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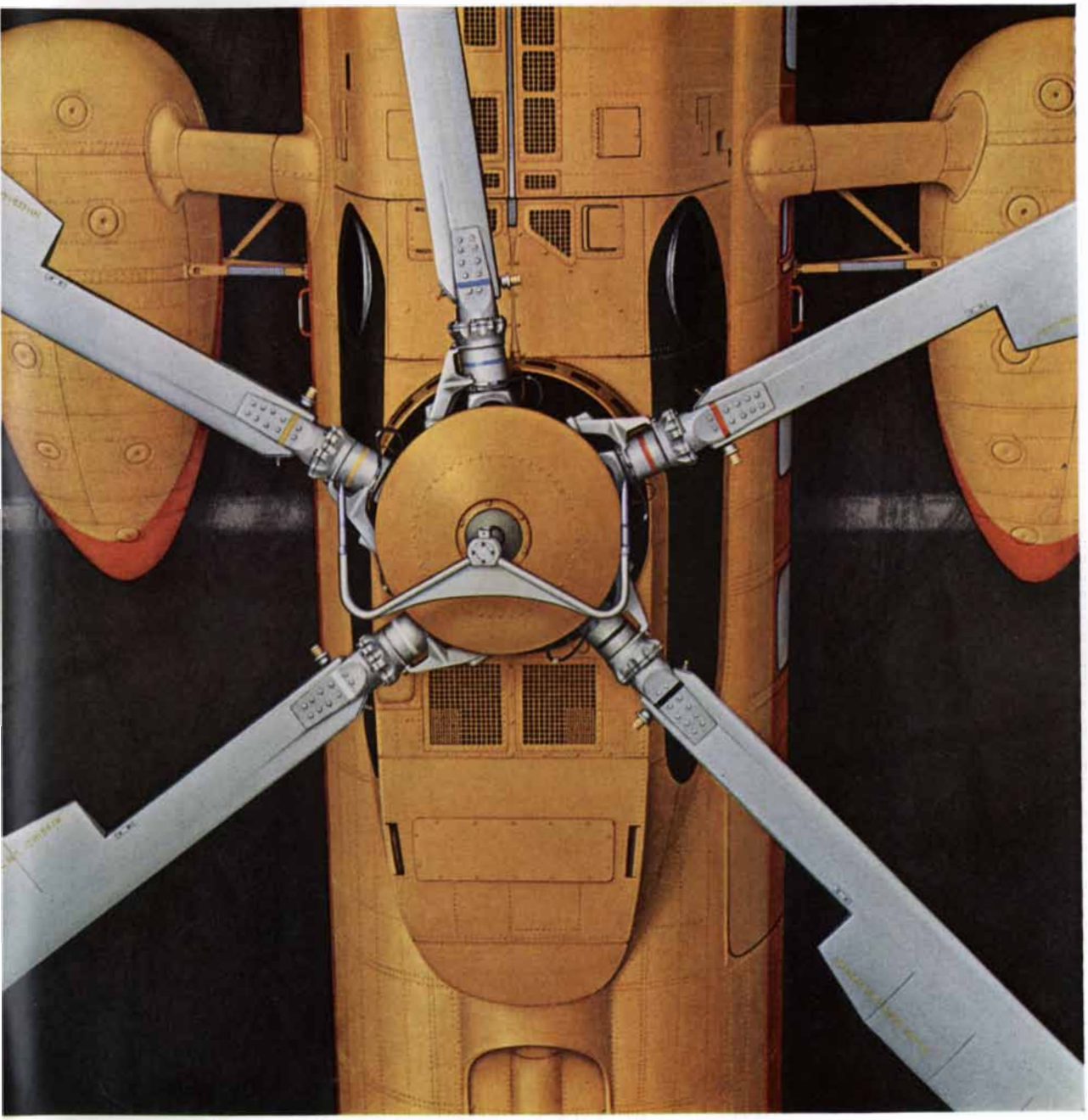

HELICOPTERS

SIXTY CENTS

April 1967

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We want everyone to fly.

EASTERN

ALPHATIZED STEEL

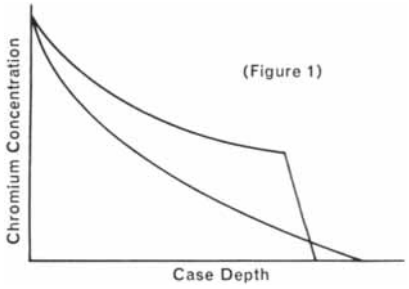
A versatile new product, formable as drawing quality cold rolled sheet, with corrosion resistance similar to stainless steel. Its coating is a diffusion layer rich in chromium, with a strong metallurgical bond.

by Dr. Murray J. Roblin, Research Manager

The principal reason for selecting a particular alloy is often related to surface properties. Appearance, corrosion resistance, oxidation properties or resistance to wear can be so vital that the metallic system or alloy is chosen for these properties alone. Then, in many cases, the matrix properties are not suitable for the intended application, or are uneconomic.

Metallurgists have recognized this problem for some time and have devised a number of ways to alter surface properties to more suitably match matrix and surface properties. One example is case hardening of steels by carburizing, nitriding or cyaniding to provide a hard wear resistant surface and tough ductile matrix. Another approach is to coat the base material with another metal, plastic or oxide as in galvanizing, chrome plating, anodizing and enameling.

Considerable strides have been made in coating technology. However, the most important technical problem facing



(Figure 1)

the researcher is obtaining good adhesion between surface layer and substrate. Most coatings are additive, and bonding is often not metallurgical in nature. Therefore the amount of deformation a coated product can undergo and still retain a continuous adherent layer is generally restricted. Thus, coating must often be the final operation in a product's manufacture.

One technique which overcomes these limitations is to coat the substrate with a metal which does not form intermetallic compounds or other brittle phases, and to diffuse the coating into the base metal. This provides a diffusion layer rich in the coating metal, one that is metallurgically bonded. Thus the base metal can be deformed rather extensively with the coating retaining adherence and uniformity.

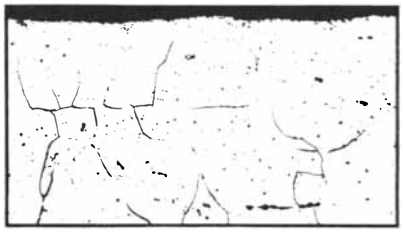
Chromizing is one such system, and three separate processes are practiced today. All use gaseous media to provide chromium access to the part involved. In July, 1961 this process was modified by Gasalloy Steel Corporation to apply the process concepts to a sheet product in coil form.

The present Alphatizing technique is to place a large coil, wound with twisted wire between the wraps, into a high temperature furnace containing a chromium source. Once the steel reaches the required temperature under a deoxidizing atmosphere, a halide gas is introduced, and flows through the chromium source and between the wraps into both surfaces of the steel, where a chromium atom is deposited and an iron atom picked up. The latter is returned to the chromium source, where the process is repeated.

A uniform, chromium rich layer is built up on the surface and diffuses into the matrix. The surface chromium content is controlled by the chromium potential of the gas, and the depth of case by the length of time the process is carried out at temperature.

By carrying out the process above the austenitizing temperature (1670° F for iron) a chromium gradient can be achieved with a higher average chromium content than would be possible for the same period in the ferrite region (Figure 1). The reason for the double gradient is that the diffusion rate in austenite (γ iron) is much slower than in ferrite (α iron). Initially the base material is austenitic (γ iron) until the chromium concentration is built up to 13% at or near the surface when the structure transforms to ferrite (α iron) and the velocity of diffusion increases.

Figure 2 shows that the structure of the chromium rich case is columnar. Al-


(Figure 2)

though on etching the coating appears to have a sharply defined boundary, this is purely an etching effect. The coating has a gradual change of composition with distance and should be distinguished from electro-deposits, vapor coating and others where it is abrupt. It is this integration of the coating with the base and the high average chromium concentration of the case which result in the remarkable properties of Alphatized steel.

Alphatized steel has a surface chromium concentration greater than 26%, an average chromium content of 19% and a case 1.5 mils thick as measured to a 10-12% chromium concentration. Thus it has surface properties—appearance and oxidation and corrosion resistance—similar to a chromium stainless steel, with the forming characteristics of a low carbon steel sheet. The coating is ductile, adherent and does not spall or flake upon severe deformation of the base.

The process is not limited to chromium deposition. While much additional research will be necessary, the process can be applied to any system which forms a gaseous metal halide. This could extend the process to many systems providing specialized surface properties for a wide variety of applications.

This work in extending the versatility of steel is a small part of the 24-hour-a-day research at Youngstown. If you believe Youngstown can help you solve a steel problem, call at your convenience or write Department 251A7.

Youngstown Steel

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"I won't buy a Renault no matter how good it is."

"...no matter how good it is." Isn't that just superb?

The reasoning behind that statement is sad enough. But what's really tragic about it is that we helped bring some of it on ourselves.

A few years ago, we admit, some Renault cars and dealers fell a trifle short of perfection. So we can appreciate why a few former owners swore they'd never buy another one ...a few years ago.

What we can't appreciate is why they're still talking like that.

You see, we did some swearing of our own.

We fixed everything that needed fixing and then some. When you're the seventh largest car-maker in the world, you don't just sit around wringing your hands.

In fact, if everything weren't absolutely A-1 now, do you think we'd be talking about it?

The February '67 issue of *Road Test Magazine,* for instance, a kind of consumer guide for car buyers, rates the Renault 10 ahead of all other imports in its class.

Unfortunately, the problem doesn't end with former owners. Some people who know nothing about our troubles of a few years back have also sworn off Renault.

Oh it's nothing personal, mind you. They simply hate all little foreign cars.

Typically, they've ridden around in a friend's little car. (Those people know who they are and they know what little cars we're talking about.)

So they're absolutely certain that any car for $1647* has to be a noisy, hard-riding little machine.

Anyway, with all the swearing going on for one reason or another, many people won't even test drive the Renault 10.

And that's a shame.

Because if ever there was a car to make all the swearing stop, it is the Renault 10.

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Established 1845 **SCIENTIFIC AMERICAN** April 1967 Volume 216 Number 4

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover depicts the rotor head and parts of the blades of a 28-passenger Sikorsky S-61N helicopter, designed for commercial airlines. The view is from above; part of the fuselage is seen, as are two sponsons, wheel housings that also provide stability in water landings, and even the tire marks on the runway surface. A fairing called a "beanie" covers the hinges and bearings of the rotor head, which permit the blades three degrees of freedom (see "The Changing Helicopter," page 38). It is because the blades can "lead" or "lag" in the horizontal plane that the angles between various pairs of blades are different. The bands of color on each blade and on the hub constitute a color code for replacing blades removed for servicing.

THE ILLUSTRATIONS

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What's Going On Up There?—A Report from General Dynamics

When a broadcaster calmly announces that the launch rocket has been jettisoned, the capsule is in orbit 115 miles above the earth and that the crew is in excellent shape, ever wonder...

Who told *him?*

How does *anyone* know what is happening to that one particular speck, invisible in the vastness of space and moving at five miles per second?

He knows because the facts do come back—through a communication system as essential to space research as any satellite.

Some day man may colonize the planets, but first a vast amount of information is needed.

Every space flight today, manned or not, is basically a fact-finding mission—whether to learn more about cosmic radiation, the ability of a human to function in zero gravity, or scores of little-known aspects of space.

"Needle in a haystack":

To collect the information in the first place, earthbound mission controllers must stay in touch with the spacecraft from the instant of launch, know where it is and where it is going.

The National Aeronautics and Space Administration does the job through a worldwide network of stations—many parts of which have been built by General Dynamics—that track and collect information from the space vehicles. This network is tied into control centers which, depending on the mission, may be in Florida, Texas, California—or aboard an instrumentation ship on the high seas.

From the moment a space shot starts, a transmitter follows the programmed path of the space vehicle, beaming a continuous-wave radar signal on a specific assigned frequency. A transponder aboard the spacecraft receives the signal, changes it to a different frequency, and transmits it back to earth.

As the spacecraft moves, the length of time for the signal's round trip changes. The differences are continually measured and computed against the original program, with the spacecraft's position, speed and path displayed visually for the controllers.

If the spacecraft is straying, mission controllers can order the vehicle to make the necessary corrections that will put it back on the right path.

Collecting the facts:

More than direction is involved.

Even before launch and on through flight, literally hundreds of sensors in and on the launch vehicle and its payload—in a manned flight even on the astronauts' bodies—are measuring as many different kinds of data.

Some sample the goings-on outside the spacecraft: radiation, meteorite contact, temperature. Others keep track of conditions inside: fuel consumption, engine operation. Still others may report on crew members' heartbeats and skin temperatures, or on cabin conditions such as oxygen content.

Each of these measurements is converted into electrical signals to be radioed back to earth. The more complex the spacecraft and its launching vehicles, the more information must be sent. Ground stations must receive and digest millions of "bits" of information every second. Printed, this would be enough to fill ten average Sunday newspapers every minute.

All this information is sent down a single radio beam. The process is similar to the multiplexing which allows scores of individual telephone conversations to go over a single wire or microwave beam simultaneously.

Command function:

Picture an eight-lane highway, packed solid with cars, interrupted by a one-lane bridge. At the entry to the span, a policeman alternately directs one car from each highway lane in sequence to keep a solid stream flowing across the bridge. At the other end, another policeman directs each car back into the same lane it started from.

Now multiply the speed of the process a millionfold. Instead of eight lanes, more than 200 sensors; instead of a bridge, one radio beam; instead of the policeman, a commutator which alternates the input from the sensors in the proper sequence.

Although all data sent from the spacecraft are stored for later detailed analysis, much of it must be immediately available—visibly, while the event is occurring—for the controllers to exercise their command function.

Suppose an orbiting spacecraft begins to tumble, jeopardizing the mission. Sensor measurements radioed to earth indicate changes. Controllers watching the computer printouts and data displays find anomalies, analyze the problem and order corrective action. Orders are transmitted to the spacecraft whose on-board receptors pass them to the system involved. Main engines or verniers fire as necessary to put the spacecraft back on course.

The rates vary at which data is sent. During launch phase, tracking data

Filling the Holes in the Network

Requirement: Orbiting satellites are temporarily "lost" when they pass over oceans out of "sight" of land tracking stations. In view of the complexity of the forthcoming Apollo moon-shot program—particularly the critical need for uninterrupted contact with the Apollo vehicle and its three-man crew—this ocean gap had to be filled.

Solution: Three *floating* tracking stations, called Apollo Instrumentation Ships, built by General Dynamics for the U.S. Navy and NASA. The ships are fully equipped to track, maintain two-way radio contact with and receive telemetered data from orbiting satellites.

The three ships will be deployed this summer under U.S. Air Force operational command to positions in the Atlantic, Indian and Pacific Oceans. There, integrated into NASA's worldwide network of land tracking stations, they will begin their tracking and telemetry work.

In addition to their communication role, the Apollo Instrumentation Ships have been given mission control responsibility. If communication should be broken between NASA's control center in Houston and the ship then in contact with the Apollo capsule, the basic "go/no go" decisions will be made aboard the Apollo ship.

may be required every fraction of a second; after the payload is in orbit, once an hour may be enough. Heartbeat and respiration of an astronaut might be monitored constantly. But a weather satellite may "store" all the information it acquires in a full orbit, discharge it all at once upon command to a specific receiving station.

A whisper from space:

But how can this information possibly get across the hundreds, or in some cases millions, of miles of space?

One problem is that the size of the spacecraft severely limits the power available to it for radio transmitters and receivers. Commercial radio stations use as much as 50,000 watts of broadcast power. The space ship may have as little as five watts.

Receiving antennas on the ground must be able to sort out one specific whispered signal from among those coming from hundreds of other spacecraft, from other space noise including solar radiation, from the mass of radio signals bouncing around within the atmosphere—and interpret its special signal with absolute correctness.

To do this, receivers have to be big. Movable antennas built by General Dynamics have diameters up to 30 feet and can pick up a 5-watt signal from the moon. NASA uses some as big as 85 feet in diameter which have received space signals from as far as 134,000,000 miles away.

Weak ears, big voice:

The concave surface of the antenna, tuned to the specific frequency of the spacecraft it is receiving, collects and focuses the signal to a smaller hyperbolic reflector which, in turn, sends it to a series of amplifiers that boost its intensity.

To "call" the spacecraft, the problem reverses. Its antennas may be as small as five inches in diameter. The signal sent from earth may require peak power of up to 1,000,000 watts.

General Dynamics is a company of scientists, engineers and skilled workers whose interests cover every major field of technology, and who produce: aircraft; marine, space and missile systems; tactical support equipment; nuclear, electronic, and communication systems; machinery; building supplies; coal, gases.

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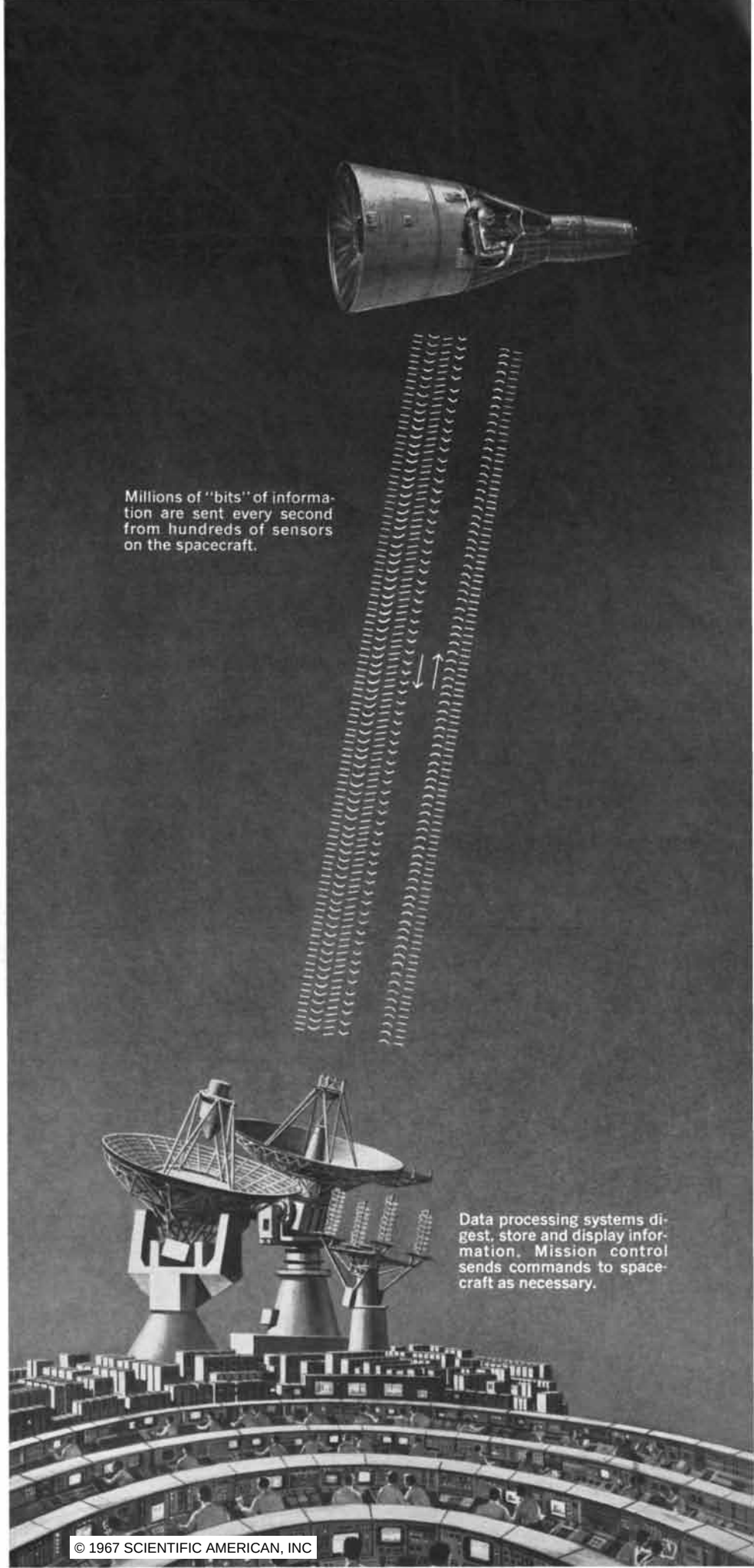

LETTERS

Sirs:

Leo L. Beranek's article "Noise" [SCIENTIFIC AMERICAN, December, 1966] does an excellent job in pointing out many ways of alleviating the distress arising from the rising noise level of modern life. However, I think he is too pessimistic when he says "the basic problem is essentially incurable; noise is an unavoidable price we must pay for a machine civilization." It is true that the world in our time is getting noisier, but our view of the past may be too idyllic. G. M. Young, in one of his essays on Victorian England, describes the fearful noise of the London streets of a century ago, with the metal-rimmed wooden wheels of heavy carts and drays pounding over the cobblestones. Young, who I believe was writing around 1930, thought that London in his day was a quieter place than it had been 80 years earlier. Certainly the use of asphalt paving instead of cobblestones, and of rubber tires instead of wooden wheels with metal rims, was a positive contribution to the reduction of noise. Of course, the huge increase of motor traffic during the past 20 years has caused the noise level of the city streets to rise again, to levels that many people find intolerable, but we should not assume that the world has necessarily been getting steadily noisier, or that it is bound to be noisier in the future than it is today.

This question raises larger issues. Since the industrial revolution began, new technology has provided mankind with great benefits. We have paid the price, in the destruction of much of our natural environment and in many forms of pollution, of which noise is one. When there were fewer people with more space, almost everyone accepted the price, but now people are multiplying at an unprecedented rate, and we are running out of space. Given the power and the increasingly subtle skills of modern technology, we can demand of the technologists that their new devices include the necessary controls to prevent pollution or to reduce it to minor proportions. When this is impossible, mankind may prefer to reject some new devices rather than to sacrifice such values as clean air and water, uncluttered space and quiet surroundings. Such an attitude would have seemed Utopian only a few years ago; today it is becoming strictly realistic.

The supersonic transport plane is a case in point. I strongly question Dr. Beranek's statement that "the coming of supersonic travel is inevitable," if he means that supersonic planes will be accepted as the primary mode of long-distance transport. The sudden shock of sonic booms is something far beyond the disturbance produced by ordinary noise; it can produce alarm reactions in sensitive people, including small children, and animals. Above all, it can awaken many people from sleep, as the Oklahoma City tests showed clearly. A supersonic night flight from Los Angeles to New York could disturb the sleep of millions of people on the ground below in order to get perhaps 200 passengers across the continent in two or three hours instead of five. Daylight flights would waken fewer people from sleep, but still there are some millions of people whose work obliges them to sleep by day. Damage from repeated sonic booms, to buildings and other structures, may be cumulative, and its cost to the community may be immense. It will also be exceedingly difficult to prove, in any given case, that the damage was due to the boom, even though in fact it was; hence homeowners may have great trouble getting compensation for such damage. Altogether it would seem wise to do far more extensive research on the effect of sonic booms on people, animals and structures—including extensive tests, with advance warning, over large cities—before continuing to invest billions of dollars in a project with so many formidable drawbacks.

JOHN T. EDSALL

The Biological Laboratories
Harvard University
Cambridge, Mass.

Sirs:

Dr. Edsall takes exception to my "pessimistic" point of view. Greater optimism than mine would be the result of positive answers to two questions: "Is our nation ready to underwrite the costs of truly quiet living?" and "How soon could quiet be effected even if we decided to go all out to achieve it?" The technology is nearly available to provide quiet surface transportation, but quiet air transportation seems decades away. I agree that more research is necessary on the effect of sonic booms on people, animals and structures and that this should be done with all dispatch. It seems to me inevitable that people will travel in supersonic aircraft. Whether they travel over the U.S. is up to our lawmakers—in other words, up to us.

LEO L. BERANEK

Bolt, Beranek and Newman, Inc.
Cambridge, Mass.

Sirs:

With reference to Marshall Gates's "Analgesic Drugs" [SCIENTIFIC AMERICAN, November, 1966] and the statement that Thomas De Quincey's *Confessions of an English Opium Eater* (1821) contained the "first detailed description of opiate addiction," it should be noted that the effects of taking opium, including addiction, were recognized much earlier. Briefly, Galen (A.D. 131–200), the famous physician, noted the symptoms in his patient the Emperor Marcus Aurelius, as did the Roman historian Dio Cassius (A.D. 155–*ca.* 230). Later, but still well before De Quincey, Garcia d'Orta (1501–1568) and Gabriele Fallopio (1523–1562) also reported addiction. Finally, John Jones, in *The Mysteries of Opium Reveal'd* (London, 1701), clearly described not only addiction but withdrawal symptoms as well.

