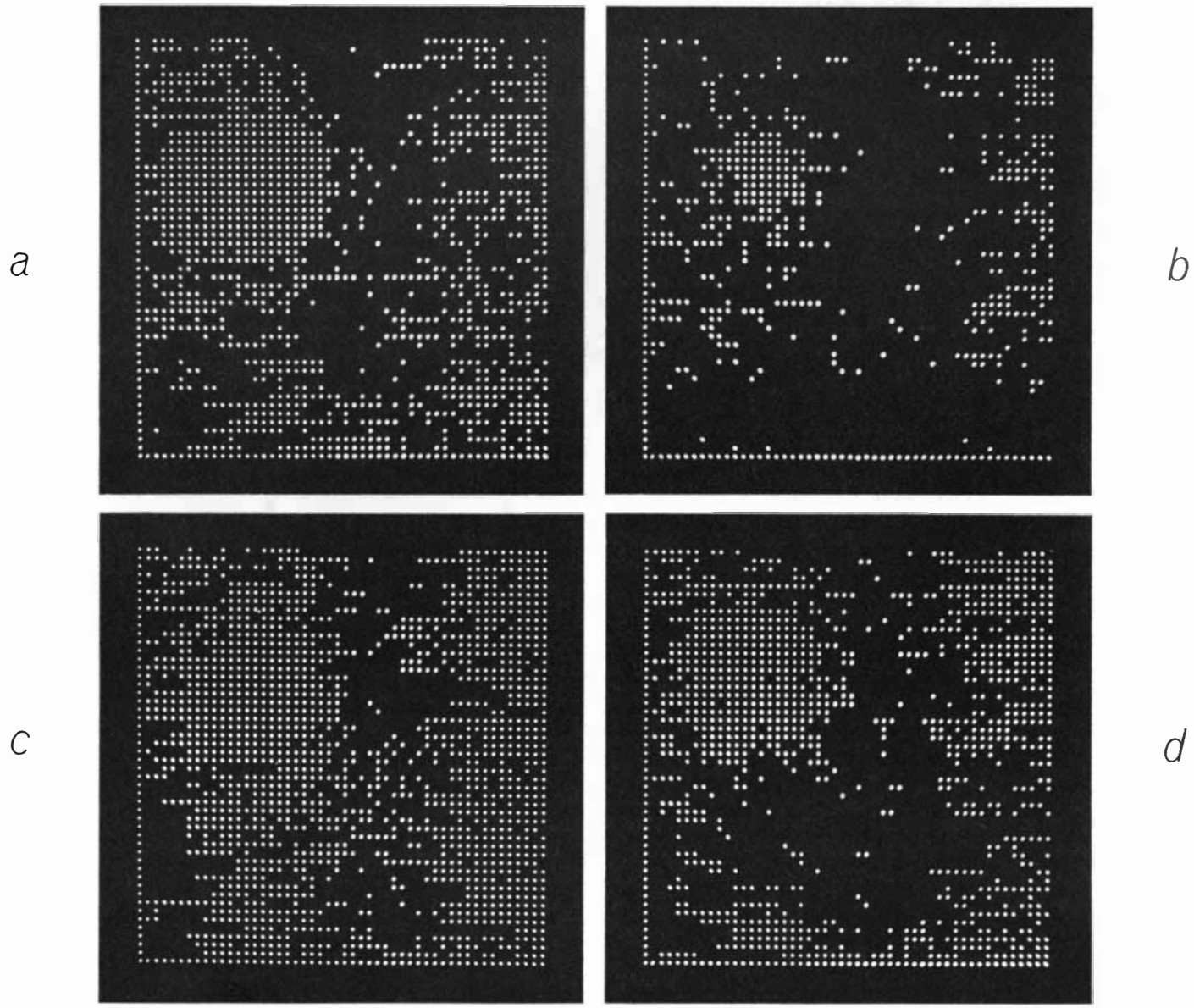
These results present a number of questions. Why, following the removal of the inferior temporal cortex, do monkeys fail completely to accomplish visual discriminations while being perfectly able to accomplish discriminations in other senses and to perform more complex tasks, such as tasks involving delayed reactions and alternation of response? The problem is complicated by the following facts. Visual information passes from the retina to a relay point called the lateral geniculate nucleus and thence to the occipital (or striate) cortex. It had long been taught that the occipital cortex then sends information out to the surrounding areas, and that the information finally reaches the inferior temporal cortex. Since our monkeys fail in visual discrimination tasks after the removal of the inferior temporal cortex, the classical teaching would seem to be supported. Other considerations nonetheless argue that the classical view must be wrong.

First of all, the anatomical evidence shows that nerve impulses would have to be relayed by three synapses in traveling from the occipital cortex to the inferior temporal region. Three synapses,

however, can get a signal from anywhere to almost anywhere else in the brain, so that this is hardly sufficient evidence for a mechanism that demands strict sensory specificity. Second, Chow, in a series of experiments confirmed by my own, removed all the tissue surrounding the occipital cortex in monkeys, so that the primary visual receiving area is totally isolated from the inferior temporal cortex. Such animals show no loss of visual performance in spite of the fact that a lesion in the inferior temporal cortex only a third or a quarter the size of the one made in the disconnection experiment will cause serious impairment on the same tasks. This makes it most unlikely that impulses reaching the inferior temporal cortex from the upper regions of the visual system account for the importance of this cortex in vision.

What, then, is the mechanism that enables the inferior temporal cortex to play such a key role in the performance of visual tasks? Where does it get its information and where does it send it? The available evidence (much of which I have had to omit in this brief account) has led me to propose that the inferior temporal cortex exerts its control by organizing the traffic in the primary visual system. Recently the pathways from the inferior temporal cortex to the visual system have been traced. Applying the methods of electrophysiology, Spinelli and I have found, for example, that we can change the size and shape of visual receptive fields by stimulating the inferior temporal cortex [*see illustration below*]. These and other experiments demonstrate beyond doubt that the inferior temporal cortex is not the passive recipient of data relayed from the primary visual cortex, as was long believed, but actively influences what enters the visual cortex. Similar results have been obtained in the auditory system by James H. Dewson in my laboratory.

An experiment that tells us a little about the meaning of this control over input is currently being completed by my associate Lauren Gerbrandt. A monkey sits in a chair inside a box that can be opened, so that he can see out, or closed. He can be stimulated through an electrode placed in the lateral geniculate nucleus (the relay station in the visual input system) while we record the level of activity in the visual cortex. When the box is closed, geniculate stimulation evokes only a small response in the cortex. When the box is open, the response is large. Gerbrandt found, however, that he could augment the strength of the cortical response when the box is closed (and only then) by stimulation of



VISUAL-RECEPTIVE-FIELD MAPS, made by the technique illustrated on the preceding page, show how information flowing through the primary visual pathway is altered by stimulation elsewhere in the brain. Map *a* is the normal response of a cell in the geniculate nucleus when a light source is moved through a raster-like pattern. Map *b* shows how the field is contracted by stimulation of the inferior temporal cortex. Map *c* shows the expansion produced by stimulation of the frontal cortex. Map *d* is a final control.

Jean Buridan
(c. 1297—c. 1358)

Woodcarving by William Ransom

"We have seen Buridan declare that the impetus of a body, moved with a given speed, was proportional to the quantity of matter of that body.... We have tried to show that the quantity of matter considered by Buridan... was... identical to the quantity of matter, or mass, as defined by Newton."[1]

[1]Pierre Duhem, *Études sur Léonard de Vinci,* De Nobele, Paris, 1955, vol. 1, p. 205. Permission to publish this translation was graciously given by Mlle. Pierre-Duhem.

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INTERSECTION OF NERVE PATHWAYS in the visual-input channel can be depicted schematically in two dimensions by an array of dots, each representing a single nerve cell. The response of each cell in turn can be visualized as corresponding to the patterns shown in the visual-receptive-field maps presented on page 80. At a given instant a stimulus arising in a particular part of the visual field will cause a certain group of cells (*color*) to respond. Simultaneously a stimulus in another part of the field will excite a different group (*black*). Gray cells are inactive at this instant. As long as the scene in the visual field remains constant, these same groups of cells will "flash" off and on many times a second. The interference patterns resulting from the interacting fields of the flashing cells may provide the opportunity for the formation of holographic patterns. This diagram first appeared in "The Physiology of Imagination," by John C. Eccles; SCIENTIFIC AMERICAN, September, 1958.

the inferior temporal cortex. The response is then as strong as when the monkey is alertly looking about, examining the world around him. This suggests to us that electrical stimulation of the association cortex crudely reproduces the neural activity that goes on naturally when the animal is actively engaged in sampling and attending his visual environment.

A detailed and satisfactory mechanism for explaining these results remains to be worked out. A tentative hypothesis supported by considerable anatomical evidence, and very recently by limited electrophysiological evidence, might go something like this. There is evidently an input from the visual pathway, rather separate from the primary visual pathway, that leads to the inferior temporal cortex. This visual input to the inferior temporal cortex triggers a process that feeds back into the primary visual system and there exercises a control over the flow of visual impulses to the visual cortex [*see bottom illustration on page 78*]. This view is based on such evidence as our ability to change the size and shape of the visual fields in the optic nerve and lateral geniculate nucleus by stimulation of the inferior temporal cortex.

This, however, can be only a part of the story. A satisfactory hypothesis also has to explain the first experiment I described, in which recordings from the visual cortex foreshadowed the monkey's intention to press either the right or the left panel when he was presented with a circle or vertical stripes. Here we have evidence that the frontal cortex and the amygdala, which are involved in registration, also affect the visual mechanism, often in a direction just opposite to what is produced by stimulation of the inferior temporal cortex.

Pathways from the visual cortex to the superior colliculus of the brainstem are well known. Recently we have traced similar pathways from the inferior temporal cortex to this same superior colliculus, which is an important structure in the visual system. (In birds the collicular region plays a role comparable to the role of the cerebral cortex in primates.) One can now begin to see how surgically isolating the visual cortex from the inferior temporal cortex does not destroy an animal's capacity to perform visual tasks. Evidently the communication link between the visual cortex and the inferior temporal cortex (which is essential to the retention of visual discriminations) is buried deep within the brainstem. Just as the brainstem serves as a convergence station for the visual system, it serves (on the basis of Dewson's evidence) a similar function in hearing. The importance of such subcortical convergences, which in turn alter the input to the cortex, has been highlighted by these experiments.

Further evidence for this cortico-subcortical mode of operation of the brain (as opposed to a transcortical mode) comes from the same group of experiments in which our animals learned to distinguish between circles and stripes while a record of their brain waves was being made. The reason for doing these experiments in the first place was that I wanted to see how the wave forms recorded from various parts of the brain would be altered by making lesions in the inferior temporal cortex after the monkeys had learned their task. I fully expected that a lesion would selectively affect one of the wave forms and would leave others unchanged. Thus (I hoped) we would be able to identify the mechanism that accounted for the monkey's failure to perform satisfactorily after the lesion. We might conclude, for example, that the lesion had interfered with the monkey's capacity to differentiate between circles and stripes or that it had interfered with some process linked to reinforcement or response. This is not what happened.

Instead of finding a selective change in one or another of these electrical waves, we found that the electrodes that provided the best differential recordings in advance of surgery subsequently showed no such differences; other electrodes whose wave forms had been undifferentiated now showed persistent and reliable differences. These differences turned out to be associated, for the most part, with responses, but in very peculiar ways that we have not as yet been able to decipher clearly.

It seems as if the frame of reference within which the brain activity had been working before the lesions were made was now shifted, and in fact was shifting from time to time. Judging by their behavior, the monkeys were as surprised by the effects of the surgery as we were. They approached their task confident of their ability to solve the problems, only to find they made errors (and hence received no peanut). This resulted in spurts, hesitations and variabil-

SCIENCE/SCOPE

The giant new Intelsat IV satellite ordered by Comsat Corp. for International Telecommunications Satellite Consortium from Hughes will have 25 times more communications capacity than any satellite now in operation. It will be able to handle 6,000 two-way telephone calls or 12 color TV broadcasts simultaneously. A unique feature will be Intelsat IV's ability to focus its power into two "spotlight" beams and point them at any selected areas.

The airborne radar system for the F-X fighter is being developed by Hughes under one of two $11-million contracts awarded by the U.S. Air Force. Winner of the competition will be selected after both radar prototypes have been flight tested and the results evaluated. The F-X will be the world's most advanced single-place, twin-engine air superiority fighter in the 1975 time period.

The U.S. Army TOW wire-guided anti-tank missile has been ordered into production under a $141-million contract awarded to Hughes. It is designed for use either as a man-carried tripod-mounted weapon or mounted on a variety of existing vehicles. It will also be employed from the Army's new Cheyenne helicopter. The Army recently demonstrated TOW to nearly 100 high-ranking military representatives of 11 foreign nations at Grafenwoehr, Germany.

A multiplexed passenger-entertainment system for the DC-10 is being built by Hughes under a $12-million contract from McDonnell Douglas. It will give the DC-10 passenger the choice of monaural or stereophonic high fidelity music or multilingual sound tracks for in-flight movies by pressing a button at his seat. Multiplexing will save miles of wiring and up to 400 pounds of weight.

Telecasts live and in 12 languages for Europe were relayed from the Olympics in Mexico by two Hughes-built satellites. NASA's ATS III and Comsat's Early Bird were used to transmit video and audio segments separately to two ground stations in Europe. The games reached Japanese viewers via microwave to a portable ground station installed by Hughes near San Jose, Calif., then via Intelsat II.

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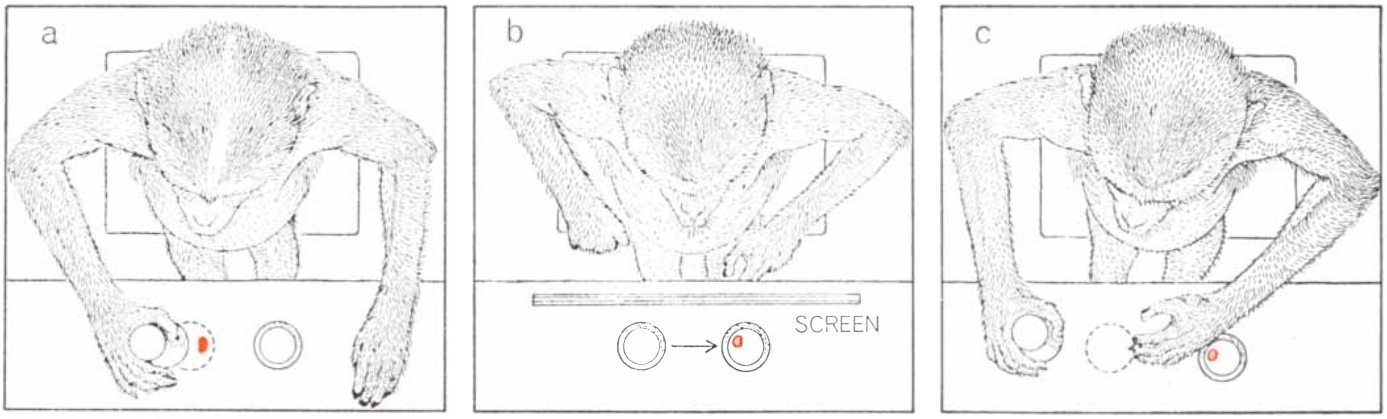


ALTERNATION TASK requires that a monkey remember which cup he lifted last in order to lift the correct one on his next trial and be rewarded with a peanut. Normally he is rewarded if he remembers to lift the cups in a simple alternating sequence: left, right, left and so on. After each trial a screen comes between him and the cups and remains there for periods that can be varied from seconds to many minutes. In part *c* of this sequence the monkey has forgotten to alternate his response. Experiments demonstrate that certain brain lesions interfere with a monkey's ability to remember what he did even a few seconds earlier. By changing the task only slightly, however, the author found that brain-damaged monkeys were no longer perplexed (*see illustration on page 86*).

ity in performance. It seemed as if they were completely baffled, not realizing, of course, that it was the inside of their heads and not the situation that we had changed. What is the explanation?

Whatever the transformations of input (holographic or otherwise) that occur in the nervous system, such transformations are in effect coding operations. In order for a code to work, that is, to be decipherable, it must be framed within a context. This context must remain stable or the information conveyed by the code will be destroyed by successive transformations. Our reading of the recordings of the electrical brain activity of the monkeys who had their inferior temporal cortex removed is that the framework within which their discriminations had been made before surgery was now disrupted and shifting. The events observed by these monkeys no longer conveyed information because their brains had in a sense become unstable.

As a hypothesis this can be tested. We are about to investigate means of providing externally the stability that the brains of the brain-damaged monkeys evidently lack. Sandra Reitz, a student in my laboratory, recently suggested that this could be done simply by increasing the spatial redundancy of the visual cues (that is, the number of identical displays) that we present to our monkeys on a discrimination task. The expectation is, if our view is correct, that this change in the task will overcome the difficulty in discrimination experienced by the monkeys with lesions of the inferior temporal cortex.

Therefore a beginning has been made in specifying the structures that participate in the organization of memory inside the brain. The next task is to discover *how* these structures accomplish the physiological processes we call remembering, whether by holographic representations or by some process even more subtle. In our concern with the storage mechanism, however, we should never overlook that aspect of memory which is of overriding importance to the process of effective remembering: the method of organizing or coding what is to be remembered.

In everyday life there are many homely examples to show that a given message is easier to remember in one form than in another. For example, rhymes are often employed in aphorisms ("A stitch in time saves nine"); many people cannot remember the number of days in the month without first recalling the jingle of their childhood. A more important example of the value of efficient coding is found in the 0–9 method of writing down numbers compared with the clumsy system of the Romans. By employing the concept of zero to indicate multiples of 10 our mathematical tasks are vastly simplified.

A coding mechanism need not necessarily be very complicated. Take, for example, the following "poem," which the neurophysiologist Warren McCulloch likes to intone with bishop-like solemnity: INMUDEELSARE/INCLAYNONEARE/INPINETARIS/INOAKNONEIS. When spaces are inserted where they belong, the message instantly becomes clear: IN MUD EELS ARE/IN CLAY NONE ARE/IN PINE TAR IS/IN OAK NONE IS. The passage has been decoded by the simple procedure of parsing, or what the psychologist George A. Miller, my sometime collaborator who is now at Rockefeller University, calls "chunking" [see "Information and Memory," by George A. Miller; SCIENTIFIC AMERICAN, August, 1956].

Many experiments with monkeys demonstrate that the frontal cortex—long regarded as the site of the "highest mental faculties" in man and primates—plays an important role in short-term memory, whatever else it may be doing. When sufficiently complex tests, comparable to those used with monkeys, are given to lobotomized patients, they too show this memory disturbance. My experiments provide strong evidence that the primate frontal cortex performs its role by means of a coding operation that seems to resemble parsing, or chunking. When the frontal cortex of a monkey is damaged, the animal has difficulty performing tasks in which he has to remember what happened just a few seconds earlier.

Typical of such tasks is one in which the monkey faces two identical cups with lids that he must raise in a particular sequence to obtain a peanut [*see illustration above*]. In the simplest case he is rewarded with a peanut at each trial if he simply remembers to lift the lids alternately: left, right, left and so on. Then he must wait a specified interval, which can be varied from a few seconds to hours, between each trial, and while he is waiting an opaque screen is interposed between him and the cups. His task, then, is to remember which lid he lifted last so that he can lift the other one on the next trial. A monkey whose frontal cortex has been resected will fail at this simple task even when the interval between trials is reduced to three seconds.

It occurred to me that perhaps the task appears to these monkeys much as an unparsed passage does to us. I there-

fore changed the task so that the rewarded sequence became left-right (long interval), left-right (long interval) and so on. There was still a mandatory pause with the screen interposed of five seconds between each left-right trial, but now a longer interval of 15 seconds was inserted between *pairs* of trials. Immediately the monkeys with frontal cortex damage performed as successfully as the control animals whose brains were intact [*see illustration on next page*]. That time-parsing was the key to the success of the brain-damaged monkeys was shown by other experiments in which the interval between trials was held constant but some other clue, such as a red light or a buzzer, was presented at every other trial. The clues were ignored; the monkeys with frontal lobe resections still failed at the task.

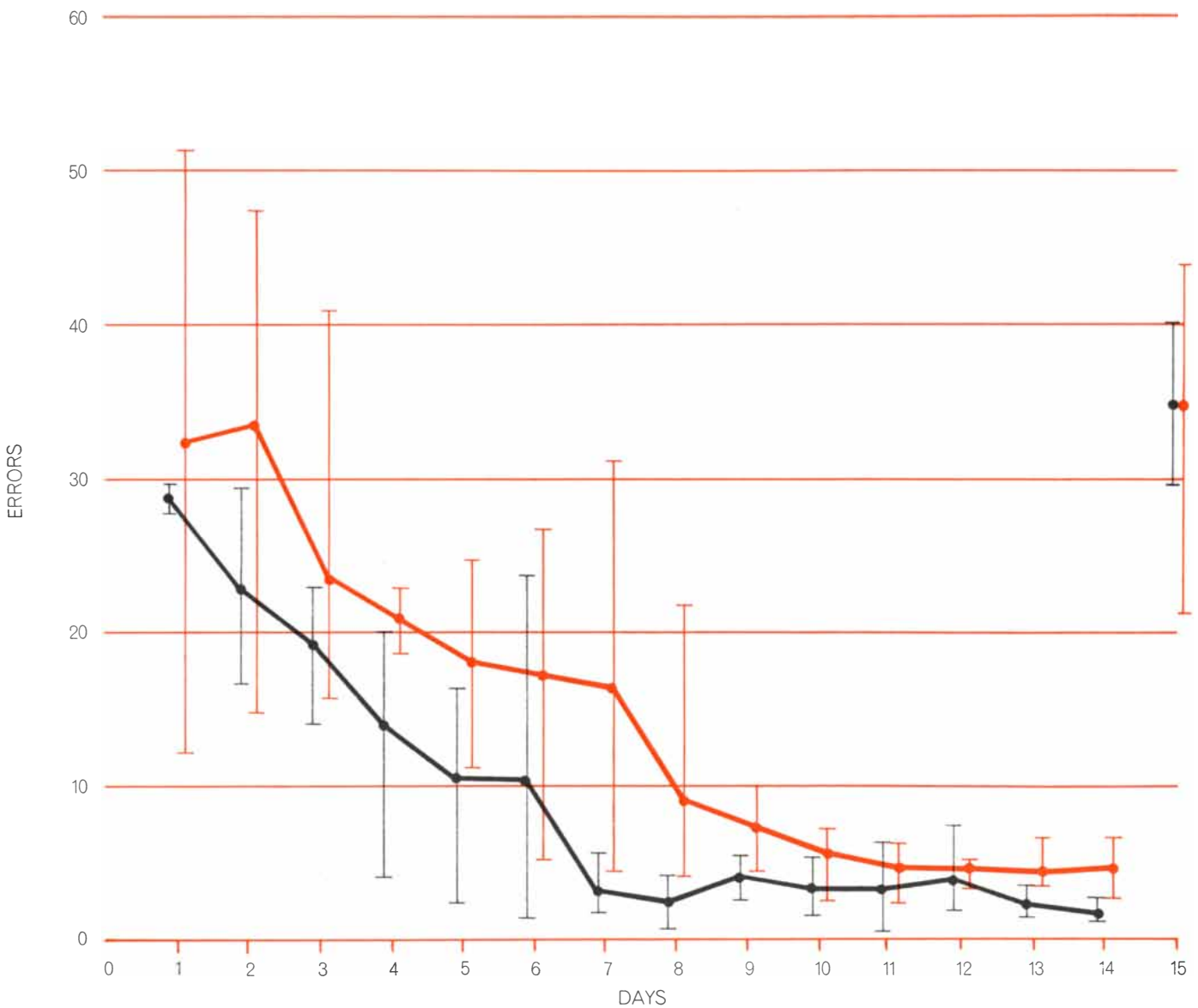
The experiment is important in several respects. First, it demonstrates at least one function of the frontal lobes, a function that may be basic to other functions. Second, it suggests that the difficulty the brain-damaged monkey has in recalling what he did last is not due simply to a premature fading of the memory trace; after all, he improved quickly when a longer interval was interposed, provided that the task was adequately structured. Third, this structuring, organizing or coding is in fact crucial to the process of recall.

Other studies show that the frontal cortex, like the posterior association cortex, exercises control over sensory information flowing into the cortical receiving areas. In many instances, as I have noted, electrical stimulation of the frontal cortex produces effects that are opposite to those produced by posterior stimulation. Our studies are not advanced enough as yet to specify which pathways from the frontal lobes may be involved. Recent work done by Donald B. Lindsley and Carmine D. Clemente at the Brain Research Institute of the University of California at Los Angeles indicates that the pathway involved may be a large tract of fibers (running in the medial forebrain bundle) that carries inhibitory impulses to the reticular formation of the brainstem. I have on occasion attempted to spell out some possible relations between neural inhibitory processes and short-term memory but such efforts are at best tentative.

Coding and recoding are thus found to be essential operations in both memory storage and remembering. I have described evidence showing clearly that storage is distributed throughout a sen-

sory system. I have also mentioned some evidence suggesting that the transformations (coding operations) that are performed within the input channels can be described in terms of convolutional integrals. The basic premise involved is that neighboring neural elements do not work independently of one another. By virtue of lateral interactions, neural elements spatially superpose the excitatory and inhibitory electrical potentials that arise among neighboring nerve cells. These transformations generate a microstructure of postsynaptic events, which can be regarded as wave fronts that set up interference patterns with other (preexisting or internally generated) wave fronts, producing in their totality something resembling a hologram. Given a mechanism capable of storing this hologram, an image could be evoked at some later time by the appropriate input. In order to be effective as codes, transformations must take place within some stable framework. To an extent this framework can be provided by the stored microstructure itself, by the parallel pathways of the input system, by the specific detector sensitivities of units in the system and by the very redundancy of the external environment. (We have no trouble recognizing automobiles because there are so many of them and they are so much alike.)

For complex and novel events, however, a more powerful organizer must come into action. Experiments conducted in my laboratory and elsewhere suggest that this organizing mechanism critically involves the association areas of the cerebral cortex. The mechanism does not, however, seem to reside within these areas. Rather, the association areas exercise control on the input system by way of deeper structures in the brainstem. In short, the function of the association areas of the cortex turns out to be that of providing a major part of the organizing process necessary to remembering: the reconstruction of an image from distributed mnemic events.



MODIFIED ALTERNATION TASK could be mastered as readily by monkeys with part of their frontal cortex removed (*colored curve*) as by normal monkeys (*black curve*). The brain-damaged monkeys had been unable to solve the standard left-right alternation task (*described in the illustration on page 84*) even when the interval between trials was only a few seconds. The task was then modified so that the interval between each left-and-right trial was kept brief (five seconds) but a 15-second pause was inserted after every right-hand trial. When this change was made, brain-damaged monkeys performed about as well as normal monkeys, as shown here. Errors are the number made each day before a monkey achieved 40 successful trials. Bars indicate the range of errors made by different monkeys. Data for the 15th day show the result when all the trials were again separated by equal intervals of five seconds.

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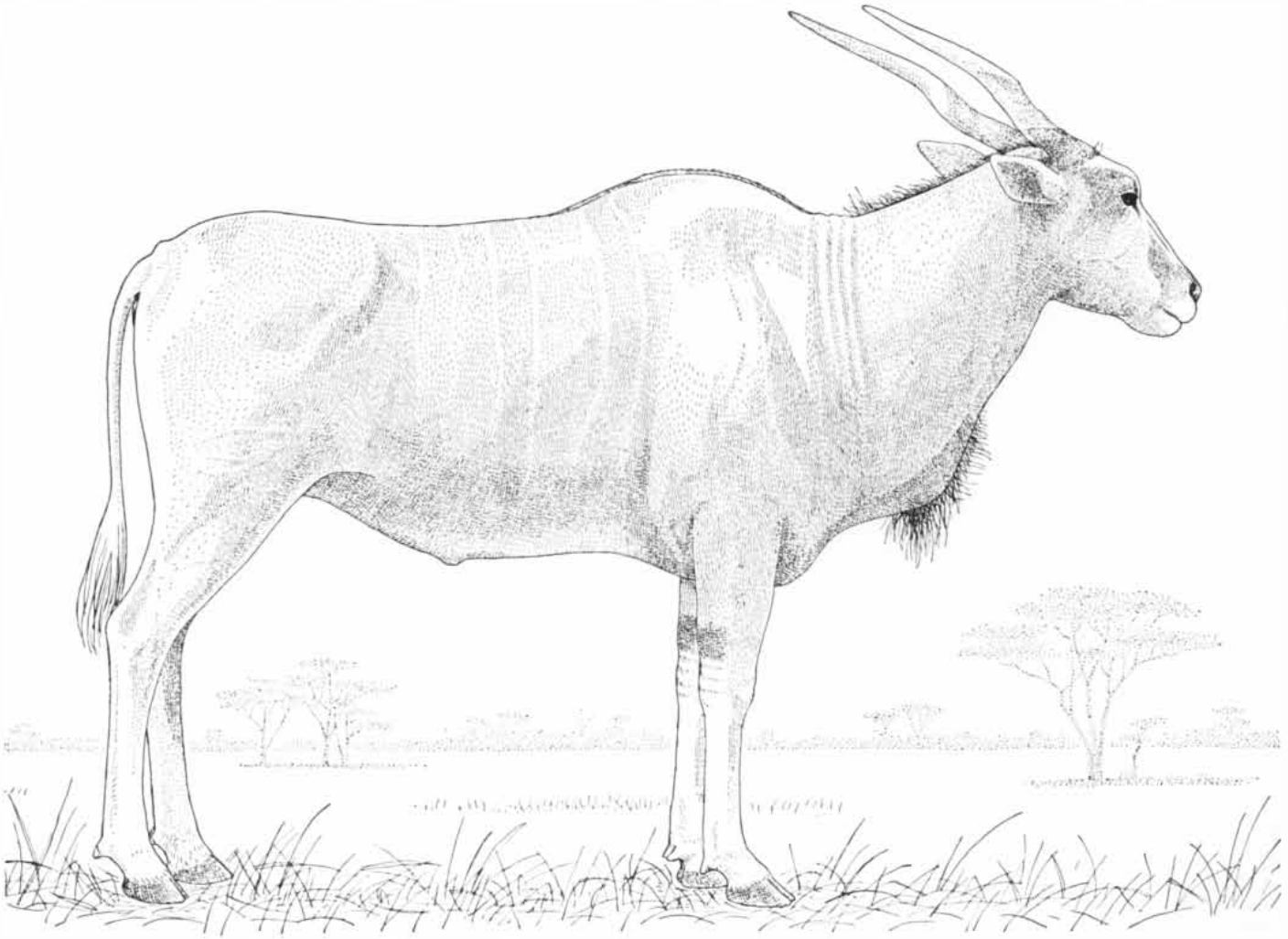
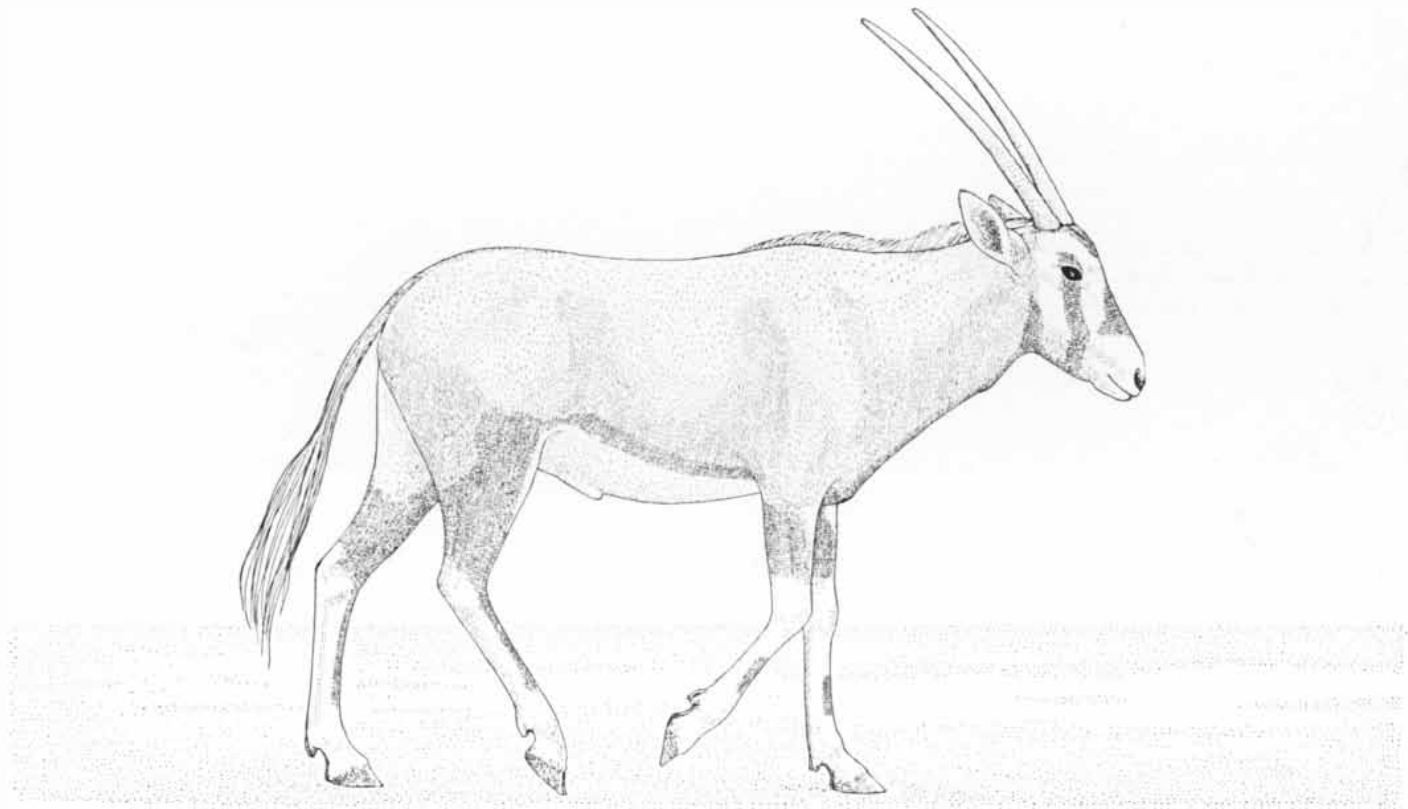


ELAND is the largest of all African antelopes. An average adult bull weighs more than half a ton and may measure six feet at the shoulder. A gregarious and docile member of the family Bovidae, the eland can thrive in drought-ridden rangeland unfit for cattle.



ORYX, another large African antelope, is four feet high at the shoulder. It is even better adapted to arid lands than the eland and is found in barren desert. The oryx, however, is far from docile. It wields its long horns readily and has been known to kill lions.

THE ELAND AND THE ORYX

These large African antelopes can survive indefinitely without drinking. Their feat is made possible by stratagems of physiology that minimize the amount of water they lose through evaporation

by C. R. Taylor

When travelers' accounts of snow on the Equator first reached 19th-century London, learned members of the Royal Geographical Society ridiculed the reports. To many zoologists today the existence of antelopes in the deserts of Africa may seem as much of a surprise as equatorial snow was to 19th-century geographers. Such an environment for any member of the family Bovidae is simply unreasonable. If the reports were accompanied by the statement that the animals survive without drinking, some zoologists would replace "unreasonable" with an emphatic "impossible." Yet it is now well known that snow covers the peaks of many equatorial mountains, and it is consistently reported by naturalists, hunters and local people that certain desert antelopes can survive indefinitely without drinking.

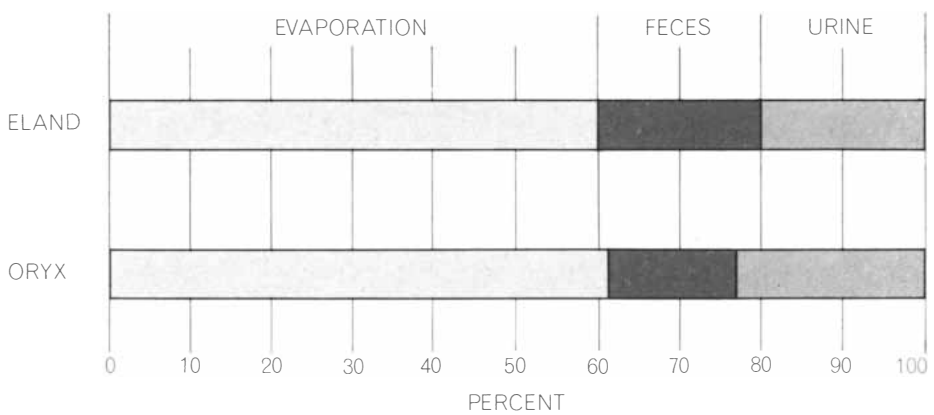
Why should desert survival without drinking seem impossible? It is certainly impossible for humans; in the course of a hot day in the desert a man can lose as much as three gallons of water as a result of sweating and evaporation. Without drinking he could not survive one such day. On the other hand, the kangaroo rat and other desert rodents thrive without drinking at all, even when eating dry food. Their water requirements are met by the very small amounts of free water in their food and by the additional water the food yields when it is oxidized in the process of metabolism. Rodents, however, are small; they can escape the high temperatures of the desert day by burrowing underground. No such shelter is available to the larger mammals. In order to regulate their body temperature during the heat of the day they must evaporate substantial quantities of water. Even the camel, probably the best-known desert animal, has the same problem. As the physiologist Knut Schmidt-Nielsen and his collaborators discovered, the camel has an unusual ability to limit its loss of water by evaporation, but it still must drink in order to survive [see "The Physiology of the Camel," by Knut Schmidt-Nielsen; SCIENTIFIC AMERICAN, December, 1959]. If the antelopes of the African desert did not have similar abilities, survival would be impossible.

Numerous eyewitness accounts identify two antelopes—the eland and the oryx—as animals that do not need drinking water. The eland (*Taurotragus*) is a large, tractable animal that occupies a variety of East African habitats, including the edge of the Sahara. It is easily domesticated, and it has often been proposed as a means of utilizing rangeland that during droughts is too arid for cattle.

Although the eland does not require water, it does not penetrate the most barren deserts. The oryx, on the other hand, is truly a desert species. Unlike the eland, it does not seek shelter during the midday heat but remains exposed to the hot sun throughout the day. The oryx is as aggressive as the eland is tractable. It wields its rapier-like horns with great facility; those who study its physiology get physical as well as mental exercise.

Some years ago, with the help of Charles P. Lyman of Harvard University, I set out to see if these two antelopes really did live in the African deserts without drinking and, if so, how. I had three simple questions. First, do the eland and the oryx possess any unusual mechanisms for conserving water? Second, if they do, how much water do they require when the mechanisms are operating? Third, can they get this amount of water in some way other than drinking? I had the opportunity to investigate these problems at the East African Veterinary Research Organization at Muguga in Kenya, where the directors (initially Howard R. Binns and later Marcel Burdin) generously provided the needed laboratory space and equipment.

The first step was to establish a laboratory environment that would simulate a hot desert and make it possible to find out how much water the antelopes lost.



EVAPORATION from the skin and respiratory tract proved to be the major avenue of water loss for antelopes allowed to drink freely in a simulated desert environment. The only means of saving significant amounts of water in the desert heat is to reduce evaporation.

I did not attempt to duplicate the desert's day and night temperature extremes, but I maintained the average daytime temperature for 12 hours and the average nighttime temperature for the same period. With heating and air-conditioning equipment I was able to rapidly raise the temperature of the animals' room to 40 degrees Celsius (104 degrees Fahrenheit) or lower it to 22 degrees C. (72 degrees F.), thus simulating the desert's average day and night temperatures.

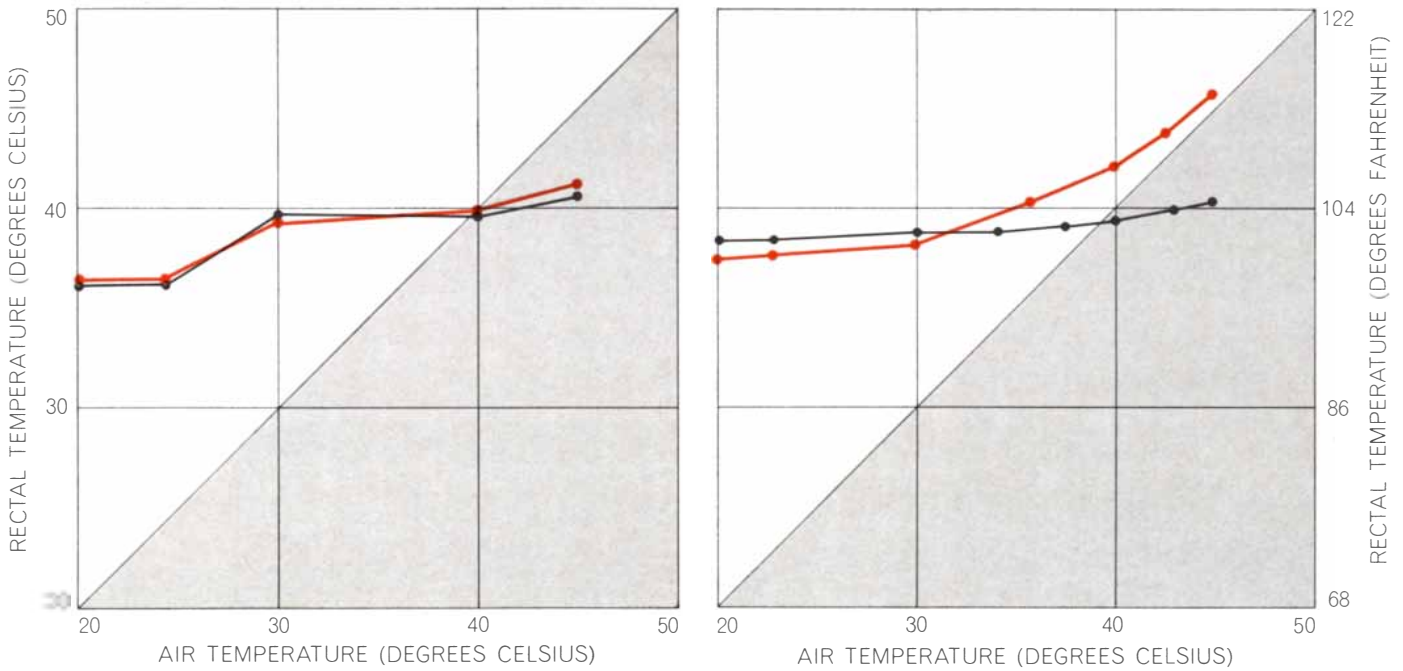
In this environment I measured the various ways the animals lost water. I found that loss by evaporation was the most important [*see illustration on preceding page*]. The function served by evaporation is to prevent the animal from overheating. Most mammals maintain their body temperature at a nearly constant level, usually about 37 degrees C. (98.6 degrees F., the "normal" point on a clinical thermometer). If their body temperature rises too high, they die; for most mammals a body temperature of 43 degrees C. (109 degrees F.) for a few hours would be fatal.

When the temperature of the environment is lower than the animal's temperature, which is usually the case, heat flows from the animal to the surroundings (by conduction and radiation). The maintenance of a constant body temperature in these circumstances requires that the animal's metabolic machinery generate an amount of heat equal to the net outward heat flow. When the environmental temperature is higher than the animal's, however, the direction of heat flow reverses and heat is transferred from the environment to the animal. If under these circumstances the body temperature is to remain constant, the heat gained from the environment, as well as the heat generated by metabolism, must be dissipated by evaporation. Each gram of water that is evaporated carries away .58 kilocalorie of heat, and the combined heat load on a man may be so great that he is obliged to evaporate more than a liter (about a quart) of water an hour.

One way the body can reduce evaporation under heat stress is to abandon the maintenance of a constant body temperature. Schmidt-Nielsen and his collaborators found that when the camel is confronted with a shortage of water, its body temperature rises during the course of the day by as much as seven degrees C. To see if the eland or the oryx had the same ability, I recorded their rectal temperature during the laboratory's hot 12-hour day. The animals had all the water they could drink, so that nothing prevented the maintenance of a constant body temperature by evaporation. Nonetheless, during 12 hours at 40 degrees C. the eland's temperature on occasion rose by more than seven degrees (from 33.9 to 41.2 degrees C.) and the oryx's by more than six degrees (from 35.7 to 42.1 degrees) before increased evaporation prevented any further rise (although usually the temperature rise was less extreme). Thus instead of spending water to maintain a constant body temperature, the animals "stored" heat in their bodies.

In an eland weighing 500 kilograms a 7.3-degree rise in temperature means that the animal has managed to store some 3,000 kilocalories. To dissipate the same amount of heat by evaporation would cost it more than five liters of water. In the wild, as the lower night temperature allows a reversal of heat flow from the animal back to the environment, this stored heat is dissipated by conduction and radiation rather than by evaporation.

I found that when the eland and the oryx were exposed to the high experimental temperature and had water available to drink, their body temperature usually increased by three or four degrees during a 12-hour day. After three or four hours' exposure the animals' evaporative processes accelerated sufficiently to prevent a further rise in their temperature, which remained below the temperature of the laboratory even at the end of the full 12 hours. In the wild such a pattern of gradual warming before an increase in evaporation means that the animals might get past the hottest hours



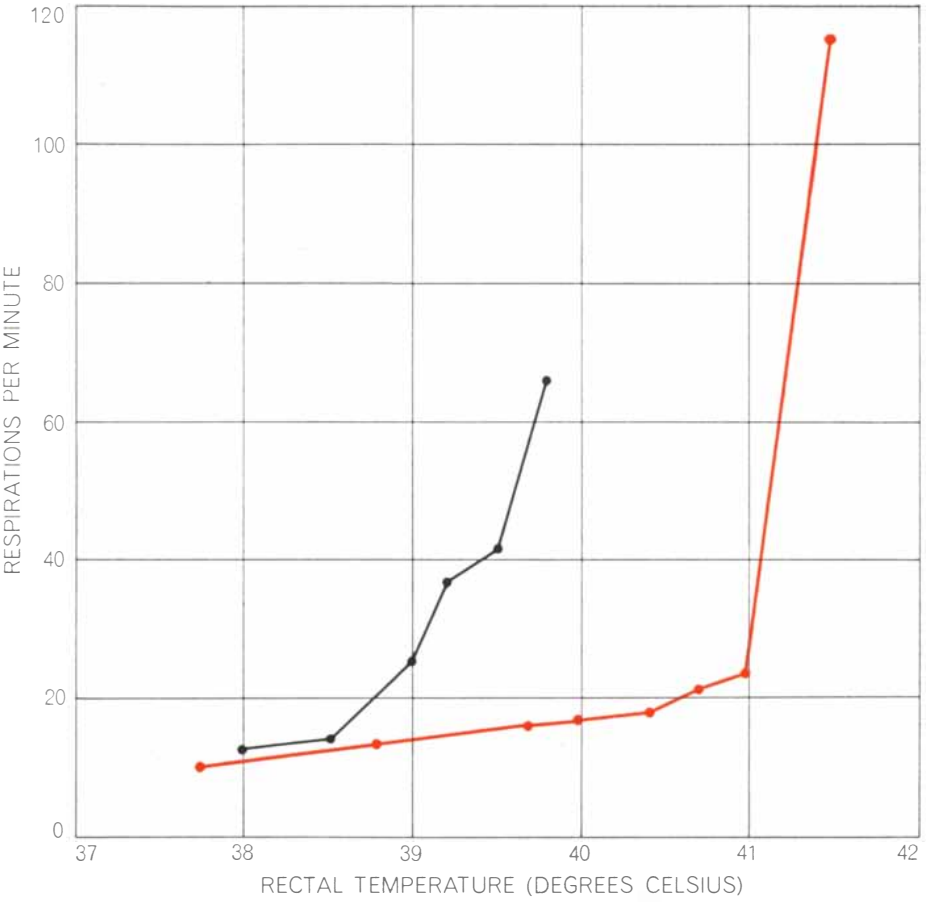
RISE IN TEMPERATURE in the author's test enclosure brings much the same physiological response from the eland (*left*) whether abundantly watered (*black*) or dehydrated (*color*) as from the oryx (*right*) when abundantly watered (*black*). At air temperatures over 40 degrees Celsius, the animals' rectal temperatures no longer remain higher than the temperature of the environment (*diagonal connects points where air and rectal temperature are equal*). Instead evaporative cooling keeps rectal temperature below air temperature, so that heat flows from the environment to the animal. The temperature of the dehydrated oryx (*color*), however, continues to rise, and heat flows from animal to environment. The dehydrated oryx therefore gains no heat from its surroundings.

of the day before expending precious water for cooling.

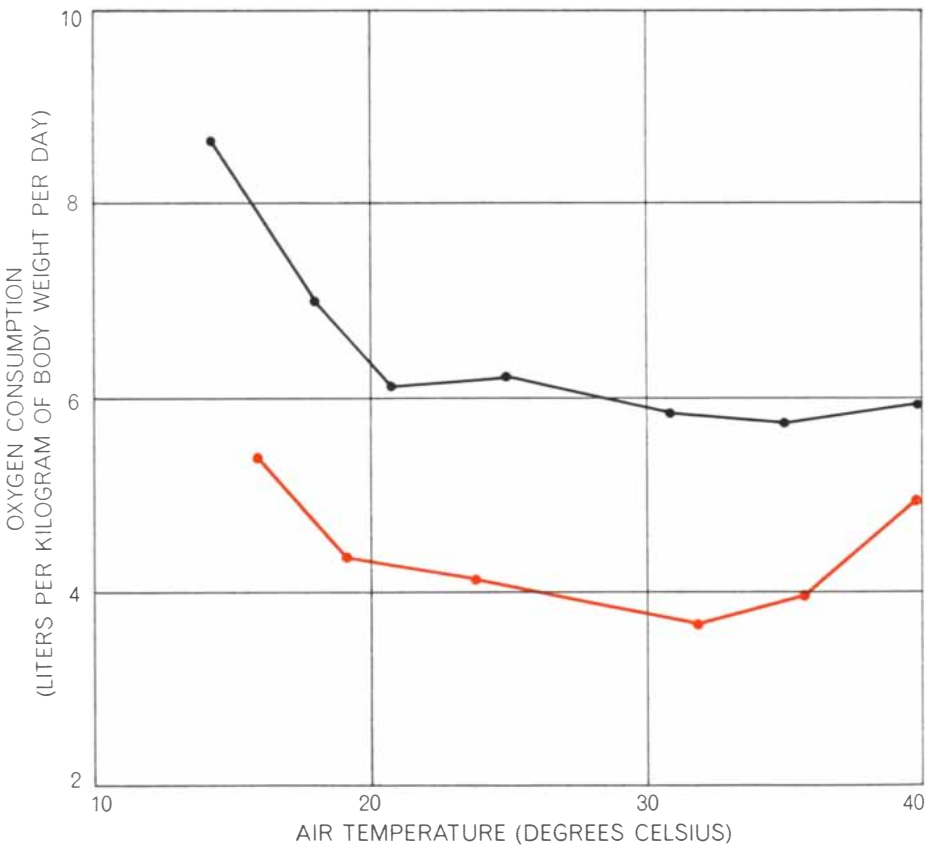
These first observations showed that in desert-adapted antelopes, as in the camel, water loss was reduced by the increase in body temperature. So far, however, I had measured the responses of the antelopes only under circumstances where they had been free to drink as much water as they wanted; this was a long way from testing their reported ability to get along without drinking at all. Before making my next series of measurements, therefore, I restricted the animals' water intake until they became dehydrated and lost weight. They were given just enough water to keep them at the point where they maintained their body weight at 85 percent of their original weight. I then exposed them to the same experimental 12-hour hot days as before. The body temperature of the dehydrated eland still remained below the temperature of the environment, even after 12 hours at 40 degrees C., and of course this can only be achieved by maintaining a high rate of evaporation. The temperature of the dehydrated oryx, in contrast, routinely exceeded that of the environment by a wide enough margin for metabolic heat to be lost by conduction and radiation; evaporation did not increase during the entire 12-hour exposure.

Although I had selected 40 degrees C. as the temperature of the hot periods, I knew that the desert air temperature is higher for a few hours every day, and that the solar radiation at midday near the Equator is literally searing. During the worst heat of the day the eland moves into the shade but the oryx appears to be oblivious of the intense heat. Oryx species with the lightest-colored coat are the ones that penetrate farthest into the desert; the coat's reflectivity must help to reduce the radiant heat gain. Unless the coat is perfectly reflective, however, an oryx standing in the hot desert sun should absorb far more heat than one in the laboratory at 40 degrees C.

I decided to test the animals' reactions to an even more severe heat load by raising the laboratory temperature to 45 degrees C. (113 degrees F.). Dehydrated or not, the eland managed to maintain its temperature some five degrees below the new high. So did the oryx, when it was supplied with water. The dehydrated oryx's physiological response was quite different. Its temperature rose until it exceeded the temperature of the laboratory and remained above 45 degrees C. for as long as eight hours without evident



EVAPORATIVE COOLING through panting rather than through sweating is characteristic of the dehydrated oryx. When abundantly watered (*black*), an oryx not only sweats but also starts panting as its temperature reaches 39 degrees C. Although dehydrated oryx (*color*) does not sweat, it pants vigorously once its temperature exceeds 41 degrees C.



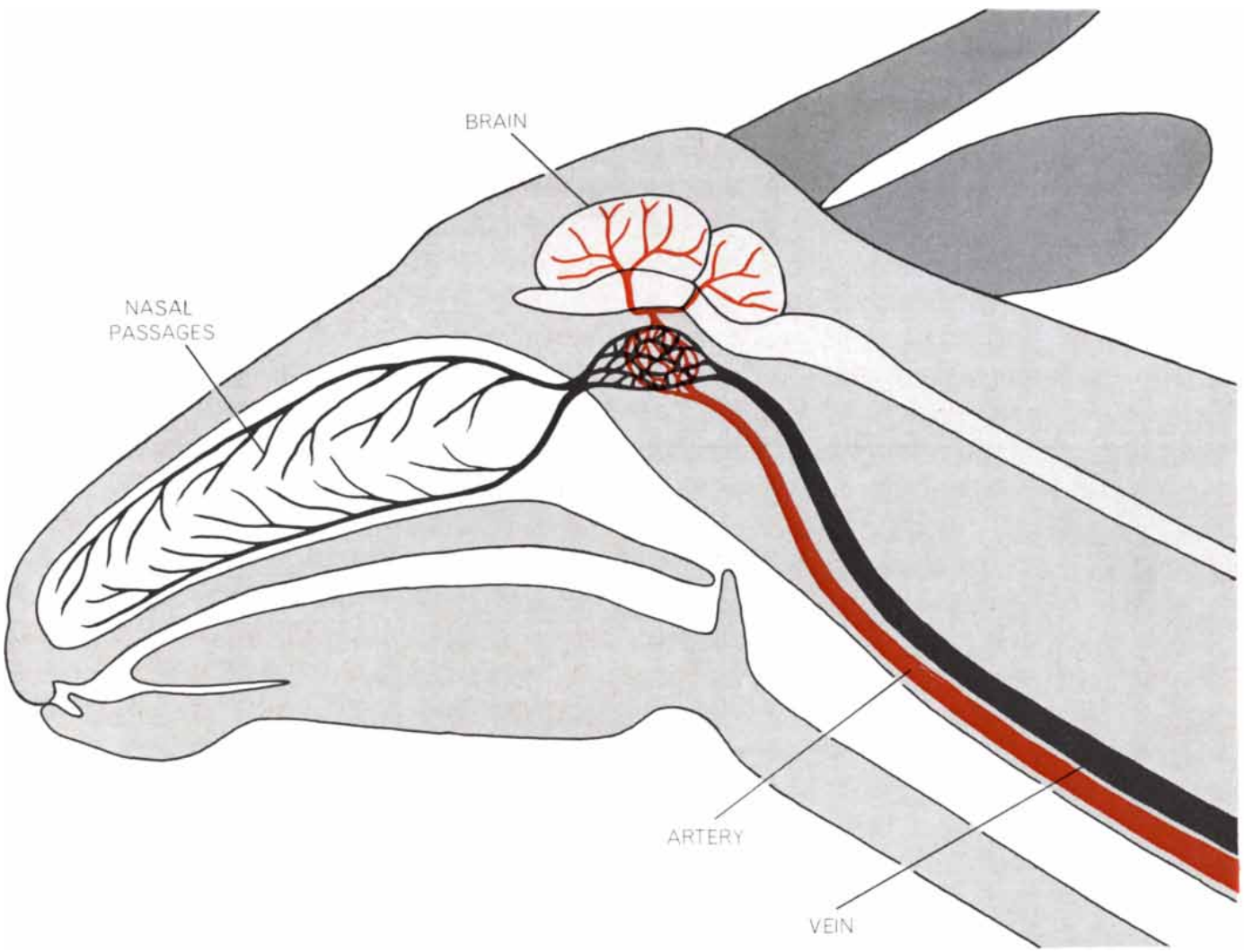
ORYX'S OXYGEN CONSUMPTION varies with the temperature of the environment and is drastically reduced by dehydration (*color*). As a result the dehydrated oryx generates much less metabolic heat and the quantity of heat to be lost by evaporation is reduced.

ill effect. I believe such a high continuous temperature has been observed in only one other mammal: the small desert gazelle *Gazella granti*. This hyperthermia in both the oryx and the gazelle enables them to save large amounts of water even under severe heat loads, and this is probably the critical factor in their survival under desert conditions.

How do the oryx and the gazelle survive these high internal temperatures? The brain, with its complex integrative functions, is probably the part of the body most sensitive to high temperatures. It is possible that in both animals the brain remains substantially cooler than the rest of the body. As the external carotid artery, which supplies most of the blood to the brain in these animals, passes through the region called the cavernous sinus, it divides into hundreds of small parallel arteries. Cool venous blood from the nasal passages drains into the sinus, presumably reducing the temperature of the arterial blood on its way to the brain. Evidence for this view is that, when temperature readings are taken during exercise, the brain of a gazelle proves to be cooler than the arterial blood leaving the heart by as much as 2.9 degrees C. Mary A. Baker and James N. Hayward of the University of California at Los Angeles have demonstrated that such a mechanism also operates in the sheep.

The manner in which an animal increases evaporation to keep cool can make a difference in the amount of heat it gains from a hot environment. Some animals pant, some sweat and some spread saliva on the body. An animal that depends on sweating or salivation for loss of body heat will necessarily have a skin temperature that is lower than its internal temperature. The blood must flow rapidly to the skin, carrying the internal heat to the evaporative surface. Conversely, a high skin temperature and a low flow of blood to the skin reduces the rate of heat flow from the hot environment to the animal. If the animal can pant rather than sweat, it can dispose of body heat by respiratory evaporation and at the same time have a higher skin temperature that minimizes its accumulation of environmental heat. Accordingly I wanted to find out whether the oryx under heat load increased its evaporation by sweating, by panting or by both. I also wondered what effect dehydration might have on the relative importance of the two evaporative routes. When I measured sweating and panting in an oryx freely supplied with water, I found that the evaporation rate increased in both routes but that evaporation from the skin accounted for more than 75 percent of the total. When the animal was deprived of water, it did not sweat at all in response to heat, but it began to pant when its body temperature exceeded 41 degrees C.

David Robertshaw of the Hannah Dairy Research Institute in Scotland and I had previously found that the sweat



COUNTERCURRENT COOLING of arterial blood on its way from heart to brain occurs in the cavernous sinus, where the carotid artery ramifies into hundreds of smaller vessels (*color*). There venous blood (*black*) from the oryx's nasal passages, cooled by respiratory evaporation, lowers the arterial blood temperature. A brain cooler than the body temperature may be vital to desert survival.

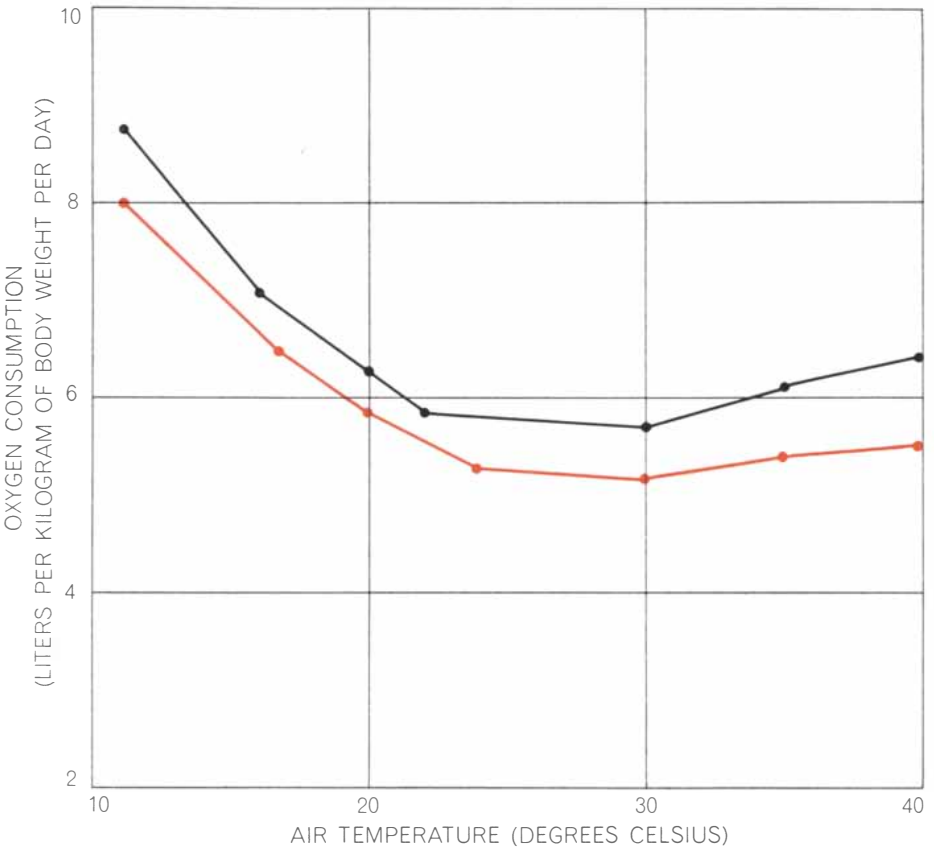
glands of the oryx are controlled by nerve cells that release adrenalin. For example, an oryx can be made to sweat by means of a small intravenous injection of adrenalin. When we gave the same doses of adrenalin to a dehydrated oryx, the animal also sweated. The response makes it clear that the sweat glands of a dehydrated oryx can still function, but that the animal's nervous system has simply stopped stimulating them.

Increases in the temperature of the body and of the skin are not the only stratagems that minimize evaporation. A lowering of the animal's usual metabolic rate would reduce the amount contributed to the total heat load by the animal itself. To see whether or not this potential saving was being accomplished, I measured the metabolic rate of both the eland and the oryx over a broad range of temperatures. The metabolic rate of the dehydrated eland was somewhat reduced, but in the oryx the reduction was much greater. At 40 degrees C. the observed reduction in the metabolic rate of the oryx was sufficiently low to reduce its evaporation by 17 percent as compared to evaporation from animals freely supplied with water.

Taken together, these findings indicate that when water is scarce, the eland and the oryx reduce their rate of evaporation during the hot desert day in various ways. Both animals store heat; both decrease the heat flow from the environment, the eland by seeking shade and the oryx by accommodating to an extreme body temperature; both decrease the amount of metabolic heat they produce.

What about water loss during the night? When the sun goes down, of course, the antelopes are no longer under a heat load from the environment. The heat generated by their own metabolic processes is easily lost to the cooler surroundings by means other than evaporative cooling. Nonetheless, some evaporation, both from the respiratory tract and from the skin, continues at night.

The water lost through the skin at night is not lost through sweating. It is probably lost through simple diffusion. Skin is slightly permeable to water; even apparently dry-skinned reptiles lose appreciable amounts of water through the skin. So do the eland and the oryx. During the 12-hour cool night in the laboratory I found that both animals, when they had free access to water, lost about half a liter of water per 100 kilograms of body weight through the skin. The water loss was reduced when the animals were dehydrated; their skin seemed drier and less permeable. The water loss from the dehydrated eland was 30 percent less than when it could drink freely. In the dehydrated oryx the water loss from the skin was reduced by nearly 60 percent.



ELAND'S OXYGEN CONSUMPTION also varies with the temperature of the environment but is only slightly reduced by dehydration (*color*). Like the oryx, the eland increases its oxygen consumption at the low temperatures of the desert night. The increase threatens both animals with a net loss of water if night feeding produces less than 10 percent water.

I wondered if the loss of water from the respiratory tract could also be reduced. As a mammal breathes, the inhaled air is warmed to body temperature and is saturated with water vapor in the respiratory tract before it reaches the lungs. Normally most mammals then exhale saturated air that is still at body temperature. Donald C. Jackson of the University of Pennsylvania School of Medicine and Schmidt-Nielsen have observed, however, that two species of small rodents manage to exhale air that is much cooler than their body temperature. The rodents apparently recondense some water vapor within the respiratory tract. This is one way water loss through respiratory evaporation could be minimized by antelopes. Two other possible means of water economy are related to oxygen requirements. First, if more oxygen can be extracted from each breath, an animal does not need to move as great a volume of air through its respiratory tract, thus reducing the loss of water to the respiratory air. Second, if the animal's oxygen consumption is lowered, the volume of inhaled air (and therefore the loss of water) is also reduced.

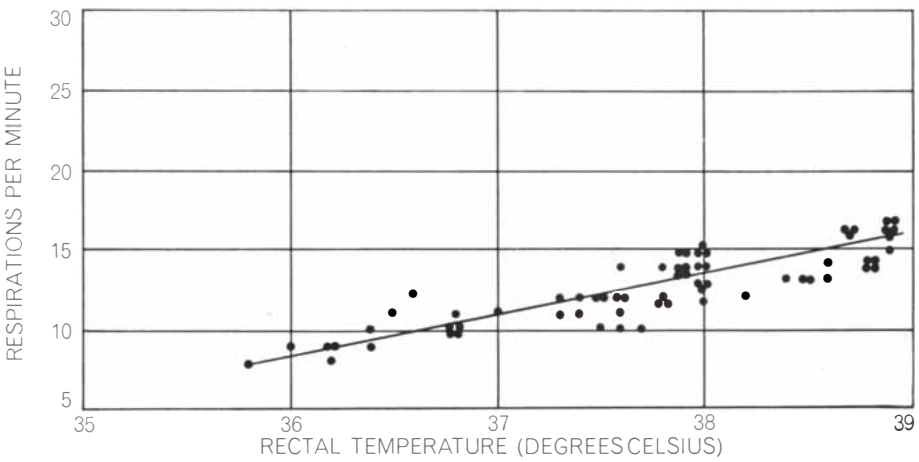
It is known that domesticated cattle exhale saturated air at body temperature. It is probable that the eland and the oryx, with their large nasal passages and relatively slow rate of respiration, do the same, so that water economy by recondensation is not available to them. Both animals have a lower body temperature at night than during the day, however, and the difference is enough to significantly reduce the amount of water needed to saturate the respiratory air. Air saturated at 39 degrees C., a typical daytime temperature for the eland, contains some 48 milligrams of water per liter. Air at the typical night temperature of 33.8 degrees contains some 25 percent less water.