JERRY STANNARD

University of Colorado
Boulder, Colo.

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RECENT FINDINGS

RESEARCH LABORATORIES

Ford

Advances in thermionic emission microscopy and the study of high temperature reactions

Transmission electron microscopy is a conventional method for studying materials (both metallic and nonmetallic) on a microscopic scale. However, this technique has a number of inherent disadvantages to it, especially in the study of high temperature reactions. These include the need to use extremely thin specimens (in the order of 1000Å), the difficulties involved in heating and measuring the temperature of such a specimen, and the contamination problems caused by the poor operating vacuums (about 10^{-5} torr at best) associated with such instruments.

Therefore, in order to study reactions which occur at high temperatures another form of electron microscopy, thermionic emission microscopy, must be utilized. This form of electron microscopy differs from the more conventional transmission electron microscopy in that the specimen itself is the source of electrons. These electrons, once emitted from the material being studied, are focussed in a suitable lens system and projected onto a fluorescent screen, yielding a metallographic image, as can be seen in Figure 1.

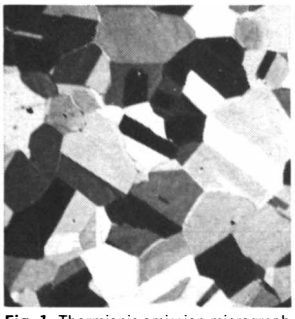


Fig. 1. Thermionic emission micrograph of an iron —0.305% carbon alloy taken at 800°C. Magnification 660X.

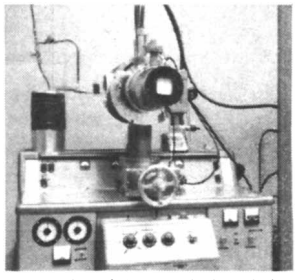


Fig. 2. View of the thermionic emission microscope. Console contains the microscope chamber, vacuum system, lens power supplies and the high voltage power supply.

While the thermionic emission microscope is the oldest form of electron microscopy, it was one of the least developed forms and the instruments associated with it had severe deficiencies. In order to eliminate the mechanical problems associated with this instrument, the scientists at Ford Motor Company's Scientific Research Staff designed and built a new thermionic emission microscope. This instrument has electron-optical lenses, a combination electrostatic-electromagnetic objective lens and a magnetic projector lens. It is capable of magnifications of from 78 to 6000 diameters with a resolution in the order of 300Å over the entire magnification range, and can be used to study reactions in the temperature range of from 450°C to 2300°C.

There are a number of important and novel features associated with this microscope. The vacuum system has an ion-getter type of high vacuum pump and is capable of operating at 10^{-8} torr with the specimen at room temperature and at 10^{-7} torr with the specimen at 1600°C. Also available is a temperature measurement and control system capable of measuring specimen temperature to better than ±5°C. The specimen at a potential of 50 KV required designing a system which is floating and isolated at this voltage. Specimen movement is controlled electronically and a measuring system devised so that the exact area of the specimen which is being viewed on the microscope can be determined. Figure 2 is a photograph of this microscope.

With an instrument of this kind, it is possible to study the reaction kinetics of phenomena which occur at temperatures above 450°C. These include such reactions as phase transformations in metallic and nonmetallic systems, recrystallization and grain growth, diffusion studies, sintering mechanisms in metal or ceramic compacts, solidification of metals, segregation, and creep. From surfaces, it can also do fundamental studies of electron emission.

One such study being made with the thermionic emission microscope is the thickening kinetics of ferrite sideplates in iron-carbon alloys. Preliminary results indicate that these plates of body centered cubic iron form in a discontinuous manner from the face centered cubic parent phase as is shown in Figure 3. It can also be seen that growth kinetics are much less than assumed diffusion control. These results indicate that ledge mechanisms of plate thickening may be operative in this reaction. Studies such as these should lead to a better understanding of the mechanism of the allotropic transformation in steel and should eventually lead to production of better alloys.

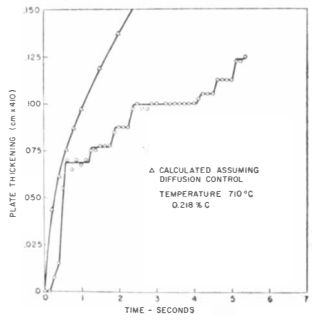


Fig. 3. Plot of ferrite sideplate thickening as a function of time for an iron —0.218% carbon alloy transformed at 710°C. The smooth curve is calculated assuming a diffusion controlled reaction.

PROBING DEEPER FOR BETTER IDEAS

Ford

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

APRIL, 1917: "Occasionally in the great crises of human history it has happened that the whole world, of whatever race, creed or tongue, by common consent has given ear to the voice of one man. Conspicuous among such occasions will ever be reckoned the joint session of the two branches of Congress, which gathered on the night of April 2nd to learn from the lips of the President of the United States why it was that the great republic, of which he is the executive head, was compelled to declare that a state of war existed between itself and the greatest military autocracy of all time. Acting as the drop of liquid with which the chemist clarifies a cloudy mixture in his test tube, the words of the President have served to remove the last doubt as to the practical unanimity of the people of this great republic on the question of the true meaning of the present world war. The conflict, in the last analysis, is a struggle between autocracy and democracy, between the right of a privileged few to rule the peoples of the world for their own private ends and the right of every nation, big or little, to govern in the interests of its collective citizenry. We enter the war not as a struggle against the German people but against that military clique which has led them, deluded and unsuspecting, into a war of aggression and attempted world conquest. The citizens of America have no quarrel with the citizens of Germany, rather they have for them and for their notable industrial and social achievements the profoundest admiration."

"In regard to the German submarine campaign, we note that there is a tendency to underestimate its potential danger. It is our belief that at the time of the Jutland fight, when the German High Seas Fleet was driven back with heavy losses and in a badly battered condition to its naval bases, Germany determined to bend its whole ship-and-engine-building capacity to the creation of a great fleet of submarines. What is the German submarine-building capacity? Is it sufficient to enable her, say within the year, to build, equip and man 1,000 or 1,200 boats? Nobody outside of Germany can answer that question, but SCIENTIFIC AMERICAN believes that she is probably well able to do this."

"A committee appointed by the British Home Secretary to inquire into the social and economic results of the Summer Time Act, 1916, has submitted its report. The committee finds a great preponderance of public opinion in favor of the new kind of time and recommends its use every summer hereafter. Other countries in Europe where the daylight-saving scheme has been tried are planning to continue it in operation, but there have been various suggestions as to the mode of operation. We note an interesting proposal, in a recent number of the *Comptes rendus,* that instead of making an abrupt change in time twice a year, all clocks be run fast so as to gain 30 seconds a day from the winter solstice to the summer solstice, and slow, so as to lose 30 seconds a day, the rest of the year. This would adjust the daily time schedule gradually to the season, and make the time at the summer solstice an hour and a half faster than at the winter solstice."

"How difficult it sometimes is to make practice conform to theory has long been and still is shown by the continued opposition to the general introduction of the metric system into the United States and England. Could we pluck up courage enough to take the first step, England would most likely follow our lead after a shorter or longer interval."

SCIENTIFIC AMERICAN

APRIL, 1867: "We learn that Mr. Siemens and Professor Wheatstone have simultaneously produced, before the Royal Society, similar machines realizing the conversion of mechanical into electrical force with remarkable perfectness and almost a minimum of loss. In the miniature experiment shown the magnetism developed surpassed the strength of two men, and the heat of the electric current was sufficient to melt iron wire. The power required being so trivial, and the movement so simple and frictionless, it would seem that these striking results might well have approximated closely an equivalent for all the mechanical power expended. This is a great result in its practical bearings. Our present mode of getting light (to illustrate grossly) is like keeping up a bonfire or heating a furnace merely to read by."

"The Emperor and Empress of France are now setting a good example, which will be followed by all Paris and consequently by all the fashionable world, namely in taking an interest in scientific lectures and experiments. We subjoin an account found in one of the latest Parisian journals:—'The usual lights at the palace of the Tuileries were extinguished, and M. Moigno, surrounded by an illustrious staff of all the celebrated electricians of Paris, threw a ray of light on a screen and after some general explanations decomposed it into the colors of the rainbow, then made to appear in these rays the peculiar lines lately discovered by Bunsen, produced by the combustion of different metals. The new electric machine of Holz, perfected by Bertsch, was put in operation by the last named. The attention of the Emperor was strongly attracted by this instrument; he came nearer to speak to the inventor; the young prince followed him, and soon the whole court was mixed with the operators, somewhat frightening the Empress when her little son handled the coils and Leyden jars. The Geissler's tubes, which become luminous by electric currents and exhibit different colors according to the chemical composition of the glass and the rarefied vapors contained in them, were exhibited and in this way the name of Napoleon III appeared in streaks of colored fire. After some other experiments the ladies of the court desired to take the shock; they joined hands, formed a circle and bravely took the discharge of some minor electric apparatus.' "

"A new red has been obtained by Coupier by a combination of two of the hydro-carbide bases of coal tar, which he has decided to be incapable of yielding a color in their separate condition. It is named *toluen red* and is pronounced the richest red yet known. The so-called aniline dyes are among the most beautiful results of chemistry. Beginning with the admired varieties of red and purple, such as *mauve, magenta,* etc., additions such as that above named have followed, including the splendid green called verdine, a blue as clear as opal or the Italian sky, a good yellow and a fair black. The intensity of these colors is shown in the fact that one grain of magenta in a million of water gives a good red, one in 10 millions a rose-pink, one in 20 millions gives a blush to the water, and one in 50 millions a reddish glow."

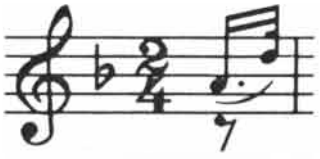
Report from

BELL LABORATORIES

ELECTRONIC GRAPHICS BY COMPUTER

Computer information is most useful when it is displayed in an easily usable form. For this reason, much effort is currently being directed toward finding better visual outputs from computers — graphs and "pictures" instead of numbers. And an important aspect of this problem is improving the graphic quality of the images.

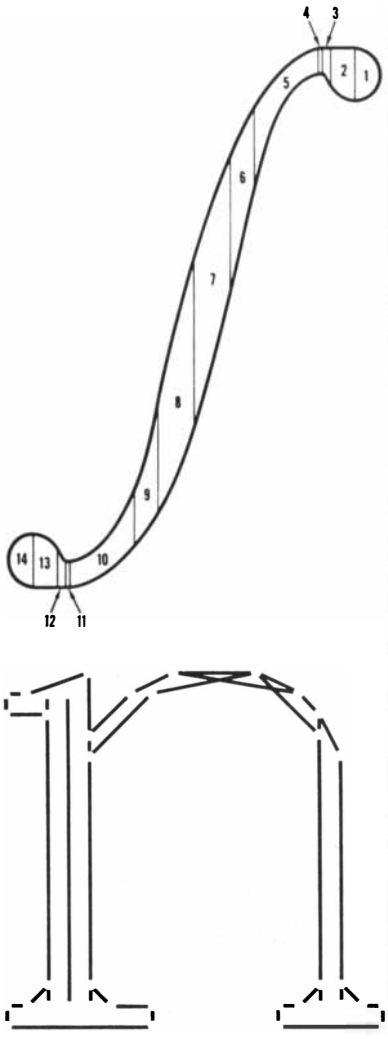
At Bell Telephone Laboratories, researchers M. V. Mathews and H. S. McDonald have devised an efficient and versatile method of "drawing" any conceivable shape or graphical design on the screen of a cathode-ray tube. For example, entire pages of text matter can be drawn on the screen in any desired type font, and then photographed. As a demonstration, the above headline, these words, and the sample mathematics and music below were produced by this experimental method.



$$\int_0^\infty \sqrt{x}\, e^{-ax}\, dx$$

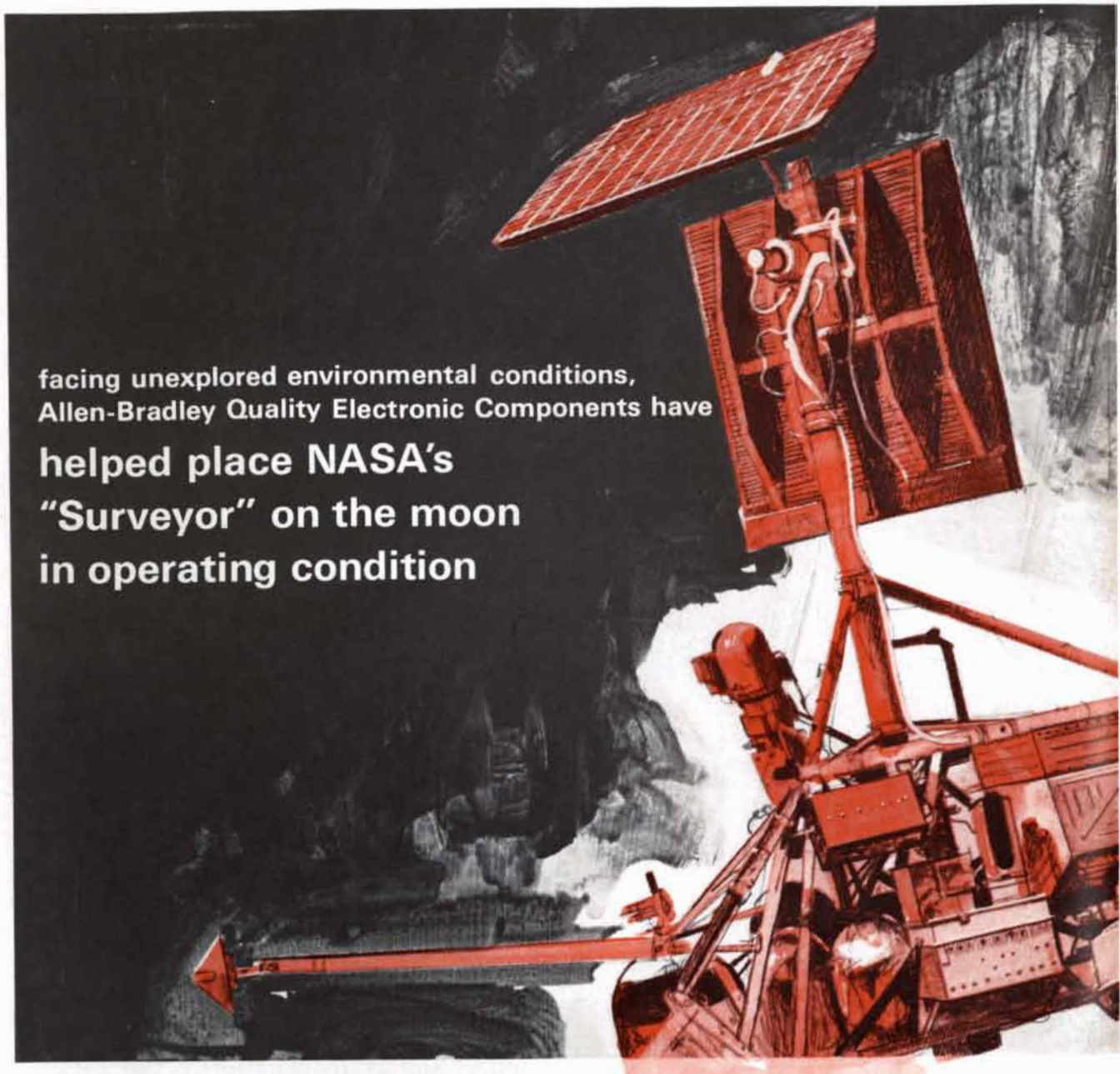
At present, information describing the shapes of each of about 450 letters and symbols is stored numerically in a computer. No masks, negatives or other physical forms of the graphics are used. An operator tells the computer what text and/or other matter is to be produced. The computer calls upon its memory and directs the motions of the electron beam in the cathode-ray tube needed to trace out the images.

Preparing material with this technique offers the advantages of current mechanical methods plus the opportunity to correct while writing, change letter style and symbol forms, arrange lines with an even right-hand margin (justification), and vary type size — all with a heretofore unattainable ease and speed.

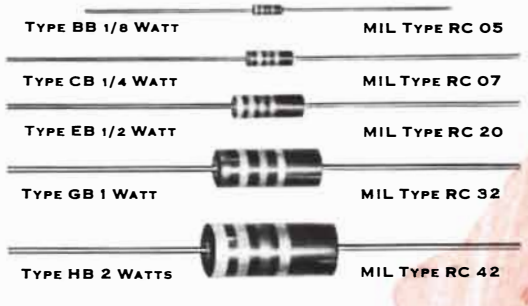


Two programming methods used to generate graphical material: An integral sign (top) is formed by the "patch" method, whereby the image is divided into a number of constituent areas or patches (fourteen patches in this case). After the areas are specified, the electron beam fills each one in. In another method, used here to form the letter "n", the electron beam follows the paths of the vector lines shown. Beam is wide enough to fill in areas between vectors.

Bell Telephone Laboratories
Research and Development Unit of the Bell System



A-B QUALITY ELECTRONIC COMPONENTS THAT CONTRIBUTED TO THE "SURVEYOR'S" SUCCESS

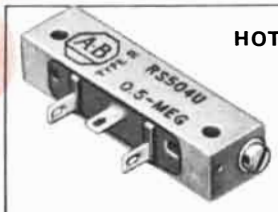


ALL A-B HOT MOLDED FIXED RESISTORS

are available in all standard EIA and MIL-R-11 resistance values and tolerances, plus values above and below standard limits. Shown actual size.

FEED-THRU CAPACITORS

A-B feed-thru capacitors have a discoidal design that eliminates all parallel resonance effects at 1000 MHz and less. Insulation resistance exceeds 100,000 megohms. Standard values are 470 uuf ±20% and 1000 uuf GMV. Special values from 6.8 uuf to 1500 uuf. Rated to 500 v DC maximum. A-B discoidal capacitors are also available in the stand-off construction.



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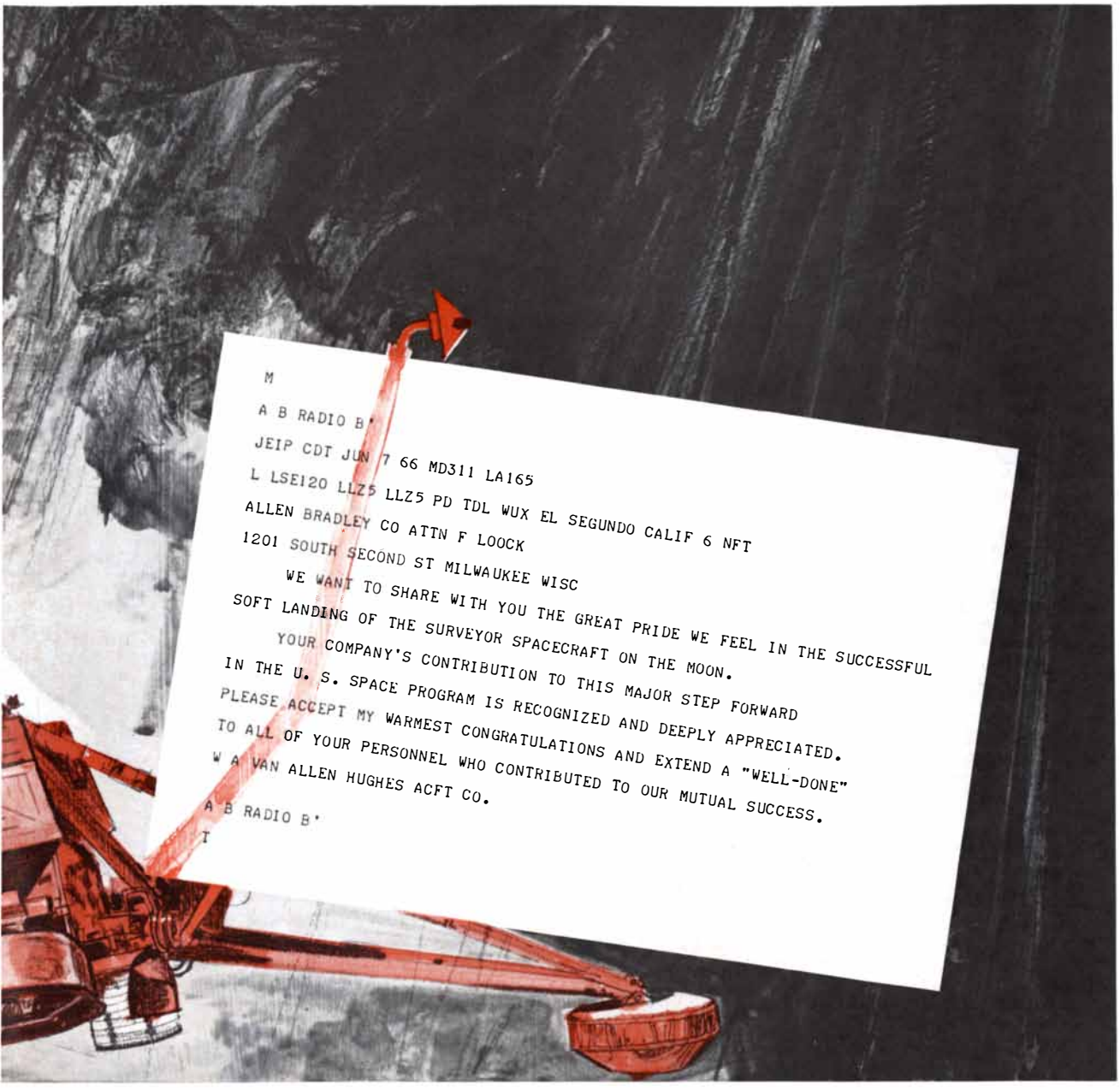
Type R trimming potentiometers provide stepless adjustment and are essentially noninductive. Molded cases are dust-tight and watertight. Rated 1/4 watt at 70°C. Values from 100 ohms to 2.5 megohms. Tolerances of ±10% and ±20%.



Why were these A-B hot molded fixed and variable resistors selected for such critical service as in the "Surveyor"? First, because no A-B hot molded resistor component has ever been known to fail catastrophically under rated load—either mechanically or electrically. Second, due to the method of manufacture, you can select one A-B resistor from among ten or from ten million, and be confident there will be no variation in electrical characteristics. Incidentally, this is *not* the first "shipment" of Allen-Bradley resistors delivered to the moon—they are "standard equipment" in "space mission" service.

There are sound economic advantages to standardizing on A-B hot molded fixed and variable resistors for use here on Earth as well! As many electronic equipment manufacturers have learned—sometimes through sad experience—no other resistors will provide the consistently high reliability of Allen-Bradley hot molded resistors. They may cost a bit more, but—you must not expect to obtain "equivalent quality" at a lower price! Allen-Bradley Co., 1204 South Third St., Milwaukee, Wisconsin 53204. In Canada: Allen-Bradley Canada Limited. Export Office: 630 Third Avenue, New York, New York, U.S.A. 10017.

A-B QUALITY

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QUALITY ELECTRONIC COMPONENTS

866-ID

THE AUTHORS

JAMES P. COMER ("The Social Power of the Negro") is a fellow in psychiatry at the Yale University School of Medicine. He writes: "My father, who died in 1955, was from rural Alabama and worked as a laborer and janitor. My mother was born in rural Mississippi and worked as a domestic before my birth and later as an elevator operator. Both were undereducated. They reared five children, all of whom hold postgraduate degrees." Comer was educated in the racially integrated schools of East Chicago, received a bachelor's degree at Indiana University in 1956 and was graduated from the Howard University College of Medicine in 1960. For two years he was a fellow in public health at Howard. In 1964 he took a master's degree in public health at the University of Michigan, joining the psychiatric residency program at Yale in the same year. "My interest in race relations," he says, "developed at an early age, in part from both troublesome and satisfying experiences as a Negro youngster in a low-income family in a racially integrated community." He adds that work as a volunteer in an agency concerned with social rehabilitation of families with problems influenced his decision "to train in psychiatry and to focus on preventive and social aspects."

RENATO DULBECCO ("The Induction of Cancer by Viruses") is resident fellow at the Salk Institute for Biological Studies. Born in Italy, he took a medical degree at the University of Torino in 1936 and remained there as a teacher and researcher until 1947. Moving to the U.S. in that year, he was at Indiana University for two years and at the California Institute of Technology for 14, including nine years as professor of biology. Dulbecco joined the Salk Institute in 1963 but spent the academic year 1963–1964 as Royal Society Visiting Professor at the University of Glasgow. Since 1964 he has served as a trustee of the Salk Institute while continuing his research activities there.