When I investigated the animals at nighttime temperatures, I found that both the eland and the oryx extracted more oxygen from the air and breathed more slowly when they had a low body temperature. When the eland's temperature is at a nighttime low of 33.8 degrees C., about twice as much oxygen is extracted from each liter of air that it breathes. As oxygen extraction increases,

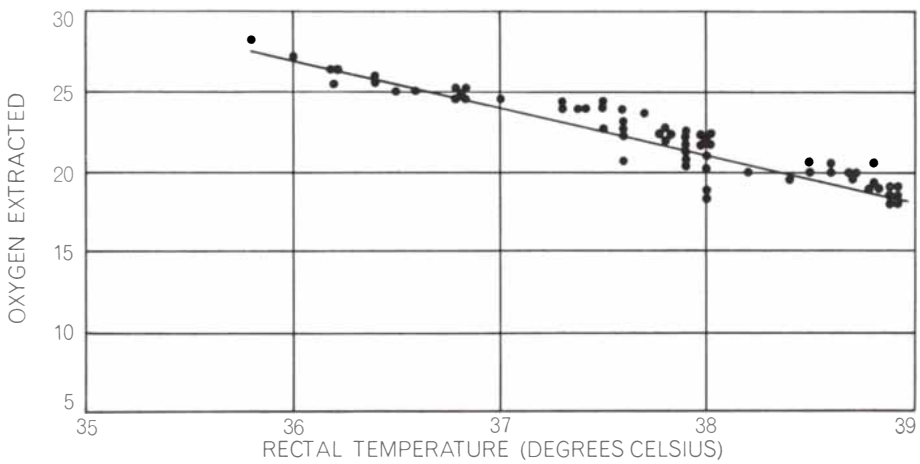
the amount of air inspired with each breath also increases. Only part of the air an animal breathes actually reaches the lung, where oxygen and carbon dioxide are exchanged. The rest fills the respiratory passages, where the air is warmed and saturated with water vapor but where no exchange of gas takes place—the "dead-space volume." As the eland breathes more deeply, the dead-space volume remains constant but a greater proportion of the total inspired air reaches the lungs: the same amount of oxygen is extracted from each volume of air within the lungs but the volume has been increased. Any animal that breathes more slowly and more deeply will extract more oxygen from the inspired air and lose less water (and heat) with its expired air.

Is water economy also aided by a lower oxygen consumption? I had already found that in both the eland and the oryx the rate of metabolism is reduced when the animals are dehydrated. During the cool nighttime period the metabolic rate of the dehydrated eland was about 5 percent lower than the rate of the freely watered eland, and the metabolic rate of the dehydrated oryx was more than 30 percent lower than the rate of the freely watered oryx. Other things being equal, then, when water is scarce in the wild, the respiratory water loss of both antelopes would be reduced by an amount equal to the reduction in their metabolic rate. Although some loss of water through respiration remains unavoidable, it is minimized by the combination of lowered body temperature, increased oxygen extraction and reduced metabolism.

When I measured oxygen consumption at various temperatures, I found that metabolism increased at temperatures below 20 degrees C. This seemed odd, because both antelopes frequently encounter temperatures below 20 degrees C. at night. The increase, which only serves to keep the animals warm, would not be necessary if the animals had a slightly thicker fur, which would also reduce the heat gain during the hot day. It seems possible that such an adaptation has not appeared because the increased metabolism at night means the difference between a net loss or gain of water. If an animal increases its metabolism at night, it also eats more, takes in more free water with its food and generates more oxidation water. At the same time additional water is lost by breathing more air to get the necessary additional oxygen. When one calculates the amount of water needed in the food to offset a net loss of water through increased metabolism at night, it works out at about 10 percent water content in the food. Thus if the eland and the oryx feed at night on plants with a water content higher than 10 percent, they achieve a net gain of water. As we shall see, they favor plants that have a water content considerably above this level.



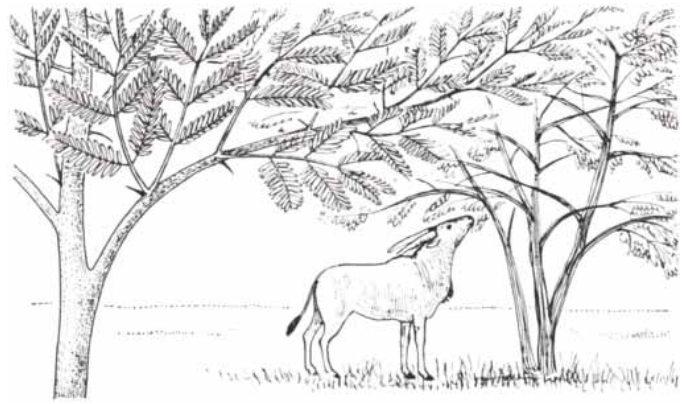
RESPIRATION RATE of an eland is controlled by the animal's temperature, decreasing as the temperature falls. When it breathes more slowly, the eland also breathes more deeply, so that a greater part of each breath reaches the lung areas where gas exchange occurs.

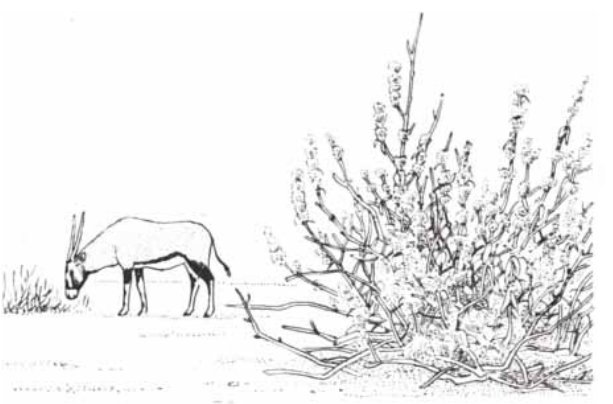


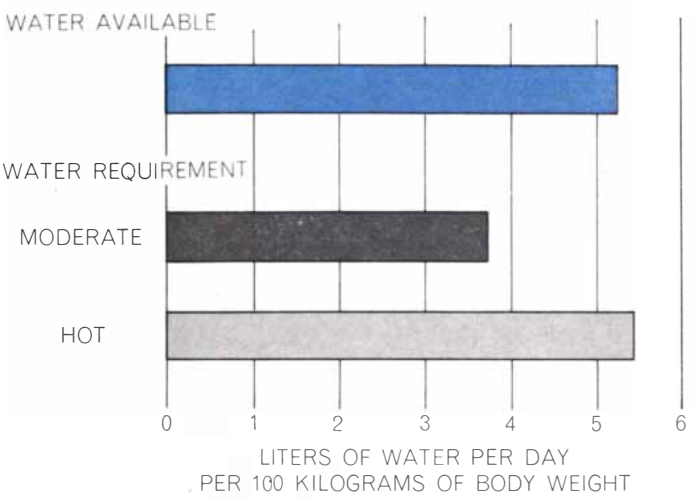
OXYGEN EXTRACTION from each breath of air increases as the eland's temperature falls and the animal breathes more slowly and deeply (*see upper illustration*). Because the eland's oxygen needs are met by a lesser volume of air, respiratory water loss is reduced.

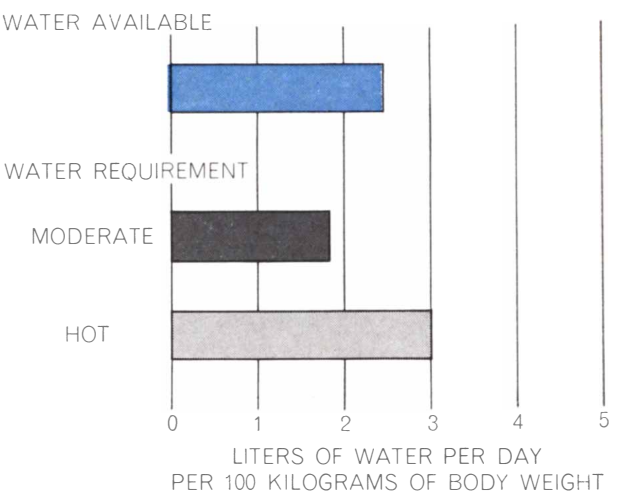
Having found that the two animals do indeed possess unusual mechanisms for conserving water, I next undertook to find out how much water—or rather how little—each required. To do this I kept dehydrated animals in two contrasting laboratory environments. One was the usual alternation of 12-hour hot days and cool nights; the other was constantly cool. In the cool environment the dehydrated eland managed to stay at an even 85 percent of its original weight when its total water intake (free water in food, oxidation water and drinking water) was slightly in excess of 3.5 liters per 100 kilograms of body weight per day. The dehydrated oryx got by on scarcely half that amount: a little less than two liters per 100 kilograms. On a regime of cool nights and hot days the eland's water requirement increased to nearly 5.5 liters and the oryx's to three liters. These findings brought me to a final question: Could the two animals obtain this minimum amount of water without drinking?

The eland not only finds shade beneath acacia trees; acacia leaves are one of its favored foods. I collected acacia leaves and measured their moisture content. Even during a severe drought they contained an average of 58 percent water. Calculating the weight of acacia leaves that an eland would ingest in a day to meet its normal metabolic requirements, I found that the leaves would provide about 5.3 liters of water per 100 kilograms of body weight, or almost ex-









SURVIVAL WITHOUT DRINKING is possible for the oryx and the eland because their food contains almost all the water they need. Even in droughts the leaves of the acacia (*left*), the eland's preferred fodder, are 58 percent water. The leaves of a shrub, *Disperma,* and other fodder preferred by the oryx (*right*) contain little water by day but may average 30 percent water at night. Thus the amount of water each animal can obtain by feeding (*color*) is more than the animal needs for survival in a moderate environment (*black*) when dehydrated and closely approaches the quantities necessary for both antelopes' survival under desert conditions (*gray*).

actly the amount needed by the dehydrated eland for survival. An eland that obtains this much water by browsing only can probably live indefinitely without drinking.

The oryx favors grasses and shrubs, particularly a shrub of the genus *Disperma.* In the daytime these plants are so dry their leaves fall apart when they are touched; my measurements showed that they contain as little as 1 percent water. At first this seemed an impossible contradiction. Nonetheless, there is a way for the oryx to get all the water it needs by grazing. As long ago as 1930 the British naturalist Patrick A. Buxton observed that at night dry grass collects moisture from the desert air, even when there is no dew. The reason is that the drop in nighttime temperatures raises the relative humidity of the desert air and that the dry plant material can absorb moisture. To determine whether or not this mechanism was of importance to the oryx, I exposed some of the plants to laboratory air of the same average temperature and humidity as desert night air. Within 10 hours the formerly parched plants had acquired a water content of 42 percent.

In the wild, of course, the plants would not always contain this much water. At sunset their water content would be less, but later at night the plants could be substantially cooler than the surrounding air because of radiation to the night sky and thus might collect more water than the plants in the laboratory experiment. It seems entirely possible that by eating mainly at night the oryx could take in food containing an average of 30 percent water. If this is the case, the oryx, which needs only half as much water as the eland, would also be independent of drinking water as it roams the desert.

Hence we see that both eland and oryx have unusual physiological and behavioral adaptations for life in an arid environment. It is therefore tempting to conclude that ranching eland and oryx in arid regions would be an excellent way to expand Africa's meat supply. The conservation of beautiful and interesting species would be an additional benefit. Serious problems, however, exist in getting antelope protein off the hoof and to the market at a price competitive with beef (equivalent to about 28 cents per pound in most of East Africa). The success of the antelopes in arid regions with sparse vegetation depends on their low density per square mile; this makes it difficult to locate them in the vast areas where they live. To harvest them economically would require the development of inexpensive ways to find, kill, butcher and transport them from the isolated deserts to the cities and towns of Africa. The alternative to wild ranching —domestication, fencing and concentrated feeding—dissipates the physiological and behavioral advantages of antelopes over cattle. In fact, there is every reason to believe man's intensive breeding of cattle for meat production has produced an animal superior to antelopes under these conditions. Tapping the potential of antelope meat awaits economists and agriculturists who can solve these seemingly insurmountable problems.

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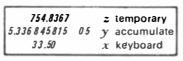

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The Control of Vibration and Noise

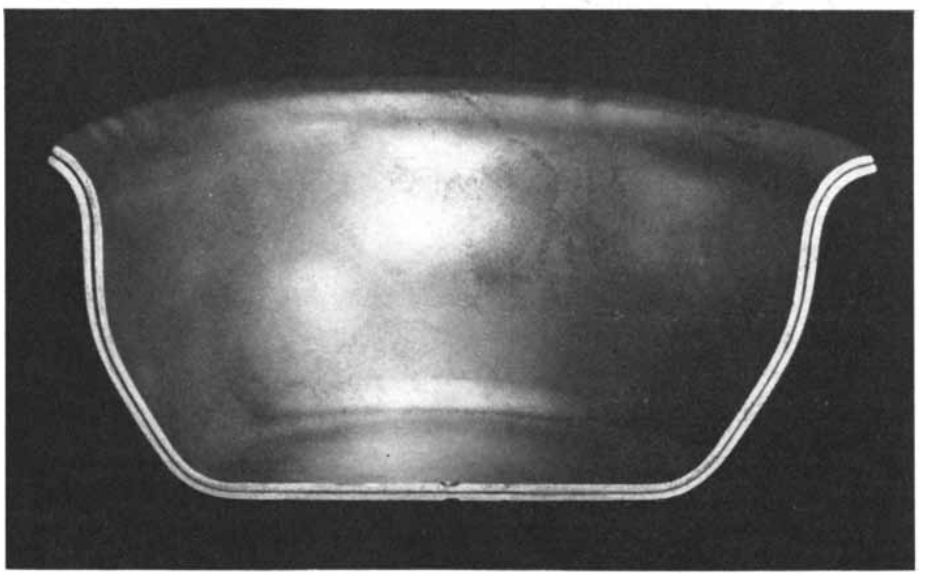
The addition of constrained-layer damping to the conventional techniques of isolation and absorption provides the necessary technology to control almost all excessive vibration and noise

by Theodore P. Yin

Noise pollution has come to be recognized in recent years as one of the most unwelcome accompaniments of an industrialized urban society. The psychological and physiological effects of excessive noise range from the distracting to the destructive. Furthermore, noise and its mechanical counterpart, vibration, have been implicated in the failure of many physical structures. Public awareness of the detrimental effects of uncontrolled noise and vibration has led to comprehensive legislation establishing industrial standards, building codes and transportation requirements to limit the transmission of harmful noise or to specify adequate protective equipment for workers in noisy environments. The demand for quieter household appliances and other consumer items has led to an increasing concern on the part of manufacturers with the acoustic and vibratory performance of their products.

As a result the control of excessive noise and vibration now occupies the attention of a substantial group of technologists. Their efforts have already yielded a variety of techniques for the dissipation of unwanted acoustical and vibrational energy. One of the most promising of these new techniques, called constrained-layer damping, has been investigated by our group in the Elastomer Chemicals Department of E. I. du Pont de Nemours and Company. Basically this technique provides for the dissipation of mechanical energy in the form of heat generated by the physical distortion of a layer of viscoelastic material sandwiched between the vibrating structure and a thin metal constraining layer.

In order to appreciate the novelty of this approach, it will be helpful first to examine the nature of the phenomenon we are undertaking to control and then to review briefly the two major conventional control techniques employed at present.

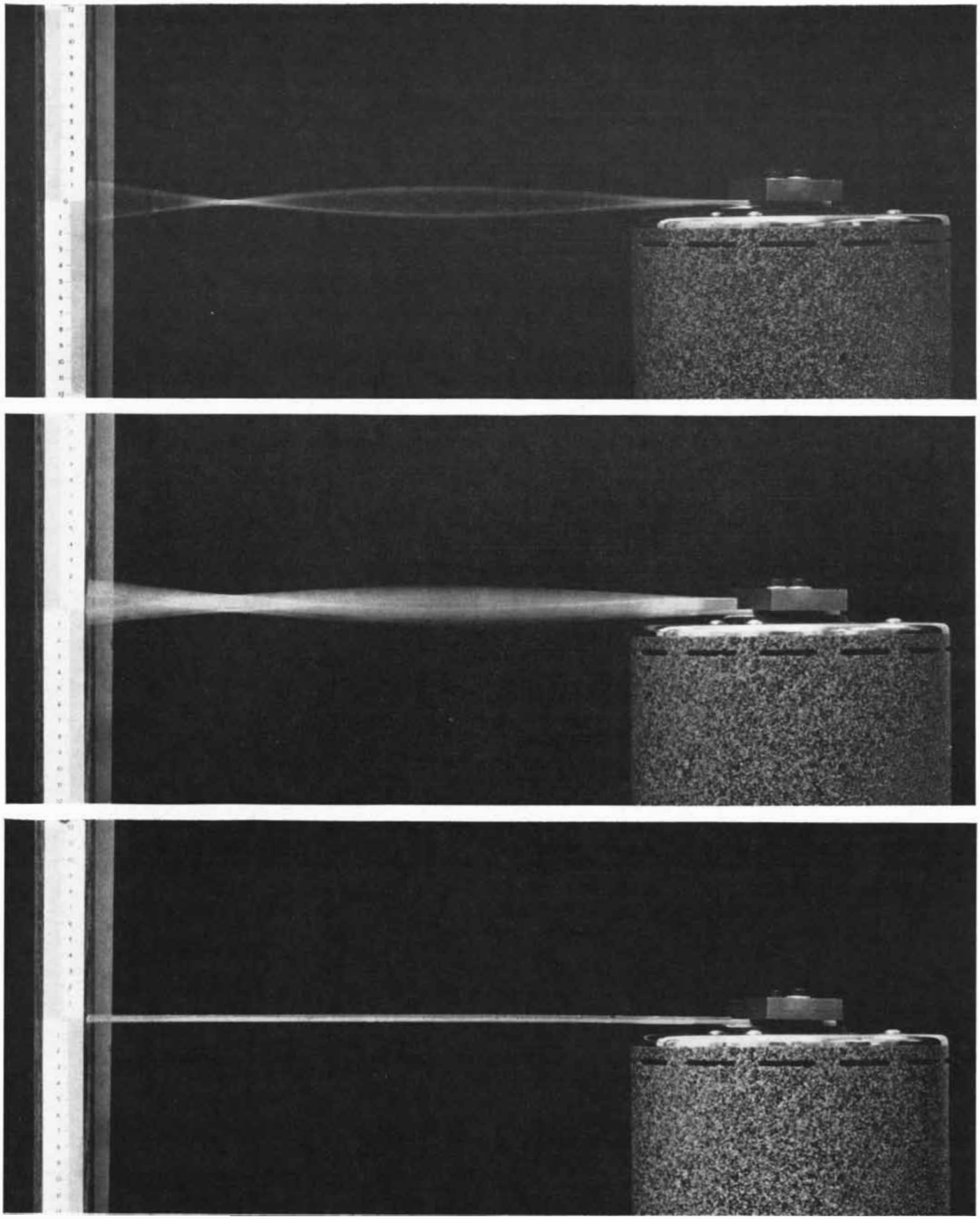


PRINCIPLE of constrained-layer damping is demonstrated by this photograph, which shows a cross section of a tublike structure composed of two rigid steel layers separated by a thin viscoelastic damping layer. When the entire structure vibrates, the mechanical energy of vibration is dissipated by its conversion into heat within the damping layer.

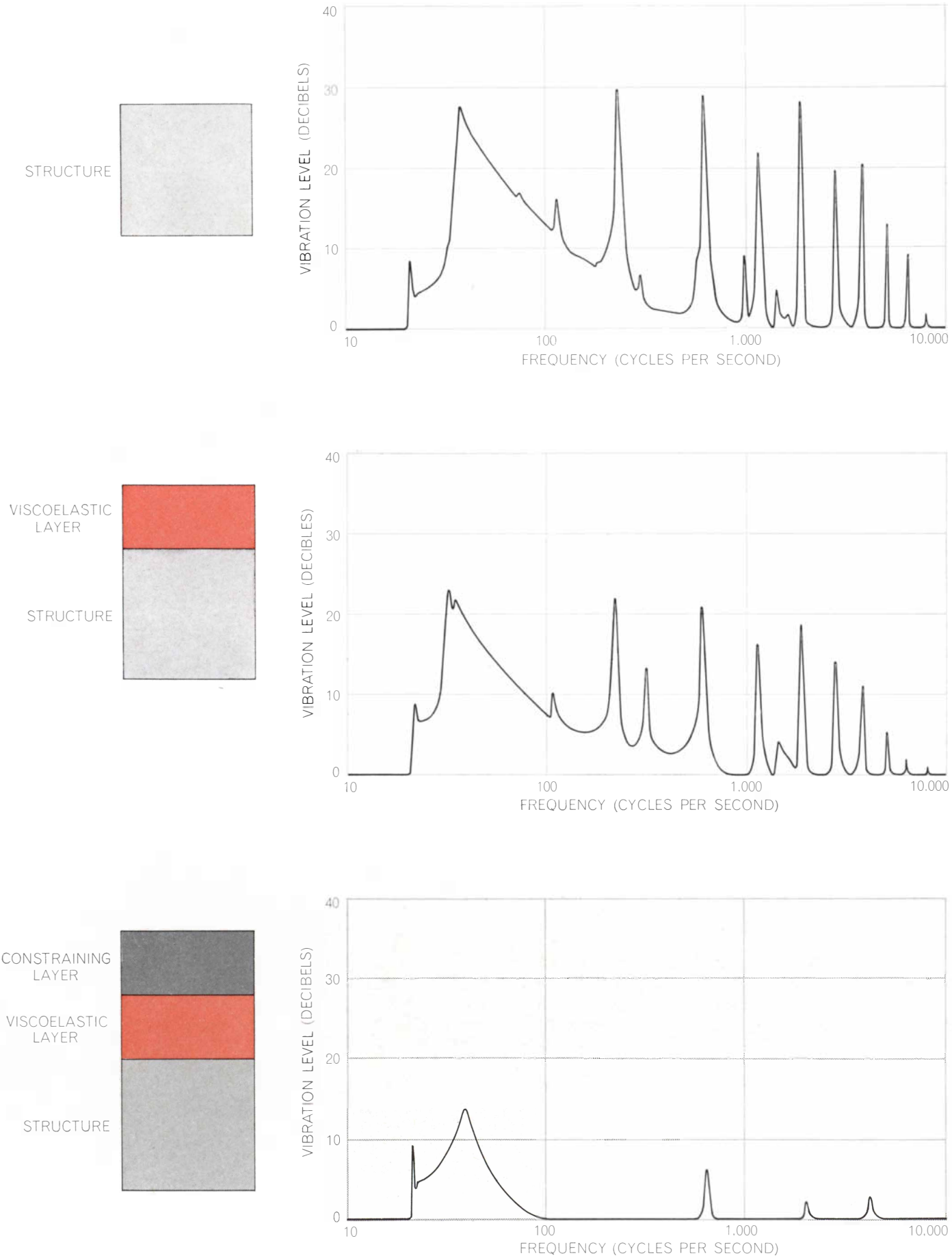
Every problem having to do with excessive noise or vibration originates in the periodic motion of a structure, be it the engine of an outboard motorboat or the vocal cords of an outraged fisherman. In responding to a periodic energy input the structure may have enough inertia to remain stationary. Then it simply serves as a path for energy transmission. If the structure has insufficient inertia, it may be excited into a "forced" vibration, in which case it responds as a rigid body experiencing a uniform periodic acceleration at a rate that is controlled by its mass.

In addition to mass, however, each structure is further characterized by its flexibility, which is the combined effect of its composition, geometry and boundary conditions. These factors determine a set of natural frequencies of vibration, which can be demonstrated with a bowed violin string whose length and tension are varied. This phenomenon is known as "resonant" vibration, and the frequencies of resonant vibration, or "characteristic modes," are highly specific for each structure.

If the forcing frequencies of the energy input coincide with one or more of a structure's characteristic modes, the structure will no longer respond as a rigid body. Instead of merely experiencing uniform acceleration, it will resonate as a flexible body at one or more of its characteristic modes. Such resonant vibrations may involve bending, twisting or other complicated types of motion. When this happens, the opposing reactions resulting from the mass and the rigidity of the structure cancel each oth-



EFFECTS OF DIFFERENT DAMPING TREATMENTS on a vibrating aluminum reed are demonstrated in the three photographs on this page. The top photograph shows the untreated reed being vibrated at a frequency of about 100 cycles per second by means of a vibrating machine attached to one end of the reed (*right*). The reed is 42 inches long, half an inch wide and an eighth of an inch thick. The reed is in resonant vibration, that is, one or more of its natural frequencies of vibration, or "characteristic modes," which are determined by its mass and rigidity, coincide with the "forcing" frequency of the vibrator. The middle photograph shows an identical reed being vibrated in the same characteristic mode after being coated with a viscoelastic damping layer a quarter of an inch thick. This treatment reduces the reed's resonant vibrations by a barely perceptible amount. The bottom photograph shows another identical reed, again being vibrated in the same mode but this time after being treated with a viscoelastic damping layer 1/50 inch thick covered by a steel constraining layer 1/32 inch thick. The resonant vibrations have disappeared almost entirely.



FREQUENCY SPECTRA of a resonating stainless-steel cantilever beam an eighth of an inch thick are shown here (*right*) along with cross-sectional drawings of the beam in three different test situations (*left*). At top the beam is untreated. At middle the beam has been treated with a 1/16-inch viscoelastic layer. At bottom the beam has been treated with a 1/16-inch viscoelastic layer constrained with a 1/16-inch aluminum layer. The virtual elimination of high-frequency vibrations in this case is particularly desirable.

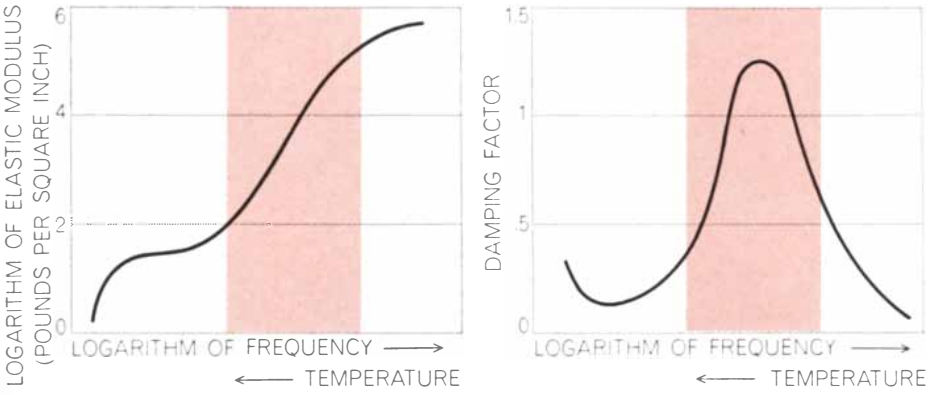
er and the acceleration is greatly amplified: the resonant vibration becomes many times greater than the forced vibration excited by the same energy input. The noise produced by such resonant vibrations often creates the most difficult problems of control by the conventional techniques, since the resonating structure, rather than the primary energy source, becomes the new source of excessive mechanical energy to be contended with.

More often than not the energy source is not directly exposed to a human receiver. Energy can be transmitted through a solid body, in which case it is recognized as mechanical vibration, or it can be converted into acoustical energy at an interface and transmitted through the air in the form of pressure waves. The receiver will then be subjected to the sensation of sound.

For a given amount of mechanical energy at the source the receiver's degree of irritation depends on two factors. The first is the efficiency of energy transfer at the interface between the source and the transmission medium. The second is the sensitivity of the receiver. The efficiency of interfacial energy transfer between two mediums depends on the closeness of the match between their acoustical impedances. (Impedance is defined as the product of the density of the material and the velocity at which it transmits vibrations.) For example, measured in units of grams per second per square centimeter, the impedance for steel is approximately 2.7 million, for soft elastomers about 10,000 and for air about 42. Consequently energy transfer between two solids (that is, vibration) is much more efficient than energy transfer between a solid and the air (that is, noise).

Human beings, however, are much more sensitive to noise than they are to vibration. For instance, the minimum acceleration level that can be sensed by touch is about one dyne per square centimeter, whereas the threshold of hearing corresponds to only about .0002 dyne per square centimeter. For mechanical, as opposed to human, receivers vibration-control criteria vary over a broad range, depending on the ruggedness of the components. For example, the instruments used in the aerospace industry have an upper limit of 20 dynes per square centimeter, whereas those employed in mining or metalworking operations can tolerate 3,000 dynes per square centimeter.

Finally, since the human ear will tolerate a greater intensity of low-frequency noise than of high-frequency noise, not only the volume but also the quality of a given noise spectrum is significant. Although the frequency range of the normal human ear extends from 25 to 16,000 cycles per second, the most important region for communicating by speech is between 250 and 2,000 cycles per second.



ELASTIC MODULUS AND DAMPING FACTOR are the two variables chosen to characterize an elastomer as a candidate for a specific application in constrained-layer damping. (The damping factor of a material is defined as the ratio of its viscous modulus to its elastic modulus.) For each elastomer these values exhibit an enormous variation over an extended range of vibration frequency and temperature. When the vibration frequency is low or when the temperature is high, the elastomer is soft and rubbery. When the vibration frequency is high or when the temperature is low, the elastomer is hard and plastic-like, yet still highly resilient. Between these two extremes is a transition zone (*color*) where the frequency and the temperature are such that the elastomer reacts with the low resilience necessary to dissipate mechanical energy and the elasticity needed for structural integrity.

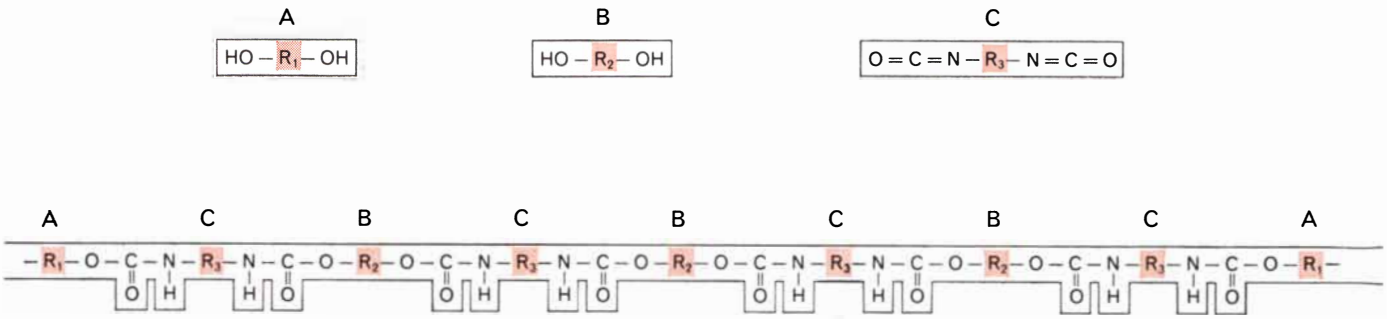
The most widely used conventional means of controlling excessive noise and vibration is the isolation technique. As the term indicates, this approach attempts to isolate the mechanical energy of a vibrating structure so as to prevent its being transmitted into surrounding areas. This is done by installing a soft, elastic separator along the transmission route. Not only is physical contact thereby avoided; the impedance mismatch at the boundary is magnified, proportionately reducing the efficiency of energy transfer. Automobile-engine mounts are an example of vibration control by isolation. The mechanical energy produced by the vibrating engine is not reduced, but it is effectively denied access to the passenger compartment.

Isolators are usually coil springs, pads of elastomer or suitable combinations of these two structures to provide optimum isolation and load-bearing characteristics. The mechanics of isolating vibration are well understood, and the necessary physical properties for the isolators have also been determined. The efficiency of their performance is expressed in terms of transmissibility.

The performance of an isolator is always highly dependent on frequency. Only when the forcing frequency of the vibrating source is well above the natural frequency of the assembly (source plus isolator) does the transmissibility become appreciably less than unity. Improper choice of an isolator could actually result in a situation in which the natural frequency of the assembly is close to the forcing frequency. If this happens, vibration transmission is magnified rather than reduced.

A second approach to the control of noise and vibration, called acoustical absorption, is suited primarily for architectural applications. The objective of this technique is to intercept airborne acoustical energy and protect human ears from exposure to intense pressure waves. Acoustic tiles and baffles are designed to have low surface impedance, comparable to the impedance of air. They are made from porous materials readily penetrated by air, which then expends its energy in frictional flow against the walls of the mazelike interstices.

Even with a perfect impedance match the efficiency of absorption depends primarily on the thickness of the absorbent material compared with the wavelength of the impinging acoustical signal. The greater the ratio, the greater the absorption. Therefore it is more practical to absorb high-frequency (short wavelength) noise with porous material than it is to absorb low-frequency (long wavelength) noise. The efficiency of this mechanism of attenuating acoustical energy by frictional loss is fairly low. If the noise intensity is high, acoustic tiles can-



MOLECULAR STRUCTURE of an elastomer determines its viscoelastic properties. An elastomer is a long, chainlike molecule chemically bonded together (polymerized) during synthesis from smaller molecules called monomers. In this example three monomers—two glycols (*A*, *B*) and a diisocyanate (*C*)—have been polymerized under closely controlled conditions of relative content and distribution. The essential characteristics of the elastomer are maintained under extremes of temperature or frequency by dispersing flexible "blocks" of *A* along the entire length of the chain. The transition zone of the elastomer can then be regulated to fall at specific temperatures and frequencies by controlling the length and distribution of the *B* and *C* blocks. The *R* groups are variable.

not reduce the intensity to any reasonable level. In such cases acoustical barriers are often used, sometimes in conjunction with absorbent materials. Such barriers range from rigid enclosures of the noise source to special earmuffs for the receiver.

The newest approach to the problem of controlling excessive noise and vibration is based on a mechanism to dissipate the vibrational energy of the resonating structure itself, before this energy is converted into more noticeable mechanical vibration or acoustical noise. Constrained-layer damping accomplishes this aim by the use of a rigidly backed thin layer of viscoelastic material applied directly to the surface of the primary vibrating structure. As the entire structure vibrates, the soft viscous damping layer is subjected to a "shear" deformation between the primary structure and the rigid backing. In this way the mechanical energy of vibration is significantly dissipated by its conversion into heat within the damping layer.

For a given energy input the amplitude of a resonant vibration depends on the "damping factor" of the structure, which is defined in general terms as the ratio of the mechanical energy dissipated as heat per vibration cycle to the mechanical energy stored and recoverable. Most structural materials, such as steel and aluminum, have a low inherent damping factor. It is usually much less than .01, which corresponds to a resonant amplification of at least 40 decibels, or 100 times greater than the forcing amplitude. Hence in order to attenuate excessive vibrations by external damping, materials with very high energy-dissipation capacities must be brought into play. Special elastomers are employed in constrained-layer damping assemblies to provide this necessary capacity.

E. M. Kerwin, Jr., and his associates at Bolt, Beranek and Newman, Inc., were the first to make a detailed theoretical analysis of the vibration mechanics of such composite structures. They clearly recognized that the efficiency of such a damping treatment does not depend on the energy-dissipation capacity of the damping layer alone. It also depends on the degree of coupling for the three layers, which controls their ability to respond in unison to vibration.

The coupling requirement reflects the importance of energy transfer in vibration control. Without proper mechanical coupling to provide optimum impedance matching of the three layers, the energy in the primary vibrating structure could not be efficiently transferred to the damping layer and the dissipation mechanism could not be fully utilized. Moreover, recognition of the energy-transfer prerequisite makes clear the necessity for the stiff constraining layer. Kerwin's

VISCOELASTIC PROPERTY of an elastomer consists in its dual response to an external mechanical force. In the absence of such an external force (*left*) each elastomer chain assumes a random configuration, not unlike a strand of spaghetti. When an external force is imposed on the chain (*center*), it will respond by changing from a random form into a more extended one, much as a coil spring does on stretching. When the external force is removed (*right*), the elastomer reacts more like a coil spring that has been immersed in a viscous liquid. In overcoming the viscous resistance from the neighboring molecules the elastomer transfers a part of its stored mechanical energy to its surroundings in the form of heat. The same sequence is repeated with each cycle of vibration.

analysis explicitly indicates that in order to achieve the potential high efficiency of constrained-layer damping, the geometry of the composite structure and the physical properties of the damping layer must be properly optimized.

At Du Pont we have recently completed an experimental program to test the constrained-layer damping mechanism with composite plates, beams and tubular structures and a variety of elastomers. Our results have substantially verified the theoretical analysis. The contributions of various factors have been isolated, and in most instances it has been possible to predict actual performance over a wide range of geometries and materials.

For example, we have demonstrated that the vibration amplitude of a resonating steel plate can be reduced by a factor of 30 with an added weight (the weight of the constrained-layer assembly) of only 18 percent [*see illustration on page 100*]. An earlier version of a damping treatment without the constraining layer was also tested, and it compared unfavorably with the present approach on an equal-weight basis. The earlier version, called homogeneous damping, is used for such applications as the undercoating of a car.

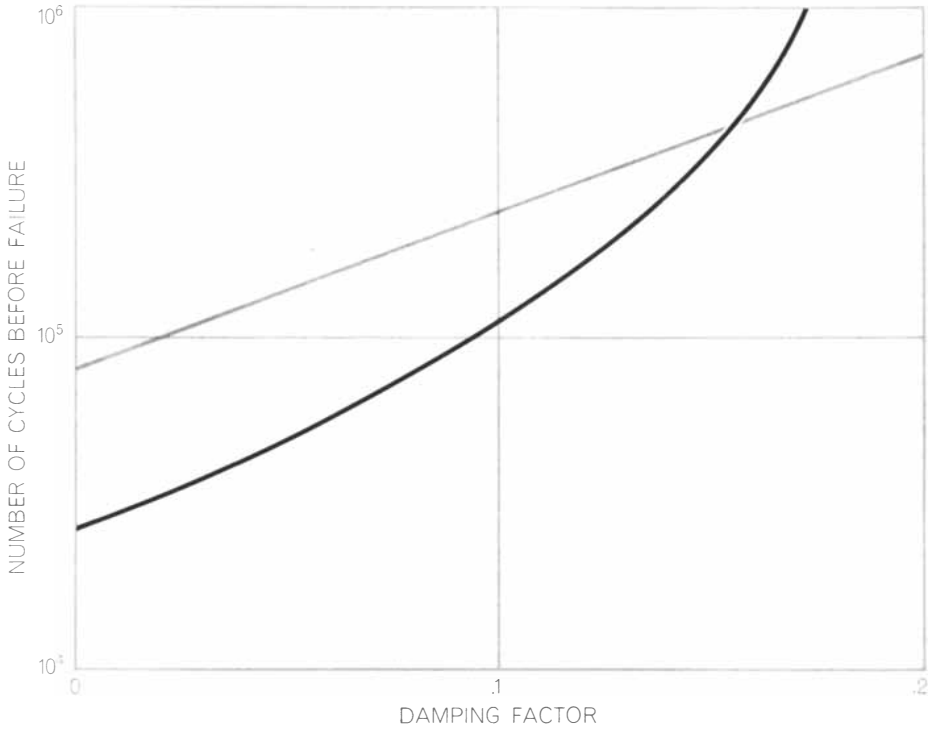
Unlike the two main conventional control mechanisms, whose requirements have sometimes been met by materials other than elastomers, the mechanics of constrained-layer damping demand materials with the dual capacities of energy dissipation and load-bearing strength. This combination of properties is found only in elastomers, and for each elastomer such desirable characteristics are present only within well-defined regions of temperature and excitation frequency.

It is natural to ask why elastomers should be unique in this respect. The answer lies in their molecular structure. Elastomers are composed of long, chain-like molecules, tangled together without appreciable morphological regularity. The chains are chemically bonded together (polymerized) during synthesis from smaller molecules (monomers). A typical polymer chain may consist of hundreds, even thousands, of repetitive monomer units. In the absence of an external force each chain assumes a random configuration not unlike a strand of spaghetti.

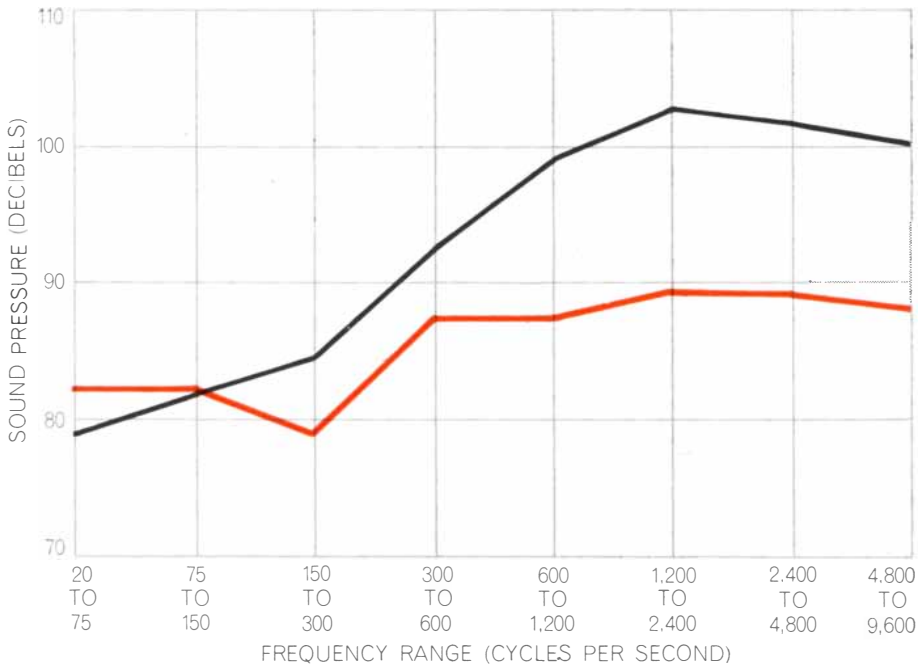
Supported by the thermal energy of the environment, each molecule also is in constant coordinated Brownian motion. When an external force is imposed on the chain, it will respond by changing from a random form into a more extended one, much as a coil spring does on stretching. When the external force is removed, however, an ideal coil spring will immediately retract to its original length and recover all the applied mechanical energy. Not so the elastomer. Its response to an external force is not as spontaneous nor is its energy recovery as complete. An elastomer reacts somewhat like a coil spring immersed in a viscous liquid. During the process of deformation the elastomer "coil" encounters a viscous resistance from neighboring molecules. In overcoming this resistance the elastomer transfers a part of its stored mechanical energy to its surroundings as heat. The same sequence is repeated with each cycle of vibration.

This dual response of an elastomer to an external force—acting partly like a viscous liquid with an energy-dissipation capacity and partly like an elastic spring with a load-bearing structural integrity—is termed the viscoelastic property. These opposing characteristics can be represented by two independent variables: the viscous modulus and the elastic modulus. The ratio of these two variables is the damping factor, which was defined above in more general terms as the ratio of the mechanical energy dissipated as heat per vibration cycle to the mechanical energy stored and recoverable.

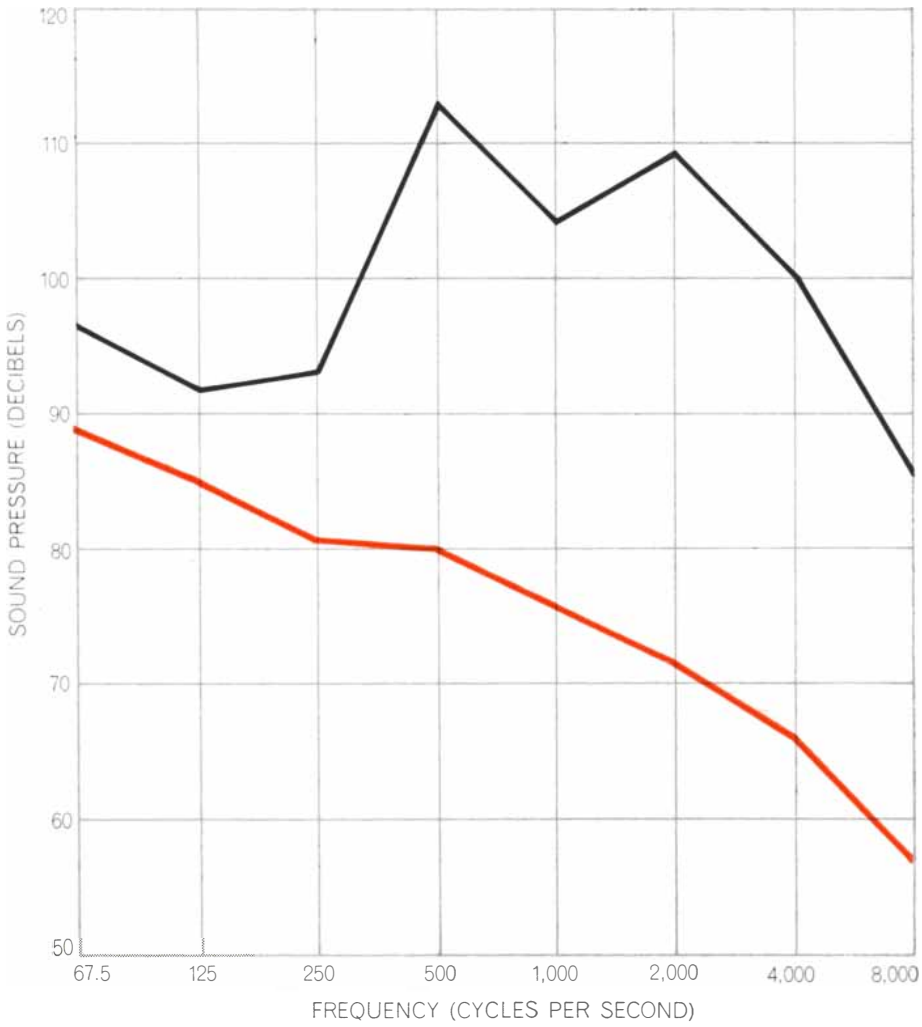
Elastic modulus and damping factor are the two variables in the mechanics of constrained-layer damping chosen to characterize an elastomer as a candidate for a specific vibration-control application. For each elastomer these values exhibit an enormous variation over an extended range of vibration frequency and temperature [*see illustration on page 101*]. When the vibration frequency is low, the molecular chain has ample time to respond and would also encounter little viscous resistance, since this property varies directly with the frequency. Under these conditions the elastomer is soft and resilient, exhibiting its familiar rubbery characteristics. At the other extreme the chain configuration is unable to respond quickly enough to high-frequency vibrations and remains essentially immobile, making the elastomer hard and plastic-like, yet still highly resilient. Between these extremes is a transition zone where the frequency is such that the elastomer reacts with precisely the low resilience necessary to dissipate mechanical energy and the elasticity needed for structural integrity. Under such circumstances it functions as a useful damping material. On the frequency scale the transition zone covers a breadth of about four logarithmic



ACOUSTIC-FATIGUE LIFE of a resonating structure is primarily a result of its damping factor. The data represented in this graph indicate that acoustic-fatigue life can be extended as much as 100 times by replacing a plain metal sheet by a composite panel of equal weight containing a sandwiched layer of damping material. The straight line was obtained under conditions of shock excitation, the curved line under conditions of periodic excitation.



INDUSTRIAL NOISE produced by high-speed rolls in a manufacturing plant was reduced substantially by applying a viscoelastic layer to the cylindrical interior surface of the rolls and constraining this layer by a concentric aluminum sleeve. The black curve shows the noise level before the treatment, the colored curve the noise level after the treatment.



URBAN NOISE—the screech of railroad-car wheels on a sharp curve—was measured before and after a treatment consisting of a constrained-layer attachment to the flange of the wheel plus a superimposed homogeneous damping layer. The overall noise reduction was more than 25 decibels; moreover, the high-frequency components were reduced the most.

decades, and its location depends on the molecular structure of the elastomer.

Temperature also affects the utility of an elastomer for damping applications, but in a direction opposite to the effect of frequency. At low temperatures there is not enough thermal energy for the molecular chain to respond to vibration. It remains hard and unyielding. At high temperatures the internal viscosity is very low, just as it is at low frequencies. On the temperature scale the same transition zone, specific for each elastomer, has a width of about 25 degrees Celsius.

Since frequency and temperature are readily measured for any problem in the area of vibration or noise control, it is clear that a viscoelastic damping material should be selected whose transition zone falls within the desired frequency and temperature regions. If a series of elastomers with known damping characteristics covering the entire spectrum of practical applications were available, this would be a simple matter. The success of constrained-layer damping hinges on the feasibility of synthesizing just such a family of polymers.

There are three primary features of an elastomer molecule that determine its viscoelastic properties: (1) the chemical nature of the monomer, (2) the relative content of comonomers when different monomers are copolymerized, or linked in the same chain, and (3) the distribution of comonomers along the chain, whether random or by definite pattern. In one-monomer polymers and in random-distribution copolymers the viscoelastic properties are fixed for each composition. If the distribution of comonomers along the molecular chain can be controlled, however, the same basic ingredients can be manipulated to achieve a wide range of damping properties.

At Du Pont we have copolymerized two types of glycol with a diisocyanate under closely controlled conditions of relative content and distribution [*see top illustration on page 102*]. By effectively dispersing flexible "blocks" of one glycol along the entire chain length, the essential characteristics of the elastomer are maintained even under extremes of temperature or frequency. Then by judicious control of blocks consisting of the other glycol and the diisocyanate the transition zone of the elastomer can be regulated to fall at specific temperatures and frequencies.

In this way a product can be synthesized to satisfy the requirements of a specific need for constrained-layer damping. The mating of polymer chem-

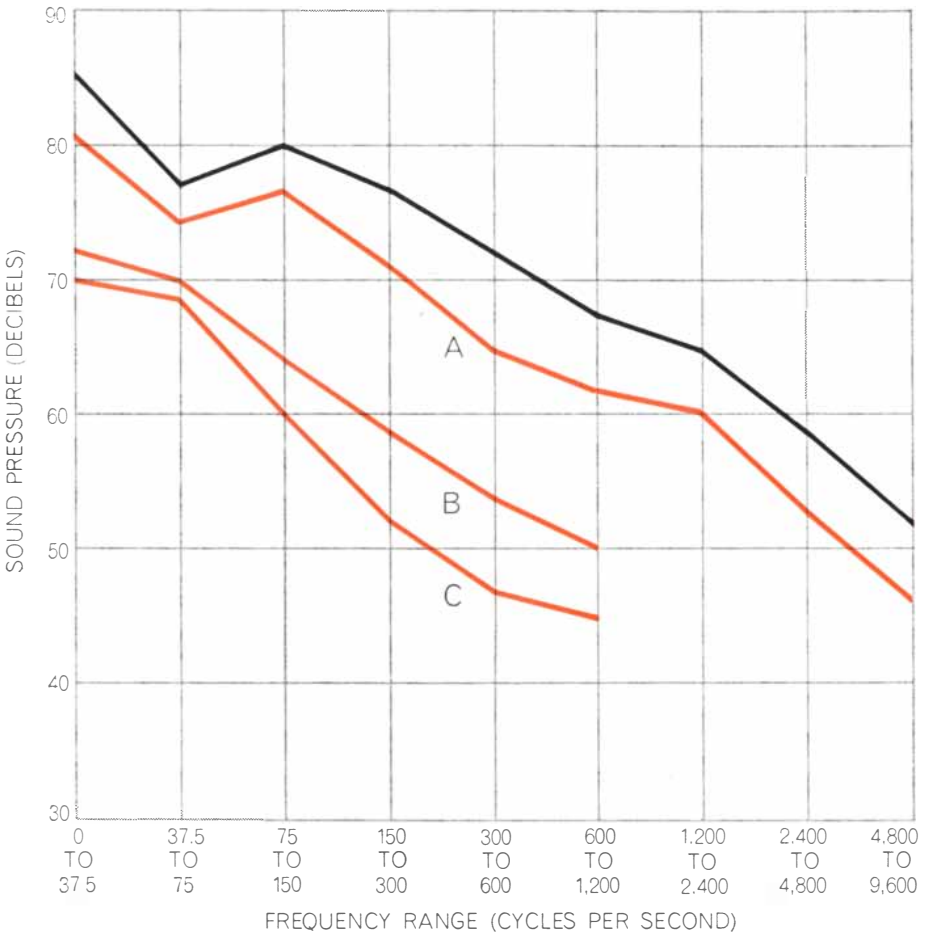
istry and vibration mechanics has thus produced an effective new technique to control resonant vibration and structure-borne noise. Each composition has a useful temperature region of 35 degrees C. and a useful frequency region of four logarithmic decades; the entire family covers a temperature range from −30 degrees to 100 degrees.

A number of experimental studies on the use of constrained-layer damping to control vibration and noise have been conducted at Du Pont and elsewhere. I shall briefly describe four of these studies as representative examples.

The first is concerned with the excessive vibration of light structural members, which can lead to acoustic fatigue and metal failure by fracture. Aircraft wing and fuselage components are a case in point. G. Kurtze and W. Westphal of West Germany have compared the fatigue life of steel and aluminum sheet with the life of composite panels that have a constrained layer of viscoelastic material. Their results show that the fatigue life of a resonating structure, under either shock or periodic excitation, is primarily a function of its damping factor [*see illustration on page 103*]. Fatigue life can be extended as much as 100 times by replacing a plain metal sheet by a composite panel of equal weight containing a sandwiched layer of damping material.

The second example, having to do with industrial noise, provided such an improvement that the experimental design was adopted as standard plant practice. At a Du Pont manufacturing plant high-speed rolls on production lines created an intense high-frequency impact noise under certain operating conditions. A viscoelastic layer was applied to the cylindrical interior surface of the rolls and was constrained by a concentric aluminum sleeve. The reduction in noise level effected by this means is substantial [*see top illustration on opposite page*].

A common urban noise—the screech of railroad-car wheels on a sharp curve—is the problem that was taken up in the next example. The cause of this ear-piercing noise is the resonant vibration of the wheels. The Soundcoat Company, Inc., is working on a solution to the problem based on an external damping treatment to the wheels that effectively suppresses the objectionable noise. Their solution consists of a constrained-layer attachment to the flange of the wheel plus a superimposed homogeneous damping layer. The entire treatment represents only a 4 percent increase in the weight of the wheel.



HOUSEHOLD NOISE produced by a portable dishwasher was subjected to all three vibration-control mechanisms: isolation, absorption and constrained-layer damping. The black curve shows the noise profile of the untreated machine. The colored curves show the effect of isolation (*A*), isolation plus constrained-layer damping (*B*) and all three treatments (*C*). Again the more annoying high-frequency noise components were reduced the most.

Here noise levels were measured before and after addition of the damping layers under three service conditions: (1) in the open, on a sharp curve, (2) inside a tunnel and (3) inside the train terminal. A significant improvement in noise level was achieved at all three locations [*see bottom illustration on opposite page*]. In quantitative terms the reduction was more than 25 decibels; moreover, the high-frequency components that contributed so much to the screeching noise were replaced by low-frequency hums.

Noise pollution in the home is a broad area covered by the last example, which involves a commercial portable dishwasher. This study was a laboratory project at Du Pont rather than a commercial solution, but it is an interesting illustration of how all three vibration-control mechanisms (isolation, absorption and constrained-layer damping) can be combined for maximum effectiveness.

When we compared the noise profile of the untreated machine with a parallel measurement of the vibration levels made with an accelerometer, it became obvious that the four panels of the inner tub, because of their large surface area, were the primary source of noise radiation. Vibrations from the motor were transmitted through the bottom of the tub to the wall panels, which also reflected the noise from the impact of high-velocity water sprays.

We first improved on the isolation of vibration by replacing the existing elastomer isolator with a softer mount and by putting elastomeric washers on the bolts to prevent metallic contacts from acoustically short-circuiting the transmission path. A constrained-layer damping treatment was then applied to the exterior of the inner tub, consisting of a viscoelastic layer 1/32 inch thick and a constraining layer of aluminum foil .018 inch thick. Lastly, the half-inch space between the tub and the outside casing was filled with a low-density, open-celled fiber-glass mat to provide an acoustical absorption medium to further muffle the sound.

The individual effects of each of the three treatments were measured separately [*see illustration above*]. The over-

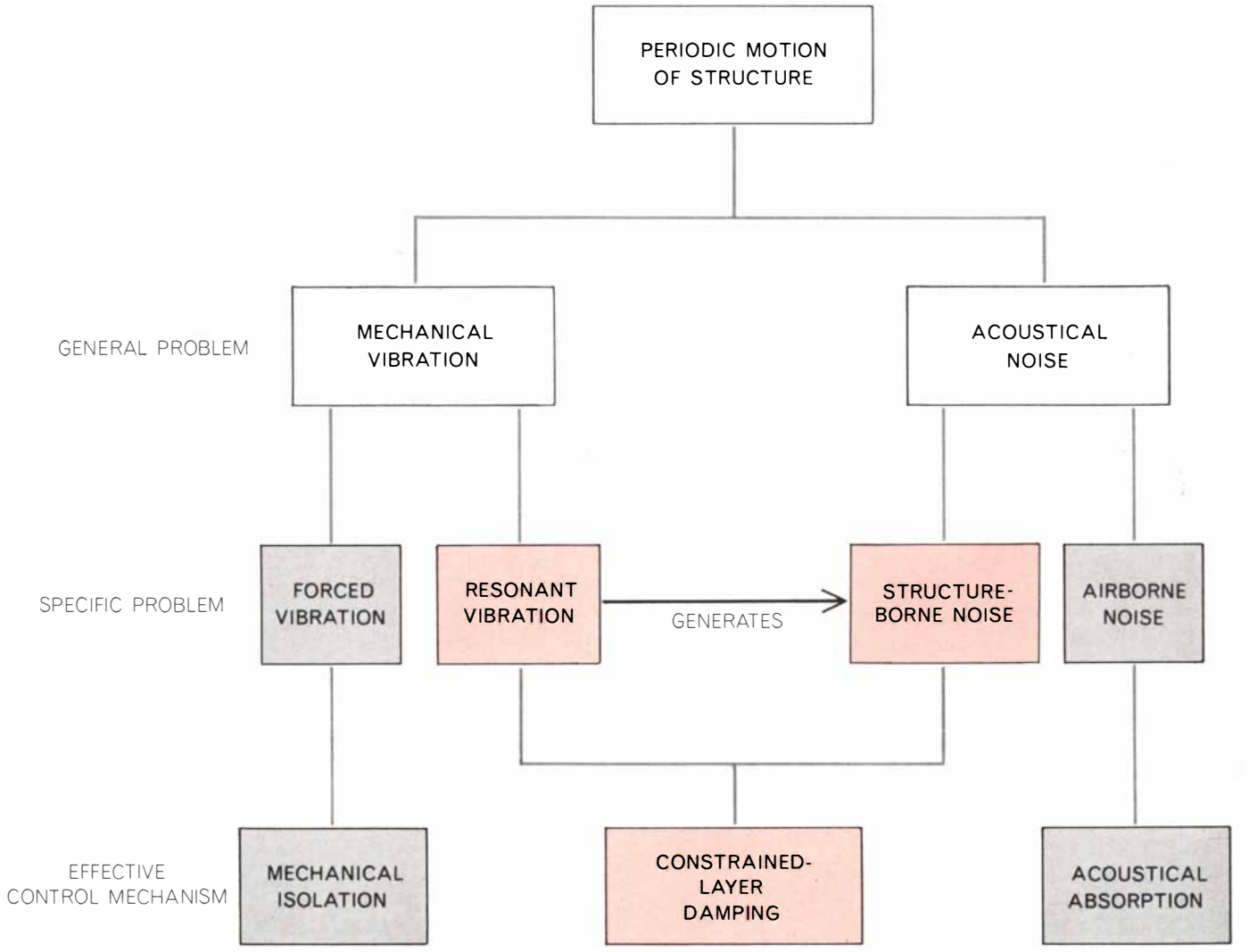
all noise level was reduced from 85 to 70 decibels. More important, the quality of the noise was greatly modified for the better. The more annoying high-frequency components were decreased as much as 40 decibels, which corresponds to a reduction of noise level by a factor of 100.

Of course, a nearly ideal solution of this type has a price tag, and I do not mean to imply that commercial equipment should be provided with such complete noise-suppressing construction. Nonetheless, there are broad areas where the application of constrained-layer damping, alone or in combination with other stratagems, can economically overcome noise pollution arising from structure-borne vibrations.

It is possible to estimate just where constrained-layer damping can be expected to be most useful, by classifying the problem areas of vibration and noise control according to their origin [*see illustration below*]. When the problem is transmission of forced mechanical vibration from the motions of a rigid structure, isolation is the most effective control method, since the originating vibration is of no major concern to the receiver. In the case of resonant vibrations, treatment directly at the source can best reduce both the mechanical vibration and the structure-borne noise. It is here that constrained-layer damping has proved to be a powerful remedy. Some noise, however, cannot be treated at its source. A notable example is the human voice. Thus acoustical absorption is the mechanism commonly employed for airborne noise.

Constrained-layer damping is no cure-all. It cannot replace isolation and absorption, nor for that matter can it solve such problems as the supersonic "boom." The essential contribution of constrained-layer damping is that it provides a compact, lightweight, low-maintenance system, based on precalculated requirements, that will selectively attenuate structure-borne resonant vibrations up to 25,000 cycles per second at temperatures from −30 degrees C. to 100 degrees.

With the addition of constrained-layer damping to the older stratagems of isolation and absorption, the tools necessary for controlling most kinds of excessive vibration and noise are now available. Their proper application, however, requires an understanding of the underlying mechanics before practical proposals can be made. It might well turn out that in some instances the expense of analyzing a problem and securing the solution will exceed the materials and labor cost for the recommended treatment. Moreover, if the proposed treatment is not properly designed, the vibration and noise could be amplified rather than reduced. In short, adequate technology is now at hand, if we choose to use it, for the diminution of much irritating and destructive noise pollution.



CLASSIFICATION OF PROBLEMS in the area of the control of vibration and noise makes it possible to estimate just where constrained-layer damping can be expected to be most useful. When the problem is transmission of forced mechanical vibration from the motions of a rigid structure (*left*), isolation is the most effective control method. In the case of resonant vibrations (*center*), constrained-layer damping has proved to be a powerful remedy. Airborne noise (*right*) is best handled by acoustical absorption.

LIFE ON THE HUMAN SKIN

The skin is an ecosystem, with a microscopic flora and fauna and diverse ecological niches: the desert of the forearm, the cool woods of the scalp and the tropical forest of the armpit

by Mary J. Marples

When someone is told that his skin supports a large population of microorganisms, he may look a bit uneasy and respond that he takes a shower every morning. His unease will scarcely be lessened by the information that showering or bathing, which washes away some of the skin, exposes microorganisms hidden in its crevices and therefore increases the total population on the skin surface. The mere thought may well induce involuntary scratching.

If, on the other hand, one considers the skin from the standpoint of its natural inhabitants rather than in terms of the appearance, comfort and defense mechanisms of the human host, a fascinating world comes into view. The skin is then seen as a kind of soil with attributes that are beneficial or harmful for the organisms it supports. This environment and the populations that live in it form an ecosystem, a discrete world whose living and nonliving components, all interacting with one another, exist in equilibrium.

Strictly speaking there is only one ecosystem, the ecosystem of the entire earth, but in ecology (which studies the mutual relations between organisms and their environment) localized areas such as a desert, a forest, a pond or a stream are treated as being independent. The skin of course differs from the inorganic substrate of terrestrial ecosystems. Whereas the earth's crust is composed of solid minerals, the nonliving surface of the skin is constantly renewed from below and is supplied with glandular secretions. The skin is nonetheless uniquely qualified to serve as an ecosystem. An enormous amount of information has been gathered concerning its structure and function; indeed, the characteristics of the human skin are probably better understood than those of any other naturally inhabited area. Furthermore, the cutaneous fauna and flora are readily accessible. Repeated sampling does not lead to any permanent change in their population structure, and most of the cutaneous species can be grown in the laboratory.

In spite of these obvious advantages investigations into cutaneous ecology have been sporadic and have been mainly concerned with the pathogenic, or disease-causing, species. Only recently have studies been undertaken of the natural cutaneous organisms, microbes that are harmless or even beneficial and that live in large numbers on the skin of most human beings. Some of these organisms are potential pathogens; although they are harmless on the skin surface, they may cause disease if they penetrate the deeper cutaneous layers. The study of skin ecology is thus essential to the control of skin and wound infections, and it may also help to elucidate problems that classical ecology has failed to solve. In what follows I shall outline the information about the natural cutaneous world that is currently available by considering the questions: What is this world like? What lives there? What happens when a newcomer arrives?

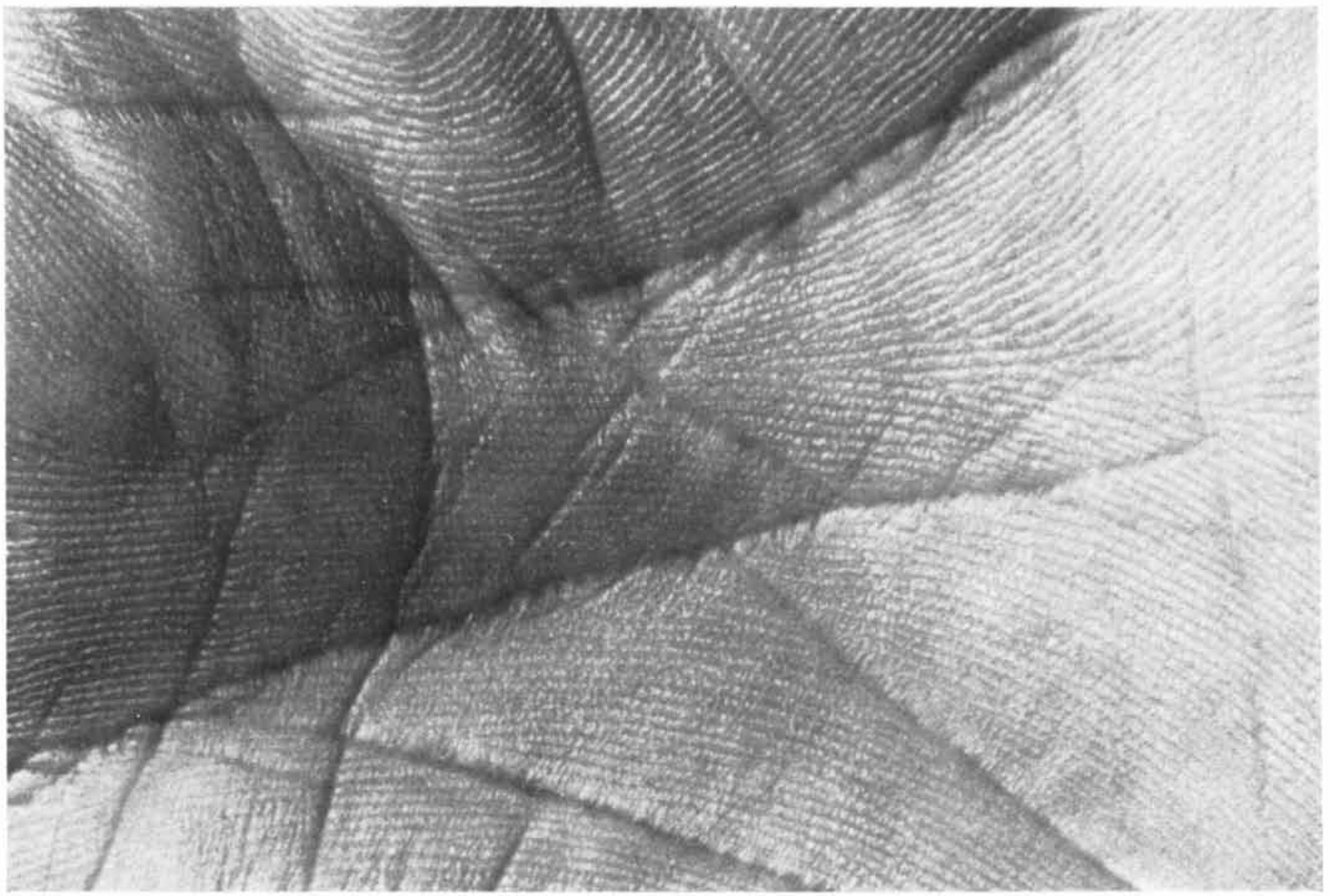
The surface of the skin is a distinctly unstable environment for the organisms that live on it. The most superficial cutaneous layer, the stratum corneum (horny layer), consists of flat, scalelike "squames" made up of the fibrous protein keratin. The squames are continuously replaced from below by epidermal cells that die in the process of manufacturing keratin, and during the host's various activities the squames are always being shed. From the viewpoint of a microorganism on the skin the squames are enormous flat boulders of inert material, boulders that suddenly curl up and float away, bearing with them any organism that happens to be aboard.