ALFRED GESSOW ("The Changing Helicopter") is assistant director of research in physics and mathematics in the National Aeronautics and Space Administration. He writes that his "early ambition was to be a designer and builder of bridges and dams." Accordingly he studied engineering at the City College of the City of New York, receiving a bachelor's degree in civil engineering in 1943. A year later, after graduate work on the helicopter, he obtained a master's degree in aeronautical engineering at New York University. For the next 15 years he was at the Langley Research Center of the National Advisory Committee for Aeronautics, predecessor of NASA. During that time he wrote a textbook on helicopter aerodynamics, served as technical director of the American Helicopter Society and was founding editor-in-chief of the *Journal of the American Helicopter Society*. He went to NASA headquarters in Washington eight years ago, first administering a program of basic research in aerodynamics and fluid mechanics and then serving as chief of fluid physics research before taking his present position.

JOHN NAPIER ("The Antiquity of Human Walking") is reader in anatomy at the Royal Free Hospital School of Medicine of the University of London and director of the school's Unit of Primate Biology and Human Evolution. Son of a former professor of tropical medicine at the University of Calcutta, Napier was educated in England, receiving a medical degree from St. Bartholomew's Hospital in London. In 1963 he obtained a D.Sc. from the University of London. Napier's principal interests are teaching and research in primate biology. With his wife he is about to publish a textbook on the primates. Napier has appeared on numerous television programs dealing with primates and human evolution.

WERNER H. WAHL and HENRY H. KRAMER ("Neutron-Activation Analysis") are with the Union Carbide Corporation, Wahl as director of radiopharmaceuticals of Neisler Laboratories, Inc., a subsidiary of Union Carbide, and Kramer as group leader in the nucleonics program at Union Carbide's Sterling Forest Research Center. Wahl was graduated from the University of Buffalo in 1954 and received master's and doctor's degrees from Purdue University. He joined Union Carbide in 1957. Kramer was graduated from Columbia College in 1952 and obtained a doctorate in physical chemistry from Indiana University in 1960. He has been involved in work on a variety of problems using nuclear techniques.

H. F. GARNER ("Rivers in the Making") is associate professor of geology at

the University of Arkansas. He was graduated from Iowa State University in 1949 and received master's and doctor's degrees from the State University of Iowa. He was a geologist with oil companies before joining the faculty of the University of Arkansas in 1956. Garner writes: "I have traveled, studied and worked in North and South America, Europe and Africa on geologic problems, particularly paleoclimatology insofar as that subject relates to stratigraphy and fluvial geomorphology." Garner and a number of other workers are preparing a paleoclimatic map of South America during the coldest part of the ice ages in Pleistocene time; the map will be presented at the next session of the International Association for Quaternary Research in Paris. Garner says that in his spare time he enjoys "hunting, fishing and painting."

HARALD ESCH ("The Evolution of Bee Language") is assistant professor of biology at the University of Notre Dame. He was born and educated in Germany, receiving a doctorate from the University of Würzburg in 1960. For some years he divided his interest between radiobiology and bees. In 1962 he joined the Radiation Research Institute at the University of Munich. He writes: "I had to devote most of my time to radiobiological research, but my contract contained a provision for me to have a sabbatical leave in 1964 to study the communicative behavior of Brazilian bees. Working full time on bees in Brazil, I realized that it was not a good idea to split my time between bees and radiation research." At Notre Dame his principal research is on bees.

HANNES ALFVÉN ("Antimatter and Cosmology") is professor of plasma physics at the Royal Institute of Technology in Stockholm. He received a Ph.D. from the University of Uppsala in 1934 and has worked for many years in the fields of hydromagnetics and plasma physics as they apply to cosmic physics. The hydromagnetic waves known as Alfvén waves are named after him. Among the books he has written are *On the Origin of the Solar System, Cosmical Electrodynamics* and, most recently, *Worlds-Antiworlds.*

MAXWELL H. BRAVERMAN, who in this issue reviews *Marcello Malpighi and the Evolution of Embryology,* by Howard B. Adelmann, does research in embryology at the Allegheny General Hospital in Pittsburgh.

How Union Carbide started a boom in Minnesota.

70 years ago, Minnesota's Mesabi Range was like a loaf of raisin bread. The raisins were pockets of rich, soft iron ore. The bread was a hard, low-grade iron ore, called taconite. It was a big loaf, about 110 miles long, three miles wide and 500 feet deep. So for fifty years, nobody bothered with the bread. They just dug out the raisins.

But 20 years ago, the raisins started to run out. And the miners were in trouble. Taconite is about 30 percent iron, so there was still enough iron in the loaf to last America's steel industry for at least 200 years. But you had to drill it and blast it—and taconite is harder than most steels, which made drilling almost impossible.

So Union Carbide invented the jet-piercer. Instead of a drill, it has a 4,000-degree flame. It heats the rock so fast it cracks away in small pieces that are blown clear. With a jet-piercer, you can make holes in taconite at up to 50 feet an hour. Then you can blast. And you've got a whole new industry on your hands.

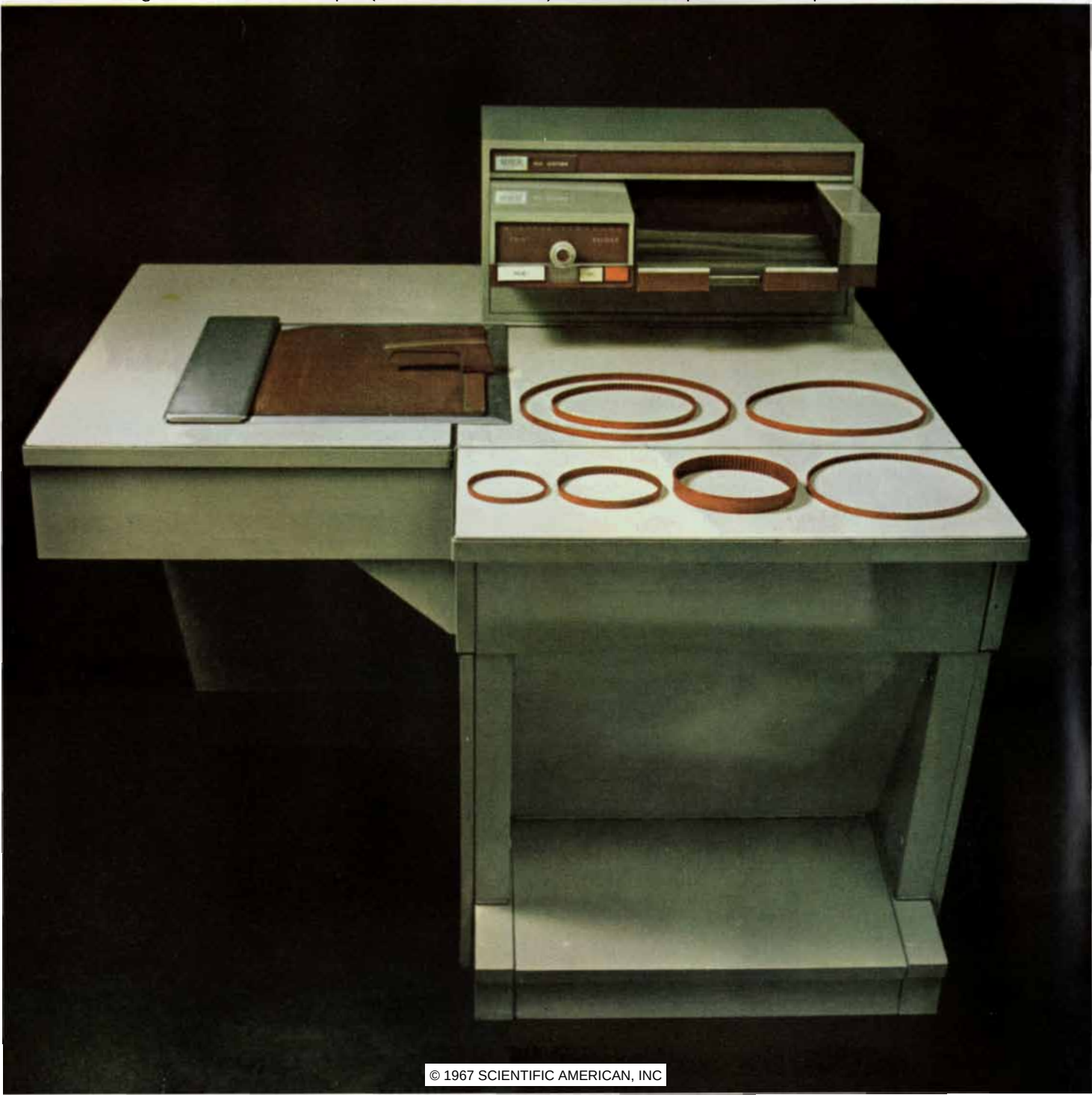
Breaking down tough problems is Union Carbide's business. And there isn't much that we don't get into.

UNION CARBIDE

THE DISCOVERY COMPANY

Rubber timing belts, continued.

Several timing belts are used in this copier (seven are shown in red). Smoothness of operation is an important consideration here.



UNIROYAL
U.S. RUBBER

Last month Uniroyal told you how its timing belt invention helps create new products. Here's how it is changing the power transmission field.

When Uniroyal invented the timing belt some 17 years ago, we had no idea how dramatically it would change the art of power transmission.

All we hoped to do was solve the slippage problem inherent with V-belts, the noise and wear problems inherent with gears and chains. We succeeded, for our patented timing belt sold under the registered "PowerGrip" trade name is essentially a rubber belt with teeth that act like gears to provide a positive drive that is efficient and quiet.

It requires no maintenance. Gears and chains must be lubricated. Ordinary V-belts must be retensioned. Timing belts need no attention except for replacement, which is seldom necessary.

Uniroyal timing belts are available in stock sizes to meet a wide range of applications. Lengths range from 6 inches to 15 feet. Widths up to 5 inches. Also in "made-to-order" sizes.

Timing belts are versatile. You'll find them hidden in hundreds of different products.

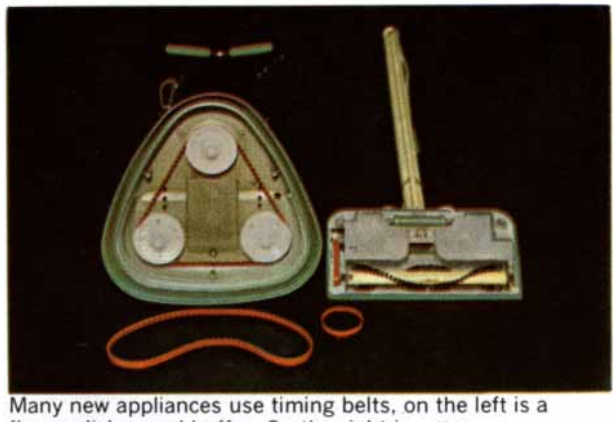
Timing belts are helping a planetarium duplicate the intricate movements of the universe. Timing belts drive the voice mechanism in talking dolls.

Timing belts enable designers to design smaller product envelopes than they'd ever considered possible before. Or power systems that would have been mechanically impossible or uneconomic.

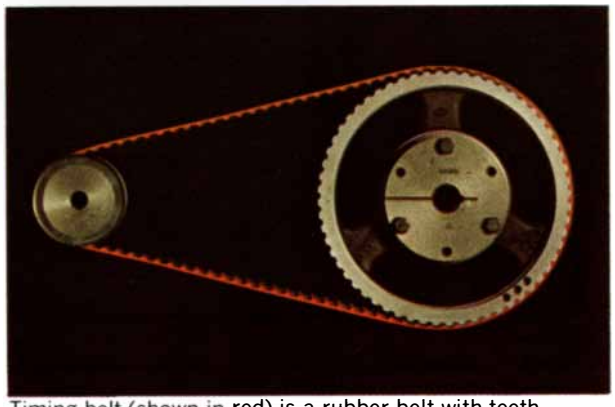
Their low cost and high efficiency account for their use in appliances, floor polishers, planers, saws, sanders, sweepers, polishers, lawn mowers.

Their durability accounts for their use in heavy duty industrial machinery: milling machines, lathes, drill presses, saws, joiners, grinders. (Rubber timing belts are particularly useful where abrasive material is present. A resilient material like rubber resists abrasion better than metal.)

Timing belts are only one of our industrial products that might help you with a new product you're working on. If you have a problem that one of our rubber, chemical or plastic products might solve, we'd like to hear from you.



Many new appliances use timing belts, on the left is a floor polisher and buffer. On the right is a "power-nozzle" attachment for a vacuum cleaner.



Timing belt (shown in red) is a rubber belt with teeth which mesh together with the teeth in metal sprockets to provide a positive drive.

Write to Uniroyal Technical Advisory Service, 1230 Avenue of the Americas, New York, N.Y. 10020.

We'd like to help you. After all, we have almost 1,500 patents and we'd like to put a few more of them to work.

Uniroyal holds more patents than any other rubber company.

A Hertz girl did a little something extra for a customer and got a 336 foot fan letter instead of a raise.

A short while ago, Hertz' Shirley Duensing spent an hour on the phone calling every Hertz office she could reach to find a sports car for a customer.

In return, the customer spent an hour at a computer writing her what must be the world's longest thank you note.

The customer was so pleased with the service he got from Miss Duensing, he even went so far as to suggest she deserved a raise.

The customer went too far.

Miss Duensing and 11,799 other Miss Duensings and Mr. Duensings who work for Hertz are used to doing little extra somethings for customers.

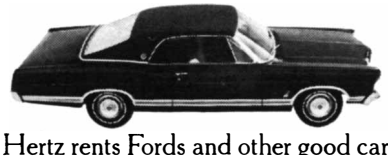
It's something they get themselves into when they come to work for us.

When you're number one in rent a cars and have a competitor who's just dying to see you become number two, going beyond the call of duty is an everyday thing.

So if somebody at Hertz does something nice for you and you feel like sending us a little thank you note—or a big one—do us a favor.

Send a carbon to our competition.

It's the underdog that's keeping the top dog on top.



Hertz rents Fords and other good cars.

Established 1845 SCIENTIFIC AMERICAN April 1967 Volume 216 Number 4

The Social Power of the Negro

How is it that immigrants such as the Irish and the Italians have been able to evolve group power in the U.S., whereas Negroes have not? The principal reason is an unrecognized disunity among Negroes

by James P. Comer

The concept of "black power" is an inflammatory one. It was introduced in an atmosphere of militancy (during James Meredith's march through Mississippi last June) and in many quarters it has been equated with violence and riots. As a result the term distresses white friends of the Negro, frightens and angers others and causes many Negroes who are fearful of white disapproval to reject the concept without considering its rationale and its merits. The fact is that a form of black power may be absolutely essential. The experience of Negro Americans, supported by numerous historical and psychological studies, suggests that the profound needs of the poorest and most alienated Negroes cannot be met—and that there can therefore be no end to racial unrest—except through the influence of a unified, organized Negro community with genuine political and economic power.

Why are Negro efforts to achieve greater unity and power considered unnecessary and even dangerous by so many people, Negro as well as white, friends as well as enemies? I believe it is because the functions of group power —and hence the consequences of political and economic impotence—are not understood by most Americans. The "melting pot" myth has obscured the critical role of group power in the adjustment of white immigrant groups in this country. When immigrants were faced with discrimination, exploitation and abuse, they turned in on themselves. Sustained psychologically by the bonds of their cultural heritage, they maintained family, religious and social institutions that had great stabilizing force. The institutions in turn fostered group unity. Family stability and group unity—plus access to political machinery, jobs in industry and opportunities on the frontier—led to group power: immigrants voted, gained political influence, held public office, owned land and operated businesses. Group power and influence expanded individual opportunities and facilitated individual achievement, and within one or two generations most immigrants enjoyed the benefits of first-class American citizenship.

The Negro experience has been very different, as I shall attempt to show in this article. The traumatic effects of separation from Africa, slavery and the denial of political and economic opportunities after the abolition of slavery created divisive psychological and social forces in the Negro community. Coordinated group action, which was certainly appropriate for a despised minority, has been too little evident; Negroes have seldom moved cohesively and effectively against discrimination and exploitation. These abuses led to the creation of an impoverished, undereducated and alienated group—a sizable minority among Negroes, disproportionately large compared with other ethnic groups. This troubled minority has a self-defeating "style" of life that leads to repeated failure, and its plight and its reaction to that plight are at the core of the continuing racial conflict in the U.S. Only a meaningful and powerful Negro community can help members of this group realize their potential, and thus alleviate racial unrest. The importance of "black power" becomes comprehensible in the light of the interrelation of disunity, impotence and alienation.

The roots of Negro division are of African origin. It is important to realize that the slave contingents brought out of Africa were not from a single ethnic group. They were from a number of groups and from many different tribes with different languages, customs, traditions and ways of life. Some were farmers, some hunters and gatherers, some traders. There were old animosities, and these were exacerbated by the dynamics of the slave trade itself. (Today these same tribal animosities are evident, as in Nigeria, where centuries-old conflict among the Ibo, Hausa and Yoruba tribes threatens to disrupt the nation. A significant number of slaves came from these very tribes.)

The cohesive potential of the captives was low to begin with, and the breakup of kinship groupings, which in Africa had defined people's roles and relations, decreased it further. Presumably if the Africans had been settled in a free land, they would in time have organized to build a new society meeting their own needs. Instead they were organized to

meet the needs of their masters. The slaves were scattered in small groups (the average holding was only between two and five slaves) that were isolated from one another. The small number and mixed origins of each plantation's slaves made the maintenance of any oral tradition, and thus of any tribal or racial identity and pride, impossible. Moreover, any grouping that was potentially cohesive because of family, kinship or tribal connections was deliberately divided or tightly controlled to prevent rebellion. Having absolute power, the master could buy and sell, could decree cohabitation, punishment or death, could provide food, shelter and clothing as he saw fit. The system was engraved in law and maintained by the religious and political authorities and the armed forces; the high visibility of the slaves and the lack of places to hide made escape almost inconceivable.

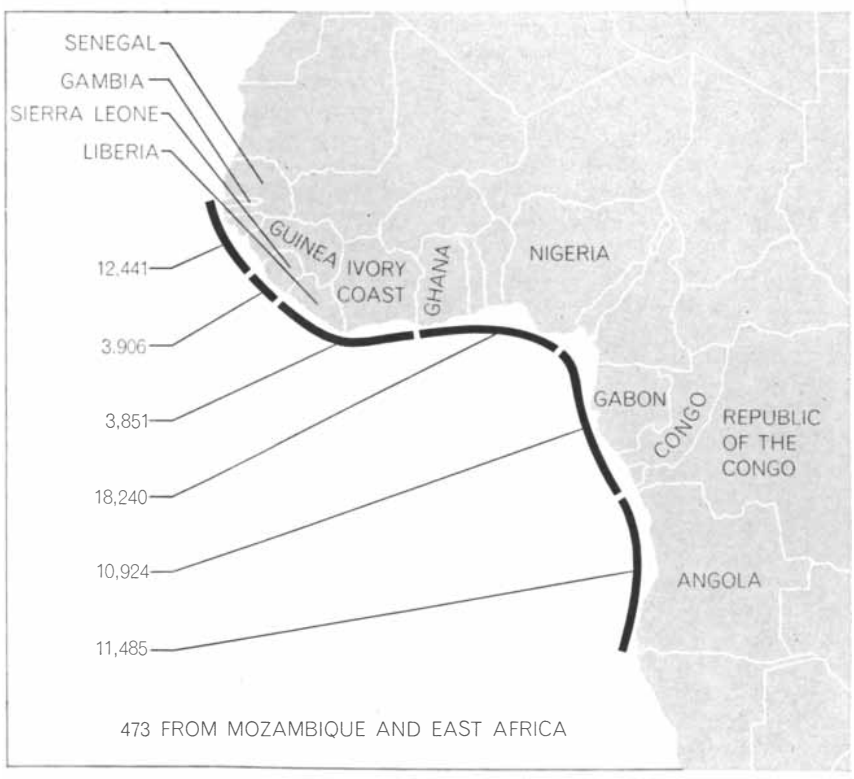
The powerless position of the slave was traumatic, as Stanley M. Elkins showed in his study of Negro slavery. The male was not the respected provider, the protector and head of his household. The female was not rearing her child to take his place in a rewarding society, nor could she count on protection from her spouse or any responsible male. The reward for hard work was not material goods and the recognition of one's fellow men but only recognition from the master as a faithful but inferior being. The master—"the man"—became the necessary object of the slave's emotional investment, the person whose approval he needed. The slave could love or hate or have ambivalent feelings about the relationship, but it was the most important relationship of his life.

In this situation self-esteem depended on closeness or similarity to the master, not on personal or group power and achievement, and it was gained in ways that tended to divide the Negro population. House slaves looked down on field hands, "mixed-bloods" on "pure blacks," slaves with rich and important masters on slaves whose masters had less prestige. There was cleavage between the "troublemakers" who promoted revolt and sabotage and the "good slaves" who betrayed them, and between slave Negroes and free ones. The development of positive identity as a Negro was scarcely possible.

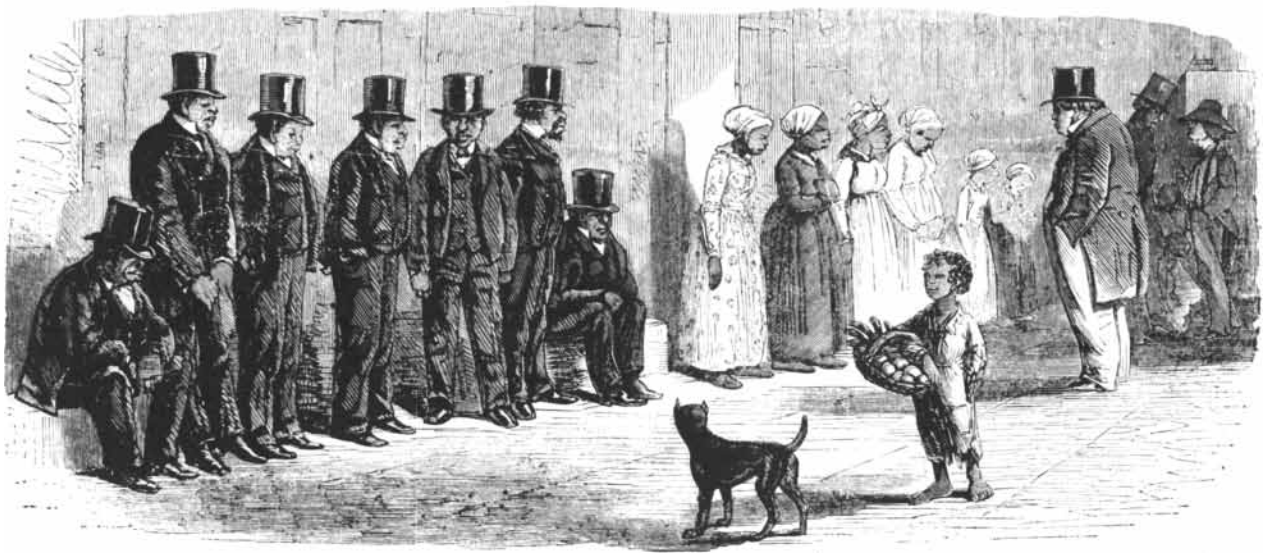
It is often assumed that with the end of the Civil War the situation of the free Negroes was about the same as that of immigrants landing in America. In reality it was quite different. Negroes emerging from slavery entered a society at a peak of racial antagonism. They had long since been stripped of their African heritage; in their years in America they had been unable to create much of a record of their own; they were deeply marked by the degrading experience of slavery. Most significant, they were denied the weapons they needed to become part of American life: economic and political opportunities. No longer of any value to their former masters, they were now direct competitors of the poor whites. The conditions of life imposed by the "Black codes" of the immediate postwar period were in many ways as harsh as slavery had been. In the first two years after the end of the war many Negroes suffered violence and death at the hands of unrestrained whites; there was starvation and extreme dislocation.

In 1867 the Reconstruction Acts put the South under military occupation and gave freedmen in the 11 Southern states the right to vote. (In the North, on the other hand, Negroes continued to be barred from the polls in all but nine states, either by specific racial qualifications or by prohibitive taxation. Until the Fifteenth Amendment was ratified in 1870, only some 5 percent of the Northern Negroes could vote.) The Reconstruction Acts also provided some military and legal protection, educational opportunities and health care. Reconstruction did not, however, make enough land available to Negroes to create an adequate power base. The plantation system meant that large numbers of Negroes remained under tight control and were vulnerable to economic reprisals. Although Negroes could outvote whites in some states and did in fact control the Louisiana and South Carolina legislatures, the franchise did not lead to real power.

This lack of power was largely due to the Negro's economic vulnerability, but the group divisions that had developed during slavery also played a part. It was the "mixed-bloods" and the house slaves of middle- and upper-class whites who had acquired some education and skills under slavery; now many of these people became Negro leaders. They often had emotional ties to whites and a need to please them, and they advanced the cause of the Negroes as a group most gingerly. Moreover, not understanding the causes of the apathy, lack of achievement and asocial behavior of some of their fellows, many of them found their Negro identity a source of shame rather than psychological support, and they were ready to subordinate the



VARIED ORIGIN of Negroes imported as slaves helps to explain divisions among Negro Americans. The map shows, as an example, the origin of slaves landed in South Carolina between 1733 and 1785. Even slaves from the same region were often from different tribes. Unlike white immigrants, Negroes had no common bonds of history, traditions and customs.



SLAVERY made any organized Negro community impossible, stripped Negroes of racial pride and group traditions and created divisions among them. This engraving from *Harper's Weekly* shows house slaves lined up for auctioning by a trader in New Orleans.

needs of the group to personal gains that would give them as much social and psychological distance from their people as possible. The result was that Negro leaders, with some notable exceptions, often became the tools of white leaders. Throughout the Reconstruction period meaningful Negro power was being destroyed, and long before the last Negro disappeared from Southern legislatures Negroes were powerless.

Under such circumstances Negro economic and educational progress was severely inhibited. Negro-owned businesses were largely dependent on the impoverished Negro community and were operated by people who had little education or experience and who found it difficult to secure financing; they could not compete with white businesses. Negroes were largely untrained for anything but farm labor or domestic work, and a white social structure maintaining itself through physical force and economic exploitation was not likely to provide the necessary educational opportunities. Minimal facilities, personnel and funds were provided for the "Negro schools" that were established, and only the most talented Negroes were able—if they were lucky—to obtain an education comparable to that available to whites.

As John Hope Franklin describes it in *Reconstruction after the Civil War,* the Reconstruction was ineffective for the vast majority of Negroes, and it lasted only a short time: Federal troops had left most Southern states by 1870. While Negroes were still struggling for a first foothold, national political developments made it advisable to placate Southern leaders, and the Federal troops were recalled from the last three Southern states in 1877. There was a brief period of restraint, but it soon gave way to violence and terror on a large scale. Threats and violence drove Negroes away from the polls. Racist sheriffs, legislators and judges came into office. Segregation laws were passed, buttressed by court decisions and law enforcement practices and erected into an institution that rivaled slavery in its effectiveness in excluding Negroes from public affairs—business, the labor movement, government and public education.

At the time—and in later years—white people often pointed to the most depressed and unstable Negro and in effect made his improvement in education and behavior a condition for the granting of equal opportunities to all Negroes. What kind of people made up this most disadvantaged segment of the Negro community? I believe it can be shown that these were the Negroes who had lived under the most traumatic and disorganized conditions as slaves. Family life had been prohibited, discouraged or allowed to exist only under precarious conditions, with no recourse from sale, separation or sexual violation. Some of these people had been treated as breeding stock or work animals; many had experienced brutal and sadistic physical and sexual assaults. In many cases the practice of religion was forbidden, so that even self-respect as "a child of God" was denied them.

Except for running away (and more tried to escape than has generally been realized) there was nothing these slaves could do but adopt various defense mechanisms. They responded in various ways, as is poignantly recorded in a collection of firsthand accounts obtained by Benjamin A. Botkin. Many did as little work as they could without being punished, thus developing work habits that were not conducive to success after slavery. Many sabotaged the master's tools and other property, thus evolving a disrespect for property in general. Some resorted to a massive denial of the reality of their lives and took refuge in apathy, thus creating the slow-moving, slow-thinking stereotype of the Southern Negro. Others resorted instead to boisterous "acting out" behavior and limited their interests to the fulfillment of such basic needs as food and sex.

After slavery these patterns of behavior persisted. The members of this severely traumatized group did not value family life. Moreover, for economic reasons and by force of custom the family often lacked a male head, or at least a legal husband and father. Among these people irresponsibility, poor work habits, disregard for conventional standards and anger toward whites expressed in violence toward one another combined to form a way of life—a style—that caused them to be rejected and despised by whites and other Negroes alike. They were bound to fail in the larger world.

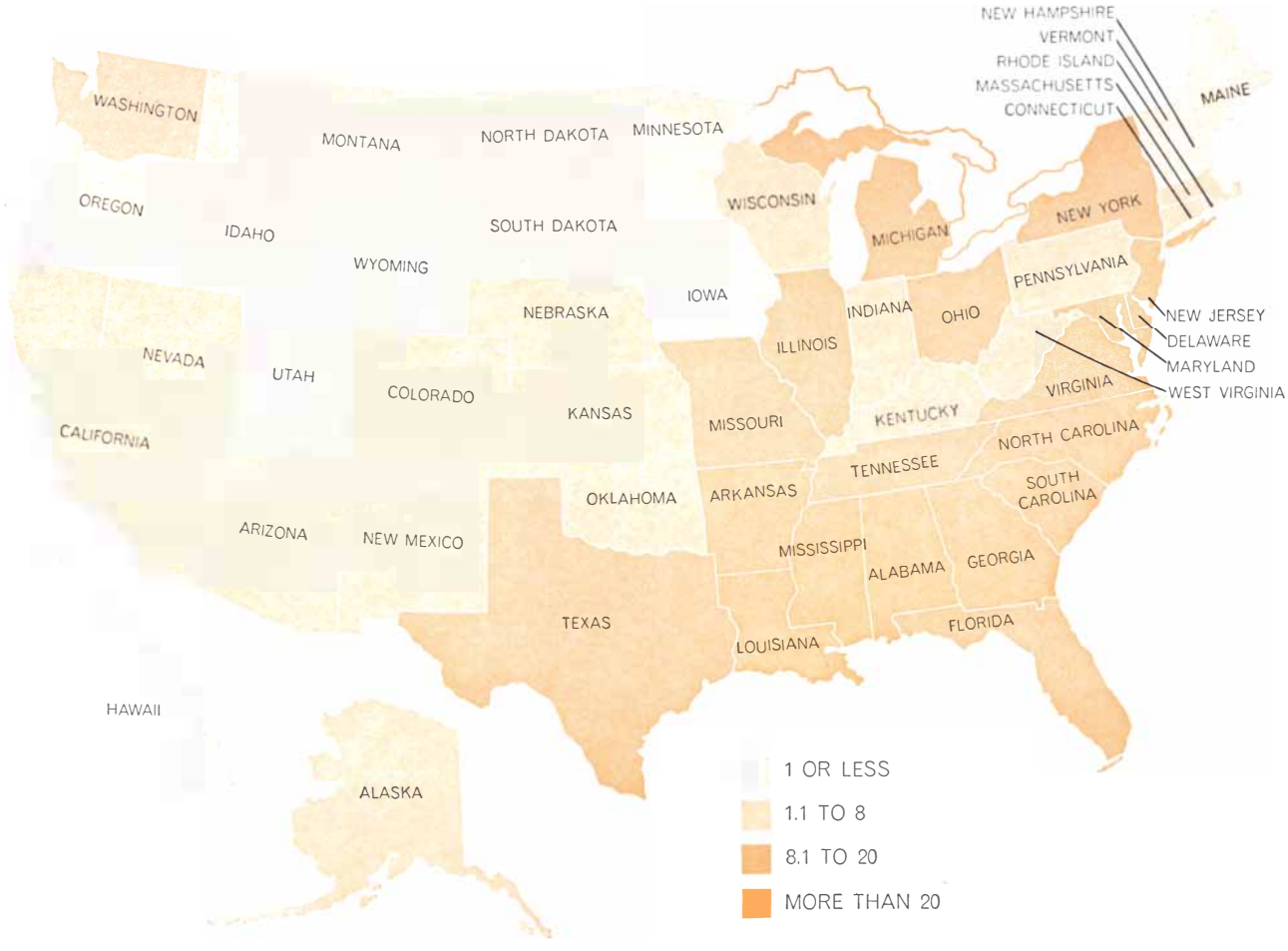
When they did fail, they turned in on their own subculture, which accordingly became self-reinforcing. Children born into it learned its way of life. Isolated and also insulated from outside influences, they had little opportunity to

change. The values, behavior patterns and sense of alienation transmitted within this segment of the population from generation to generation account for the bulk of the illegitimacy, crime and other types of asocial behavior that are present in disproportionate amounts in the Negro community today. This troubled subgroup has always been a minority, but its behavior constitutes many white people's concept of "typical" Negro behavior and even tarnishes the image many other Negroes have of themselves. Over the years defensive Negro leaders have regularly blamed the depressed subgroup for creating a bad image; the members of the subgroup have blamed the leaders for "selling out." There has been just enough truth in both accusations to keep them alive, accentuating division and perpetuating conflicts, and impeding the development of group consciousness, cooperation, power and mutual gains.

It is surprising, considering the harsh conditions of slavery, that there were any Negroes who made a reasonable adjustment to freedom. Many had come from Africa with a set of values that included hard work and stability of family and tribal life. (I suspect, but I have not been able to demonstrate, that in Africa many of these had been farmers rather than hunters and gatherers.) As slaves many of them found the support and rewards required to maintain such values through their intense involvement in religion. From this group, after slavery, came the God-fearing, hardworking, law-abiding domestics and laborers who prepared their children for responsible living, in many cases making extreme personal sacrifices to send them to trade school or college. (The significance of this church-oriented background in motivating educational effort and success even today is indicated by some preliminary findings of a compensatory education program for which I am a consultant. Of 125 Negro students picked for the program from 10 southeastern states solely on the basis of academic promise, 95 percent have parents who are regular churchgoers, deeply involved as organizers and leaders in church affairs.)

For a less religious group of Negroes the discovery of meaning, fulfillment and a sense of worth lay in a different direction. Their creative talents brought recognition in the arts, created the blues and jazz and opened the entertainment industry to Negroes. Athletic excellence provided another kind of achievement. Slowly, from among the religious, the creative and the athletic, a new, educated and talented middle class began to emerge that had less need of white approval than the Negroes who had managed to get ahead in earlier days. Large numbers of Negroes should have risen into the middle class by way of these relatively stable groups, but because of the lack of Negro political and economic power and the barriers of racial prejudice many could not. Those whose aspirations were frustrated often reacted destructively by turning to the depressed Negro subgroup and its way of life; the subculture of failure shaped by slavery gained new recruits and was perpetuated by a white society's obstacles to acceptance and achievement.

In the past 10 years or so the "Negro revolt"—the intensified legal actions,



STATE-BY-STATE DISTRIBUTION of the Negro population is given as of 1960. The shading indicates each state's Negro population as a percent of the state's total population. In the North it is the big-city states that have the higher concentrations of Negroes.

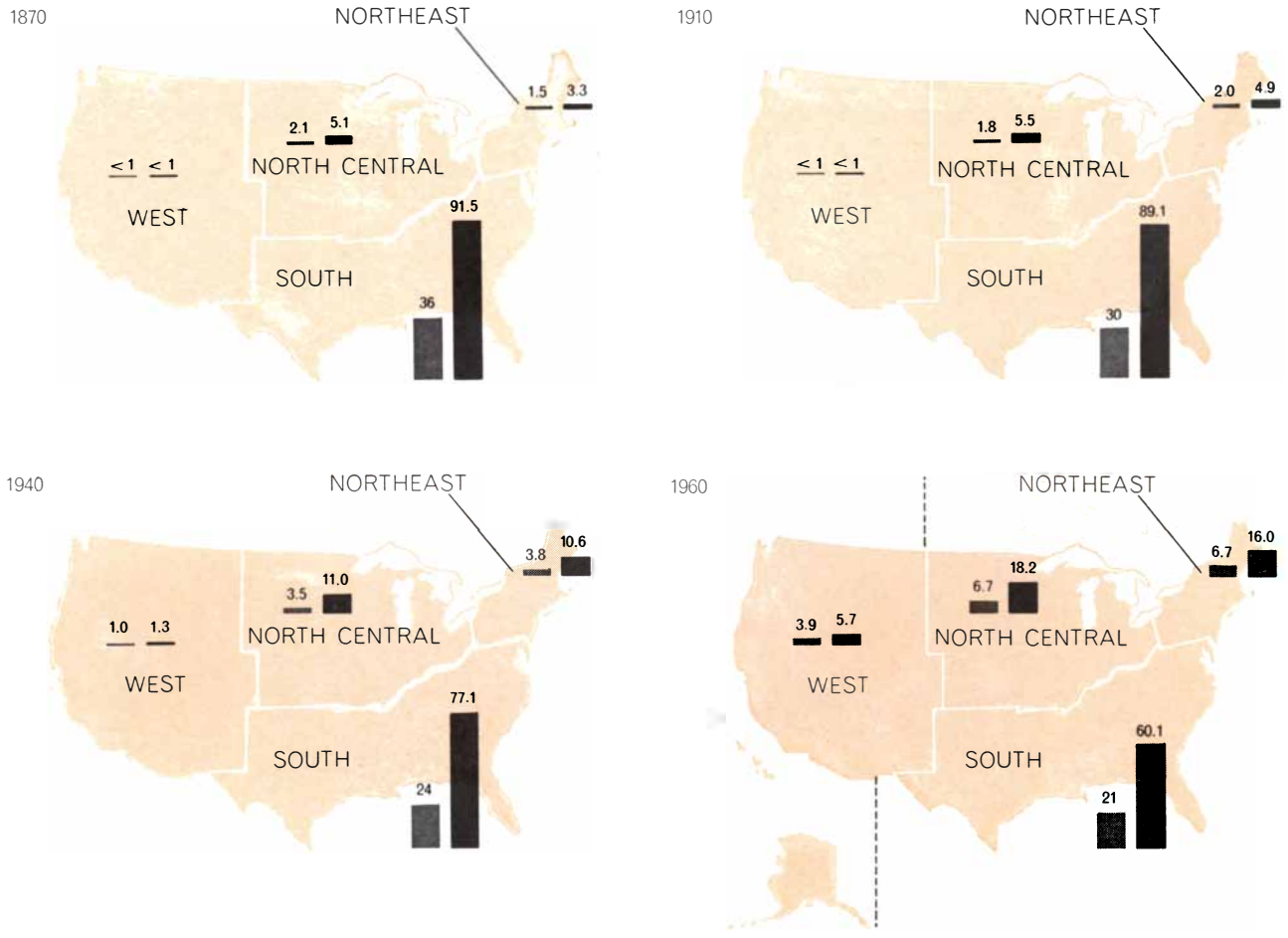
nonviolent demonstrations, court decisions and legislation—and changing economic conditions have brought rapid and significant gains for middle-class Negroes. The mass of low-income Negroes have made little progress, however; many have been aroused by civil rights talk but few have benefited. Of all Negro families, 40 percent are classified as "poor" according to Social Security Administration criteria. (The figure for white families is 11 percent.) Low-income Negroes have menial jobs or are unemployed; they live in segregated neighborhoods and are exploited by landlords and storekeepers; they are often the victims of crime and of the violent, displaced frustrations of their friends and neighbors. The urban riots of the past few years have been the reaction of a small segment of this population to the frustrations of its daily existence.

Why is it that so many Negroes have been unable to take advantage of the Negro revolt as the immigrants did of opportunities offered them? The major reason is that the requirements for economic success have been raised. The virtually free land on the frontier is gone. The unskilled and semiskilled jobs that were available to white immigrants are scarce today, and many unions controlled by lower-middle-class whites bar Negroes to keep the jobs for their present members. The law does not help here because Negroes are underrepresented in municipal and state legislative bodies as well as in Congress. Negroes hold few policy-making positions in industry and Negro small businesses are a negligible source of employment.

Employment opportunities exist, of course—for highly skilled workers and technicians. These jobs require education and training that many Negroes, along with many white workers, lack. The training takes time and requires motivation, and it must be based on satisfactory education through high school. Most poor Negroes lack that education, and many young Negroes are not getting it today. There are Negro children who are performing adequately in elementary school but who will fail by the time they reach high school, either because their schools are inadequate or because their homes and subculture will simply not sustain their efforts in later years.

It is not enough to provide a "head start"; studies have shown that gains made as the result of the new preschool enrichment programs are lost, in most cases, by the third grade. Retraining programs for workers and programs for high school dropouts are palliative measures that have limited value. Some of the jobs for which people are being trained will not exist in a few years. Many students drop out of the dropout programs. Other students have such self-defeating values and behavior that they will not be employable even if they complete the programs.

A number of investigators (Daniel P. Moynihan is one) have pointed to the structure of the poorer Negro family as the key to Negro problems. They point to an important area but miss the crux of the problem. Certainly the lack of a stable family deprives many Negro children of psychological security and of the values and behavior patterns they need in order to achieve success. Certainly



REGIONAL DISTRIBUTION of the Negro population is shown. The gray bars give each census region's Negro population as a percent of the region's total population; the solid bars show what percent of the total U.S. Negro population was in each region.

many low-income Negro families lack a father. Even if it were possible to legislate the father back into the home, however, the grim picture is unchanged if his own values and conduct are not compatible with achievement. A father frustrated by society often reacts by mistreating his children. Even adequate parents despair and are helpless in a subculture that leads their children astray. The point of intervention must be the subculture that impinges on the family and influences its values and style of behavior and even its structure.

How, then, does one break the circle? Many white children who found their immigrant family and subculture out of step with the dominant American culture and with their own desires were able to break away and establish a sense of belonging to a group outside their own—if the pull was strong enough. Some children in the depressed Negro group do this too. A specific pull is often needed: some individual or institution that sets a goal or acts as a model. The trouble is that racial prejudice and alienation from the white and Negro middle class often mean that there is little pull from the dominant culture on lower-class Negro children. In my work in schools in disadvantaged areas as a consultant from the Child Study Center of Yale University I have found that many Negro children perceive the outside culture as a separate white man's world. Once they are 12 or 14 years old—the age at which a firm sense of racial identity is established—many Negroes have a need to shut out the white man's world and its values and institutions and also to reject "white Negroes," or the Negro middle class. Since these children see their problems as being racial ones, they are more likely to learn how to cope with these problems from a middle-class Negro who extends himself than from a white person, no matter how honest and free of hostility and guilt the white person may be.

Unfortunately the Negro community is not now set up to offer its disadvantaged members a set of standards and a psychological refuge in the way the white immigrant subcultures did. There is no Negro institution beyond the family that is enough in harmony with the total American culture to transmit its behavioral principles and is meaningful enough to Negroes to effect adherence to those principles and sufficiently accepted by divergent elements of the Negro community to act as a cohesive force. The church comes closest to performing this function, but Negroes belong to an exceptional number of different denominations, and in many cases the denominations are divided and antagonistic. The same degree of division is found in the major fraternal and civic organizations and even in civil rights groups.

There is a special reason for some of the sharp divisions in Negro organizations. With Negroes largely barred from business, politics and certain labor unions, the quest for power and leadership in Negro organizations has been and continues to be particularly intense, and there is a great deal of conflict. Only a few Negroes have a broad enough view of the total society to be able to identify the real sources of their difficulties. And the wide divergence of their interests often makes it difficult for them to agree on a course of action. All these factors make Negro groups vulnerable to divide-and-conquer tactics, either inadvertent or deliberate.

Viewing such disarray, altruistic white people and public and private agencies have moved into the apparent vacuum—often failing to recognize that, in spite of conflict, existing Negro institutions were meeting important psychological needs and were in close contact with their people. Using these meaningful institutions as vehicles for delivering new social services would have strengthened the only forces capable of supporting and organizing the Negro community. Instead the new agencies, public and private, have ignored the existing institutions and have tried to do the job themselves. The agencies often have storefront locations and hire some "indigenous" workers, but the class and racial gap is difficult to cross. The thong-sandaled, long-haired white girl doing employment counseling may be friendly and sympathetic to Negroes, but she cannot possibly tell a Negro youngster (indeed, she does not know that she should tell him): "You've got to look better than the white applicant to get the job." Moreover, a disadvantaged Negro —or any Negro—repeatedly helped by powerful white people while his own group appears powerless or unconcerned is unlikely to develop satisfactory feelings about his group or himself. The effects of an undesirable racial self-concept among many Negroes have been documented repeatedly, yet many current programs tend to perpetuate this basic problem rather than to relieve it.

A solution is suggested by the fact that many successful Negroes no longer feel the need to maintain psychological and social distance from their own people. Many of them want to help. Their presence and tangible involvement in the Negro community would tend to balance the pull—the comforts and the immediate pleasures—of the subculture. Because the functions of Negro organizations have been largely preempted by white agencies, however, no Negro institution is available through

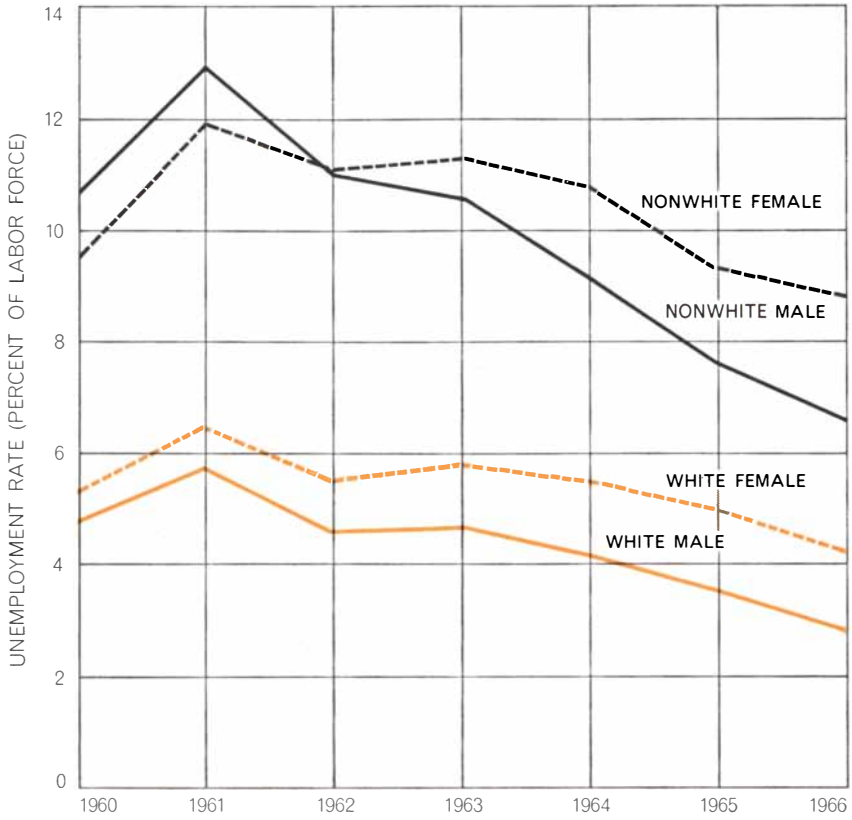
LACK OF EDUCATION has handicapped Negroes. The charts compare segregated public school services for whites (*colored bars*) and Negroes (*gray bars*) in 17 Southern states and the District of Columbia in the years 1933–1934 (*three top charts*) and 1939–1940 (*bottom*).

which such people can work to overcome a century of intra-Negro class alienation.

Recently a few Negroes have begun to consider a plan that could meet some of the practical needs, as well as the spiritual and psychological needs, of the Negro community. In Cleveland, New York, Los Angeles and some smaller cities new leaders are emerging who propose to increase Negro cohesiveness and self-respect through self-help enterprises: cooperatives that would reconstruct slums or operate apartment buildings and businesses providing goods and services at fair prices. Ideally these enterprises would be owned by people who mean something to the Negro community—Negro athletes, entertainers, artists, professionals and government workers—and by Negro churches, fraternal groups and civil rights organizations. The owners would share control of the enterprises with the people of the community.

Such undertakings would be far more than investment opportunities for well-to-do Negroes. With the proper structure they would become permanent and tangible institutions on which the Negro community could focus without requiring a "white enemy" and intolerable conditions to unify it. Through this mechanism Negroes who had achieved success could come in contact with the larger Negro group. Instead of the policy king, pimp and prostitute being the models of success in the subculture, the Negro athlete, businessman, professional and entertainer might become the models once they could be respected because they were obviously working for the Negro community. These leaders would then be in a position to encourage and promote high-level performance in school and on the job. At the same time broad measures to "institutionalize" the total Negro experience would increase racial pride, a powerful motivating force. The entire program would provide the foundation for unified political action to give the Negro community representatives who speak in its best interests.