The uneven surface of the cutaneous world is pierced at intervals by two types of orifice. One is the duct of the eccrine sweat gland, a spring from which oozes a weak saline solution containing a small quantity of nitrogenous substances and other nutrients. The flow from the gland varies and the solution evaporates, so that in some ways the conditions resemble those of a pool at the edge of the sea, with its frequent changes of water level and salinity.

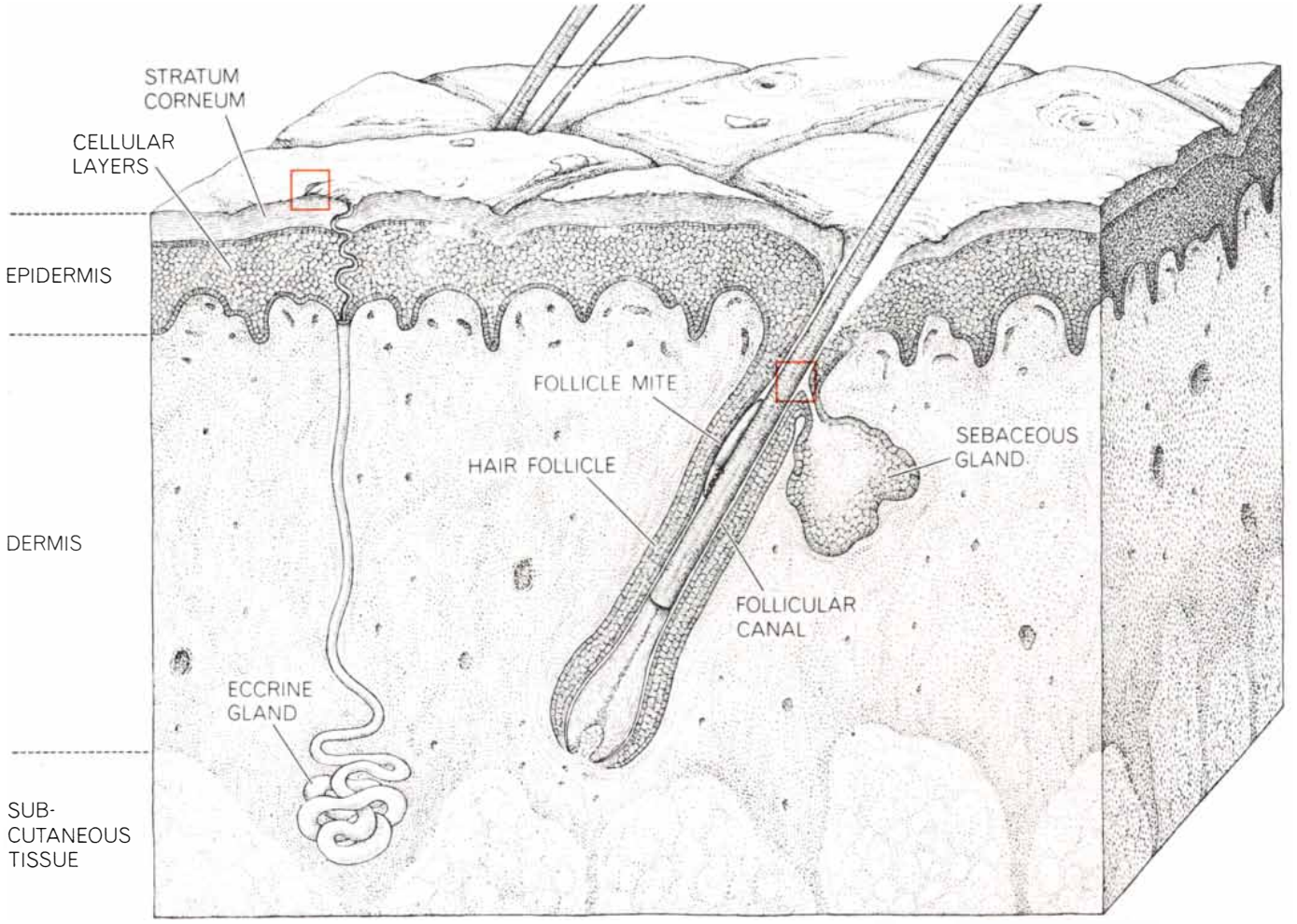
The other cutaneous opening is the hair follicle, a cylindrical infolding of the skin from which projects the hair, a tall tree trunk of hard keratin. The hair follicle exudes sebum, which is manufactured by the sebaceous glands. Sebum is a complex secretion containing a high proportion of lipids, or fatty substances. It mixes with sweat and spreads over the epidermal surface adjacent to the hair follicle. Sweat glands and hair follicles are not evenly distributed over the body but vary in size and density. These variations, together with other factors, confer a special character on certain areas of the skin. For example, the axilla, or armpit, is provided with coarse hairs that receive secretions from specialized structures, the apocrine sweat glands. The external canal of the ear has glands that produce ear wax, and the palm of the hand and the sole of the foot have many sweat glands but are without hair follicles.

The glandular secretions and the byproducts of the process that forms keratin provide free amino acids as nutrients for the inhabitants of the skin. Carbohydrates in a readily available state and

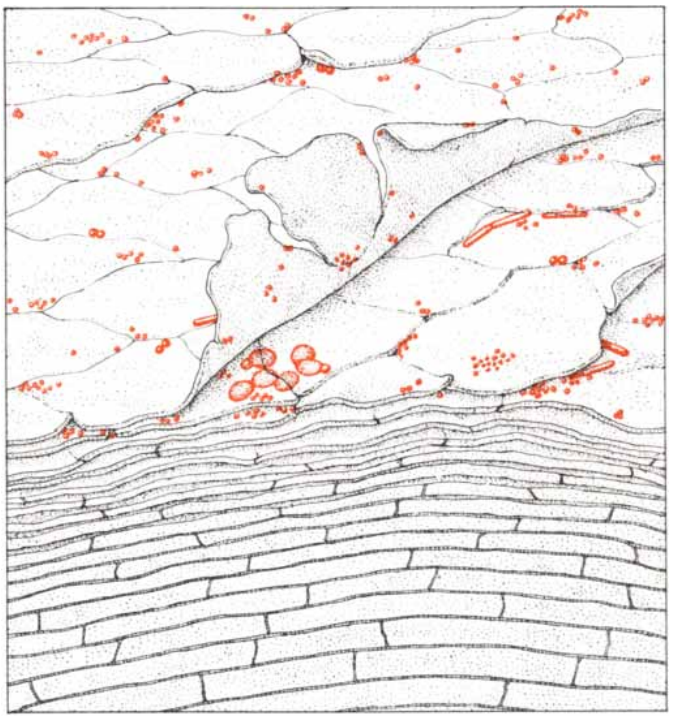
TERRAIN OF AN ARID GRASSLAND, a typical ecosystem on the surface of the earth, appears in this aerial photograph of an area in northwestern Texas. The principal feature of the terrain is the stream valleys, which support a somewhat denser vegetation.



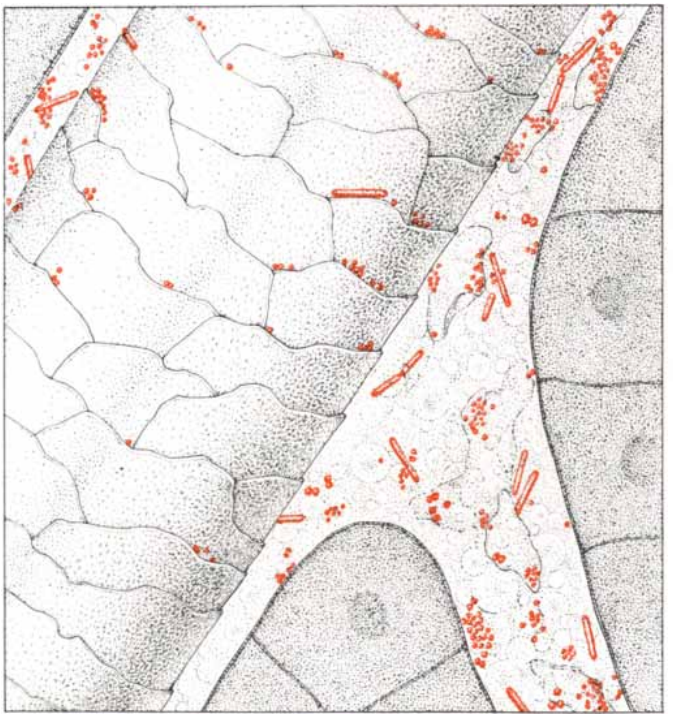
TERRAIN OF THE HUMAN SKIN is seen in this photograph of part of the palm of the hand. The palm and the sole of the foot differ from other areas of the skin in that they have no hair follicles. Thus they support a somewhat different population of microorganisms.



HABITAT OF NORMAL MICROORGANISMS is displayed in an idealized section. *Demodex folliculorum*, the follicle mite, is the only faunal form that resides in healthy, undamaged skin. Scarcely visible to the unaided eye, it is 400 times larger than an average bacterium. The squares indicate regions of the skin that appear below in an enlarged view. *Demodex* inhabits the skin of most adults.



UPPER LAYER of the skin, the stratum corneum, consists of flat, scalelike "squames" that curl up and flake off. Lodged under and around the squames are bacteria and yeastlike cells of fungi (*color*).



HAIR FOLLICLE houses many bacteria. The illustration at top of this page shows the skin enlarged 50 diameters. In this drawing and the one at left the skin is enlarged about 1,000 diameters.

certain of the vitamins appear to be less abundant, but there is no direct evidence that they are in inadequate supply. The climate of the skin is pleasantly warm and is subject to little variation, except on the feet. The temperature and the water supply are favorable for microbial growth, although for many species the slight acidity of the skin is something of a handicap.

Let us now consider the species that are likely to be found on healthy, undamaged skin. The ecologist Eugene P. Odum divided the living members of a classical ecosystem into three main groups: the producers (chiefly green plants that utilize solar energy to manufacture organic substances out of inorganic ones), the consumers (animals that derive their energy directly or indirectly from plants) and the decomposers (mainly fungi and bacteria that break down dead plants and animals and thus return the essential elements to the soil substrate). To what extent are these physiological groups represented on the skin? There are no true producers; the host himself is the great producer. The microorganisms live, as Adam and Eve did, in a paradise where all their needs are supplied. There is only one animal consumer, the follicle mite *Demodex folliculorum*. This microscopic creature lives, mates and breeds in and around the eyelashes, the hair follicles of the outer nose folds and the chin and a few other restricted areas. *Demodex* inhabits the skin of most adult humans. The remaining cutaneous organisms are yeasts, bacteria and perhaps viruses. It is not easy to fit host-supported communities into Odum's metabolic groups, but the inhabitants of the skin can be regarded either as consumers that utilize cutaneous secretions or as decomposers of the by-products of keratin manufacture.

Among the residents of the healthy skin are several pathogenic species that live in an uneasy balance with the host. After a long period during which they remain harmless, a change of the internal or external cutaneous environment can upset the equilibrium; then these species multiply and penetrate the horny layer. A good example is the fungi that give rise to "athlete's foot." These fungi often inhabit the sole of the foot and the spaces between the toes without causing more than minimal changes in the skin. Then a change in the host environment—a move to the Tropics, a temporary failure of hygiene, a change in immunological status—will lead to proliferation of the fungi and the appearance of disease.

Only a few yeasts are represented in the normal skin flora. Some of them are partially or entirely dependent on lipids and grow most abundantly on the scalp and in greasy areas of the face, such as the folds of the nose and the ear. Less prevalent than these forms are a group of yeasts that grow between the toes but are never harmful.

The dominant members of the cutaneous community are bacteria. The types that are present can be divided into Gram-positive and Gram-negative organisms, according to their reaction to the Gram stain. This simple staining method, named for the Danish bacteriologist Hans Christian Joachim Gram, is most useful in bacteriology in that the two groups it distinguishes differ not only in chemical characteristics but also in physiology and in pathogenic properties. On healthy skin the Gram-positive bacteria predominate and are represented by two groups. One is the aerobic (oxygen-utilizing) cocci, whose cells are spherical; the other is the diphtheroids, whose rodlike shape varies among individual bacteria. Almost all the cocci are harmless, except in very special circumstances, but one species, *Staphylococcus aureus,* is the cause of pimples, boils and more serious infections (among them infections of the newborn and hospital wound infections).

Staphylococcus aureus has received much attention in recent years, primarily because of its capacity to acquire resistance to antibiotics. The chief domicile of this species is the nostrils. In many infants it is also found in the umbilicus and the abdominal skin; in the adults it colonizes the perineum (the region between the genitalia and the anus). Normally it does not cause pathological changes in the skin.

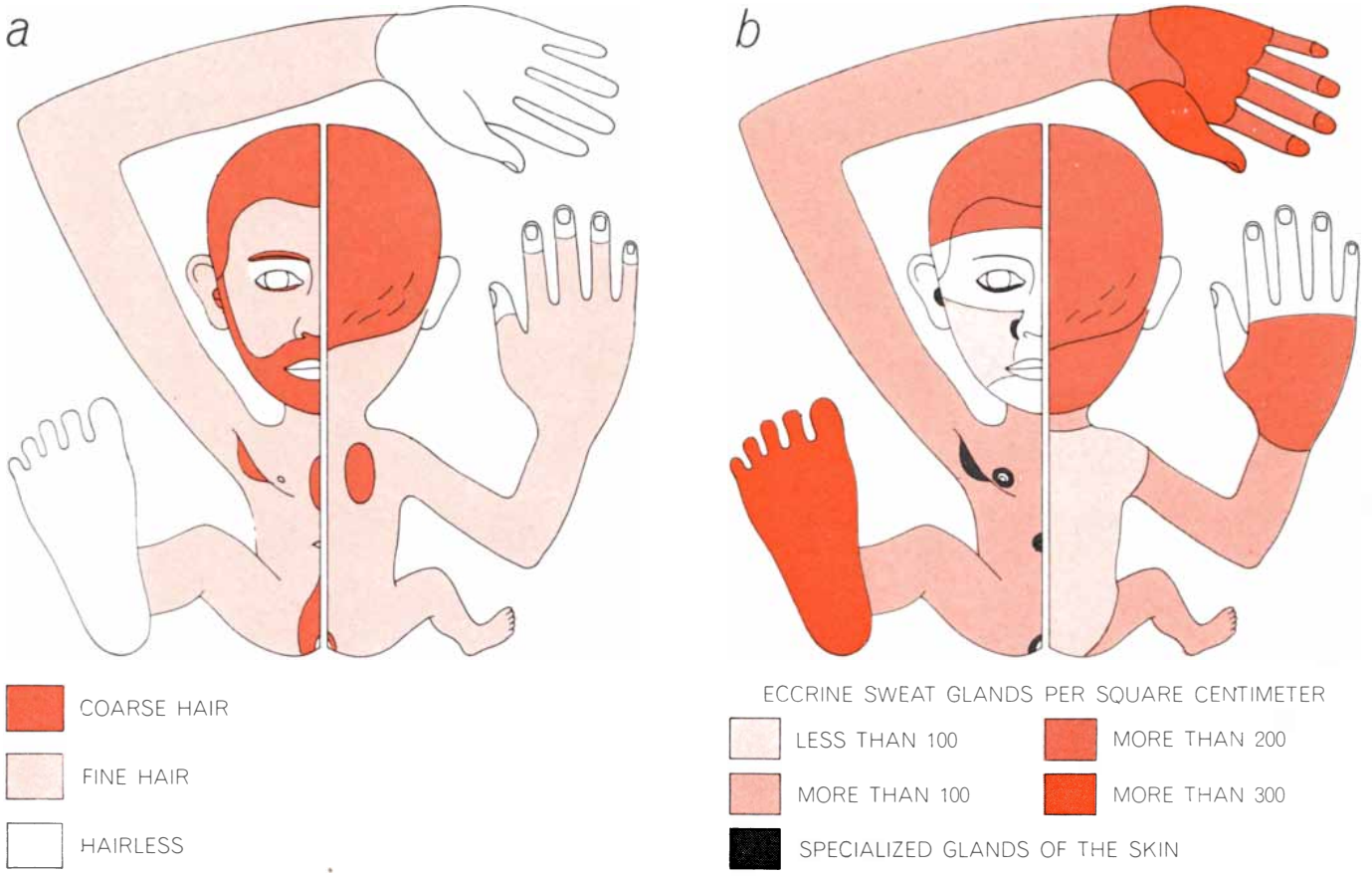
The diphtheroids can be divided into three ecological groups. One consists of the species *Corynebacterium acnes,* the "acne bacillus," which is anaerobic and lives in the depths of the hair follicle. The other diphtheroids are aerobic; they separate into two types, one requiring lipid nutrients and the other not requiring them.

On the skin of most people the Gram-negative strains of bacteria are also found. One group, the *Mimeae,* which includes potential pathogens, appears to be common on the feet of children and adult males but is seldom found on adult females.

It is impossible to say to what extent viruses inhabit the healthy skin, since their presence is difficult to recognize in the absence of damage to the host. Inasmuch as viruses are parasites on living cells and there are no living cells in the upper layer of skin, any cutaneous viruses would have to be living in deeper levels. On the other hand, the viruses that parasitize bacteria (bacteriophages) are present on the skin in significant numbers. For example, many strains of *Staphylococcus aureus* are known to be lysogenic, which is to say that they carry a virus partner whose genetic material is linked to their own. Recently Leopoldo F. Montes of the University of Alabama Medical Center has demonstrated that all stages of the bacteriophage life cycle are represented in one of the cutaneous diphtheroids. It is likely that bacteriophages also infect other species of cutaneous bacteria.

How densely populated is the human skin? The determination of the number of individuals of each kind per unit of area or volume is a major preoccupation of the classical ecologist, and this is perhaps the best-documented aspect of cutaneous ecology, at least so far as bacteria are concerned. As in other branches of ecology, however, it is difficult to secure consistent and reproducible observations, not least because several sampling methods are employed at the present time. In spite of the great variation in measurements, it is clear that people differ significantly in the density of the populations they support. These differences are maintained over considerable time intervals, so that some people consistently have a high bacterial count and others a low one. Such differences can also be demonstrated between the sparsely inhabited desert of the forearm, the more heavily populated tropical forest of the axilla and the cool dark woods of the scalp. It is generally agreed that the densest bacterial populations are found on the face and the neck and in the axilla and the groin; the trunk and the upper arms have much sparser populations. The microbial community on the sole of the foot and between the toes is large and diverse.

One of the most reliable sampling techniques has been perfected by workers at the University of Pennsylvania. Peter Williamson of this group has reported that in adult males the axilla is the most densely inhabited area, with a mean population of 2.41 million bacteria per square centimeter of epidermis. The mean counts for the scalp and the forehead were also high (respectively 1.46 million and 200,000 per square centimeter). In contrast, the counts taken



from the back averaged only 314 bacteria per square centimeter. The forearm counts divided into two groups, one with an average of 4,500 bacteria per square centimeter, the other with only 105 bacteria per square centimeter. These figures refer only to aerobic bacteria. There is evidence that in the areas of the skin supplied with large sebaceous glands anaerobic organisms may outnumber the aerobic ones 10 to one.

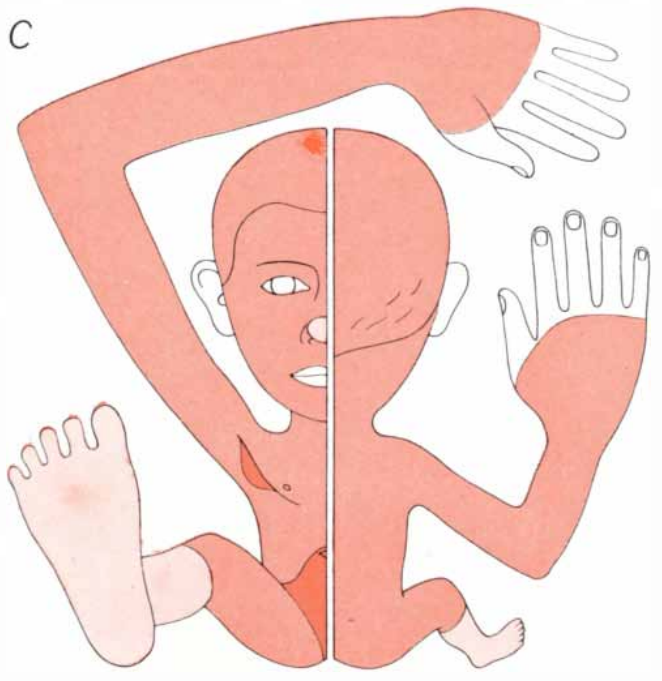
One cannot readily determine if these figures indicate that the skin is densely populated compared with other habitats. Should the cutaneous populations be compared with the microbial community of a small terrestrial area or with the medium-sized or larger organisms of bigger areas? Kitty Paviour-Smith of the University of Oxford has sampled the population of animal organisms other than protozoans in a salt meadow in New Zealand. She obtained a maximum figure of 7.6 million metazoans per square meter. The lowest count obtained by Williamson (for the forearm) works out to 1.05 million bacteria per square meter, making the forearm more sparsely populated than a salt meadow. On the other hand, the populations of the forehead and axilla are much larger (respectively two billion and 24.1 billion per square meter). It seems that there are many more aerobic bacteria on the salt meadow of the skin than there are metazoans in a salt meadow in New Zealand.

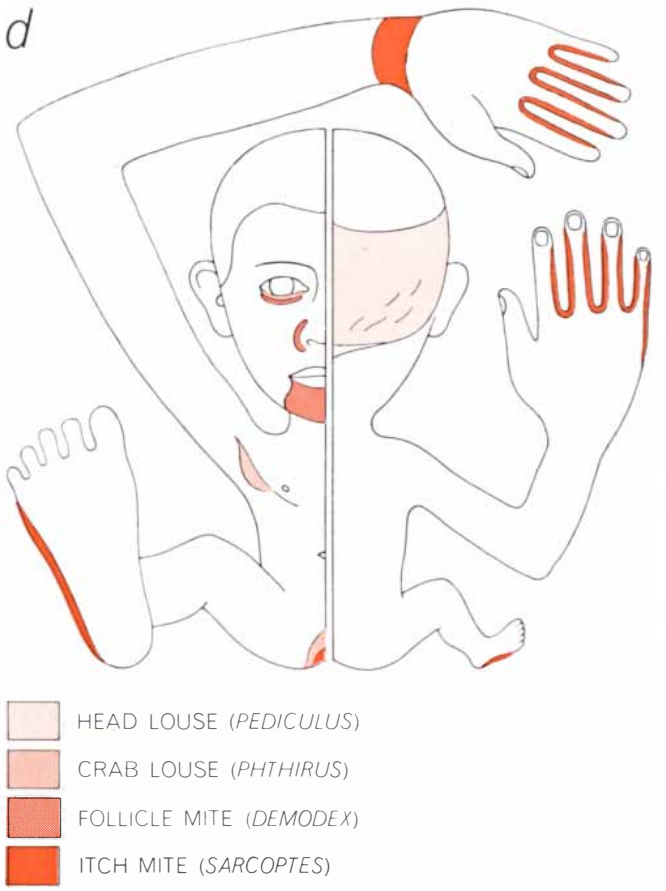
The best terrestrial ecosystem for purposes of comparison with the skin is probably an ordinary soil. Both the soil and the skin lack producer organisms and obtain their organic material from without: the soil from above (in the form of dead plant material) and the skin from below. In both soil and skin there is an extensive nonliving matrix that is permeated by solutions, and the living organisms in both are grouped around structures that penetrate the surface to deeper layers. In the soil the densest populations of microorganisms are in the rhizosphere, the region that surrounds plant roots. The comparable region in the skin is the hair follicle.

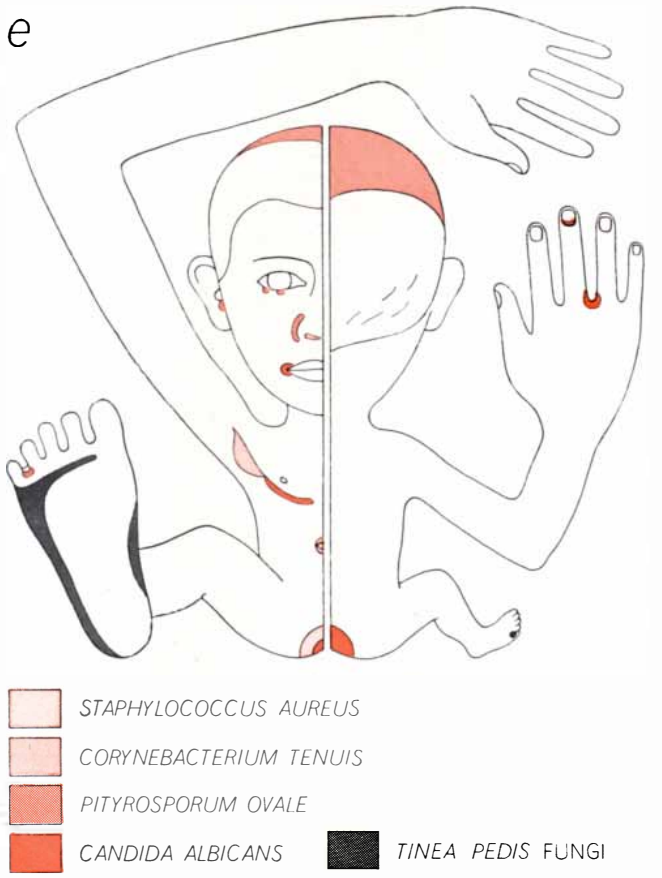
There are many estimates of the number of bacteria and fungi in the soil; the figures fall (according to soil type) in the range of 10 million to 10 billion individual organisms per gram. There are few figures for bacteria per unit weight of skin, but the University of Pennsylvania workers report an average of 530,000 bacteria per milligram of scurf (the surface of the epidermis). This would indicate a count around 530 million per gram of scurf, a figure within the range for fertile soil. It would appear that at least some areas of the skin are as densely populated with microorganisms as natural soils.

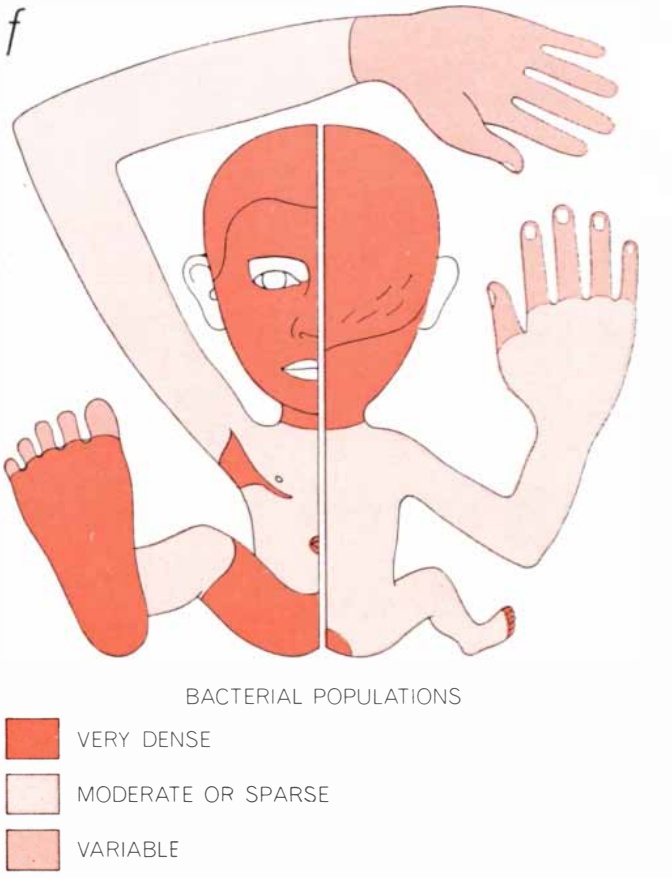
Numerous efforts have been made to determine how pathogenic staphylococci spread from one host to another. These investigations have been directed toward the control of cross infection in hospitals but have brought to light much that is relevant to the transfer of members of the normal flora. The acquisition of a cutaneous flora begins very early in life. An infant delivered by Cesarian section has no cutaneous inhabitants, but Imrich Sarkany of the Royal Free Hospital in London has shown that the skin of a baby born by the normal route carries a sparse population of cocci and diphtheroids derived from the mother's birth canal. The community is augmented soon after birth both directly by contact with adults and indirectly by aerial transmission.

This flora has distinctive characteristics. There is apparently a greater variety of potential pathogens on the skin of infants than there is on the skin of older individuals. Several harmless species not found in adults inhabit the skin of older children. This may be due, at least in part, to the fact that children come in contact with the soil more often than adults do. Many of the soil organisms, however, cannot survive in a cutaneous habitat, so that the juvenile skin flora

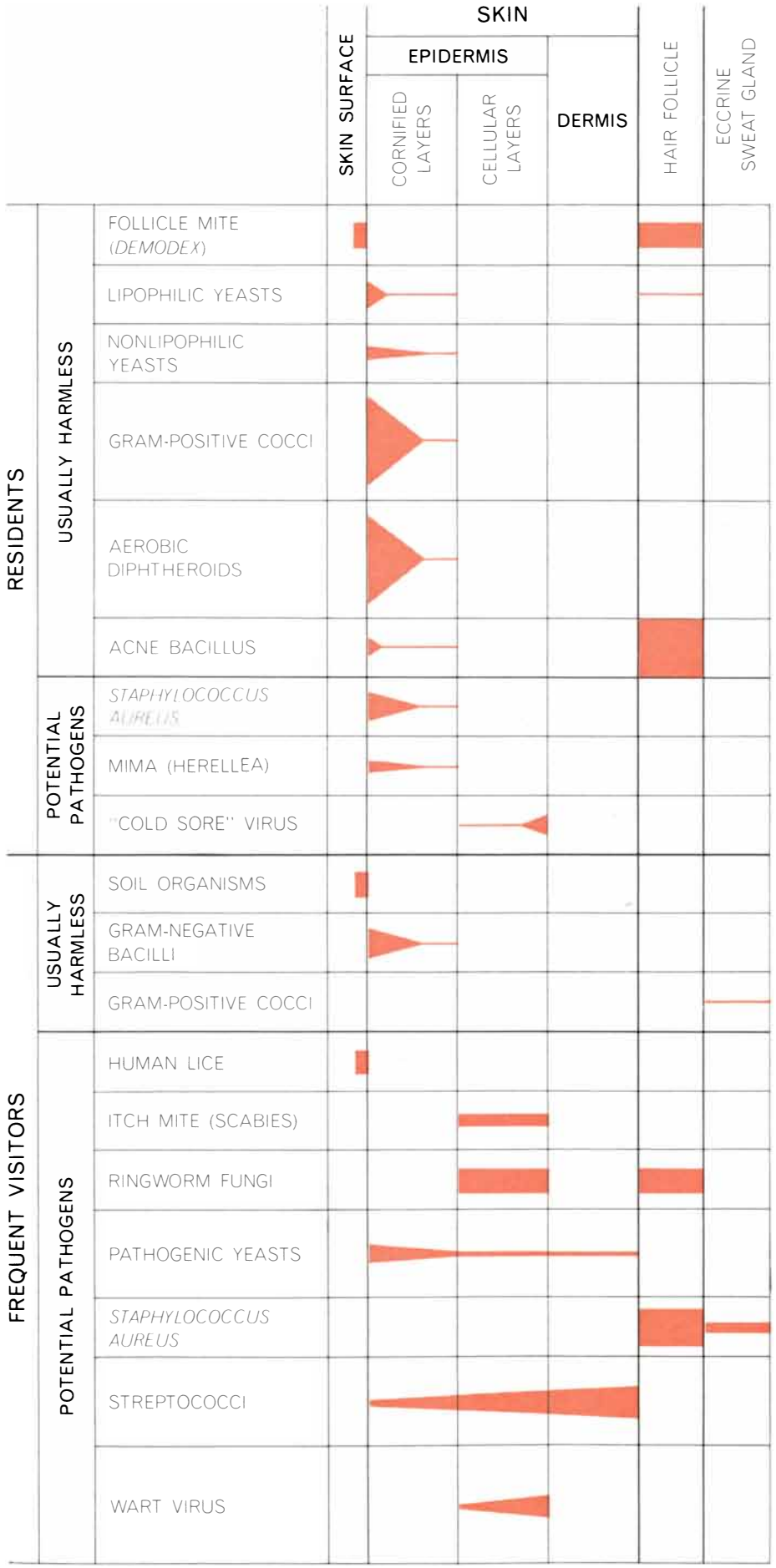








DISTORTED FIGURES display specialized habitats. The distribution of hair (*a*) is that of an adult male. Skin temperatures (*c*) are those of an adult at rest in an environment of 73 degrees Fahrenheit. Except for the follicle mite, the fauna (*d*) are pathogens; they are not entirely confined to areas indicated. At *e*, the *Corynebacterium tenuis* group forms nodules on hair; the yeast *Pityrosporum ovale* increases when dandruff is present; fungus *Candida albicans* causes infections. At *f*, only oxygen-utilizing bacteria are included.