That, after all, has been the pattern in white America. There was, and still is, Irish power, German, Polish, Italian and Jewish power—and indeed white Anglo-Saxon Protestant power—but color obviously makes these groups less clearly identifiable than Negroes. Churches and synagogues, cultural and fraternal societies, unions, business associations and networks of allied families and "clans" have served as centers of power that maintain group consciousness, provide jobs and develop new opportunities and join to form pressure and voting blocs.



UNEMPLOYMENT RATE is higher among nonwhite workers than among white; the ratio has been about two to one in the past decade. Younger Negroes have been hardest hit.

The "nationality divisions" of the major parties and the balanced ticket are two reminders that immigrant loyalties are still not completely melted.

The idea of creating Negro enterprises and institutions is not intended as a rejection of genuinely concerned white people or as an indictment of all existing organizations. White people of good will with interest, skills and funds are needed and—contrary to the provocative assertions of a few Negroes—are still welcome in the Negro community. The kind of "black power" that is proposed would not promote riots; rather, by providing constructive channels for the energies released by the civil rights movement, it should diminish the violent outbursts directed against the two symbols of white power and oppression: the police and the white merchants.

To call for Negro institutions, moreover, is not to argue for segregation or discrimination. Whether we like it or not, a number of large cities are going to become predominantly Negro in a short time. The aim is to make these cities places where people can live decently and reach their highest potential with or without integration. An integrated society is the ultimate goal, but it may be a second stage in some areas. Where immediate integration is possible it should be effected, but integration takes place most easily among educated and secure people. And in the case of immediate integration an organized and supportive Negro community would help its members to maintain a sense of adequacy in a situation in which repeated reminders of the white head start often make Negroes feel all the more inferior.

The power structure of white society—industry, banks, the press, government—can continue, either inadvertently or deliberately, to maintain the divisions in the Negro community and keep it powerless. Social and economic statistics and psychological studies indicate that this would be a mistake. For many reasons the ranks of the alienated are growing. No existing program seems able to meet the needs of the most troubled and troublesome group. It is generally agreed that massive, immediate action is required. The form of that action should be attuned, however, to the historically determined need for Negro political and economic power that will facilitate Negro progress and give Negroes a reasonable degree of control over their own destiny.

The Induction of Cancer by Viruses

Normal cells cultured in glassware can be transformed into cancer cells by several viruses. Such "model" systems are studied to find how the virus, with fewer than 10 genes, can produce the change

by Renato Dulbecco

Cancer, one of the major problems of modern medicine, is also a fascinating biological problem. In biological terms it is the manifestation of changes in one of the more general properties of the cells of higher organisms: their ability to adjust their growth rate to the architectural requirements of the organism. To learn more about cancer is therefore to learn more about this basic control mechanism. Over the past decade dramatic advances in our knowledge of cancer have resulted from the use of viruses to elicit the disease in simple model systems. A certain understanding of the molecular aspects of cancer has been attained, and the foundation has been laid for rapid progress in the foreseeable future.

A cancer arises from a single cell that undergoes permanent hereditary changes and consequently multiplies, giving rise to billions of similarly altered cells. The development of the cancer may require other conditions, such as failure of the immunological defenses of the organism. The fundamental event, however, is the alteration of that one initial cell.

There are two main changes in a cancer cell. One change can be defined as being of a regulatory nature. The multiplication of the cells of an animal is carefully regulated; multiplication takes place only when it is required, for example by the healing of a wound. The cancer cell, on the other hand, escapes the regulatory mechanisms of the body and is continuously in a multiplication cycle.

The other change of the cancer cell concerns its relations with neighboring cells in the body. Normal cells are confined to certain tissues, according to rules on which the body's overall architecture depends. The cancer cell is not confined to its original tissue but invades other tissues, where it proliferates.

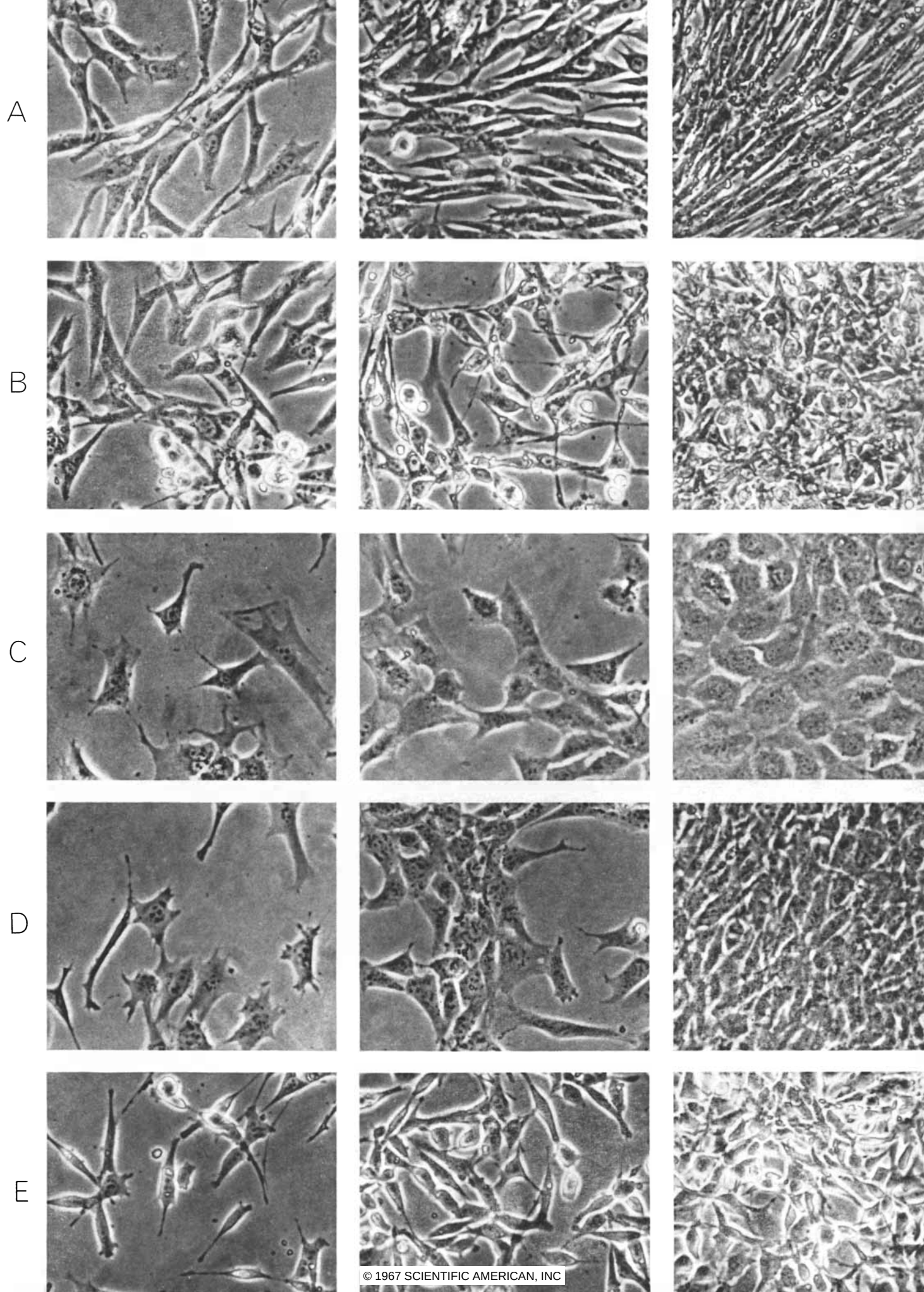
The basic biological problem of cancer is to identify the molecular changes that occur in the initial cancer cell and determine what causes the changes. The particular site in the cell affected by the changes can be approximately inferred from the nature of the changes themselves. For example, a change in the regulation of cell growth and multiplication must arise from a change in the regulation of a basic process in the cell, such as the synthesis of the genetic material deoxyribonucleic acid (DNA). The alterations in relations with neighboring cells are likely to flow from changes in the outside surface of the cell, which normally recognizes and responds to its immediate environment.

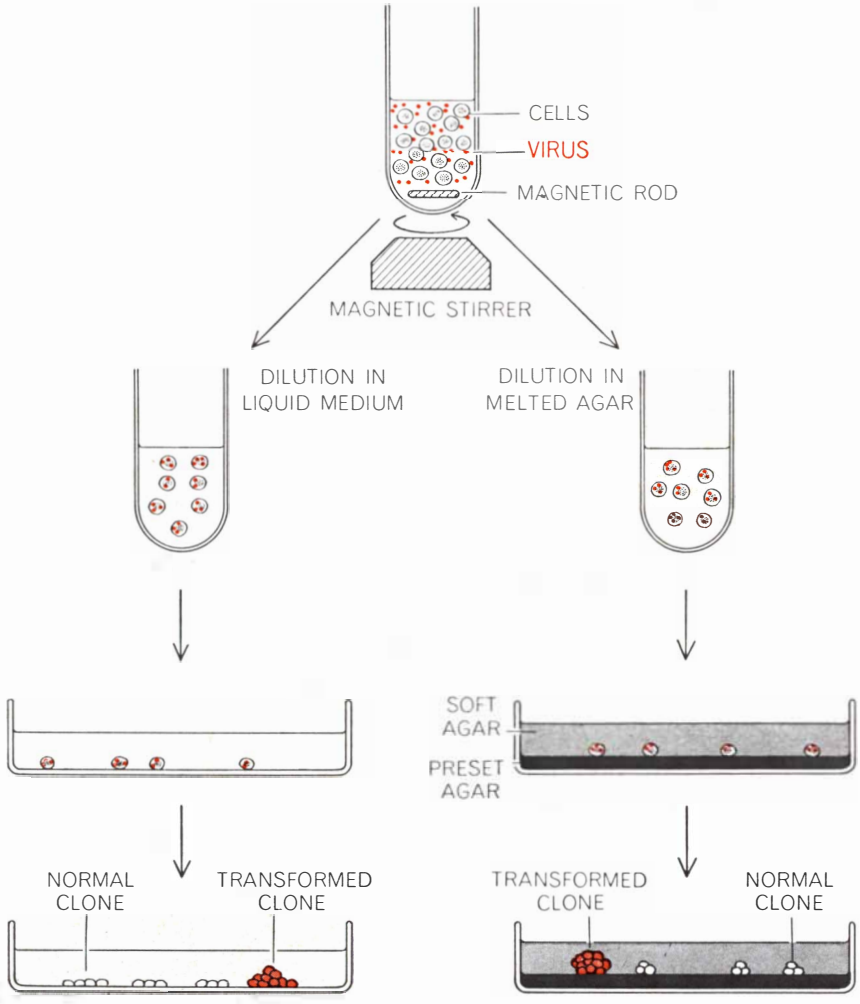
Experimental work directed toward the solution of this central problem makes use of cancers induced artificially rather than cancers that occur spontaneously. Spontaneous cancers are not suitable for experiments because by definition their occurrence cannot be controlled; moreover, when a spontaneous cancer becomes observable, its cells have often undergone numerous changes in addition to the initial one. In recent years model systems for studying cancers have been developed by taking advantage of the fact that animal cells can easily be grown in vitro—in test tubes or boxes of glass or plastic filled with a suitable liquid medium. This is the technique of tissue culture.

Since the use of tissue culture has many obvious experimental advantages, methods for the induction of cancer in vitro have been developed. The most successful and most widely employed systems use viruses as the cancer-inducing agent. In these systems the initial cellular changes take place under controlled conditions and can be followed closely by using an array of technical tools: genetic, biochemical, physical and immunological.

It may seem strange that viruses, which are chemically complex structures, would be preferable for experimental work to simple cancer-inducing chemicals, of which many are available. The fact is that the action of cancer-inducing chemicals is difficult to elucidate; they have complex chemical effects on a large number of cell constituents. Furthermore, even if one were to make the simple and reasonable assumption that chemicals cause cancer by inducing mutations in the genetic material of the cells, the problem would remain enormously difficult. It would still be almost impossible to know which genes are affected, owing to the large number of genes in which the cancer-causing mu-

NORMAL AND TRANSFORMED cells are shown on the opposite page in three stages of density, or growth, increasing to the right in each row. Normal cells (*A*, *C*) tend to adhere to one another and form either a pattern of bundles (*A*) or a mosaic-like arrangement referred to as pavement (*C*). Cells that have been transformed by viruses (*B*, *D*, *E*) generally overlap one another and form irregular patterns. The cellular bodies are dark gray and contain a lighter round or oval nucleus in which two or more dark nuclei are embedded. Two of the cultures (*A*, *B*) are a strain of hamster cells identified as "BHK." The other three cultures are "3T3" cells derived from a mouse. Two of the cultures (*B*, *E*) have been transformed by polyoma virus; one (*D*) has been transformed by simian virus 40, also known as SV 40. The cells were photographed in the living state by the author, using a phase-contrast microscope, at the Salk Institute for Biological Studies.





TRANSFORMATION EXPERIMENT produces cell colonies that differ in appearance, depending on the nature of the culture medium. BHK (hamster) cells are first incubated with polyoma virus for about an hour at 37 degrees centigrade, being stirred constantly. During this time viral particles enter the cells. The infected cells are then diluted either in a liquid medium or in melted agar and transferred to culture dishes. In the agar system the melted agar is poured on a layer of preset agar. The dishes are incubated at 37 degrees C. Cell colonies in the liquid medium develop in contact with the bottom of the container, whereas those in agar form spherical colonies above the preset agar layer. The results of using the two kinds of media are shown in the photographs on the opposite page.

tation could occur. It is estimated that there are millions of genes in an animal cell, and the function of most of them is unknown. With viruses the situation can be much simpler. As I shall show, cancer is induced by the genes of the virus, which, like the genes of animal cells, are embodied in the structure of DNA. Since the number of viral genes is small (probably fewer than 10 in the system discussed in this article), it should be possible to identify those responsible for cancer induction and to discover how they function in the infected cells. The problem can thus be reduced from one of cellular genetics to one of viral genetics. The reduction is of several orders of magnitude.

A number of different viruses have the ability to change normal cells into cancer cells in vitro. In our work at the Salk Institute for Biological Studies we employ two small, DNA-containing viruses called the polyoma virus and simian virus 40 (SV 40), both of which induce cancer when they are inoculated into newborn rodents, particularly hamsters, rats and, in the case of the polyoma virus, mice. Together these viruses are referred to as the small papovaviruses.

In tissue-culture studies two types of host cell are employed with each virus. In one cell type—the "productive" host cell—the virus causes what is known as a productive infection: the virus multiplies unchecked within the cell and finally kills it. In another type of cell—the "transformable" host cell—the virus causes little or no productive infection but induces changes similar to those in cancer cells. This effect of infection is called transformation rather than cancer induction because operationally it is recognized from the altered morphology of the cells in vitro rather than from the production of cancer in an animal.

In the experimental work it is convenient to employ as host cells, particularly for transformation studies, permanent lines of cellular descent, known as clonal lines, that are derived from a single cell and are therefore uniform in composition. By using these clonal lines the changes caused by the virus can be studied without interference from other forms of cellular variation; one simply compares the transformed cells with their normal counterparts. Two lines that are widely employed are the "BHK" line, which was obtained from a hamster by Ian A. Macpherson and Michael G. P. Stoker of the Institute of Virology of the University of Glasgow, and the "3T3" line, which was obtained from a mouse by George J. Todaro and Howard Green of the New York University School of Medicine. BHK cells are particularly suitable for transformation by the polyoma virus; 3T3 cells are readily transformed by SV 40 and less easily by the polyoma virus.

In a typical transformation experiment a suspension of cells in a suitable liquid medium is mixed with the virus [*see illustration at left*]. The cells are incubated at 37 degrees centigrade for an hour; they are stirred constantly to prevent them from settling and clumping together. A sample of the cells is then distributed in a number of sterile dishes of glass or plastic that contain a suitable nutrient medium. The dishes are incubated at 37 degrees C. for a period ranging from one to three weeks. The cells placed in the dishes settle and adhere to the bottom. There they divide, each cell giving rise to a colony [*see illustration at left on opposite page*]. If the number of cells is sufficiently small, the colonies remain distinct from one another and are recognizable to the unaided eye after about 10 days' incubation; they can be studied sooner with a low-power microscope. When the colonies are fully developed, they are usually fixed and stained. Colonies of normal and transformed cells can be recognized on the basis of morphological characters I shall describe. By picking a colony of transformed cells and reseeding its cells in a fresh culture, clonal lines of transformed cells can be easily prepared. The transformation of BHK cells can also be studied by a selective method that in-

volves suspending the cells in melted agar, which then sets. Transformed cells give rise to spherical colonies, visible to the unaided eye, whereas normal cells grow little or not at all [*see illustration at right below*].

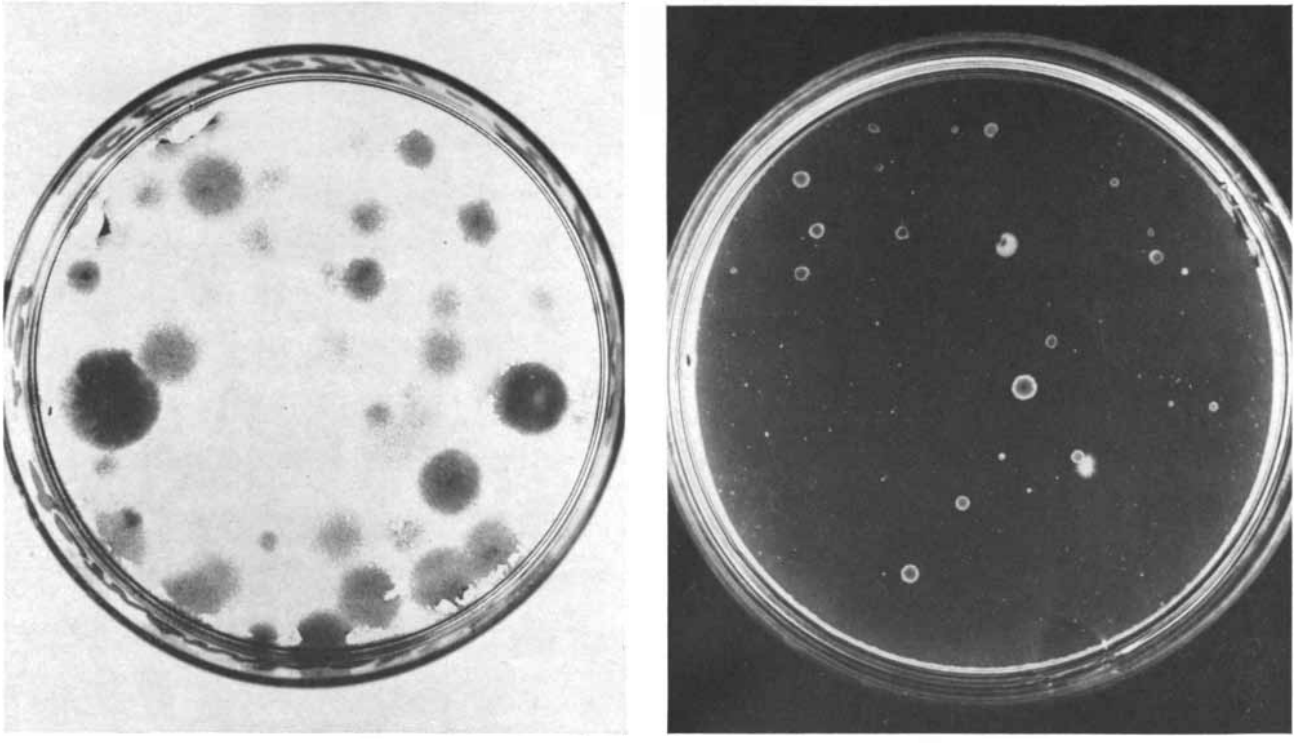
Colonies of transformed cells, and cultures derived from such colonies, differ morphologically from their normal counterparts in two obvious ways; these differences show that changes have occurred in the regulatory properties of the cells and also in the way they relate to their neighbors. The transformed cultures are thicker because they continue to grow rapidly, whereas normal cultures slow down or stop; in addition the transformed cells are not regularly oriented with respect to each other because they fail to respond to cell-to-cell contact. The altered response to contacts can be best appreciated in time-lapse motion pictures of living cultures.

In sparse BHK cultures the cells move around actively; if a cell meets another cell in its path, it usually stops moving and slowly arranges itself in contact with and parallel to the other cell. In this way a characteristic pattern of parallel lines and whorls is generated, since the cells do not climb over each other. In a culture of a derivative of the BHK line transformed by polyoma virus the same active movement of the cells is observed. When a cell meets another in its path, however, it continues to move, climbing over the other. In this way the arrangement of the cells becomes chaotic, without any discernible pattern [*see illustration on page 29*].

These alterations of the transformed cells indicate their intimate relatedness to cancer cells. The relatedness is shown in a more dramatic way by the ability of the transformed cells to grow into a cancer when injected, in sufficient number, into a live host that does not present an insurmountable immunological barrier to their survival. For example, BHK cells, which were originally obtained from a hamster, can be transplanted into hamsters; similarly, cells of inbred strains of mice can easily be transplanted into mice of the same strain. The injection of roughly a million transformed cells into a hamster or mouse will be followed by the development of a walnut-sized tumor at the site of inoculation in about three weeks. Untransformed cells, on the other hand, fail to produce tumors.

A crucial finding is that the transformation of healthy cells is attributable to the genes present in the viral DNA that penetrates the cells at infection. The viral genes are the units of information that determine the consequences of infection. Each viral particle contains a long, threadlike molecule of DNA wrapped in a protein coat. Each of these molecules is made up of two strands twisted around each other. Attached to the molecular backbone of each strand is the sequence of nitrogenous bases that contains the genetic information of the virus in coded form. There are four kinds of base, and the DNA molecule of a papovavirus has some 5,000 bases on each strand. Each species of virus has a unique sequence of bases in its DNA; all members of a species have the same base sequence, except for isolated differences caused by mutations.

The double-strand molecule of DNA is so constructed that a given base in one strand always pairs with a particular base in the other strand; these two associated bases are called complementary. Thus the two DNA strands are also complementary in base sequence. Complementary bases form bonds with each other; the bonds hold the two strands firmly together. The two strands fall apart if a solution of DNA is heated to a fairly high temperature, a process



TWO KINDS OF CELL COLONY are depicted in these photographs made in the author's laboratory. Colonies formed by 3T3 (mouse) cells exposed to SV 40 particles grow on the bottom of a plastic dish under a liquid nutrient medium (*left*). The two large, dark colonies on opposite sides of the culture dish consist of transformed cells. The other colonies are made up of normal cells. Colonies formed by BHK (hamster) cells exposed to polyoma virus are suspended in agar (*right*). Transformed cells create large spherical colonies, which appear as white disks with gray centers. Colonies of normal cells are small or invisible.

called denaturation. If the heated solution is then slowly cooled, a process called annealing, the complementary strands unite again and form double-strand molecules identical with the original ones.

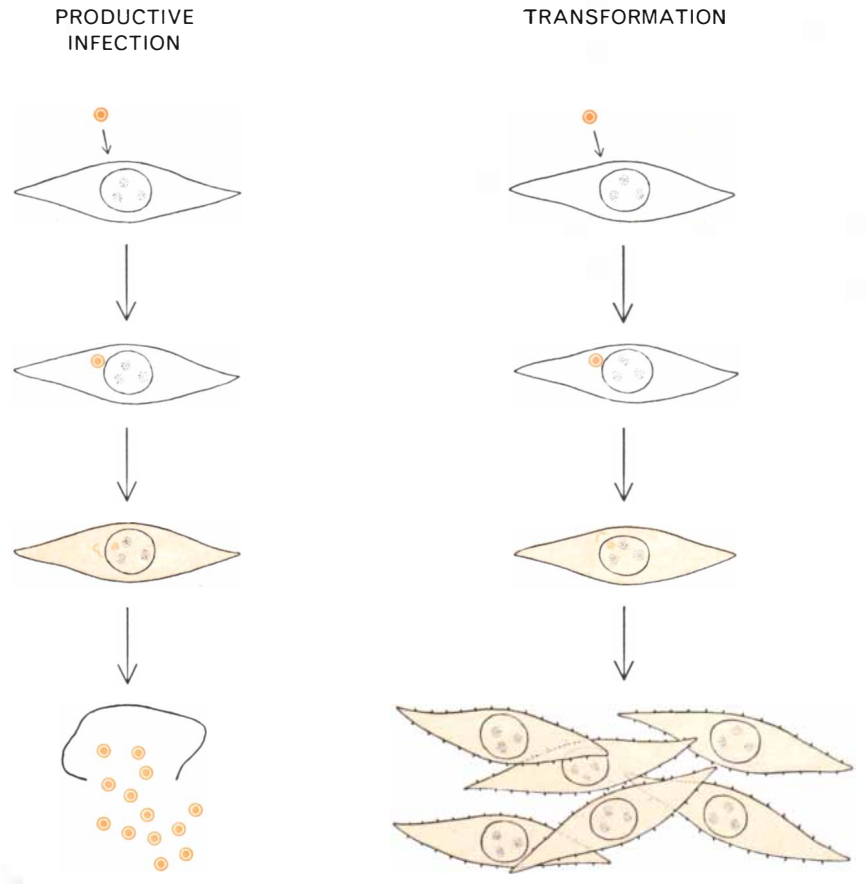
When suitable cells are exposed to a virus, a large number of viral particles are taken up into the cells in many small vesicles, or sacs, which then accumulate around the nucleus of the cell. Most of the viral particles remain inert, but the protein coat of some is removed and their naked DNA enters the inner compartments of the cell, ultimately reaching the nucleus. Evidence that cell transformation is caused by the viral DNA, and by the genes it carries, is supplied by two experimental results.