SKIN INHABITANTS that are relatively plentiful in the upper cornified (horny) layers of the epidermis diminish in number in the deeper layers. Pathogenic streptococci and yeasts may pass through a breach in the skin to reach the dermis and the deeper tissues.

does not mirror the flora of the larger environment. By the same token, most cutaneous organisms do not multiply in soil or dust, although some can survive for an appreciable time. It is for this reason that contact with other humans (and to a lesser extent with other mammals) is far more important in the transfer of cutaneous microorganisms than contact with an inanimate object, however dirty it is.

One might think that once the characteristic adult cutaneous community was established there would be no further exchange of inhabitants between individuals. It is here that our analogy of each individual as a discrete world breaks down. In man, if the pattern of staphylococcus can be regarded as a model, there is a constant transfer of microorganisms from one carrier to another, even when stringent preventive measures are taken.

R. R. Davies and W. C. Noble of St. John's Hospital for Diseases of the Skin in London have shown that staphylococci are transmitted on tiny "rafts" of skin shed from the body. The most satisfactory raft from the point of view of the coccus has a size somewhere in the range of 14 microns (.014 millimeter). Each raft can carry perhaps four viable microbial units. As the host moves about these fragments of skin are shed, and there is every reason to think that the flora is also shed and presumably is available to a new host. Thus the dispersal of microorganisms goes on almost constantly; even the gentle exercise involved in dressing and undressing is accompanied by the shedding of an appreciable number of bacteria-bearing rafts.

The term "raft" suggests a comparison with the way geographically isolated islands become populated. It is believed the atypical animal and plant populations of remote islands are partly the result of fortuitous transfer on natural rafts (a dead tree, say) that carry organisms across the water. A well-documented example of such transfer is provided by Krakatoa, the island in the East Indies that was sterilized by a huge volcanic explosion in 1883. Charles S. Elton of the University of Oxford states that in 1933, 50 years later, Krakatoa had been reclothed in jungle, and that at least 720 species of insects and more than 30 species of vertebrates (including nonflying forms) had managed to cross the 25 miles of water that separates the island from its nearest neighbor.

One might compare Krakatoa with a newborn infant, and indeed the success

of some pathogens in establishing themselves in an infant host may be the result of their being the first to arrive. The infant, however, is exposed to many organisms other than the ones carried on aerial rafts; sooner or later he makes direct contact with well-colonized relatives and friends. Since it is now possible to rear germ-free animals from birth in special chambers, it would be interesting to expose such an animal to aerial inoculation only and then observe what kind of skin flora it develops. So far as I am aware this experiment has not been undertaken.

Microorganisms depart from the host, then, by air and by contact. What happens when such an organism arrives at a fully colonized individual? Elton has shown that the newcomer is most successful where there is an ecological niche that is not exploited by an indigenous inhabitant, and that invasion into an established and complex community is very difficult. An example is afforded by the surprising number of birds that have succeeded in colonizing New Zealand during the past 100 years. There seems to be no doubt that this has been made possible by catastrophic changes in the ecosystem of the region that have resulted from its invasion by Europeans. New niches have been opened up for the colonizers, perhaps including niches vacated by the former fauna.

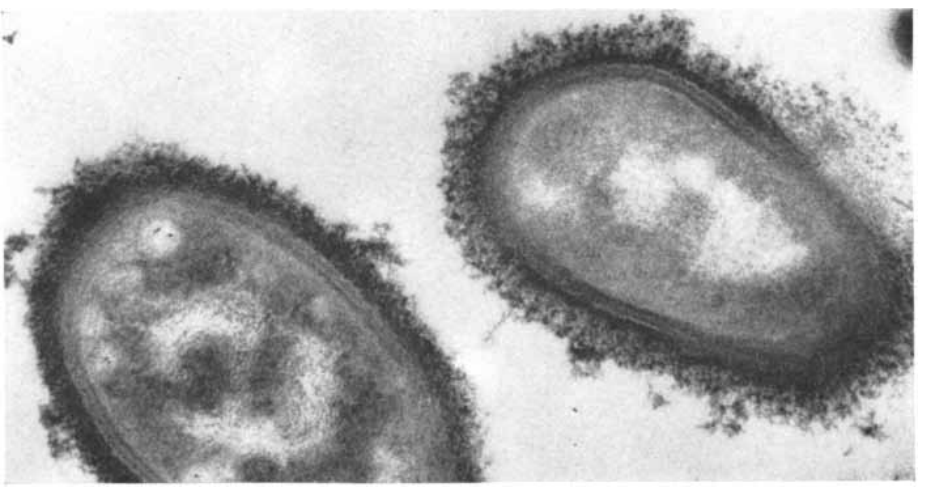
In considering the ecological niches of the skin we are again obliged to speak in terms of pathogens, since so little is known about the activities of the harmless species. There is evidence that, as in the classic ecological situation, the invader can establish itself less readily when there is competition with a resident flora. Thus attempts to control staphylococcus cross infection by treating carriers with antibiotics have not been very successful because a resistant strain is likely to replace the original inhabitants of the nostrils. On the other hand, Henry R. Shinefield and his colleagues at the University of California School of Medicine have had considerable success in controlling infection in maternity wards. The infants and those with whom they had contact were inoculated with a staphylococcus of low virulence, so that strains of greater virulence would have to compete with a resident for the habitat.

The nostril habitat of staphylococci is a rather special one, but the situation probably is much the same on the "outer" surface of the skin. Although pathogenic organisms constantly alight on the skin, they find it a most unfavorable environment and in the absence of injury have great difficulty colonizing it. This "self-sterilizing" capacity of the skin does not, as the term suggests, seem to be an attribute of the skin itself. Rather it is the characteristic displayed by all well-developed ecosystems, namely that all influences tend to maintain the status quo.

This homeostasis is clearly evident in the ecosystem of the skin, and we know something—albeit not a great deal—about the processes involved. The skin is an unfavorable habitat for the vast majority of microorganisms because it is extremely rare for species whose headquarters are in the soil, the water and elsewhere in our surroundings to multiply on the skin surface. Provided that it is undamaged, the skin is also unfavorable for exploitation by most human pathogens. There are a variety of reasons for this. The skin is too acid for some species. (This "acid mantle" was once regarded as a major protective feature, but there is now good evidence that many pathogens that fail to establish themselves are not inhibited by it.) There seems to be little doubt that much of the skin is too arid for colonization by some species. The constant shedding of the surface skin layers is another process that hinders the establishment of invaders. From the ecological standpoint, however, the most interesting defense mechanism is one that results from the metabolic activities of the resident flora. It has been known for some years that unsaturated fatty acids are an important component of sebum collected from the skin surface, and that they inhibit the growth of several bacterial and fungal cutaneous pathogens. More recently it has been shown that these substances are a metabolic product of the Gram-positive members of the cutaneous community, which break down (by means of specific enzymes) the more complex lipids in freshly secreted sebum.

This activity of the Gram-positive species helps to protect the skin from invasion by potential pathogens. The Gram-positive species also (but not necessarily by the same means) exert a restrictive effect on the population growth of Gram-negative organisms. In the healthy axilla Gram-positive species predominate but small numbers of Gram-negative organisms are also present. If a deodorant that contains an antibiotic with a selective action against the Gram-positive species is regularly applied, the cutaneous population gradually changes to a Gram-negative one of approximately the original density. Withdrawal of the deodorant is followed by a return to a predominantly Gram-positive flora. It would seem that some attribute of the cocci and diphtheroids in the axilla is a limiting factor for Gram-negative organisms. The fact that the axillary odor is absent while the Gram-negative bacteria are dominant also indicates that it is the metabolic by-products of the Gram-positive species that confer this odor on us.

It is clear that a complex and fascinating community maintains itself on the surface of each one of us. Perhaps it is not amiss to suggest that we might profit from considering our own importance to the inhabitants of that ecosystem. When one feels about to be overwhelmed by the "acts of God" and man-inspired catastrophes that threaten and afflict us, one might take comfort in the thought that some action of which one is scarcely aware is a cataclysm in the cutaneous world.



TWO SKIN BACTERIA are diphtheroids, a group common on healthy skin. This electron micrograph of *Corynebacterium minutissimum* was made by Leopoldo F. Montes of the University of Alabama Medical Center. The magnification is about 40,000 diameters.

MATHEMATICAL GAMES

Dr. Matrix gives his explanation of why Mr. Nixon was elected President

by Martin Gardner

After the internationally esteemed numerologist Dr. Matrix sold Squaresville, his hippie rehabilitation center (see this department for last January), I lost track of his whereabouts until November 4. It was the day before Election Day and Iva, Dr. Matrix' half-Japanese daughter, telephoned to say that she and her father were in New York for a few days. Could I join them the next day for dinner? Of course I was delighted, and we arranged to meet at three o'clock on the Promenade at Rockefeller Center, the little street that runs from Fifth Avenue to the gilt statue of Prometheus in the fountain by the Lower Plaza.

It was a light gray, overcast but pleasantly mild afternoon when I found the two of them sauntering counterclockwise around the breezy, beflowered Promenade. Dr. Matrix was his usual imposing figure—tall, gray-haired, his alert green eyes observing everything with intense interest. Iva was wearing her black hair upswept and lacquered; her flapping miniskirt caught the eye of every male on the Promenade. An exotic perfume diffused up my nasal passages as we exchanged affectionate kisses on the cheek.

We found an empty wooden bench in front of the French bookstore on the Promenade's downtown side. They had just returned, Iva told me, from Djakarta in Indonesia, where her father had been invited by the governor to advise him on the operation of Hwa Hwee, the city's popular numbers game. I recalled reading in *The New York Times* (Sunday, June 9, 1968) that since this ancient Chinese gambling game had been legalized in Djakarta early in 1968, the city's four million inhabitants had become so obsessed by it that even the country's appalling economic and political troubles had been forgotten.

Without going into the elaborate ritualistic details, Hwa Hwee begins each day at 11:00 A.M., when a number from 1 through 36 is selected in great secrecy. The number is placed in a cylinder; the cylinder goes into a red cloth bag; the bag is hung from the roof of a Buddhist "praying room" inside a small gambling hall in Glodok, the Chinese district. At intervals throughout the day a series of cryptic clues are issued to the public. Betting continues until 11:00 P.M. Precisely at midnight the winning number is announced by messengers who ride scooters through the city calling "Hwa Hwee!" followed by the winning number. Minimum bets are 250 rupiah (about 75 cents), and all winners are paid 25 to one. Profits to the city, which are enormous, have been used mainly to build new schools. For three months Dr. Matrix had been working with Tan Eng Giap, who provides the riddles for each day's number, on ways to guard against cheating and to discourage the rise of "black Hwa Hwee," illegal betting spots that were springing up everywhere in poorer sections of the sprawling city.

"Mr. Giap, whose initials backward spell GET, is a clever man," said Dr. Matrix. "I met him years ago when he was a croupier at an illegal gambling house in Djakarta. His clues are quite ingenious."

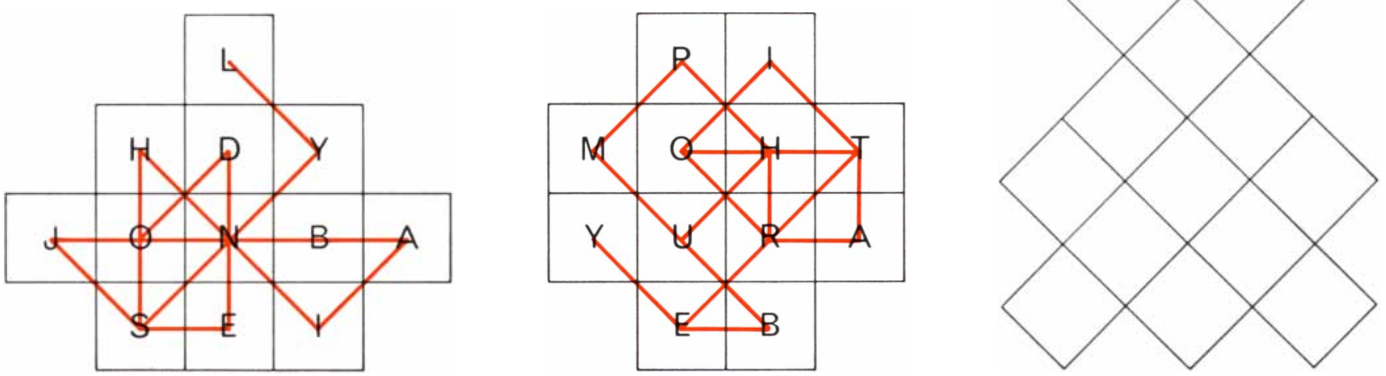
"I wish I could stay longer," Iva said to me as she stood up, "but there's some shopping I must do. We'll be meeting again in a few hours. Remind me to tell you about the trouble we once got into in Chicago when Father was hired by the Syndicate to give them advice about *their* numbers game."

"I presume," Dr. Matrix said after Iva had left, "you'll want to ask me about the outcome of today's voting."

"You presume correctly."

"Nixon undoubtedly will be the 37th president. Note that 37 is a prime number. Interesting, because the only other president who was a Quaker was Herbert Hoover, and he was the last prime-number president, the 31st."

I began to write in my notebook while Dr. Matrix continued his analysis. "Nixon's great advantage, of course, is that his name ends in *ON*. There've been nine previous *ON* presidents, from George Washington to Lyndon Johnson, but only one *EY* president, William McKinley. Nixon's been counting heavily on this. That's why he's kept stressing the slogan 'Nixon's the *ON*e.' Wallace will



Three spelling matrices. Fill the one at right to spell RICHARD MILHOUS NIXON

do fairly well because he alone has the double letter in his name, like so many earlier presidents of this century. Humphrey's initials, *HHH*, with their upside-down and mirror-reflecting symmetry, will get him more votes than he would otherwise have got and that should make it a close decision. In addition, *H* is the eighth letter of the alphabet and 888 also is the same upside down and mirror-reflected. The three eights add up to 24, the sum of the digits in 1968. Unfortunately, all of this is insufficient to counter the stronger advantages of *ON* over *EY*."

"Don't you think it strange," I said, "that the last two significant third-party movements have both been led by a Wallace? Henry Wallace, left of center, in 1948. Now George Wallace, right of center, just 20 years later."

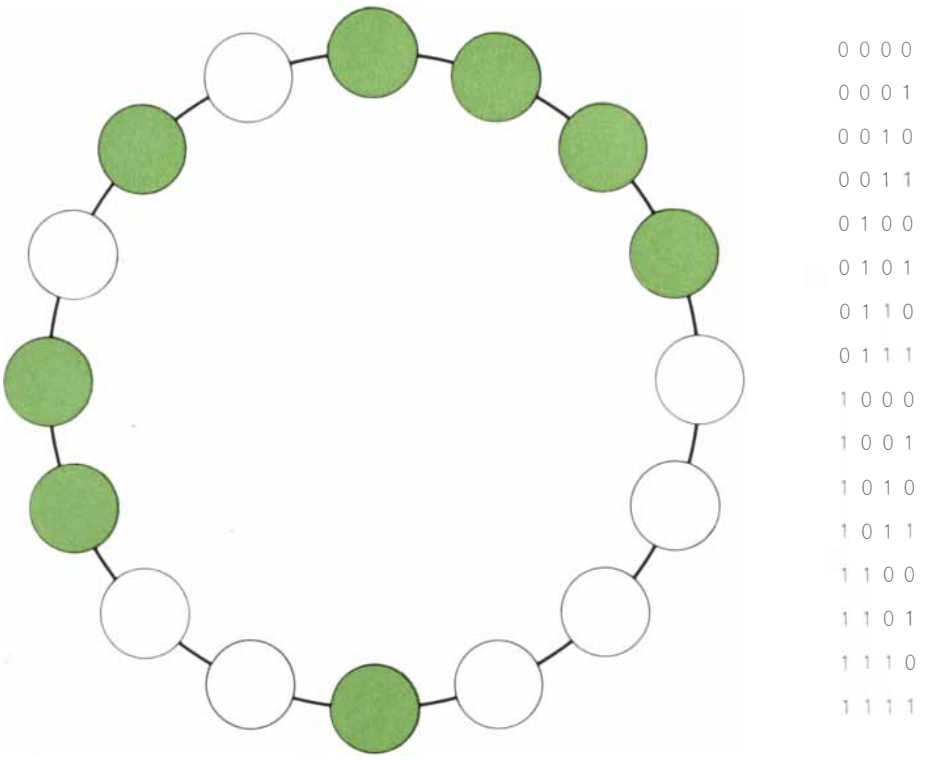
"Paralleled, of course," said Dr. Matrix, "by the equally strange right-left reversal involving two other last names, Joseph McCarthy and Eugene McCarthy. Have you noticed that the first names of the two Wallaces combine to make Henry George? He ran for mayor of this city in 1886—note that 86 is 68 backward—on his single-tax program. It was as simplistic and self-defeating as the two Wallace movements."

Dr. Matrix had other curious comments on the names of the three presidential candidates but space allows me to give only the following word puzzles, which he said he had prepared specially for my use. They belong to a class he called "minimal king's-tour spelling matrices." Old puzzle books often contain rectangular matrices with a letter in each cell. By moving from cell to cell in the manner of a chess king one tries to spell out a proverb, or as many names as possible of flowers, animals and so on. Most puzzles of this type are on the dull side, but Dr. Matrix had thought of a way to make them combinatorially less trivial. The idea is to take the full name of a prominent person, a name preferably with no double letters (although double letters can be accommodated by the rule that a cell may be counted twice), and design a symmetrical pattern of square cells on which the name can be spelled by a single "king's tour." There is one further proviso: the pattern must be minimal in the sense that no letter appears on it more than once.

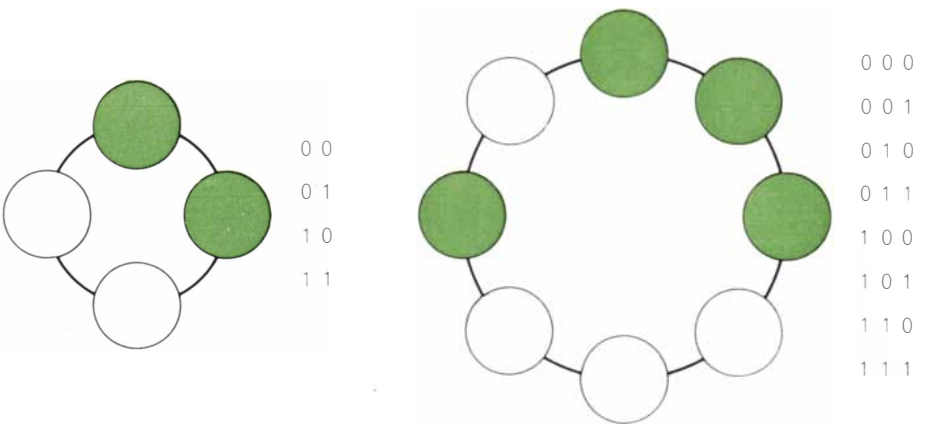
Dr. Matrix then showed me two remarkable examples [*see illustration on opposite page*]. The colored line on the pattern at the left indicates how a king can be placed on *L* and then moved one square at a time in any direction (as the king moves in chess) to spell LYNDON BAINES JOHNSON. On the center pattern HUBERT HORATIO HUMPHREY can be spelled in the same way. This is quite an elegant pattern: it has fourfold symmetry and the placing of the 12 letters is unique except for rotations and reflections. Can the reader place the 13 different letters in RICHARD MILHOUS NIXON on the cells of the pattern at the right so that a king's tour will spell the new president's full name? The answer, which also may be unique, will be given next month.

"I assume you have read Edward Jay Epstein's eye-opening hatchet job on Big Jim Garrison, the New Orleans district attorney, in *The New Yorker* [July 13, 1968]," I said. "It explained how Garrison derived Jack Ruby's unlisted Dallas telephone number from that mysterious number 19106 in Lee Harvey Oswald's notebook." (The digits in 19106 are rearranged by taking the first digit, then the last, then the second, then the second from last and finally the center digit. This produces 16901. Subtracting 1300 yields 15601, which was Ruby's private telephone number.)

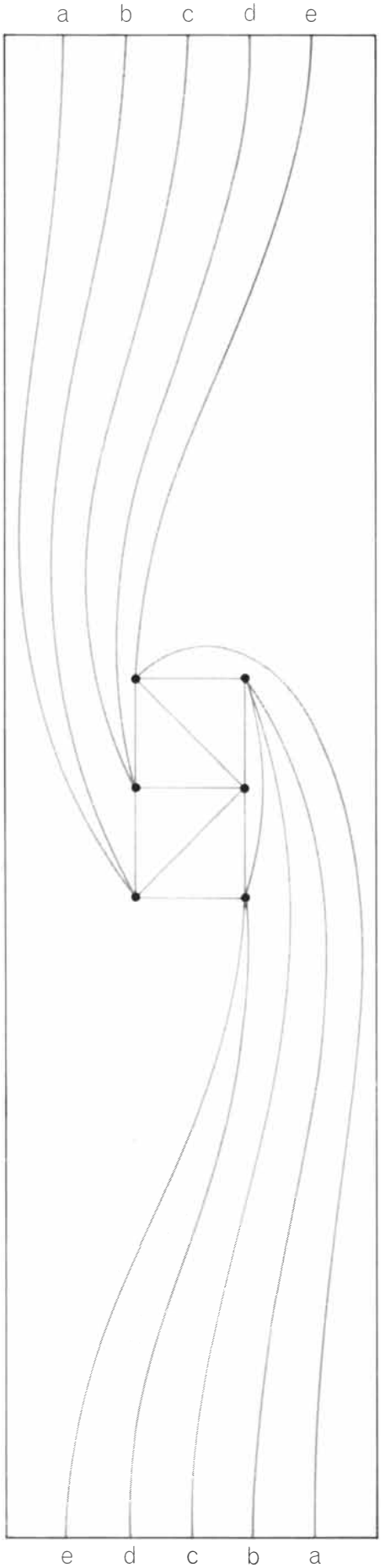
Dr. Matrix' emerald eyes glittered with amusement. "Extremely crude numerology. A much simpler way to decode 19106 is to partition it 1–9–10–6. Using the familiar code of *A* equals 0, *B* equals 1, *C* equals 2 and so on, the four numbers translate as *BJKG*. The *K* ob-



Combinatorial bracelet with 16 quadruplets of jade* (1) *and pearl* (0) *beads



***Combinatorial bracelets for doublets* (left) *and triplets* (right)**



Answer to Möbius strip problem

viously stands for Kennedy and the remaining letters, *BJG,* are the initials of Big Jim Garrison."

"I must write Mark Lane about that," I said, chuckling as I recorded the details.

We stood up and began a leisurely stroll along Fifth Avenue.

"The coming year should prove interesting," Dr. Matrix remarked. "The number 69 is the same upside down. Moreover, 69 backward is 96 and SIXTY-NINE and NINETY-SIX are anagrams."

We paused to look into a window in which copies of James D. Watson's recent best seller *The Double Helix* were displayed. "Crick, Watson *and* Wilkins shared their 1962 Nobel prize," Dr. Matrix mused. "Have you noticed that AND is DNA backward?"

I pointed up the street to the enormous numerals 666 on top of the Tishman Building at 666 Fifth Avenue. "Any comments?"

"We've discussed the Book of Revelation's Mark of the Beast before," he said with a sigh. "Frankly, the topic bores me. A skillful numerologist such as myself can easily find 666 in anybody's name. Consider Vincent Lopez, the orchestra leader who fancies himself a numerologist. [Lopez' book *Numerology: How to Be Your Own Numerologist* was published by Citadel Press in 1961.] I once amused myself by numbering the alphabet backward, starting with 101 for Z and ending with 126 for A. In this code the letters of V. LOPEZ have the values 105, 115, 112, 111, 122, 101. They add to 666. Or take my own full name, Irving Joshua Matrix. Each name has six letters. Perhaps *I'm* the Beast. Amusing, but of course utterly trivial."

"You once told me," I said as we waited for the traffic light at 52nd Street to change, "that every integer has unique numerological properties."

"Naturally."

I pointed to the street sign. "How about 52?"

"It's the number of cards in a deck," Dr. Matrix answered promptly, "as well as the number of weeks in a year. You might be surprised to know that if you take the names of the 13 card values from ACE to KING and count all the letters you'll find there are exactly 52. The four suits correspond to the four seasons and the 12 picture cards to the 12 months. Add the values of all 52 cards, plus 1 for the joker, and you get 365, the days of the year."

I aimed my mechanical pencil at a sign that said "Store open weekdays from 9 to 5" and asked Dr. Matrix what he could do with that.

"Nine over five, or nine-fifths, added to the square root of nine-fifths is 3.1416+; a remarkable approximation to pi, is it not? That was discovered last year by my friend Fitch Cheney. You might ask your readers to write the first three digits of pi, 314, drawing the 4 so that its two nonhorizontal bars meet at the top, and then hold it up to a mirror. They'll get a pleasant surprise."

As we approached 57th Street we crossed the avenue and walked into Tiffany's. "Iva's going to meet us here in about 10 minutes," Dr. Matrix said, glancing at his wristwatch. "I'm buying her an unusual bracelet for her birthday next month."

The bracelet Dr. Matrix had asked Tiffany's to make consisted of 16 spherical beads, all the same size, half of them jade and half pearl. Instead of alternating the pearl and the jade, however, he had had the two kinds of beads strung in what appeared to be a haphazard manner [*see top illustration on preceding page*].

"Do you see the order behind this arrangement?" Dr. Matrix asked.

I studied the bracelet for several minutes before admitting that I could perceive no order at all.

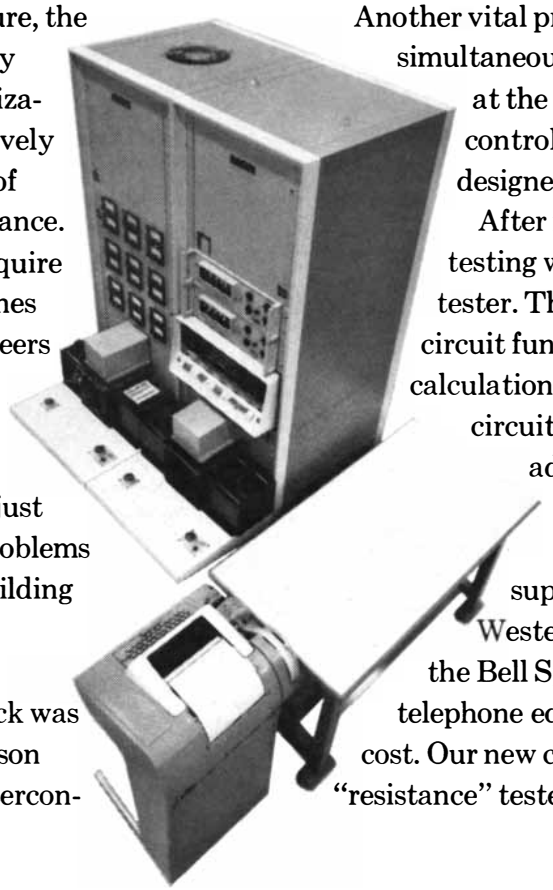
When a penny is flipped n times, Dr. Matrix explained, the number of equally probable ways it can fall is 2 to the power of n. Two flips have four possible outcomes: HH, HT, TH and TT. Three flips have eight possible outcomes, four flips have 16 and so on. The same applies to the different arrangements of n beads in a row when each bead can be either of two different colors. An interesting combinatorial problem now presents itself. Is it possible to arrange 2^n beads in a circle, half of them one color and half another, so that every possible n-tuple combination will be represented by n adjacent beads as you go around the circle?

The answer is yes [see "The Mathematician as an Explorer," by Sherman K. Stein; SCIENTIFIC AMERICAN, May, 1961]. There is a unique solution when n equals 2 [*see bottom illustration on preceding page*]. If you go around the circle in either direction, taking the beads two at a time, you find all four possible doublets. When n equals 3, the solution is also unique. Circle either way, taking adjacent beads three at a time, and you encounter all eight possible triplets. Of course, the beads can be arranged in reverse order, but since a reversal is obtained merely by turning over

The "resistance" came, appropriately enough, not from people but from the resistors on thin film integrated circuits. These resistors, which are made of tantalum sputtered onto a ceramic base, must be precisely adjusted, measured and tested before they leave the factory. Since some variations are inevitable in mass manufacture, the necessary precision is achieved by controlling the electrolytic anodization of the tantalum. This effectively reduces the cross-sectional area of the resistors, including the resistance.

Manual anodizing would require acres of expensive testing machines and scores of operators. So engineers at Western Electric's Allentown Plant began to think in terms of a computer-controlled tester which would simultaneously adjust many resistors. The technical problems encountered in designing and building such a machine represented a tremendous challenge.

But the toughest nut to crack was how to establish a ratio-comparison technique, to adjust resistors interconnected by many circuits. This technique was also needed to provide speed in testing circuit function efficiency according to precise but different requirements. The computer would use this test information for the different circuits to control the anodization circuitry for adjustment of the resistors.



Another vital problem was the need for simultaneous adjustment of many resistors at the same time. Another computer-controlled switching system was designed especially for the job.

After months of experimentation and testing we came up with a satisfactory tester. This machine measures the circuit function, makes the appropriate calculations, commands the anodizing circuitry to make the proper adjustment of the resistors, and tests them ... all in microseconds.

As the manufacturing and supply unit of the Bell System, Western Electric's job is to supply the Bell System with the best possible telephone equipment at the lowest possible cost. Our new computer-controlled "resistance" tester is helping us to do just that.

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the bracelet or circling it in the other direction it is not considered as being different. You might suppose a new triplet solution could be obtained by taking the "complement" of this solution—changing each white bead to colored and each colored bead to white—but actually the resulting bracelet is identical with the one shown.

The minimal-length bracelet showing all possible quadruplets of jade and pearl beads will have 2^4, or 16, beads. It was such a bracelet that Dr. Matrix had prepared for Iva. Go in either direction around that bracelet [*top of page 117*], taking the beads four at a time, and you will be able to check off all 16 combinations of 1 and 0 (with the 1 standing for jade and the 0 for pearl, or vice versa); the 16 arrangements correspond to binary forms of the numbers 0 through 15.

Reversing the order of the beads provides no new solution because it is equivalent to turning over the bracelet or circling it in the opposite direction. In this case, however, the complement (obtained by interchanging colors) does produce a new solution. There are eight basically different arrangements that solve the triplet problem, considering complements as being different but not reversals. The reader knows of two: the one shown and its complement. Can he find the other six? All eight will be given next month.

On the busy sidewalk outside Tiffany's, while Iva was admiring her bracelet, Dr. Matrix extended his hand. "I'm sorry that I have other plans and can't join you two for dinner and the evening."

"So am I," I said as we gripped hands, but I didn't really mean it.

A way to solve last month's Möbius-surface puzzle is shown on page 118. The problem was to join six spots on the surface with connecting lines so that every pair of spots is joined by a line and no lines intersect. Assume that the strip is given a half-twist before the ends are joined; points *a*, *b*, *c*, *d* and *e* at the bottom will then meet the corresponding points at the top. As explained last month, the surface must be thought of as having zero thickness, and its lines as being "in" the strip, like ink lines that have soaked through, rather than "on" it. From this graph one can derive a map of six regions on the Möbius surface, each pair with a common border segment so that six colors are required for coloring the map [see this department for July, 1963].

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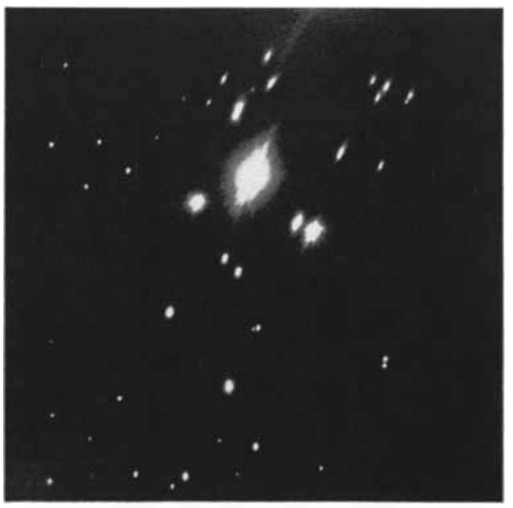

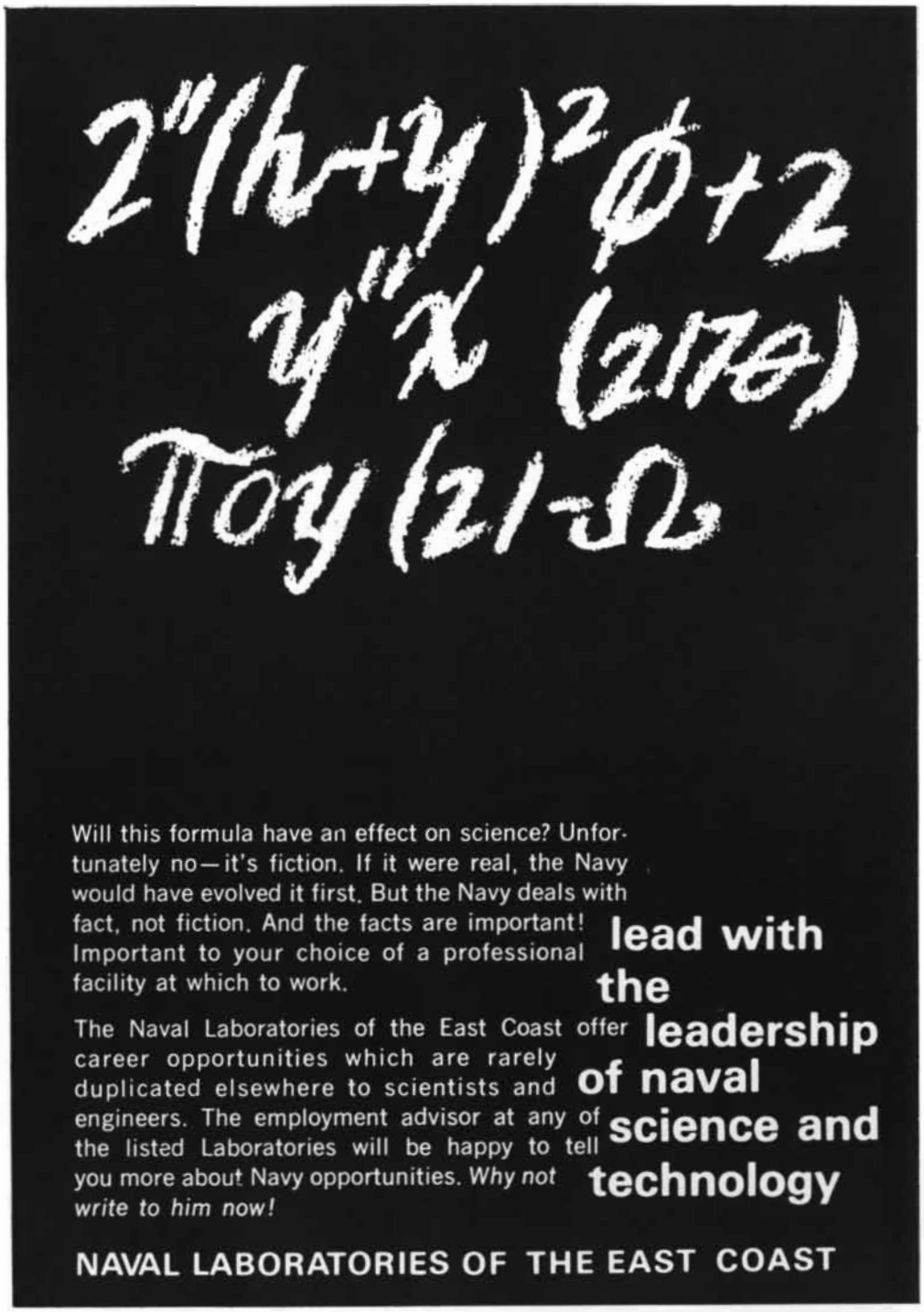

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Fact—The facilities and equipment of the Naval Laboratories of the East Coast are unsurpassed. Every lab not only is completely up to date, but each also has highly specialized equipment pertinent to its mission. One lab has one of the world's largest high-field magnetic installations. Another has the highest-speed deep water basin for testing everything from hull design for ice breakers to hydrofoils. Other unique facilities are: a high level radiation lab; highly sensitive radio telescope stations; very sophisticated oceanographic vessels; electromagnetic environment simulation facilities; an anechoic test facility.

Fact—Graduate education opportunities at the Naval Labs are almost limitless. Each lab has a program for graduate training right at the facility. Advanced courses are offered in association with the graduate schools of nearby universities. Scientists and engineers take full advantage of these courses—nearly one-third of all the lab's professional people are enrolled in advanced studies at all times. The Navy is strongly supporting this education effort. Another facet is the long range education program which provides for selected employees a year's study on a university campus, tuition and expenses paid, with income still provided by the Navy.

Fact—Each Laboratory has its own coterie of experts, well recognized in their fields by scientific and professional societies whose papers are regularly published. Lab professionals hold hundreds of patents. One of the advantages to being at one of the Labs is the opportunity to work with eminent professionals in fields like: fluid mechanics; underwater propulsion; space and missile surveillance; scale damage modeling; high pressure effects on materials; sonar and hydro mechanics. Every scientist and engineer working at a Naval Lab has the opportunity to meet with and discuss the work of men breaking new ground in fields like these.

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THE AMATEUR SCIENTIST

Simple ways to calculate the orbits of space vehicles

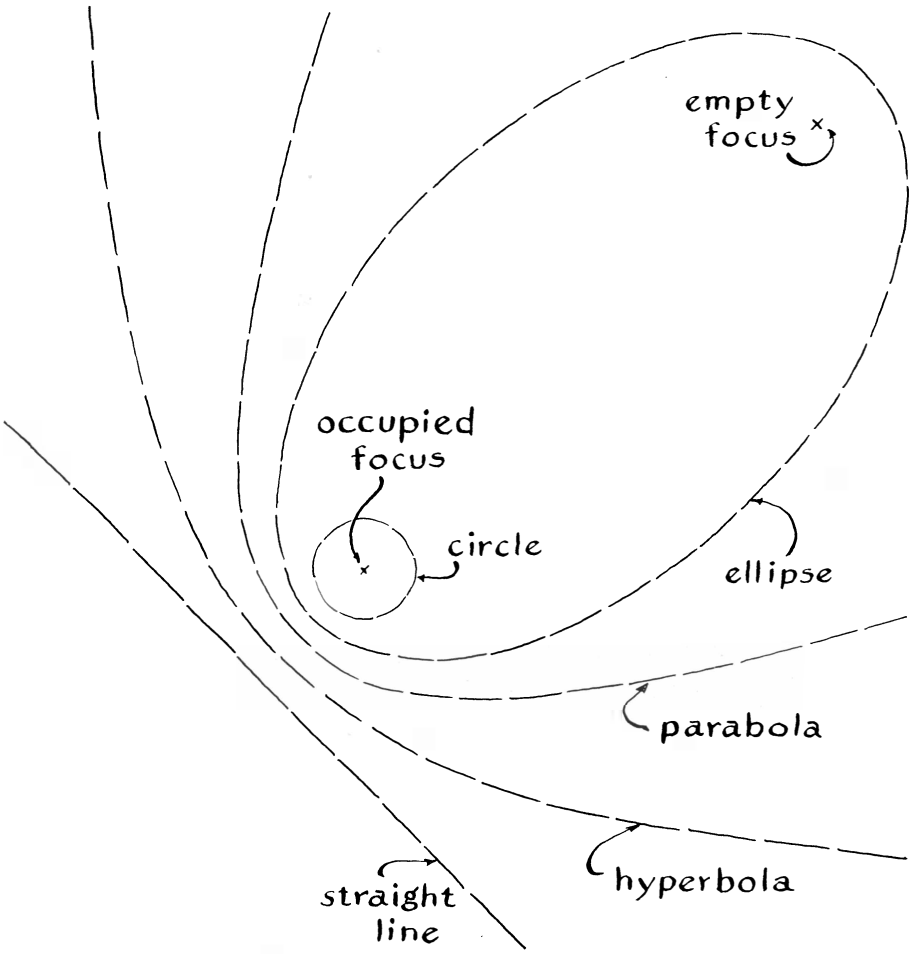
Conducted by C. L. Stong

Each time a manned satellite is sent aloft the world waits anxiously to learn if it has gone into orbit. News reports of the event sometimes include pictures of technicians feeding data into computers that forecast the characteristics of the orbit. This tends to create the impression that space navigation is totally beyond the resources of amateurs—that the prediction of orbits is something that can be done only by experts in astrodynamics who have access to electronic computers. There is some truth in this assumption. Still, it is not the whole truth, says Stephen A. Kallis, Jr., an aerospace technologist of Acton, Mass. Kallis maintains that a reasonably satisfactory prediction of where, how fast and how far a space vehicle will go can be made by anyone who can count on his fingers, and he insists that it is a lot of fun to do.

"The ease with which predictions can be made mathematically," Kallis writes, "depends largely on how accurate the results must be to satisfy the person who seeks the information. Consider the husband who asks his wife what time dinner will be ready. Doubtless he would be satisfied if she answers, 'In about 10 minutes.' An answer of 'Nine minutes, 25 and six-tenths seconds' might strike him as excessively precise if he merely wants to know if it is time to wash his hands. On the other hand, imagine the response of a professional astronomer waiting to photograph an eclipse of the sun if he were told that the eclipse would occur 'sometime' that morning.

"If the amateur is willing to settle for something less than split-second accuracy, the prediction of orbital characteristics is fairly easy. I have calculated a number of predictions in the sands of a Florida beach, using a seashell as the writing instrument. The simplified predictions ignore small differences between calculated orbits and actual orbits caused by such factors as the pressure exerted on the satellite by sunlight, collisions with dust particles in space and the slow precession, or rotation, of the orbit.

"In addition I revise nature a bit in the interest of simplification. First, I assume that all the planets travel around the sun in circular orbits. In actuality most of the orbits are slightly elliptical. Second, I assume that space vehicles are affected by only one gravitational field—again an assumption that is not true. The universal law of gravitation states that every particle of mass in the universe attracts every other particle. The force falls off very rapidly with distance, however. Space probes are affected minutely by the gravitation of a distant planet, but the effect can be ignored for closely approximating the shape of a predicted orbit. Third, I assume that the orbits of all the planets lie in the same plane, which is another assumption that can be made without doing violence to the desired accuracy. Only Mercury and Pluto are extreme exceptions in any case. For example, the orbit of Mercury is inclined seven degrees from the plane of the ecliptic; the difference between the inclined and coplanar orbits produces an arrival-time deviation that is small in relation to the time required by a space probe to reach its orbit.



Conic-section paths of bodies in space

I $$v_c = \frac{v_{cs}(R^{1/2})}{(R+h)^{1/2}}$$

II $$a = \frac{r}{2} \times \frac{v_p^{\,2}}{v_p^{\,2} - v^2}$$

III $$h = \frac{(v_{cs})^2 R}{v_c^{\,2}} - R$$

IV $$v_t = \left(v_p^{\,2}\left(1 - \frac{r}{2a}\right)\right)^{1/2}$$

Formulas devised by Stephen A. Kallis, Jr.

"In discussing the technique of predicting orbits I use one mathematical symbol that is not always taught in arithmetic courses. I substitute an exponent for the radical sign that is used customarily for indicating roots. For example, if a represents a number, the symbol $a^{1/2}$ means 'the square root of a.' Thus if $a = 9$, then $a^{1/2} = 3$. Similarly, I use the fractional exponent to indicate the multiplication of a root by itself. The number of multiplications to be made is indicated by the numerator of the exponent. For example, in absolute terms, if $a = 9$, then $9^{1/2} \times 9^{1/2} \times 9^{1/2} = 9^{3/2} = 3 \times 3 \times 3 = 27$. Again, if $a = 4$, then $a^{3/2} = 8$. Incidentally, much of the pain of extracting a square root can be avoided by using a six-place table of logarithms, and a desk calculating machine can take over the drudgery of doing multiplications and divisions. These, however, are merely laborsaving techniques. You get the same results with pencil and paper.

"Thus equipped, you are set to proceed. All bodies travel in space along one or another of the familiar set of curves known as the conic sections: the circle, the ellipse, the parabola, the hyperbola and the straight line [*see illustration on preceding page*]. Of these curves only two—the circle and the ellipse—form a closed path. Therefore satellites that orbit the earth or any other natural body must travel in one or the other of these paths.

"If a satellite is given barely enough velocity to stay aloft, it will pass through all points on its orbit at its minimum altitude and its path will be a circle. The satellite is then said to have 'circular velocity.' If the satellite has somewhat more than this minimum velocity when it passes through its point of minimum altitude, the path will elongate into an ellipse that reaches maximum altitude at a point on the orbit directly opposite the point of minimum altitude. The satellite is then said to have an 'elliptical velocity.'

"As more and more velocity is imparted to the satellite or any other space vehicle the ellipse expands until at one critical velocity it opens into a parabola. At this velocity the probe overcomes the gravitational attraction of the earth and plunges into space, never to return. It has achieved one of many possible 'escape velocities,' in this case 'parabolic velocity.' Should even more velocity be imparted to the probe, the path will bend into one of many possible shallower curves known collectively as the hyperbolas and will have 'hyperbolic velocity.' If it were possible for the probe to acquire infinite velocity, the hyperbolic path would flatten into a straight line, the final curve in the family of conic sections.

"To compute the behavior of a satellite at any velocity we first need to know its parabolic velocity with respect to a selected body such as the earth. The selected body is known as the 'primary.' Initially, for the purpose of this discussion, we may assume an airless, nonrotating primary body. It turns out that parabolic velocity is the velocity an object would acquire by falling through a distance equal to the radius of the attracting primary body at a constant gravitational acceleration equal to the acceleration at its surface.

"One might consider the parabolic velocity of the earth. The average radius of the earth is 2.09029×10^7 feet. (The term 10^7 means that the decimal point of the preceding figure must be moved seven places to the right; the notation in this case is merely another way to write 20,902,900 feet.) The acceleration of the earth's gravity is 32.174 feet per second per second. The distance a body falls is equal to half of the product of the acceleration of gravity multiplied by the square of the time during which the body falls. The time of fall is equal to the square root of half of the product of the distance divided by the acceleration of gravity. In these conditions an object falling one earth radius would need a time of $(1/2 \times 2.09029 \times 10^7/32.174)^{1/2}$, or 1,140.1, seconds. The velocity acquired by a body that falls through a known distance at a constant acceleration is equal to the acceleration of gravity multiplied by the time of fall, in this example $32.174 \times 1{,}140.1$, or approximately 36,680, feet per second. To convert the velocity into miles per second divide 36,680 by 5,280 (the number of feet in a mile) to get 6.945 miles per second. This, then, is the parabolic velocity of an earth satellite, the minimum velocity the object must have to escape from the earth's gravitational field.

"What velocity must a satellite have to orbit the earth in a circular path? Interestingly enough, the circular velocity of an object orbiting any planet at any altitude is equal to the parabolic velocity at the altitude of interest divided by the square root of 2. Expressed in algebraic notation the formula is $v_c = v_p/2^{1/2}$, in which v_c represents circular velocity and v_p represents parabolic velocity. Using this formula in the case of an earth satellite, the circular velocity at sea level is equal to 36,680/1.42, or 25,830, feet per second. Transforming feet into miles yields 25,830/5,280, or 4.892, miles per second. A satellite could not orbit the earth at sea level, of course, because it would be burned up by friction with the air. Nevertheless, the figure is most useful for computing orbits at higher altitudes.

"If we let v_{cs} stand for the circular velocity of a satellite at the surface of the primary body, R for the radius of the primary body and h for the altitude of the satellite above the body, the circular velocity at the selected altitude is equal to $v_{cs} \times R^{1/2}/(R+h)^{1/2}$. When the circular velocity at the selected altitude has been determined, the parabolic velocity at the same altitude is computed simply by multiplying the circular velocity by the square root of 2. This figure is useful for determining the additional velocity that must be imparted to a deep-space probe to launch it from an orbiting vehicle.

"What of orbits that are neither parabolas nor circles? Between these two limits lies the region of elliptical orbits [*see illustration on opposite page*]. An ellipse is a closed curve with two focal points. The center of gravitational attraction always lies at one of these two foci. When a satellite is on an elliptical orbit around its primary body, the point of closest approach is known as the 'peri-position.' In the case of the earth this point is called the 'perigee,' in the case of the sun the 'perihelion,' in the case of an unspecified star the 'periastron' and so on. At its peri-position the orbiting body is always traveling faster than the circular velocity but always traveling slower than the corresponding parabolic velocity.

"A line drawn through the two foci of

an ellipse so that it extends to the ellipse itself is known as the major axis of the ellipse. One-half of this length, extending from the center of the ellipse to either point of intersection with the curve, is called the semimajor axis, usually denoted by the letter *a;* the dimension is most useful for making orbital computations. Another important line can be drawn from the body that is in orbit to the center of its primary body. This line, which is called the radius vector, changes in length continuously if the orbit is an ellipse but remains constant in length if the orbit is a circle.

"The semimajor axis of an ellipse can be computed easily if the parabolic velocity, the peri-position velocity and the peri-position radius vector of the orbiting body are known. It is equal to half of the peri-position radius vector multiplied by the quotient of the square of the parabolic velocity divided by the difference between the square of the parabolic velocity minus the square of the velocity at the peri-position, as shown symbolically by the accompanying equation [*II on opposite page*], in which a stands for the semimajor axis, r for the peri-position radius vector, v for the velocity at the peri-position and v_p for the parabolic velocity at that altitude.

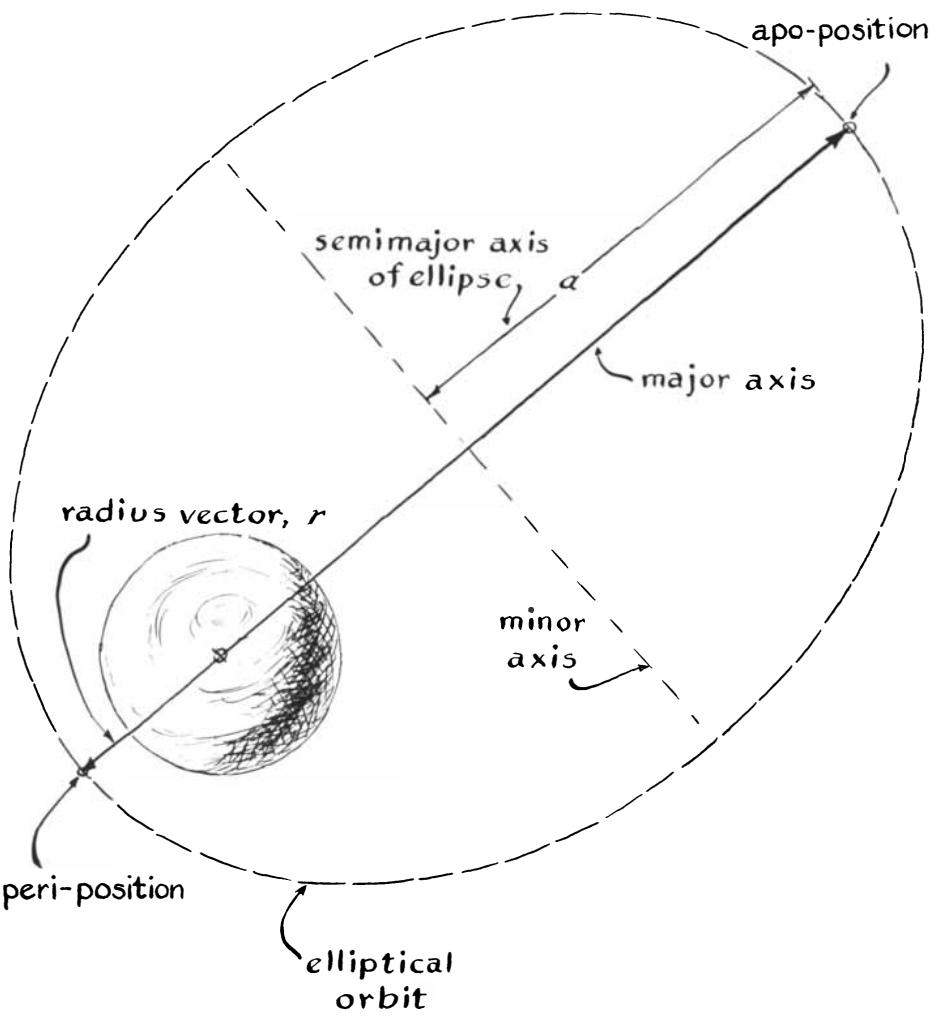
"For example, assume that a body is 400 miles above the surface of the earth at perigee and that its velocity at this point is 18,000 miles per hour. First determine the circular and parabolic velocities at a point 400 miles above the earth (h) using the procedures discussed above. The mean radius of the earth (R) is 3,958.8 miles. $R + h$ is therefore 4,358.8 miles. The parabolic velocity comes out to 23,932 miles per hour. Its square is numerically equal to approximately 572,740,000, and the square of 18,000 miles per hour is 324,000,000. Their difference is 248,740,000. Using formula II, the semimajor axis (a) is equal to $4{,}358.8/2 \times 572{,}740{,}000/248{,}740{,}000$, or 5,012, miles. Doubling this length gives the length of the major axis ($2a$) : $2 \times 5{,}012$, or 10,024, miles. The radius vector at apogee can now be found simply by subtracting the sum of the perigee radius vector plus the earth's radius, $R + h$, from the major axis: $10{,}024 - 3{,}958 + 400$, or 5,666, miles at apogee. The altitude of the satellite at apogee is then found by subtracting the earth's radius from the radius vector at apogee: $5{,}666 - 3{,}958.8$, or 1,707.2, miles.

"It was Johannes Kepler who first pointed out that the product of the velocity of an orbiting body and its radius vector is constant at the apo-point and peri-point of the orbit, which means that if three of these quantities are known, the fourth can be determined. Stated symbolically, $r_1 \times v_1 = r_2 \times v_2$, in which r_1 is the peri-radius vector, r_2 is the apo-radius vector and v_1 and v_2 are the respective velocities at these points. If the altitude of an earth satellite at perigee is 400 miles, and the velocity at this point is 18,000 miles per hour, and if its altitude at apogee is 1,707.2 miles, what is its velocity at apogee? As calculated above, the corresponding radius vector at perigee is 4,358.8 miles (earth's radius of $3{,}958.8 + 400$ miles) and the radius vector at apogee is 5,666 miles. Solving for the desired velocity at apogee is a simple matter of proportion: $r_1 \times v_1/r_2 = v_2$ or, expressed numerically, $18{,}000 \times 4{,}358.8/5{,}666$, or 13,847, miles per hour.

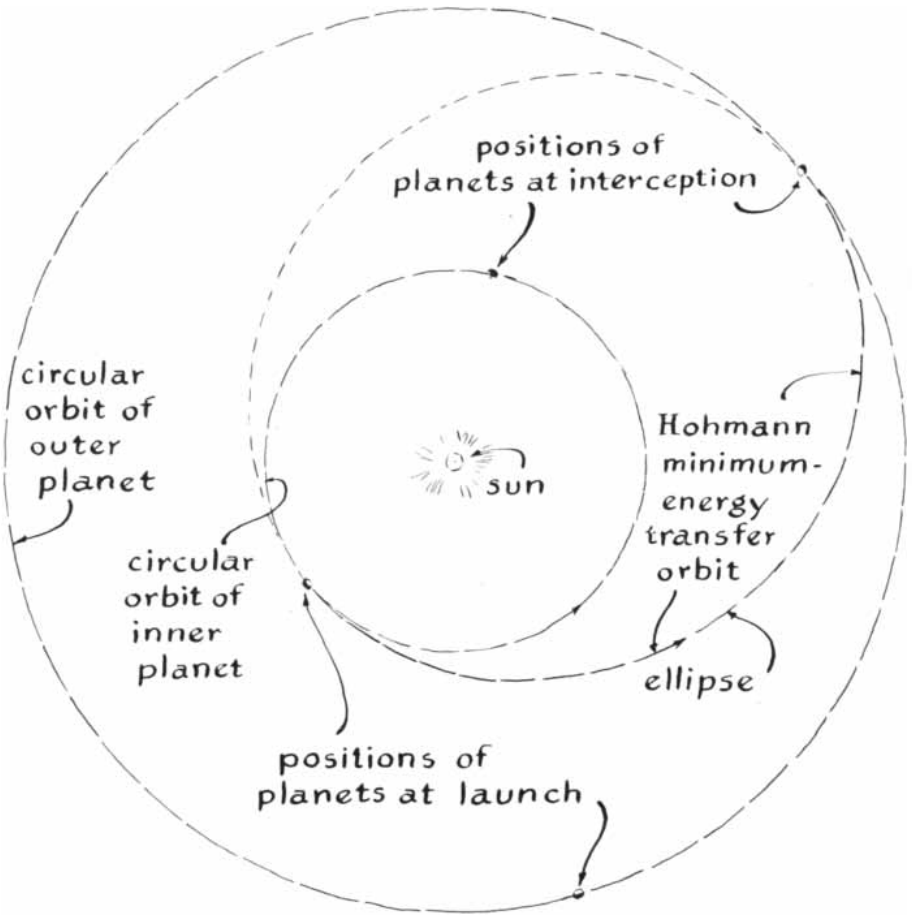
"These formulas are useful for solving other interesting problems. For example, if a body is on an elliptical orbit at an altitude of r miles at apogee and has a velocity of y miles per hour at this point, how much additional velocity must it acquire in order to leave the primary body? The answer is found by computing the parabolic velocity at r miles and subtracting the velocity at apogee.

"At what altitude does 18,000 miles per hour become the parabolic velocity of an earth satellite? To find the answer divide 18,000 by the square root of 2. This gives the circular velocity. Insert the circular velocity in the equation for circular velocity. R, v_c and v_{cs} are known but $R + h$ is unknown. To find h multiply the square of v_{cs} by R, divide the product by the square of v_c and subtract R, as indicated symbolically by the accompanying formula [*III on opposite page*].

"The same general formulas work in the case of interplanetary orbits, but for convenience distance is measured in terms of astronomical units (A.U.) instead of miles. Astronomers selected the average distance between the earth and the sun, some 93,000,000 miles, as the length of the astronomical unit. As an illustration of its use, consider the case of the planet Mercury. Mercury is about 3.6×10^7 miles from the sun, whereas



Elements of an elliptical orbit



The Hohmann orbit

the earth is about 9.3×10^7 miles from it. To put the matter another way, Mercury is 3.6/9.3, or 39 percent, of the earth's distance from the sun. Astronomers state that Mercury is .39 A.U. from the sun.

"With this unit in mind we can proceed to problems that involve 'minimum energy' probes. The term refers to the path a probe must follow if it is to consume the minimum amount of fuel. Suppose an orbiting earth satellite is to be sent to another planet, such as Venus or Mars. How much must its elliptical orbit be enlarged? How many days will the flight require? What must the spacecraft's velocity be?

"The German engineer Walter Hohmann proved in 1925 that minimum energy is required to transfer a body from one planet to another if it traverses an elliptical path that is tangent to the natural orbits of both the primary planet and the distant planet [*see illustration above*]. A path of this kind is known as a Hohmann trajectory. The Hohmann trajectory is characterized by a disadvantage: it entails the slowest trip between the primary planet and the target. With present rocket fuels and engines, however, economy of fuel is more important than shortening the time of flight.

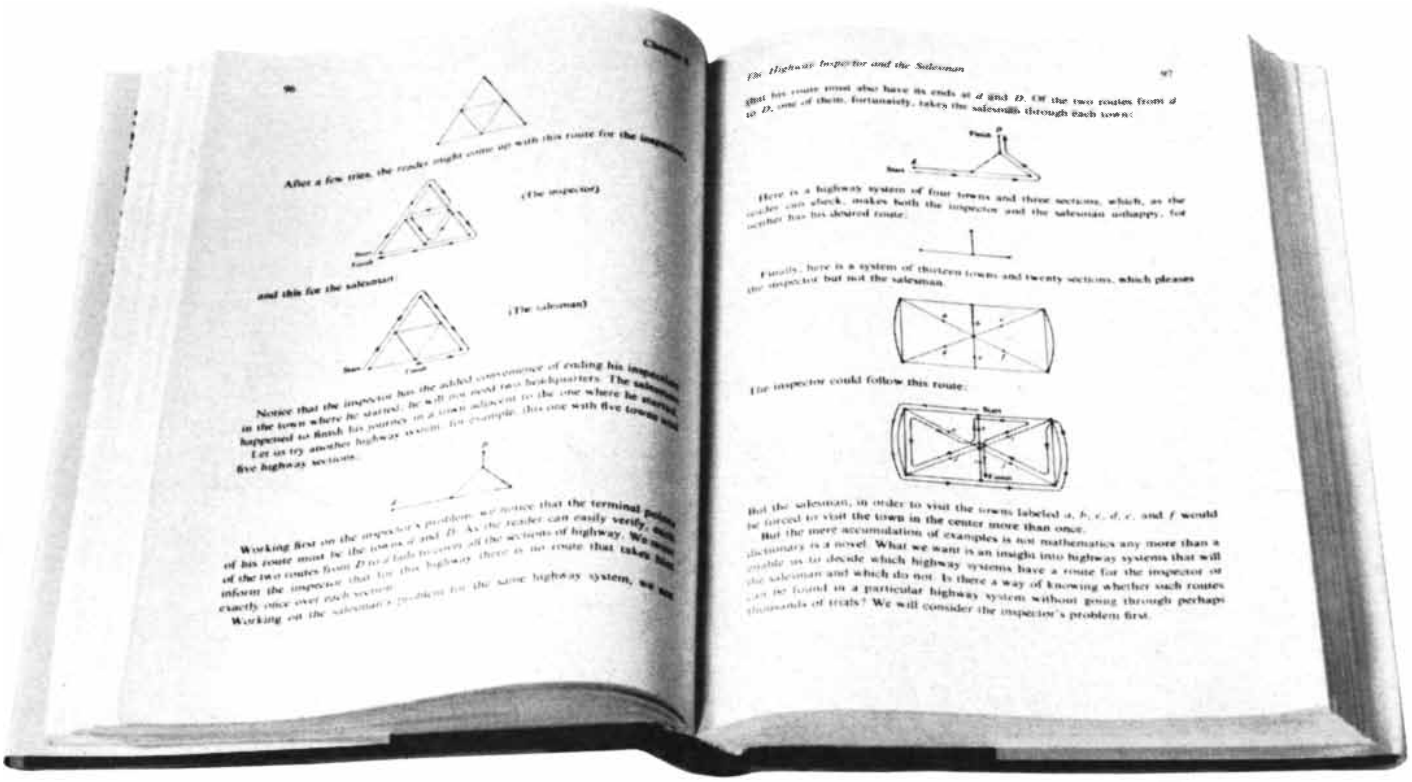
"How much time will a space probe require to travel from the earth to, say, Mars if it follows a Hohmann trajectory? First, the semimajor axis of the Hohmann ellipse must be determined. As mentioned above, the sum of the peri-radius and apo-radius vectors is equal to the major axis of the ellipse. The distance of the sun from Mars is 1.524 A.U. and from the earth 1 A.U. The major axis of the Hohmann ellipse that is tangent to the orbits of earth and Mars is therefore 2.524 A.U. The semimajor axis is 2.524/2, or 1.262, A.U.

"The time of travel can now be computed by calling on Kepler's third law, which states that the ratio of the cube of the semimajor axis of an orbit to the square of the orbital period is constant for all bodies with respect to the primary body. If a represents the semimajor axis of the Hohmann ellipse and T represents the period (the time of a single rotation), then Kepler's third law can be restated in this form: $a^3 = T^2$, or $T = a^{3/2}$. Substitute the numerical value of the semimajor axis into the equation: $T = 1.262^{3/2}$. The probe will travel over only half of the Hohmann ellipse to reach Mars. Therefore we divide by 2: $1.262^{3/2}/2$, or .70908, earth-year. Convert this to days: 365 (days per year) $\times$ .70908, or 258.81, days. In other words, if the probe were launched from the earth on March 4, it would reach Mars 258 days later, on October 17. Strictly speaking, there is no set time of flight between any two orbits, nor is it correct to say that it takes 258 days to go from the earth to Mars unless you specify that the flight follow the Hohmann trajectory. Flight time can be reduced by following a faster orbit, but at the cost of precious fuel.

"The satellite formulas are equally useful for determining the orbits of bodies around the sun. Up to this point 'radius' has been taken to mean the distance between the center and the surface of a body such as the earth. We give it a new meaning for determining orbits around the sun. The change is based on an observation by Isaac Newton that gravitation acts as though all the mass of a primary body were concentrated at the center of the body [*see illustration on page 128*]. The assumption is valid if we do not penetrate the surface of the body. Therefore we can imagine a body in the form of a vast shell around the sun, a shell equal in radius to that of the planetary orbit under consideration.

"For a satellite that orbits the sun at a radius of 1 A.U. from the sun the procedure for determining the circular velocity at this radius demonstrates that the velocity is 18.5 miles per second, which is approximately the earth's velocity. Another example: What is the circular velocity of a body in the same orbit as Jupiter, which is 5.203 A.U. from the sun? Substituting numerical values in the equation for circular velocity: $v_c = 18.5/(5.203/1)^{1/2} = 18.5/5.203^{1/2}$, or 8.07, miles per second.