The first result is that cell transformation can be produced by purified viral DNA, obtained by removing the protein coat from viral particles; this was first shown by G. P. Di Mayorca and his colleagues at the Sloan-Kettering Institute. The extraction of the DNA is usually accomplished by shaking the virus in concentrated phenol. In contrast, the empty viral coats do not cause transformation. These DNA-less particles are available for experimentation because they are synthesized in productively infected cells together with the regular DNA-containing particles. The empty coats have a lower density than the complete viral particles; hence the two can be separated if they are spun at high speed in a heavy salt solution, the technique known as density-gradient centrifugation.

A more sophisticated experiment performed at the University of Glasgow also rules out the possibility that the transforming activity resides in contaminant molecules present in the extracted DNA. The basis for this experiment is the shape of the DNA molecules of papovaviruses. The ends of each molecule are joined together to form a ring. When the double-strand filaments that constitute these ring molecules are in solution, they form densely packed supercoils. If one of the strands should suffer a single break, the supercoil disappears and the molecule becomes a stretched ring. Supercoiled molecules, because of their compactness, settle faster than stretched-ring molecules when they are centrifuged. Thus the two molecular types can be separated in two distinct bands.

By this technique polyoma virus DNA containing both molecular types can be separated into fractions, each of which contains just one type. Examination of the biological properties of these fractions shows that the transforming efficiency is strictly limited to the two bands of the viral DNA. Similarly, only the material in the two bands will give rise to productive infection. This result, among others, rules out the possibility that transformation is due to fragments of cellular DNA, which are known to be present in some particles of polyoma virus and therefore contaminate the preparations of viral DNA. The contaminant molecules have a very different distribution in the gradient.

The second result demonstrates directly that the function of a viral gene is required for transformation, by showing that a mutation in the viral genetic material can abolish the ability of the virus to transform. This important finding was made by Mike Fried of the California Institute of Technology, who studied a temperature-sensitive mutant line of polyoma virus called Ts-a. The virus of this line behaves like normal virus in cells at 31 degrees C., causing either transformation or productive infection, depending on the cells it infects. At 39 degrees C., however, the effect of the mutation is manifest, and the virus is unable to cause either transformation or infection; it is simply inactive [*see top illustration on opposite page*].



VIRAL INVASION OF CELLS can have two different results. One result is "productive infection" (*left*), in which viral particles (*color*) mobilize the machinery of the cell for making new viral particles, complete with protein coats. The cell eventually dies, releasing the particles. The other result is transformation (*right*), in which the virus alters the cell so that it reproduces without restraint and does not respond to the presence of neighboring cells. Viral particles cannot be found in the transformed cells. The tint of color in these cells indicates the presence of new functions induced by the genes of the virus. The change in the cell membrane (*lower right*) denotes the presence of a virus-specific antigen.

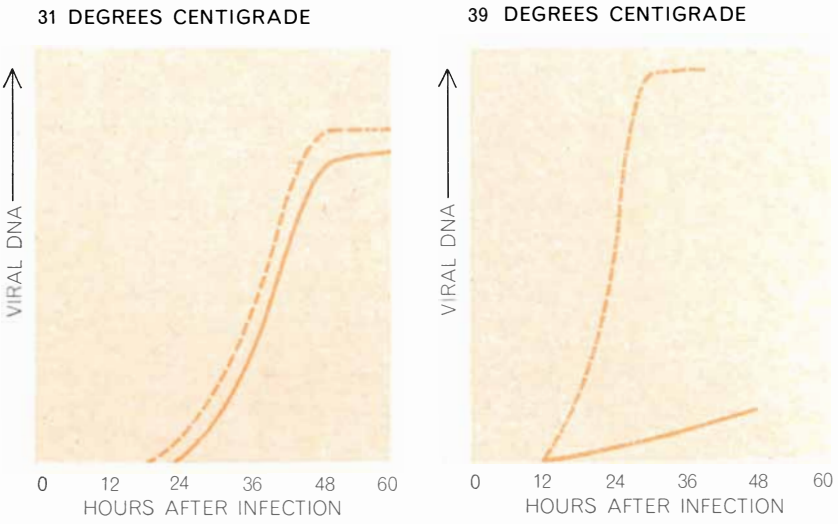
We can now inquire whether the viral gene functions needed to effect transformation are transient or continuous. In other words, do the genes act only once and produce a permanent transformation of the cell line or must they act continuously to keep the cell and its descendants transformed?

A result pertinent to this question is that the transformed cells contain functional viral genes many cell generations after transformation has occurred, although they never contain, or spontaneously produce, infectious virus. The presence of viral genes has been demonstrated particularly well by T. L. Benjamin at Cal Tech, who has shown that the transformed cells contain virus-specific

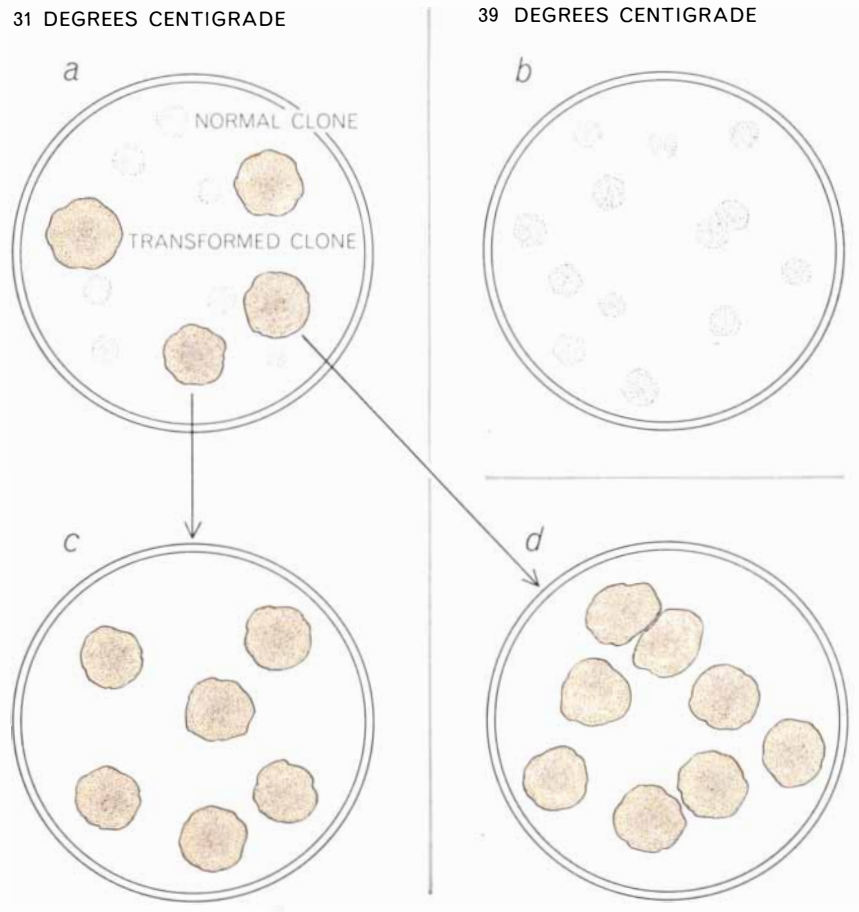
ribonucleic acid (RNA). To make the significance of this finding clear it should be mentioned that the instructions contained in the base sequence of the DNA in cells or viruses are executed by first making a strand of RNA with a base sequence complementary to that of one of the DNA strands. This RNA, called messenger RNA, carries the information of the gene to the cellular sites where the proteins specified by the genetic information are synthesized. Each gene gives rise to its own specific messenger RNA. If one could show that viral messenger RNA were present in transformed cells, one would have evidence not only that the cells contain viral genes but also that these genes are active. The viral RNA molecules can be recognized among those extracted from transformed cells, which are mostly cellular RNA, by adding to the mixture of RNA molecules heat-denatured, single-strand viral DNA. When the mixture of RNA and DNA is annealed, only the viral molecules of RNA enter into double-strand molecules with the viral DNA. The reaction is extremely sensitive and specific.

It is likely, therefore, that the viral genes persisting in the transformed cells are instrumental in maintaining the transformed state of the cells. This idea is supported by the observation that the form of the transformed cells is controlled by the transforming virus. This is seen clearly in cells of the line 3T3, which can be transformed by either SV 40 or polyoma virus. The transformed cells, although descended from the same clonal cell line, are strikingly different [*see illustration on page 29*]. Similar differences are also observed in other cell types transformed by the two viruses. Since the cells were identical before infection, the differences that accompany transformation by two different viruses can be most simply explained as the result of the continuing function of the different viral genes in the same type of cell. In fact, it is difficult to think of a satisfactory alternative hypothesis.

It must be clear, however, that there is no conclusive evidence for this continuing role of the viral genes. It is therefore impossible to exclude an entirely different interpretation of the observation. One can argue, for example, that the persistence of the viral genes is irrelevant for transformation, and that the genes remain in the cells as an accidental result of the previous exposure of the cells, or of their ancestors, to the virus. Indeed, under many other circumstances viruses are often found in association with cells without noticeably affecting them. A conclusive clarification of the



TEMPERATURE-DEPENDENT STRAINS OF POLYOMA VIRUS act normally at a temperature of 31 degrees C. (*left*) but exhibit mutated behavior at 39 degrees C. (*right*). The solid curves show the amount of viral deoxyribonucleic acid (DNA) synthesized in productive host cells containing the mutant virus. Broken curves show the viral DNA output in cells containing "wild type" (ordinary) polyoma virus. The mutant virus is called Ts-a.

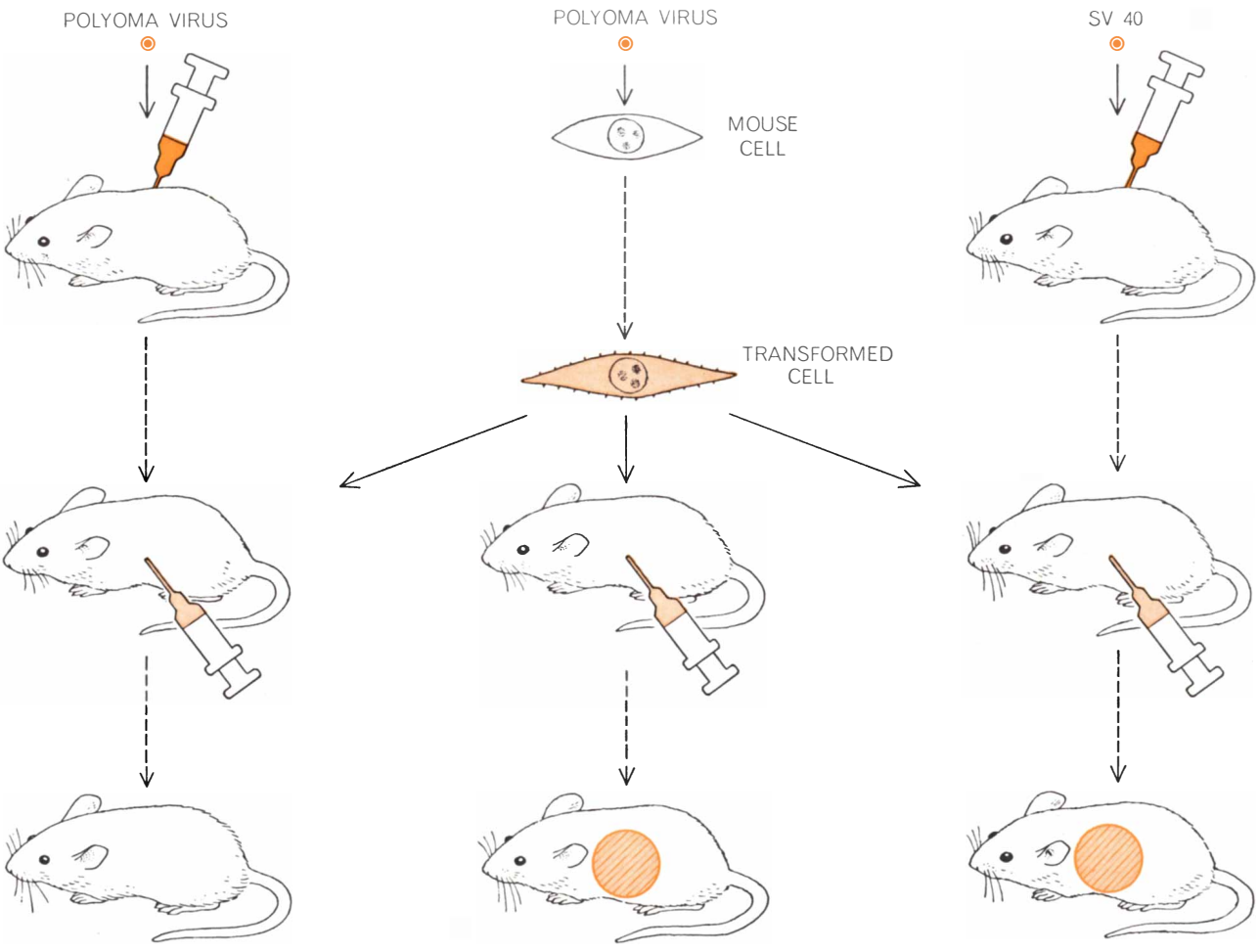


TRANSIENT ROLE OF TS-A GENE, which gives rise to temperature-dependent mutants of polyoma virus, can be demonstrated by raising the temperature of experimental cultures after the cells have been transformed by the virus. The mutant virus is able to transform cells at low temperature (*a*) but not at high temperature (*b*). Transformed cell colonies, or clones, remain transformed, as expected, at low temperature (*c*), but they also remain transformed when the temperature is raised (*d*). This experiment provides evidence that the Ts-a gene is needed for the initial transformation of the cell but is not needed thereafter.

role of the persisting viral genes is being sought by using temperature-dependent viral mutants analogous to the Ts-a mutant I have mentioned. A virus bearing a temperature-dependent mutation in a gene whose function is required for maintaining the cells in the transformed state would cause transformation at low temperature. The cells, however, would revert to normality if the ambient temperature were raised. A small-scale search for mutants with these properties has already been carried out in our laboratory but without success; a large-scale search is being planned in several laboratories.

It should be remarked that no protein of the outer coat of the viral particles is ever found in the transformed cells. Thus the gene responsible for the coat protein is always nonfunctional. This could be either because the transformed cells have an incomplete set of viral genes and the coat gene is absent or because some genes remain "silent." The silence of these genes in turn could be attributed to failure either of transcription of the DNA of the gene into messenger RNA or of translation of the messenger RNA into protein. If failure of transcription were the mechanism, transformed cells would be similar to lysogenic bacteria. Such bacteria have a complete set of genes of a bacteriophage (a virus that infects bacteria), but most of the viral genes are not transcribed into RNA. No other significant similarities exist, however, between ordinary lysogenic bacteria and transformed cells; therefore it is more likely that the coat gene is either absent or, if it is present, produces messenger RNA that is not translated into coat protein. Whatever the mechanism, the lack of expression of the coat-protein gene, and probably of other genes as well, is essential for the survival of the transformed cells, since it prevents productive infection that would otherwise kill the cells.

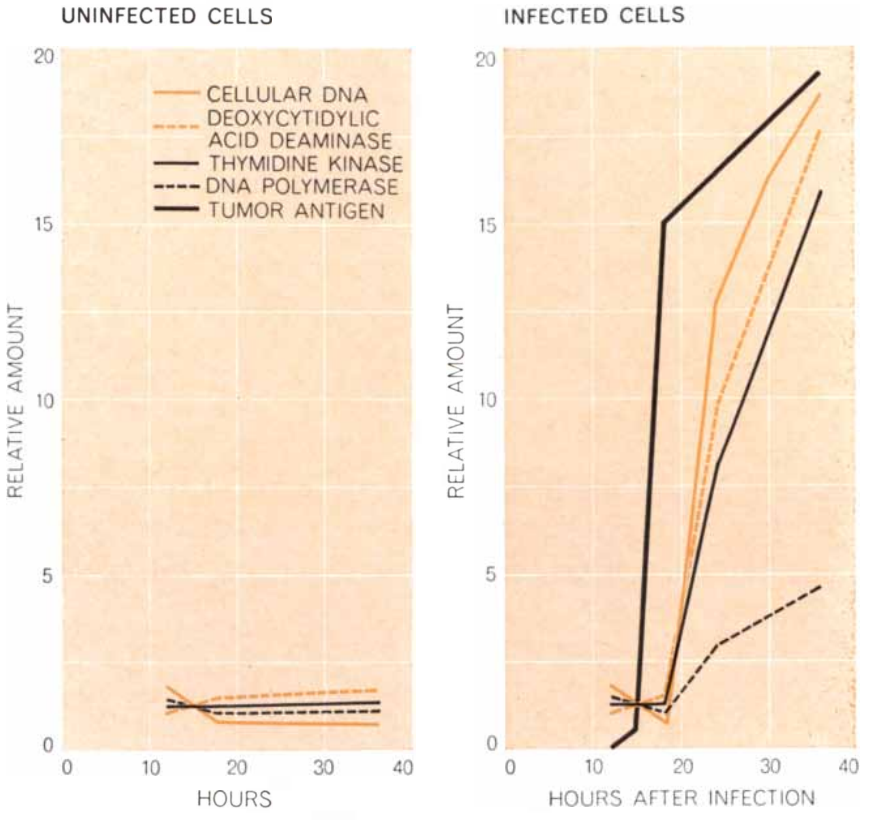
So far we have considered the genes of the virus in abstract terms. Let us now consider them in concrete ones by asking how many genes each viral DNA molecule possesses and what their functions are. The function of a viral gene is the specification, through its particular messenger RNA, of a polypeptide chain, which by folding generates a protein subunit; the subunits associate to form



IMMUNIZATION EXPERIMENT shows that an animal will not develop a tumor after receiving a massive injection of transformed cells if it has previously received a mild inoculation of the virus used to transform the cells. Thus the animal at left, which has been immunized by an injection of polyoma virus, does not develop a tumor when injected with cells transformed by polyoma virus. The animal in the middle, not so immunized, develops a tumor following the injection of polyoma-transformed cells. The animal at right, which has received an injection of a different virus, SV 40, is not immunized against cells transformed by polyoma virus, hence it too develops a tumor. It would not develop a tumor, however, if injected with cells transformed by SV 40. Cells transformed by either polyoma virus or SV 40 contain a new antigen in their surface that makes them foreign to the animal strain from which they derive and therefore subject to its immunological defenses. These defenses can be mobilized by direct injection of the virus.

a functional viral protein. The final product can be an enzyme or a regulator molecule that can control the function of other genes (viral or cellular), or it can be a structural protein such as the coat protein of the viral particles.

As I have said, each strand of the DNA of the small papovaviruses contains about 5,000 bases. Three bases are required to specify one amino acid, or one building block, in a polypeptide chain; therefore 5,000 bases can specify some 1,700 amino acids. It can be calculated from the total molecular weight of the coat protein of the viral particles and from the number of subunits it has that between a third and a fourth of the genetic information of the virus is tied up in specifying the coat protein. This genetic information is irrelevant for transformation, because no coat protein is made in the transformed cells. What remains, therefore, is enough genetic information to specify about 1,200 amino acids, which can constitute from four to eight small protein molecules, depending on their size. This is the maximum number of viral genetic functions that can be involved in the transformation of a host cell.



ACTIVATION OF DNA SYNTHESIS, along with activation of enzymes needed for its production, is a major consequence of viral infection of animal cells. Resting, uninfected cells make little DNA or enzymes associated with its synthesis (*left*). The values plotted are for kidney cells of an African monkey. When the cells are infected with SV 40, the output of DNA and associated enzymes rises steeply (*right*). Before these cellular syntheses are activated a new virus-specific protein, the "T antigen," whose role is unknown, appears.

In order to discover these viral genetic functions the properties of normal cells have been carefully compared with the properties of cells that have been either transformed or productively infected. Characteristics present in the infected cultures can be considered to result, directly or indirectly, from the action of viral genes. We shall call these new characteristics "new functions." In this way six new functions have been discovered in the infected cells, in addition to the specification of the viral coat protein [*see illustration on page 37*]. Some of the new functions can be recognized biochemically; others can be shown by immunological tests to act as new cellular antigens.

The genetic studies with the papovaviruses have not gone far enough to reveal whether each of the new functions indeed represents the function of a separate viral gene, or whether all the gene functions have been identified. On the basis of the possible number of genes and the number of new functions it is likely that most, if not all, of the gene functions have been detected. At present the new functions are being attributed to the genes, and a large-scale effort is being made to produce temperature-sensitive mutants that will affect each of the genes separately. By studying the effect of such mutations on transformation it will be possible to establish the role of each gene in an unambiguous way.

For the moment we must limit ourselves to examining the various new functions and making educated guesses about their possible role in transformation. If transformation is continuously maintained by the function of viral genes, two new functions are particularly suspect as agents of transformation. One function involves a virus-specific antigen present on the surface of transformed cells; the other is the activation of the synthesis of cellular DNA and of cellular enzymes required for the manufacture of DNA by productively infected cells.

The induction of a virus-specific antigen on the cell surface was detected independently by Hans Olof Sjögren of the Royal Caroline Institute in Stockholm and by Karl Habel of the National Institutes of Health. They have shown that if an animal is inoculated with a mild dose of SV 40 or polyoma virus, it will develop an immune response that will enable it to reject cells transformed by the virus. Whereas the cells grow to form a tumor in the untreated animals, they are immunologically rejected by and form no tumor in the immunized animals [*see illustration on opposite page*]. Rejection occurs only if the animals were immunized by the same virus used for transforming the cells. For instance, immunity against cells transformed by polyoma virus is induced by polyoma virus but not by SV 40, and vice versa. This shows that the antigen is virus-specific. The antigenic change is an indication of structural changes in the cellular surface, which may be responsible for the altered relations of transformed cells and their neighbors.

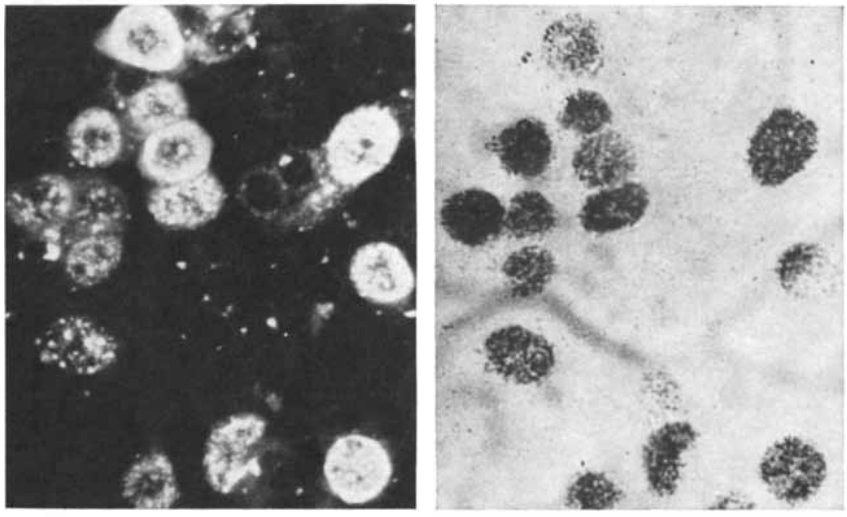
The activation of cellular syntheses, discovered independently in several laboratories, can be demonstrated in crowded cultures. If the cells in the culture are uninfected, they tend to remain in a resting stage. In these cells the synthesis of DNA, and of enzymes whose operation is required for DNA synthesis (such as deoxycytidylic acid deaminase, DNA polymerase and thymidine kinase), proceeds at a much lower rate than it does in growing cells. After infection by a small papovavirus a burst of new syn-

thesis of both DNA and enzymes occurs; a viral function thus activates a group of cellular genes that were previously inactive [*see illustration on preceding page*]. If the infection of the cells is productive, the activation of cellular syntheses occurs before the cells are killed. The activating viral function must act centrally, presumably at the level of transcription or translation of cellular genes that receive regulatory signals from the periphery of the cell; the signals themselves should be unchanged, since the cell's environment, in which the signals originate, is not changed. If the viral gene responsible for the activating function persists and operates in the transformed cells, it will make the cells insensitive to regulation of growth. Direct evidence for the operation of this mechanism in the transformed cells, however, has not yet been obtained.

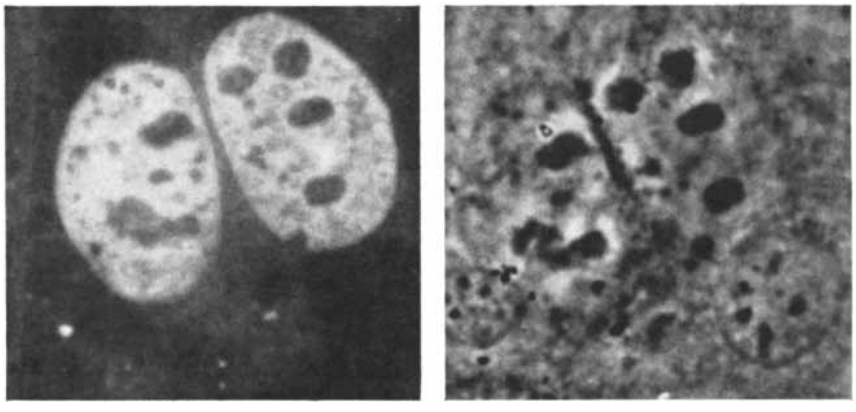
A third viral function may be connected with such activation. This is the synthesis of a protein detected as a virus-specific antigen and called the T antigen (for tumor antigen). This antigen, discovered by Robert J. Huebner and his colleagues at the National Institute of Allergy and Infectious Diseases, differs in immunological specificity from either the protein of the viral coat or the transplantation antigen [*see lower illustration on this page*]. The T antigen is present in the nucleus of both productively infected and transformed cells. In productive infection the T antigen appears before the induction of the cellular syntheses begins, and before the viral DNA replicates. Therefore the T antigen may represent a protein with a control function; for instance, it may be the agent that activates the cellular syntheses. For this assumption also direct evidence is lacking.

A fourth viral function relevant to transformation is the function of the gene bearing the Ts-a mutation, which we can call the Ts-a gene. The reader will recall that a virus line carrying this mutation transforms cells at low temperature but not at high temperature. Cells transformed at low temperature, however, remain transformed when they are subjected to the higher temperature, in spite of the inactivation of the gene [*see bottom illustration on page 33*]. Thus the function of the Ts-a gene is only transiently required for transformation. In order to evaluate the significance of this result we must also recall that in productive infection the function of the Ts-a gene is required for the synthesis of the viral DNA. Therefore the transient requirement of this function in transformation may simply mean that the viral DNA must replicate before transformation takes place. If so, the Ts-a gene is not directly involved in transformation.

Another interpretation is possible. The function of the Ts-a gene is likely to be the specification of an enzyme involved in the replication of the viral DNA, for example a DNA polymerase, or a nuclease able to break the viral DNA at specific points, or even an enzyme with both properties. The action of a specific nuclease seems to be required for the replication of the viral DNA because the viral DNA molecules are in the form of closed rings. A nuclease, in breaking one of the strands, could provide a swivel around which the remainder of the molecule could rotate freely, allowing the two strands to unwind. The enzyme, although required for the replication of the viral DNA, may also affect the cellular DNA, for instance by causing breaks and consequently mutations. Such breaks have been observed in the DNA of cells that have been either productively infected or transformed by papovaviruses. If the Ts-a gene indeed acts on the DNA of the host cell, it could play a direct role in the transformation of the cell. Its actions would appear to



SITE OF VIRAL-COAT PROTEIN SYNTHESIS in infected cells is found to coincide with the site of DNA synthesis. A culture of mouse kidney cells was exposed to radioactive thymidine (needed in DNA synthesis) some 20 hours after infection with polyoma virus. Six hours later the culture was fixed and stained with antibodies coupled to a fluorescent dye that are specific for the coat protein of the virus. When the culture was photographed in ultraviolet light (*left*), the brilliant fluorescence of the bound antibodies showed that some of the cell nuclei were rich in coat protein. Then the culture was coated with a photographic film to disclose where beta rays emitted by the radioactive thymidine would expose grains of silver. The result (*right*) shows that the nuclei rich in coat protein were the same ones that had accumulated thymidine and were thus the site of DNA synthesis.

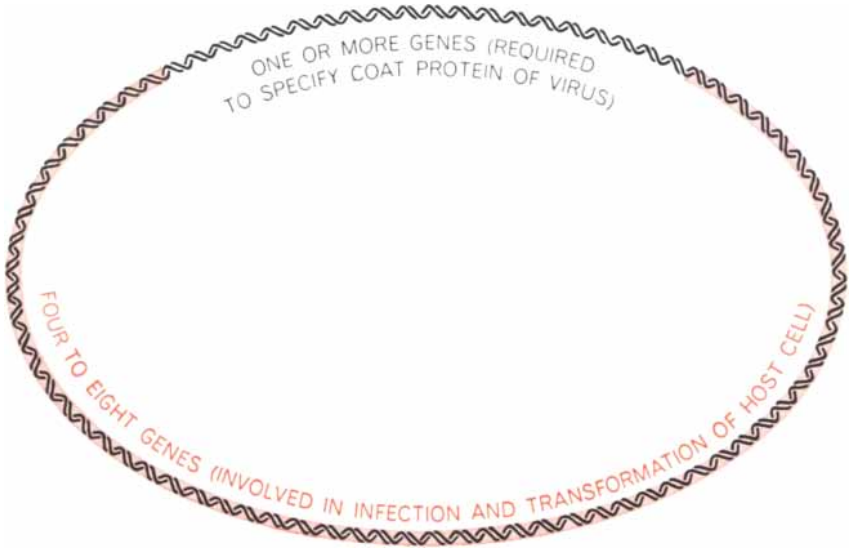


LOCATION OF T ANTIGEN in mouse cells transformed by SV 40 can be established by staining the cells with fluorescent antibodies that are specific for the T antigen (*left*). The same cells were also photographed in the phase-contrast microscope to show details of cell structure (*right*). It can be seen that the fluorescent antibodies nearly fill two large nuclei.

be transient, however, since mutations in the cellular DNA would not be undone if the Ts-a gene were subsequently inactivated by raising the temperature of the system. A more definite interpretation of the Ts-a results must await the completion of the biochemical and genetic studies now in progress in several laboratories.

The last two of the six new viral functions observed in infected cells are not sufficiently well known to permit evaluation of their possible roles in cell transformation. One of these two functions is the induction of a thymidine kinase enzyme that is different from the enzyme of the same type normally made by the host cell. Thymidine kinase participates at an early stage in a synthetic pathway leading to the production of a building block required in DNA synthesis. There are reasons to believe, however, that the thymidine kinase induced by the virus may have a general regulatory effect in activating the DNA-synthesizing machinery of the cell after infection. One reason is that the viral thymidine kinase has not been found in transformed cells. Since this enzyme is induced by many viruses containing DNA, whether or not they cause transformation, its induction by the papovaviruses may be connected exclusively with productive infection.

The last new function is one observed so far only with SV 40. After cells have been productively infected with this virus they are changed in some way so that they become productive hosts for a completely different kind of virus, an adenovirus, even though they are normally not a suitable host for such viruses. Little is known about the biochemical steps involved.



SEVEN FUNCTIONS IDENTIFIED WITH VIRUS ACTIVITY

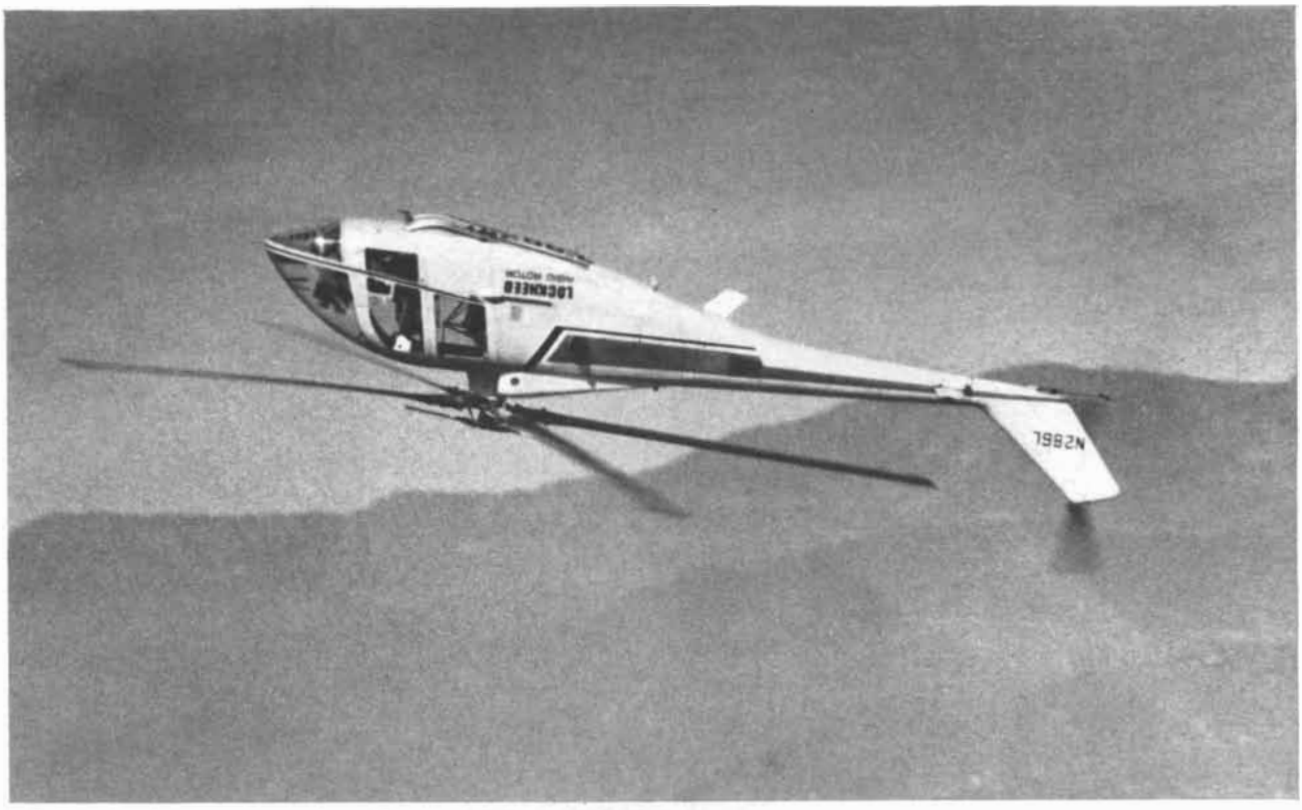
1. Specification of antigen found on surface of transformed cells
2. Specification of factor that activates synthesis of cellular DNA
3. Specification of antigen (T antigen) found in nuclei of infected and transformed cells.
4. Specification of enzyme involved in initial replication of viral DNA. (Attributed to the Ts-a gene.)
5. (Facilitation of cell infection by other viruses.)
6. (Induction of thymidine kinase enzyme.)
7. (Specification of coat protein of virus.)

SEVEN VIRAL FUNCTIONS have been identified in the infection and transformation of cells. The DNA present in the polyoma virus and SV 40 takes the form of a single ring-shaped molecule consisting of two helically intertwined strands (*top*). Each strand contains some 5,000 molecular subunits called bases that embody the genetic information of the virus in coded form. These bases, in groups of three, specify the amino acids that link together to form protein molecules. Thus 5,000 bases can specify some 1,700 amino acids, or enough to construct some six to 12 proteins. By definition it takes one gene to specify one protein. It is estimated that a third to a fourth of the bases in the viral DNA are needed to specify the protein in the coat of the virus. The remaining bases, enough for four to eight genes, specify the proteins involved in infection and transformation. Little is yet known about the fifth function in this list of seven. Functions 6 and 7 are not involved in cell transformation.

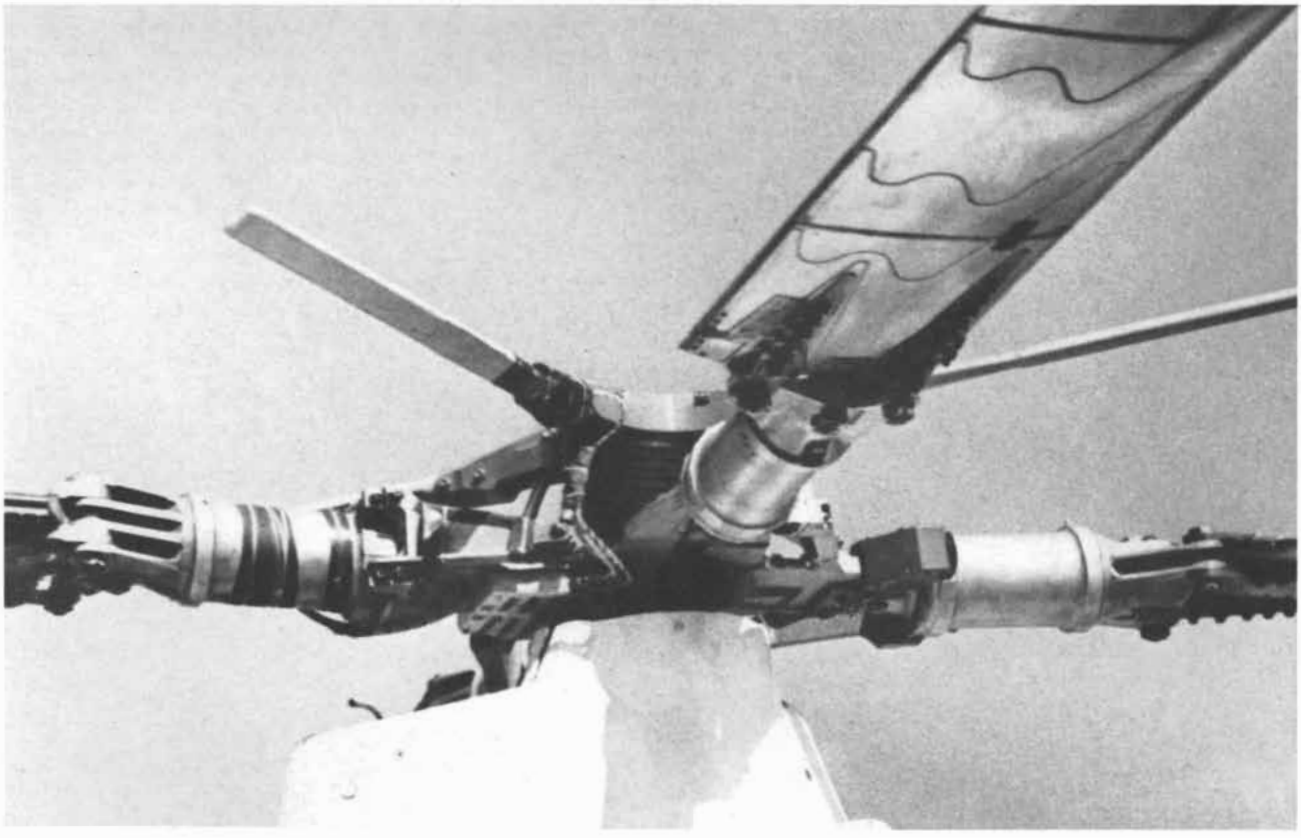
The central mechanism of cell transformation and cancer induction would appear to be contained within the half-dozen viral functions I have discussed, perhaps together with a few others as yet unknown. Thus the problem is narrowly restricted. It is likely that the dubious points still remaining will be resolved in the near future, since the dramatic advances of the past several years have set the stage for rapid further progress.

This article should not be concluded without an attempt's being made to answer a question that will undoubtedly have arisen in the minds of many readers: Why are viruses able to induce cancer at all? For the two viruses discussed in this article, at least, it seems likely that the viral functions that are probably responsible for cell transformation have been selected by evolutionary processes to further the multiplication of the virus. Because the virus is small and cannot contain much genetic information it must exploit the synthetic mechanisms of the cell, including a large number of cellular enzymes, to achieve its own replication. Furthermore, in the animal hosts in which these viruses normally multiply, most cells that can undergo productive infection are in a resting stage and have their DNA-synthesizing machinery turned off. Thus the evolution of a viral function capable of switching on this machinery is obviously quite advantageous to the virus. This function must be very similar to the function of the cellular gene that regulates cellular DNA synthesis (and overall growth) in the absence of viral infection. The functions of the viral gene and of the cellular gene, however, must differ in one point, again for selective reasons: the cellular function must be subject to control by external signals, whereas the viral function must not be. The virus-induced alteration of the cellular surface seems also to be connected, in a way not yet understood, with viral multiplication, since in many viral infections viral proteins appear on the surface of cells.

The cancer-producing action of the papovaviruses can therefore be considered a by-product of viral functions developed for the requirements of viral multiplication. These viral functions lead to cancer development because they are similar to cellular functions that control cell multiplication, but they somehow escape the regulatory mechanisms that normally operate within the cell.



RECENT DEVELOPMENT in helicopter design is the rigid-rotor helicopter, which is more stable and maneuverable than conventional models. The photograph shows the rigid-rotor Lockheed 286 doing a loop, almost never done in a conventional helicopter.



ROTOR BLADES of the 286 are attached rigidly to their hub instead of being free to "flap" and swing back and forth in the plane of rotation. This makes for mechanical simplicity and also for quicker and more powerful response to control movements. The short blades that are visible above the rotor are elements of a control gyroscope that transmits corrective forces to the rotor blades.

THE CHANGING HELICOPTER

The unique capabilities of this improbable flying machine make it adaptable to many purposes. Because of recent improvements future models will have more speed, maneuverability and carrying capacity

by Alfred Gessow

The helicopter is a familiar and accepted part of modern technology. The concept can be traced back to early Chinese tops and to Leonardo da Vinci's aerial-screw machine of 1483, and over the past two centuries many serious efforts were made to bring it to fruition in a practical aircraft. As a useful vehicle, however, the helicopter is only about 30 years old. Today, after many years of comparatively slow growth, the helicopter industry seems to be on the verge of a large-scale expansion. It seems a good time to take a fresh look at the helicopter's potentialities and consider its future.

It has been said that the helicopter exhibits a triumph of ingenuity over common sense. Who would have believed that a flying machine could fly forward, backward, sideways and straight up or down; could sit motionless in the air, and could achieve forward flying speeds of better than 200 miles per hour? On mature thought an engineer could have found more sophisticated grounds for skepticism. How, for instance, could the hovering helicopter be controlled or made stable in the absence of restoring aerodynamic forces? How could it be kept from shaking itself to pieces under the stresses induced by the various rotating systems?

The first successful approach to a helicopter was not, in fact, this breed of machine but an evolutionary precursor that depended on the propulsion system of a conventional airplane. In 1923 its inventor, the brilliant Spanish engineer Juan de la Cierva, built and flew a craft that was driven by a propeller in front but had no fixed wings; instead an arrangement of four blades turning on a vertical spindle provided the lift. This rotor was not powered; it was turned by the action of the airflow on the blades as the plane moved. The blades were hinged so that they could change their in-plane angle and move up or down, thus making automatic adjustments to the changing loads during their revolution and to lifting and banking maneuvers. The machine could fly as slow as 30 miles per hour and descend almost vertically, stopping within a few yards on the ground.

As a stall-proof, safe aircraft that could land almost anywhere, de la Cierva's "autogiro" proved to be a convenient and practical innovation. Improved versions were developed, and autogiros were employed, for example, to operate a mail service from the roof of Philadelphia's main post office. It became evident, however, that the autogiro was only a makeshift hybrid; the logical development of the machine must lead to powering the rotor. By making the rotor the driving mechanism and dispensing with the propeller, it would be possible to give the vehicle the ability to take off and climb vertically, hover in the air and perform other desirable maneuvers. Several inventors went on to this decisive step, and by the late 1930's the first true helicopters were flying. In France, Louis Bréguet built a helicopter with two rotors mounted one above the other on a coaxial hub; in Germany, Henrich Focke designed one with two side-by-side rotors that flew from Bremen to Berlin, and in the U.S., Igor Sikorsky produced a single-rotor helicopter that could make extensive cross-country flights. During World War II, several successful models were developed in this country, and U.S. designers have since led in helicopter development.

What are the essential characteristics of a helicopter? Basically its rotor blades are wings that provide lift in the same way as the fixed wings of an airplane do, but rotor lift is produced independently of the aircraft's forward speed. As the leading edge of each blade moves forward in the air at a slightly elevated pitch, it produces a pressure increase on the underside of the blade and a pressure reduction on the upper side. The consequent lifting force can keep the craft suspended in the air without the craft itself moving at all. In flight, however, the problems of stability and control become much more complex than they are in a conventional airplane. The controls of the helicopter are more elaborate and different in principle from the airplane's system of ailerons, elevators and rudders.

The helicopter's rotor blades, which in present versions of the craft vary in number from two to five and in length from 30 to 75 feet, are attached to a rotating hub by a complex system of hinges and bearings that allows each blade to be "feathered," or changed in pitch, to "flap" up and down and to swing forward and backward. These means of giving the blades several degrees of freedom are needed for control and to enable the blades to adjust to the varying loads they encounter as they simultaneously whirl about the rotor shaft and move through the air. To some extent deflection of the flexible blades also relieves the loads and can substitute for one or more hinges.

These and other design features enable the craft to be controlled and also affect its stability, or tendency to return to its original position after being disturbed by air turbulence or inadvertent control motions. The flapping and feathering hinges make it possible for the pilot to tilt the rotor so that the direction of thrust is displaced from the helicopter's center of gravity, producing a "moment," or turning force, that pitches

HEAVY LOADS can be handled in difficult locations by helicopters. This Sikorsky S-64 Skycrane is carrying a cargo container from a container ship to the shore. In some crowded or badly equipped harbors this could constitute an economic method of unloading a ship.

or rolls the craft [*see illustration on page 43*]. For the control of yaw (swinging of the nose from side to side) helicopters that are powered by a single main rotor (the prevailing type today) have a small vertical rotor mounted on the tail of the machine. The pilot can vary the pitch of the small rotor's blades (using foot pedals); therefore he is able to employ this rotor as a rudder and to control any yawing motions. The tail rotor also counteracts the torque produced by the main rotor, which otherwise would swing the craft around.

A helicopter is trickier to handle in hovering and low-speed flight than a fixed-wing airplane, and requires special training. The pilot has two control sticks for manipulation of the rotor blades. One tilts the rotor by causing the blades to feather differentially; they change their pitch, or angle of attack, as they advance and retreat. To produce a pull-up maneuver of the craft the pilot pulls this stick back, as he would in a conventional airplane. This causes the blades to increase their pitch (and lift) during their forward motion and to reduce their pitch as they move rearward. Because of the phase lag between force and displacement in such rotating systems, the plane of the blades' rotation is tilted backward and the craft climbs. Conversely, by pushing the same stick forward the pilot tilts the rotation plane forward and makes the helicopter dive. The other control stick causes all the blades to maintain a uniform pitch. By pulling upward on this stick the pilot increases the pitch so that the rotor produces greater climbing thrust; pushing it downward, he reduces the thrust.

The difficulties in handling a helicopter arise from its inherent response to control motions and disturbances. When a pilot moves the control stick to tilt a conventional rotor, for example, there is a discernible lag between his motion and the resulting roll or pitch response; this can lead to "overcontrolling." Moreover, the inherent "restoring moment," or resistance to control motions, is quite low, particularly in small helicopters. The conventional helicopter is also rather unstable in rough air. The instability is not troublesome at cruising speeds, but on steep approaches a helicopter is much more subject than the fast-moving airplane to buffeting by turbulence and gusts of wind. Although the helicopter has safety advantages over fixed-wing aircraft in some respects, notably its ability to fly slow and to cope with engine failure, its flying qualities are less satisfactory than those of the airplane in adverse conditions such as bad weather. Much research effort is therefore being devoted to finding ways of improving the stability of the craft and to developing electronic instruments for sensing flight conditions and surroundings and displaying the information to the pilot.