"Finally, there are problems of this type: How much velocity must be added to a space probe orbiting the sun in a circular path at the distance of 1 A.U. for the probe to reach Mars by a Hohmann trajectory? If we call the velocity of the probe at perihelion v_t, we can state that $v_t = v_{cs} + v_a$, where v_a is the velocity that must be added to the circular velocity (v_{cs}) at 1 A.U. If v_t and v_{cs} are known, v_a can be found by simple subtraction: $v_a = v_t - v_{cs}$. We know how to find the circular velocity, v_{cs}, but how do we find v_t? It is equal to the square root of the square of the parabolic velocity multiplied by 1 minus the radius divided by the major axis of the ellipse. The relation is expressed in algebraic notation by the accompanying for-



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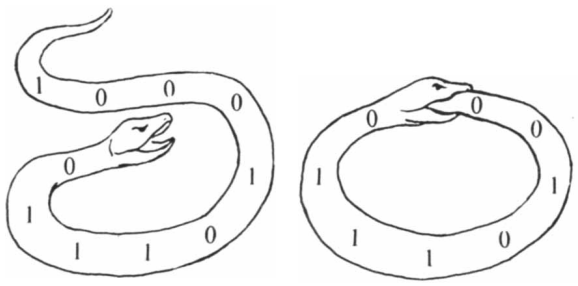

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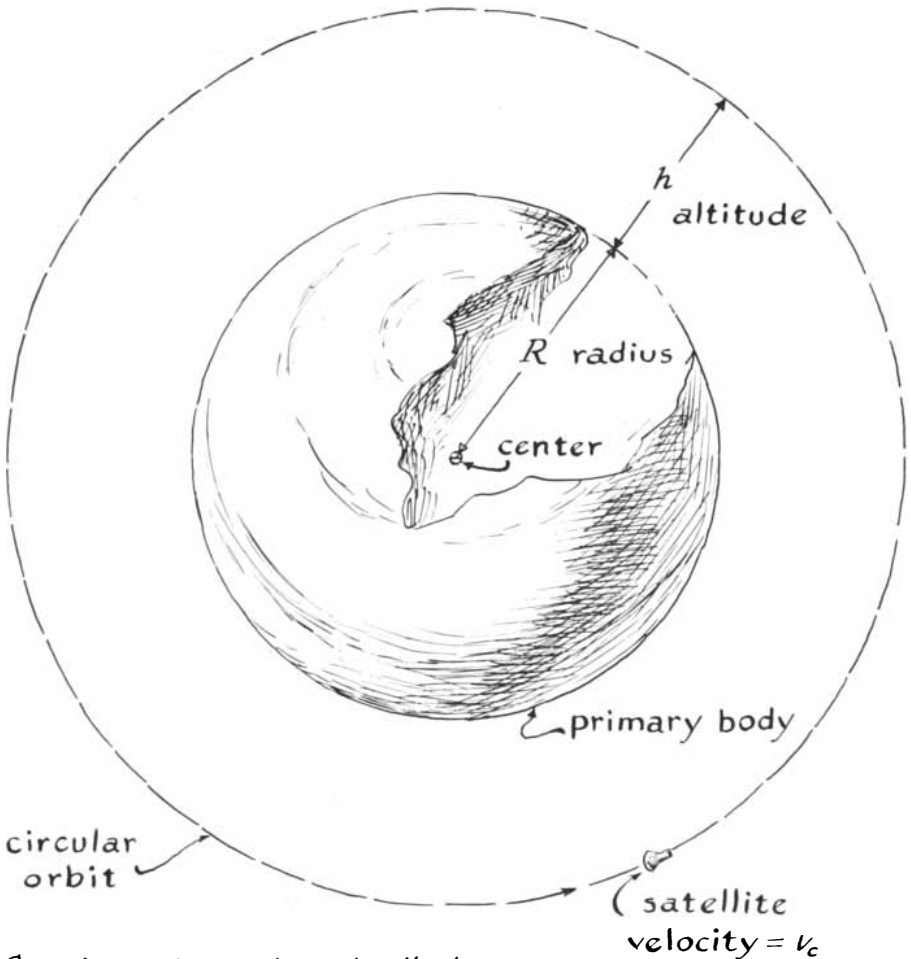
mula [*IV on page 124*], in which v_p represents the parabolic velocity, r the radius and $2a$ the major axis.

"Assume that a space probe is ready to be launched from the earth. Being on the earth, it is already orbiting the sun at the velocity of the earth. How much velocity must it have after escaping the earth to send it to Mars? The major axis of the Hohmann ellipse, represented by $2a$, is equal to the sum of the radii of the orbits of the earth and Mars. The parabolic velocity can be determined by multiplying the circular velocity (18.5 miles per second) by the square root of 2. The radius r is unity (1 A.U.), so that $v_t = (26.16^2 \times (1 - 1/2.524))^{1/2} = (684.5 \times (1 - 1/2.524))^{1/2}$, or 20.33, miles per second, which is the velocity of the probe at perihelion after it takes off from the earth. The added velocity that must be imparted to the probe for it to reach Mars is the difference between v_p and v_{cs}, or 20.33 − 18.50, or 1.83, miles per second. To solve problems of this kind for probes departing from planets other than the earth just substitute for the radius of the earth's orbit the orbital radius in A.U.'s of the other planet.

"As a practical consideration we must work with existing fuels and rocket engines and follow the Hohmann ellipse. If we had vehicles capable of acquiring any desired velocity, the computation of orbits would become far more complex. An infinite number of curves, from circles to hyperbolas, can be drawn between any two points. Only the Hohmann ellipse is mutually tangent to the primary and target orbits, and of course probes must describe either circular or elliptical orbits around their primary body or they cannot be satellite orbits. For this reason the procedure I have described is limited to the determination of only a few of the many theoretically possible orbits. Even so, it can serve as an introduction to the fascinating business of space navigation and can provide the novice with a starting point from which he will be able to proceed as far as he wants to go."



Gravitational behavior of a body in space

THE DANCE OF THE SOLIDS

by John Updike

EDITOR'S NOTE: These verses were composed after the writer had read the issue of SCIENTIFIC AMERICAN (September, 1967) devoted to materials. They appear in his forthcoming book *Midpoint and Other Poems,* and are reproduced with the generous permission of Alfred A. Knopf, Inc.

ARGUMENT: *In stanzas associated with allegory the actual atomic structure of solids unfolds. Metals, Ceramics and Polymers. The conduction of heat, electricity and light through solids. Solidity emerges as being intricate, giddy, playful.*

All things are Atoms: Earth and Water, Air
And Fire, all, *Democritus* foretold.
Swiss *Paracelsus,* in's alchemic lair,
Saw Sulfur, Salt, and Mercury unfold
Amid Millennial hopes of faking Gold.
Lavoisier dethroned Phlogiston; then
Molecular Analysis made bold
Forays into the gases: Hydrogen
Stood naked in the dazzled sight of Learned Men.

The Solid State, however, kept its grains
Of Microstructure coarsely veiled until
X-ray diffraction pierced the Crystal Planes
That roofed the giddy Dance, the taut Quadrille
Where Silicon and Carbon Atoms will
Link Valencies, four-figured, hand in hand
With common Ions and Rare Earths to fill
The lattices of Matter, Glass or Sand,
With tiny Excitations, quantitively grand.

The *Metals,* lustrous Monarchs of the Cave,
Are ductile and conductive and opaque
Because each Atom generously gave
Its own Electrons to a mutual Stake,
A Pool that acts as Bond. The Ions take
The stacking shape of Spheres, and slip and flow
When pressed or dented; thusly *Metals* make
A better Paper Clip than a Window,
Are vulnerable to Shear, and, heated, brightly glow.

Ceramic, muddy Queen of human Arts,
First served as simple Stone. Feldspar supplied
Crude Clay; and Rubies, Porcelain, and Quartz
Came each to light. Aluminum Oxide
Is typical—a Metal is allied
With Oxygen ionically; no free
Electrons form a lubricating tide,
Hence, Empresslike, *Ceramics* tend to be
Resistant, porous, brittle, and refractory.

Prince *Glass, Ceramic*'s son, though crystal-clear,
Is no wise crystalline. The fond Voyeur
And Narcissist alike devoutly peer
Into Disorder, the Disorderer
Being Covalent Bondings that prefer
Prolonged Viscosity and spread loose nets
Photons slip through. The average *Polymer*
Enjoys a Glassy state, but cools, forgets
To slump, and clouds in closely patterned Minuets.

The *Polymers*, those giant Molecules,
Like Starch and Polyoxymethylene,
Flesh out, as protein serfs and plastic fools,
The Kingdom with Life's Stuff. Our time has seen
The synthesis of Polyisoprene
And many cross-linked Helixes unknown
To *Robert Hooke;* but each primordial Bean
Knew Cellulose by heart: *Nature* alone
Of Collagen and Apatite compounded Bone.

Textbooks and Heaven only are Ideal;
Solidity is an imperfect state.
Within the cracked and dislocated Real
Nonstoichiometric crystals dominate.
Stray Atoms sully and precipitate;
Strange holes, *excitons*, wander loose; because
Of Dangling Bonds, a chemical Substrate
Corrodes and catalyzes—surface Flaws
Help Epitaxial Growth to fix adsorptive claws.

What happens in these Lattices when *Heat*
Transports Vibrations through a solid mass?
$T = 3Nk$ is much too neat;
A rigid Crystal's not a fluid Gas.
Debye in 1912 proposed Elas-
Tic Waves called *phonons* which obey *Max Planck*'s
Great Quantum Law. Although amorphous Glass,
Umklapp Switchbacks, and Isotopes play pranks
Upon his Formulae, *Debye* deserves warm Thanks.

White Sunlight, *Newton* saw, is not so pure;
A Spectrum bared the Rainbow to his view.
Each Element absorbs its signature:
Go add a negative Electron to
Potassium Chloride; it turns deep blue,
As Chromium incarnadines Sapphire.
Wavelengths, absorbed, are reëmitted through
Fluorescence, Phosphorescence, and the higher
Intensities that deadly *Laser Beams* require.

Electroconductivity depends
On Free Electrons: in Germanium
A touch of Arsenic liberates; in blends
Like Nickel Oxide, *Ohms* thwart Current. From
Pure Copper threads to wads of Chewing Gum
Resistance varies hugely. Cold and Light
As well as "doping" modify the sum
Of *Fermi* Levels, Ion scatter, site
Proximity, and other factors recondite.

Magnetic Atoms, such as Iron, keep
Unpaired Electrons in their middle shell,
Each one a spinning Magnet that would leap
The *Bloch* Walls whereat antiparallel
Domains converge. Diffuse Material
Becomes *Magnetic* when another Field
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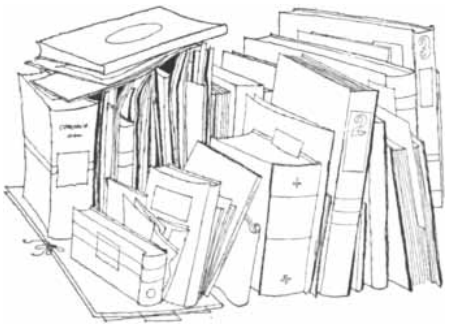

BOOKS

A collection of shorter reviews

by Philip Morrison

SPARE-PART SURGERY: THE SURGICAL PRACTICE OF THE FUTURE, by Donald Longmore. Edited and illustrated by M. Ross-Macdonald. Doubleday & Company, Inc. ($5.95). Intelligent, opinionated, blunt, a London research surgeon treats this headline topic in graphic style with plenty of diagrams and color photographs. Somehow his preface is indexed but not printed; it must have been held libelous! He begins: "Anybody old enough to understand this book is already degenerating fast." We die because of the failure of some weakest part—a kind of selective aging. Until we know the cure for all these little deaths our best attack is to replace the part. No mechanical device is likely to solve the problem; even if the marvelously compact, efficient and complex natural organ finds an acceptable and compatible substitute made of such things as nylon and transistors, the cost of the device will beat it. At the same cost a surgical team can install the biologically evolved product from a donor, and there are no charges for development, upkeep and failure. (The potential donors will be organized by the millions on a worldwide basis.) A genuinely useful artificial heart is so far a challenge well beyond our engineers, Longmore says, but even if it is made someday, it will surely cost several thousand dollars—a price people will not want to pay once they realize that "every day we inter or cremate a better 'product' by the thousand."

There is one barrier: the immune system of the body, which seeks to destroy foreign protein. How this system works we know in part; the first chapter is a good account of the old template theory and how it failed, to be replaced by the present remarkable view of mutation and selection. The understanding and management of the immune reaction is one medical prize in the future of molecular biology; meanwhile there are many partial solutions, from typing tissue for minimum reaction to temporary destruction of the immune system itself by drugs and radiation. More such measures will come; on that hope Longmore rests his view of the future.

We can do open-heart operations and kidney replacement by fitting patients into complex machines. Artificial limbs with closed-loop powered action, controlled by muscle or even by nerve impulses, are widely available, if not quite routine. Simple grafts—blood, bone, cornea, artery, heart valve—are workably done today. Longmore's account of living bone is exciting. Bone looks inert, and "certain technicians masquerading as surgeons" treated it that way. Here one can see the X ray of a virtuoso display of bone carpentry with 18 screws and two plates that destroyed more bone than the original fracture and left the patient with three years of healing and five subsequent fractures.

Not everyone will agree with this book, but it is one of the best pieces of fresh thought to be found in medical writing. One series of graphs is particularly striking: it shows the microscopic surface profile of smooth-walled plastic tubing. The lines are jagged. On the same scale the interior surface of an artery is "an almost perfect straight line." Turbulence and roughness destroy the cells of flowing blood, and we recall that blood is no simple liquid but a very special juice.

TROPICAL CROPS: DICOTYLEDONS, by J. W. Purseglove. John Wiley & Sons, Inc. ($17). Clear and attractive full-page line drawings, made mostly from the living plant by Patricia Lalla and Marjorie Wong, accompany each of about 100 entries in this two-volume work. Every entry describes a crop plant of the Tropics, beginning with its uses and extending to its botany and natural history, its husbandry, its genetic improvement, its chemical composition, its pests and diseases, and a summary of modern world trade. In an introductory chapter, and again in detail for each crop, Professor Purseglove explains the origin and spread of man's use of the plants with an easy scholarship and in a judicious way. "I am convinced," he writes, "that there was no movement of crops by man between the Old and the New World in pre-Columbian times." The only crops known to have been grown in both the New World and the Old before 1492 are the common gourd, the coconut, the kapok tree and the sweet potato. All four, and with them the cotton plant (which was found cultivated as two related but not identical species in the two hemispheres), were transported by accidental drifting across the sea without the aid of any ancient voyagers or "Pacific regattas." The case is a strong one; it rests on the haphazard nature of the transmission, some 1,800 useful crop species' *not* having been transmitted, and on the experimental verification of the viability of such seaborne materials. Gourd, coconut and kapok are almost obvious candidates for gifts from the sea.

Some minor crops, such as the perfume ingredient ylang-ylang from Réunion Island, receive only a paragraph; others, such as coffee, quite properly spread over 40 pages. The whole thing is a fascination; no up-to-date work like it exists; the classical compendiums of tropical products, for example the famous six-volume dictionary of the economic products of India by G. Watt, are older than this century.

A random dip turns up the story of hemp, the same plant yielding both the fiber once unrivaled for rope and the narcotic leaves smoked as marijuana. The Russians produce the most hemp, but they cannot travel far on their crop: the "active principle is a resin from the glandular hairs on the leaves.... Little resin is produced... in temperate countries and hotter conditions are required." The source of the bitter antibiotic flavoring of beer, the European hop, is a close relative of hemp. The largest market for Zanzibar cloves is Indonesia, where for 50 years there has been widespread use of clove cigarettes—two parts tobacco to one part clove.

It is not clear that tomato, eggplant and tobacco ought to have received detailed treatment whereas the custard ap-

ple, soursop and grain amaranth are dismissed with a few sentences. There is a tension in a reference work between economic importance and the uniqueness of the entry. The balance here is nonetheless excellent overall. The author has been a responsible agriculturist and scientist in Uganda, Singapore and Trinidad, where he is now professor; this unusually wide tropical experience is our gain. One awaits his completion of the work to treat the tropical monocotyledons, which include the marvelous banana, the palms, the yam and all the tropical grains.

HALDANE AND MODERN BIOLOGY, edited by K. R. Dronamraju. The Johns Hopkins Press ($10.95). "My brother took to making his own bombs ... going out ... along ... old waterlogged trenches ... lobbing in his bomb and watching the resultant shower of enemy arms and legs. He became immersed in this savage life.... Half a century later when I watched him letting a horsefly suck from his hand while he watched her beautiful eyes, I asked him whether *this* had anything to do with *that*. He disclaimed it so fiercely it may have been true.... Most of the officers of the Third Battalion of the Black Watch were killed; the only reason he escaped was that my father asked for him to help in his work ... countering the gas attacks.... I wonder how many now know the Black Watch songs.... He knew them all."

Thus writes the sister of J. B. S. Haldane, catching in a few lines what can be called the essence of this extraordinary man, committed in all he undertook, a grenadier and a Jainist, an aristocrat and a Communist, a man of prodigious and well-stocked memory gifted with a mind of unexcelled originality and daring. The essays here by two dozen scientists range over his life's work. In genetics his was one of the three paths from Darwin to a quantitative theory of the evolution of populations. He was an adroit and fearless critic and a man unafraid of speculation, which he generally graced with sound ideas a decade ahead of their time. He wrote on the origins of life "for 35 years and put forward at least one novel idea in every article." For a long time he was the best-trained biologist who was aware of and at home with the latest developments in physics, and he brought them to bear on biology. Some famous fancies of science fiction, such as the moons of Mars being artificial satellites, and the possibility of life animating an object as great as a star, were first published by Haldane. He saw that one gene stands for one enzyme as early as 1920; he wrote of the importance of disease resistance in natural selection long before the sickle-cell story was known. He experimented on himself, in the tradition of his physiologist father, in connection with submarine safety during World War II. He experienced oxygen narcosis, and he published a letter on the taste of nitrogen and of oxygen—tastes that emerge at high enough concentrations.

The contributors cover the world, from Stanford to Moscow and Calcutta; they include such distinguished personages as Joshua Lederberg, A. I. Oparin, Sewall Wright and Joseph Needham. Each article comments on some facet of Haldane's work and life, usually emphasizing the present state of the particular point at issue.

He went from Britain at 65 "to a one-storied ivory tower provided for me by the Government of Orissa in this earthly paradise of Bhubaneswar." There he lived fully in the Indian manner and attracted a school of young Indian biologists of great promise, a school he had never quite been able to nucleate in Britain. He died a few years later in London of a rectal carcinoma, reflective and joyous even during the final struggle with death. His famous poem on his fatal cancer is not reproduced, although it is alluded to. No scientist of our time has had so varied, complex and stormy a personal history, none so rich a pilgrimage through life.

MEN AND DINOSAURS: THE SEARCH IN FIELD AND LABORATORY, by Edwin H. Colbert. E. P. Dutton & Co., Inc. ($8.95). "England was ... a land still largely rural.... There were not even railroads. And there were no dinosaurs." Dr. Colbert, a distinguished paleontologist and a graceful writer, makes plain and personal the narrative of how dinosaurs became part of the modern world. So they are; the paleontologists of Ulan Bator today scour their deserts in heavy trucks where less than 50 years ago the Mongol shepherds watched without understanding as Roy Chapman Andrews drove down the long dry washes seeking those fossil dinosaur eggs.

Giant bones were found often enough long ago, but it was William Buckland, Oxford's first professor of geology, and his colleagues who recognized in the 1820's that a pelvis, jawbone and femur from an English slate quarry were a clear demonstration of an extinct lizard 40 feet long. Thus did the dragon become real; by the middle of the 19th century Richard Owen had named and defined the order, and full-sized restorations in concrete hunched on the grounds of the Crystal Palace exhibition at Sydenham.

America was a treasury of dinosaurs. Edward B. Hitchcock, president of Amherst College, made a lifework of collecting scaly tracks from the sandstones of the Connecticut River valley; he lovingly described them, never learning that it was not great birds but birdlike dinosaurs that had made those huge footprints. The badlands of the West knew not only Custer and the Sioux but also the war parties of Edward Drinker Cope of the Philadelphia Academy of Natural Sciences and of Othniel C. Marsh of Yale, bitter paleontological rivals whose paramilitary forays gave us complete skeletons. The dinosaurs began to come alive. "Is it not marvelous that I, so young a man, have written such an excellent memoir?" asked Franz, Baron Nopsca, a young Hungarian student on a visit to the great Brussels professor Louis Dollo. Nopsca was the most eccentric of scholars, a man who planned a filibustering expedition to Albania, served in World War I as a spy and ended as a suicide following his mercifully meant murder of his lifelong secretary and homosexual lover. Vertebrate paleontology is not as square as it might seem.

Backed by Carnegie and Morgan, the American searches of the next period made the dazzling mass dinosaur finds in Utah and Colorado; one *Diplodocus* skeleton "as big as a barn" was cast over and over in plaster, and the costly replicas were given to museums around the world. Dinosaurs have now been found almost from pole to pole. The most recent decades of the hunt extended their range to the Southern Hemisphere. One of the most evocative of the splendid photographs in the book shows Dr. Werner Janensch of Berlin just before World War I, standing tall in his topee and holding the silver-headed staff of authority over the leg bone of his Tanganyikan find, along which crouch deferentially seven half-clad Africans who were among his diggers. The picture is a microcosm of colonialism.

DEEP-SEA PHOTOGRAPHY, edited by John Brackett Hersey. The Johns Hopkins Press ($17.50). We have all seen the moon now in close-up, near side and far; here is a compendium of expert chapters on the photography of the bottom of the sea, a region perpetually dark and unknown although close at hand. The contributors are mainly American, but there is a representation of British and French practice and a single-page review of cameras and experience from

Timely and important

René Dubos
SO HUMAN AN ANIMAL

In this timely and eloquent book, one of the world's most important biologists warns that each of us faces the critical danger of losing his "humanness" to mechanized surroundings of "noise, dirt, ugliness, and absurdity." Yet he affirms that we *can* reverse our present suicidal course by learning to deal scientifically with the *real* needs of man—by supplementing our knowledge of the physical world with "a science of human life." "...likely to have an impact on society similar to or greater than, Rachel Carson's *Silent Spring* or John Kenneth Galbraith's *The New Industrial State*."—Helmut K. Buechner, *Natural History*. Reference Notes. Index. $6.95

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Acclaimed as "a masterly and important book" by *The New York Times Book Review*, *The Big Machine* is an account of the remarkable proton-synchrotron (atom smasher) at Meyrin outside Geneva, Switzerland, headquarters of CERN. The author of the best-selling *Brighter Than a Thousand Suns* describes the international laboratory surrounding this "big machine," and the dedicated efforts of the more than 2,000 people who work in day and night shifts at a yearly cost of $50,000,000. He also gives a fascinating view of scientific research in corresponding laboratories for high energy physics in the United States and the Soviet Union. Photographs. Bibliography. Index. $6.95

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a Russian designer who speaks of the need for simplicity, durability and convenience, summing up convincingly with: "Our camera is so strong that with it one may, at will, hammer nails without injuring it."

The prehistory of this technology goes back to the deep dives of the 1920's; the history begins just on the eve of World War II. Today long rolls of small-sized film (mostly black-and-white) can be exposed at any bottom depth, the cameras safe in strong Duralumin or stainless-steel cases fitted with Plexiglas windows and O-ring seals. The light is electronic flash or sometimes electrical floodlighting; most of the work is done with the equipment dangling at the end of miles of cable, although some free-floating devices have been tried. Color photographs are rare, because they are not rewarding in a region that is mainly gray with a few red-shelled beasts; the photographs reproduced here in color seem much more blue-green than the nearby light would require. Stereoscopic pairs are much used; strip mapping has been done by slow, controlled towing, and detailed photogrammetry to good precision has been started. The bottom is shown at a distance of a foot or of tens of meters, the trigger usually being an echo from the bottom or a simple tripping weight. Dredges and sleds to ride the ocean floor have been used, and also a tripod that sits on the bottom and holds a downward-looking camera that photographs the drift of immiscible red drops emitted from a syringe; this is done to measure very slow currents.

It is thrilling to see the famous manganese nodules strewn over the red clay at the bottom of the Pacific, six kilometers down. Perhaps even more exciting are the sea-bottom fauna, fishy and familiar on the shelves and slopes down to two or three kilometers but in the true depths strange and spiny and leaving even stranger tracks. There is a detailed list of data about all the photographs, and a stereoscopic viewer is folded into a pocket of this well-made book. One can view in 3-D the summit of a seamount, the crest of a mid-ocean ridge and the two-ton anchor of the lost *Thresher*.

LANDMARKS OF MAPMAKING: AN ILLUSTRATED SURVEY OF MAPS AND MAPMAKERS. Maps chosen and displayed by R. V. Tooley, text by Charles Bricker. New York Graphic Society ($32.50). A splendid example of the craft and art of bookmaking in the Netherlands today, this volume presents, in a setting of intelligent and richly illustrated historical text, about 15 large gatefold facsimile photolithographs of famous old maps—something for each continent. The majority of the maps are from Tooley's collection; the rest are from the archives of the very Amsterdam firm that published the works of Galileo and that conceived, designed and executed this book, or from the University of Amsterdam library.

A wonderful Italy of 1482, with its chocolate mountain ranges set in a rich blue sea, a West Africa by Hondius in 1606, a "New and Exact Map of all New Netherland" reworked by Allard in 1673 to celebrate the retaking of New York from the English and a 1670 East Indies published in London from retitled Dutch plates can stand as samples of what is here. In convincing color the big plates serve well to illuminate the growth of the enlightenment of Europe, as her cartography passed from classical tradition and medieval fancy to the perfected utilitarian source of power it became. Any well-heeled reader and many a library will find this volume better than any other single one to celebrate the rise of Western map making. The colored facsimile atlases of the 16th and 17th centuries now appearing from the same Dutch firm in its "Landmarks of Early Cartography" series are possible alternatives, deeper but dearer and less varied.

PLANETARY ASTRONOMY: AN APPRAISAL OF GROUND-BASED OPPORTUNITIES, by the Panel on Planetary Astronomy, Space Science Board. National Academy of Sciences ($3.50). This little brochure is handsome and is good reading. The solar system remains our home; its origin and nature are major problems for science. Yet no big telescope devotes more than 30 percent of its observing time to these problems (Palomar only 3 percent), and in the U.S. about 15 Ph.D.'s per year are granted in the field. On the other hand, the space program employs thousands of engineers and technicians in the development and launching of spacecraft to amass data for planetary science. To be sure, most of the research workers enter the field through other channels, but the balance nonetheless seems tipped. The report surveys the state of the field topically: motions, surfaces, atmospheres, interiors, techniques. There is a good deal we do not understand, from the Great Red Spot of Jupiter to the blue haze and seasonal darkening of Mars. The panel would like to see a first-rate 60-inch telescope for planetary work (in a southern location with exceptional seeing, as in Chile), a 10-foot light-collecting mirror

of modest accuracy (mainly for the infrared), big new radar antennas and a worldwide photographic patrol to watch the planets during the next five or six years. Mars will be closer in August, 1971, than in any year before 2000.

The pamphlet lacks an index, and it is unreasonably costly. The Academy owes its expert panels better publication.

SCIENCE FOR THE AIRPLANE PASSENGER, by Elizabeth A. Wood. Illustrated with photographs and with drawings by Frank M. Thayer. Houghton Mifflin Company ($4.95). The jacket carries a subtitle: How to Make Looking out the Window More Fun than Watching the Movie. Most of the time, cloud cover and movie directors being what they are, this high goal is reached. From takeoff (when you can watch the plane leave its shadow on a sunny day, and feel the forward thrust of your seat and the pressure differential between middle ear and cabin) to landing (when you might check the flight angle or notice the artful design of the control-tower windowpanes) Dr. Wood is a perceptive and clear-spoken guide. Much of what you can do involves the earth below; the shapes of standing water, the struggles that made the coastline and the distribution of population so beautifully displayed by the pattern of lights below on a clear night are only a few of the topics she explains. Clouds are often the medium of flight; a handsome photograph shows a layer of cumulus from above, from below and from within, and there is a good account of clouds and condensation trails. No one is likely to be convinced by the simplified account of adiabatic heating diagrammed here; that is all to the good, because it is almost entirely wrong. No matter, the book is generally authoritative, although never authoritarian, and mistakes seem as natural as they are infrequent.

There is quantity here too: a fine protractor right on the cover, with an account of how to measure your acceleration with it, a piece of string and a calibration curve. Heights, distances, speeds—all are open to the knowing passenger using a watch, a little arithmetic and more thought. Why power lines turn sharp corners, not sweeping ones, and how airplane windows cloud up and clear again are only two of a host of good engineering points that become visible from the air. The naturalist's knowledge is also present; the passings and returnings of the woodland creatures show up after a light snow. This book is a fine gift for a first flier or a frequent one.

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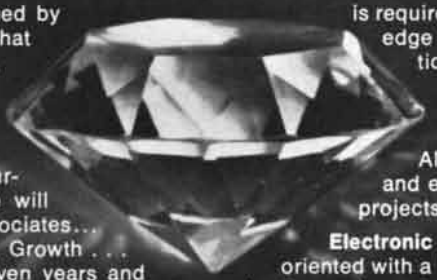

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Electronic Engineer (Senior) Should be digital oriented with a knowledge and understanding of production equipment. BSEE required with mechanical engineering experience desired.

Recording Specialist Engineer Requires degree in Physics or Electrical Engineering and at least 2 years' magnetic recording experience. Duties include developing new and improved test methods, and defining equipment requirements and generate operation procedures for new tests. Also, will perform analysis of a highly technical nature, involving test instrumentation performance and validity of test results.

Project Engineer Challenging and rewarding opportunity for an individual with a degree in Engineering. Requires 3–5 years' experience in systems and circuit design with emphasis on analog circuits. Previous supervisory experience desired. You will work in the circuit design of process and test equipment in magnetic tape manufacturing. Previous magnetic experience is not necessary.

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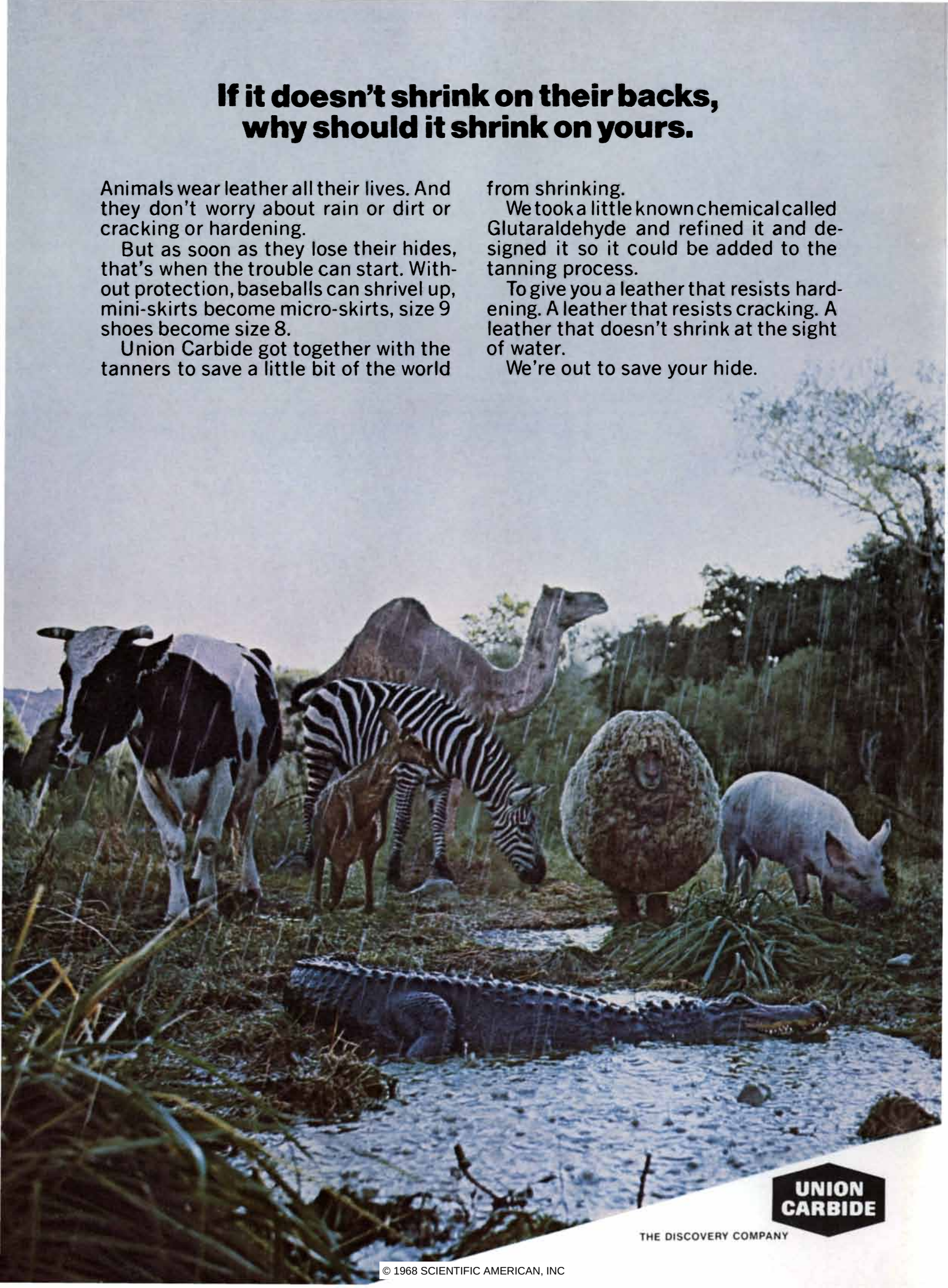

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