The factors that have held back general use of the helicopter are well understood. The machine is expensive to build and maintain, requires a large amount of power for its payload and cannot compete with the fixed-wing airplane in speed. These drawbacks may be substantially reduced, however, by several promising new ideas now under study and test.

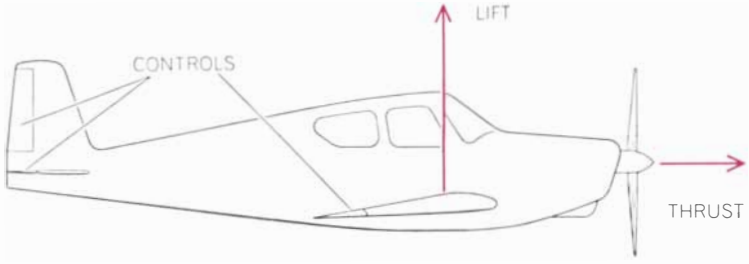
The principal reason for the high cost of construction and maintenance of the helicopter is the complex system of rotating parts involved in its propulsion, transmission and control systems. All the components must be built carefully to close tolerances, and even so the many rotating elements, acting as "inputs" and also responding to periodic loads of different frequencies, subject the craft to considerable vibration, strain and wear. One of the important contributors to the mechanical complexity and vibrations of the system is the hinging of the rotor blades to the hub, which enables them to teeter and flap. Why not, then, do away with the hinges and attach the blades rigidly to the hub, leaving them free only to feather? The first tests of this idea were unsuccessful: the rigid blades could not accommodate

themselves to the changing forces and stresses encountered during their revolution. Recently, however, the Lockheed Aircraft Corporation and others have developed rotor blades with the elastic flexibility to adjust their configuration to these forces, so that they can be attached rigidly to the rotor hub. It appears, therefore, that the system of nonarticulated (hingeless) blades can be made to work.

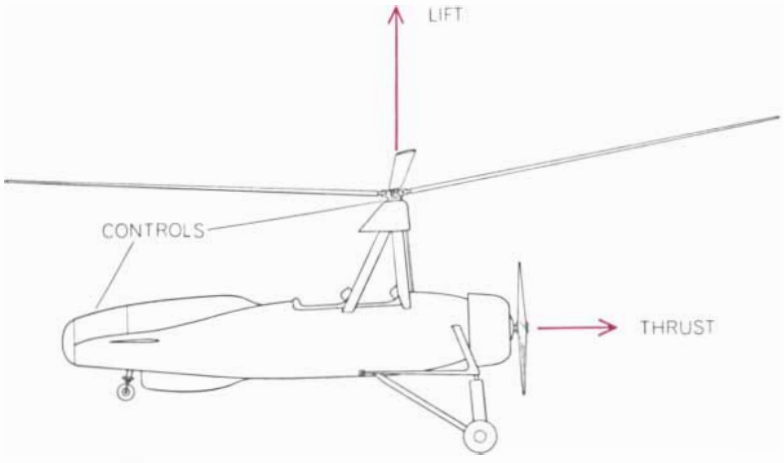
Tests of the hingeless type of rotor have shown that in addition to its mechanical simplicity and reduction of vibration it has other important advantages. It improves the helicopter's stability significantly, in several ways; for example, the hingeless rotor provides a moment, or control force, as much as 10 times more effective than that of a hinged rotor. Moreover, Lockheed has produced a compound helicopter—a craft that has not only a hingeless rotor but also a fixed wing to help in lift—that can fly as fast as 272 miles per hour. The hingeless rotor brings closer to realization the long-held concept of a hybrid aircraft that will be sustained and driven by a rotor at low flying speeds and will switch to conventional fixed-wing lift and propulsion for high-speed flight. The switch will entail stopping the rotor and either using its blades as fixed wings or folding them back out of the way. Stopping and starting a rotor during rapid flight presents difficulties if the rotor is hinged and flapping; with a hingeless rotor the difficulty would be minimized.

Progress is also being made in reducing a helicopter's power requirements, with a view to enabling it to carry larger loads and to fly at higher speeds. The power required for a helicopter to lift a given weight from the ground is governed by the Newtonian formula: force equals mass times acceleration ($f = ma$). In this case "force" represents the thrust the rotor must produce, and the formula shows that the amount of thrust it develops depends on both the mass of air the rotor sucks in and the acceleration it gives to the mass. Since the thrust is the product of these two factors, it is evident that the more air a rotor entrains, the less acceleration (or final velocity) it needs to give the air in order to produce enough thrust to lift a given load. It is also true that by minimizing the required acceleration of air one can minimize the power requirement for a given thrust.

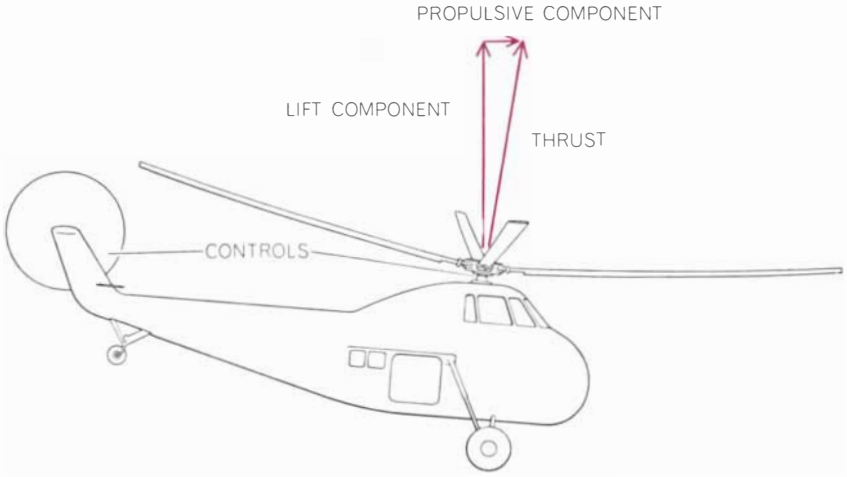
That is why a helicopter rotor, in contrast to an airplane propeller, has long blades that sweep over a wide circle and thus pull in a large volume of air. The large rotor enables the craft to make more efficient use of its power for vertical flight and hovering (at a possible sacrifice of flight speed). The relation between the size of a helicopter's rotor and the load it carries is called its "disk loading": it is the weight of the helicopter divided by the area of the "disk" swept out by the rotor. A helicopter owes its valuable ability to hover in the air without extravagant expenditure of power and fuel to its low disk loading: typically between three and 12 pounds per square foot. The fast vehicles of the vertical-takeoff-and-lift type (VTOL), using smaller rotors for hovering and vertical flight and fixed wings at high speeds, have disk loadings of up to several thousand pounds per square foot. For their high-speed capabilities they pay the price of having to use from five to



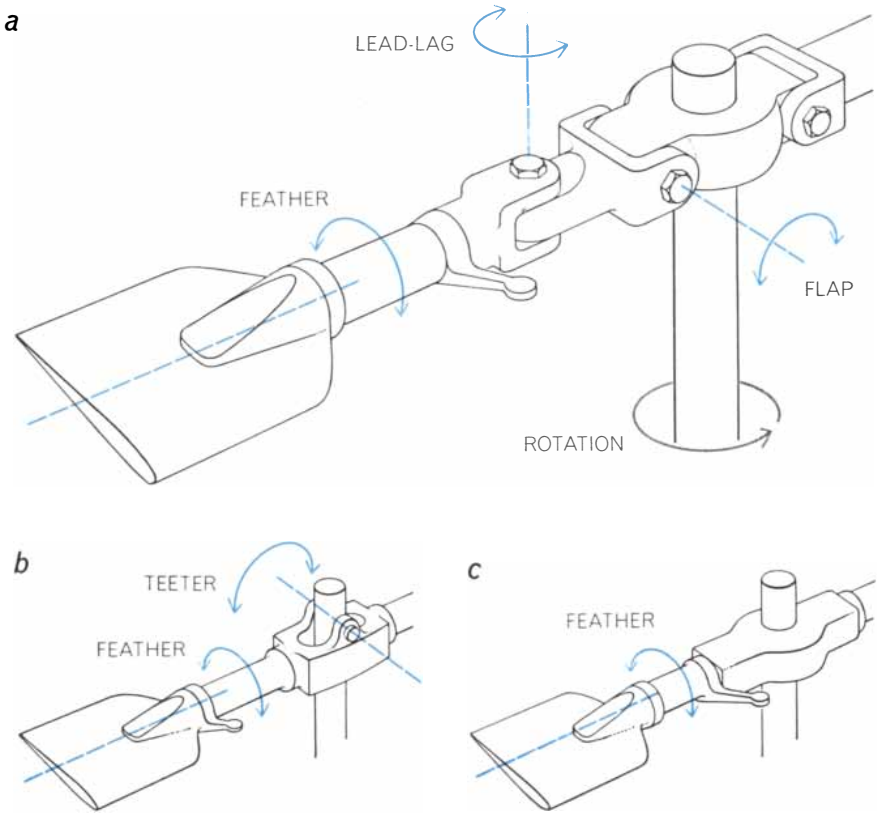
FIXED-WING AIRPLANE gets propulsive thrust, lift and control functions from different elements. Both lift and control depend on the airplane's maintaining a minimum speed.



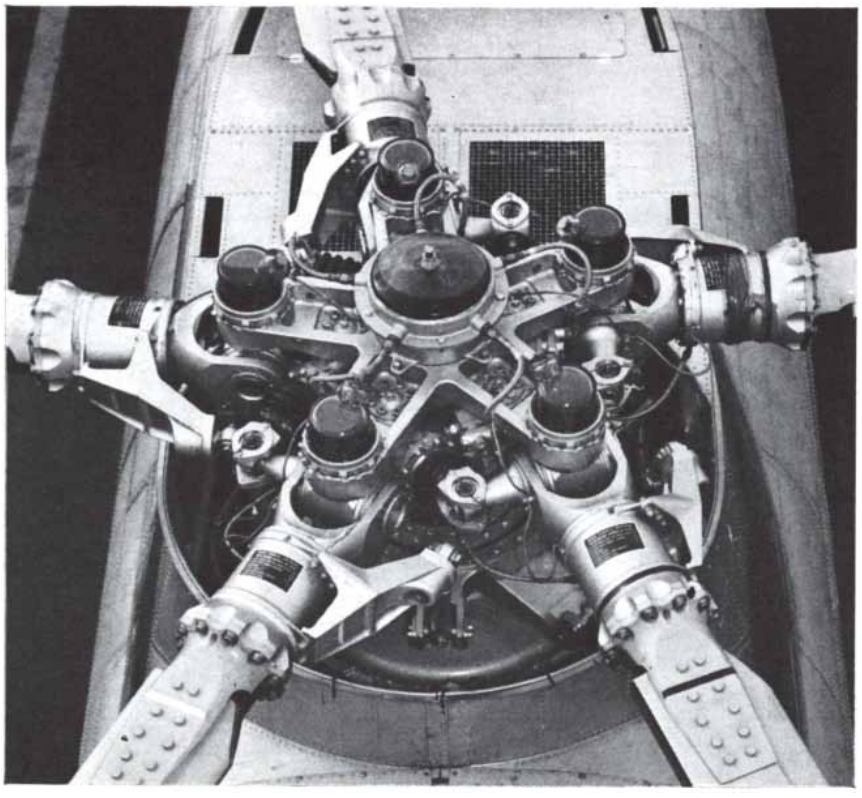
AUTOGIRO, a predecessor of the helicopter, substituted unpowered rotor blades for wings. Rotating in the wind, the blades provided lift even when the forward speed of the autogiro was low, allowing steeper takeoffs and landings, and also provided some control.



HELICOPTER rotor combines lift, propulsive thrust and control functions. Because it is completely divorced from the fuselage it permits hovering, vertical and low-speed flight.



BLADES are attached to the rotor hub by hinges that allow them to move up and down ("flap"); swing forward or backward in the plane of rotation ("lead" and "lag"), and change their pitch ("feather") about their longitudinal axes (*a*). Some rotors with only two blades have a "teetering" hinge (*b*) and are aerodynamically similar to flapping-hinge rotors. In the rigid-rotor configuration both the flapping and the lead-lag hinges are eliminated (*c*).



ROTOR HUB of the Sikorsky S-61N (the hub seen on the cover, but without its protective "beanie") is a complex assembly of hinges and bearings that permits the three motions.

25 times more power to hover than a helicopter does.

A helicopter with a very low disk loading—say one to two pounds per square foot—could lift truly massive loads with a reasonable expenditure of power. To attain this disk-loading level, however, will require improvements in blade design that will enable the blades to entrain more air without becoming too large and heavy for the aircraft.

Low disk loading is a highly desirable property for several other reasons. For one thing, it reduces the velocity of the "downwash" from the rotor, which is particularly serious in rescue work or in hovering operations over unprepared surfaces. The velocity of this downwash from present helicopters is often 30 miles per hour or more, and the VTOL types of aircraft produce winds ranging from hurricane velocities up to velocities of many hundreds of miles per hour.

The feature of low disk loading that is most appreciated by pilots is the margin of safety it provides in landing or in the event of engine failure. Like the unpowered glider, which also has a low wing loading, a helicopter with its power shut off can descend at a low rate of speed. With a disk loading of only a few pounds per square foot, its vertical rate of descent without power is about 2,400 feet per minute—roughly comparable to that of a parachute. If the helicopter has forward momentum and comes in gliding, the rate of descent may be less than half of that in vertical fall, because the forward motion of the craft causes the freely turning rotor to entrain more air. By pulling back on the control stick as he approaches the ground the pilot can convert some of the forward motion into lift that will further slow the descent; with the collective-pitch stick he can convert some rotational energy into additional lift.

The problem of increasing the flying speed of helicopters faces several limiting, or at least hindering, factors. As is true of all aircraft, the amount of drag, and hence the power requirement, increases sharply at high speed. Helicopter designers have attacked this problem by narrowing the craft's profile and streamlining it, and this has helped to give present helicopters a top speed more than double that of the early models. The designers must also cope, however, with special speed-limiting problems that arise from the revolution of the rotor blades.

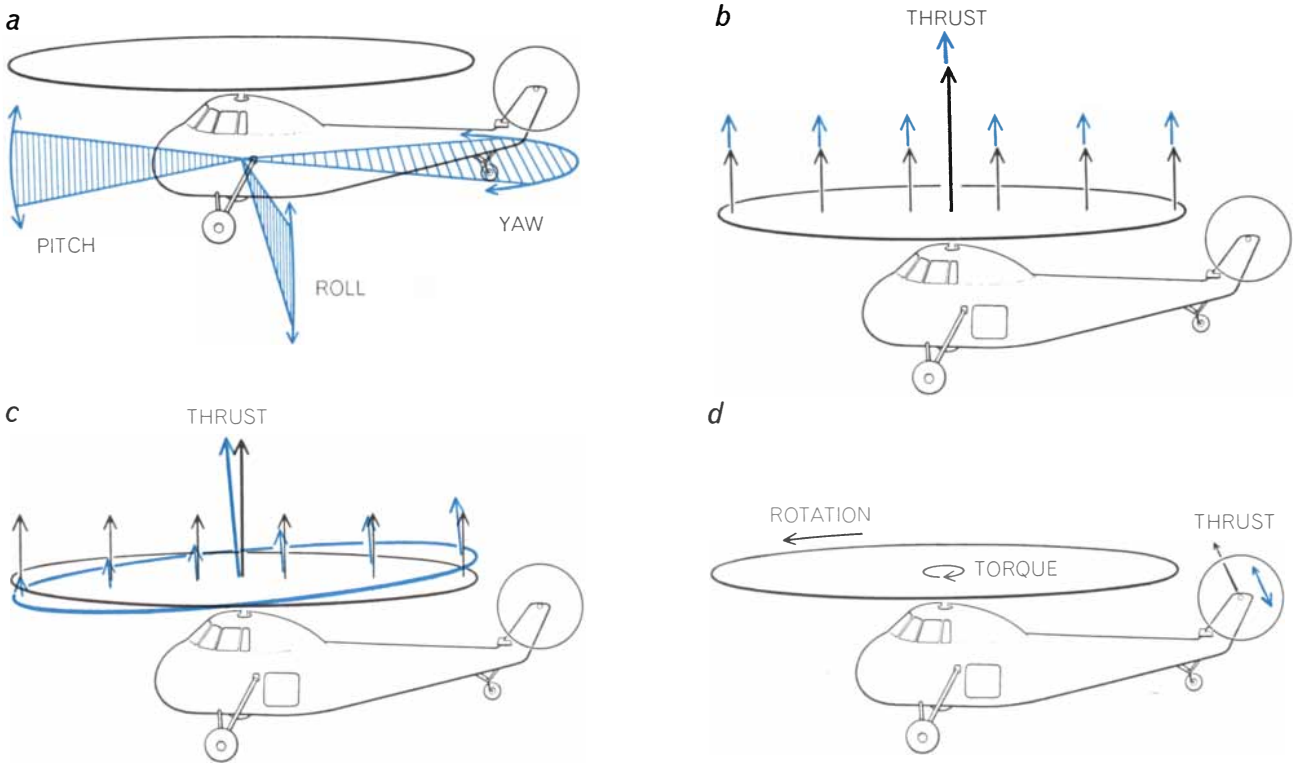
As the helicopter's forward flight speed increases there is less and less difference between the airstream veloc-

ity and the velocity of motion of the blades during the part of the cycle when they are moving rearward. Yet the retreating blades must continue to contribute their proportionate share of the lift. To do so they must increase their angle of attack, or "bite" of the air. At high flight speeds this angle becomes so steep that it produces the stall condition—a breakup of the airflow around the blade. (Whereas wing stall occurs in a fixed-wing airplane when it flies too slow, blade stall afflicts a helicopter when it flies too fast.) With the onset of blade stall the helicopter is beset with sharp increases in drag and vibration and with control difficulties.

Several methods have been employed or proposed to avoid blade stall at high flight speeds. One is to speed up the rotor, thereby ensuring that the blades will move substantially faster than the airstream during their retreating movement. This stratagem eventually encounters the problem that the rotor blades may approach the velocity of sound and produce shock-wave effects. With rapid rotation of the rotor added to high flight speed, the ends of the blades could reach surface velocities of Mach 1 (the speed of sound) or more during their forward movement. The resulting shock waves would sharply increase drag, reduce lift and cause severe twisting of the blades. These effects might be minimized by making the blade tips extremely thin.

Among other methods under study for the prevention of blade stall are increasing the number and width of the blades to reduce the loading per square foot; twisting the configuration of the blade so that the lifting action is distributed more evenly along the blade's length; blowing air from the trailing edge of the blade during its retreating phase to improve lift much as a mechanical wing-flap does, and introducing a velocity oscillation in the blades' rotation cycle—that is, making them slow down, or lag, when they are advancing and speed up when they are retreating. It remains obvious that the most effective way to improve the flight speed of the helicopter is to add features from the conventional airplane: fixed wings to carry some of the craft's weight and an auxiliary propulsion system to take over the function of forward propulsion from the rotor in high-speed cruising. It may be that in the long run the helicopter will give way to the VTOL type of aircraft, because of the latter's much higher speed capabilities. Essentially, however, the VTOL is a fixed-wing craft with only limited capability for vertical flight and none of the helicopter's safety features or special capacities such as extended hovering ability, high lifting efficiency at slow speeds and so on. It seems, therefore, that the compound helicopter, which is a moderate compromise retaining the helicopter's main features with some assistance from fixed wings and auxiliary forward propulsion, and which is capable of flying at 300 miles per hour, has a future, particularly for the many kinds of job it has proved itself peculiarly well qualified to perform.

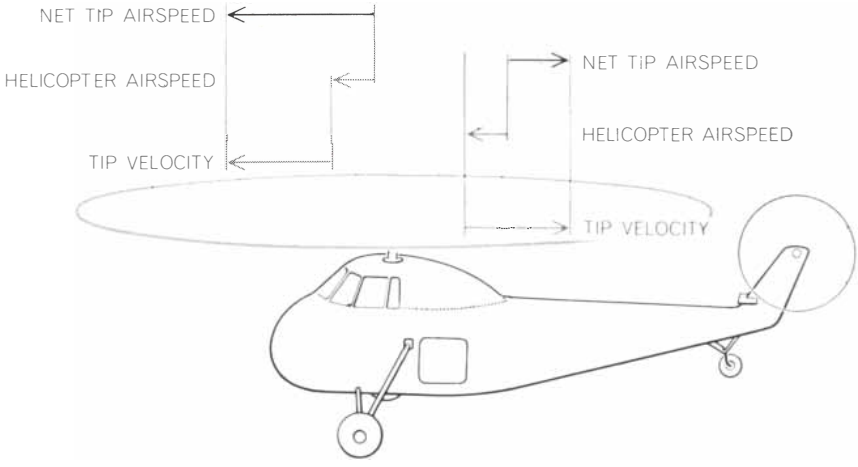
Among these jobs, as the military establishment of any nation is aware, are those required by modern military operations. The helicopter is exceptionally rugged under fire: in Vietnam the rate of loss from ground fire has been only one helicopter in every 18,000 sorties, and helicopters sent on medical missions have returned safely with as many as 100 bullet holes in the body of the craft. They are often recoverable even after they have been shot down. In a 10-month period, for example, more than 100 downed aircraft (including some fixed-wing airplanes) were retrieved and brought back for repair



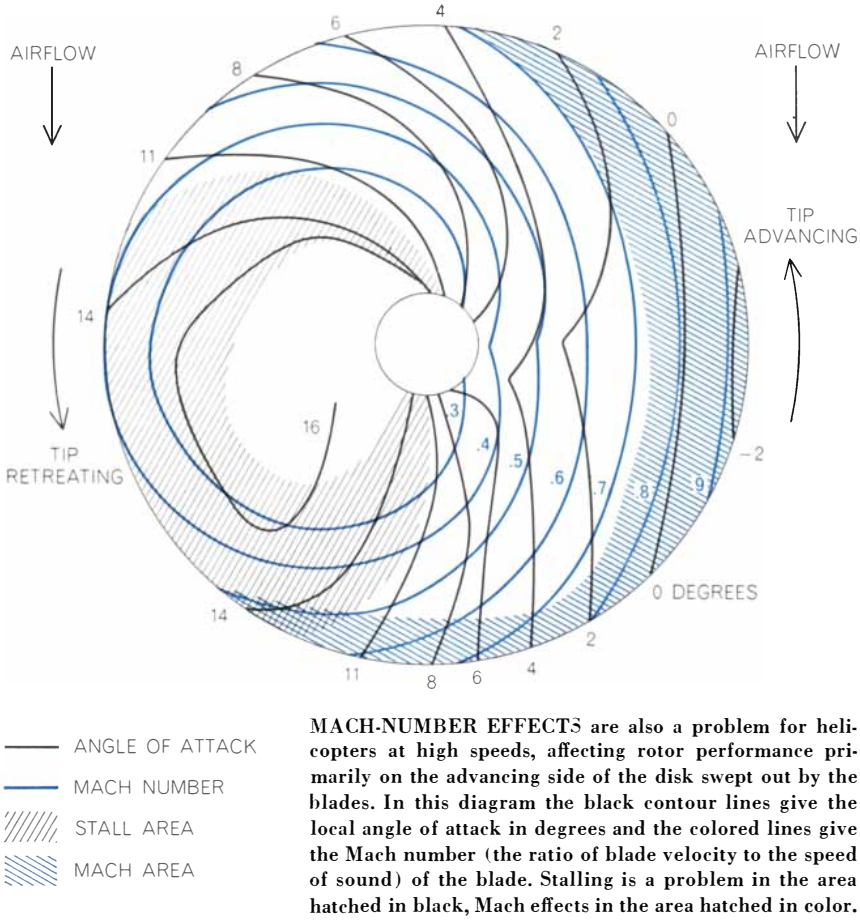
ANGULAR MOTIONS to which a helicopter is subject are pitch, roll and yaw (*a*). The thrust vector, or upward force (*large arrows*), is increased by operating a collective-pitch control stick to increase the "bite" (*small arrows*) of all the blades together (*b*). Moving a cyclic-pitch control stick varies the bite of the blades at different points in their cycle of rotation and thus tilts the thrust vector to produce a pitching (*c*) or rolling "moment." Directional control, or yaw, is accomplished by increasing the bite of the tail-rotor blades by operating foot pedals (*d*). Tail-rotor thrust also counteracts engine torque, which would swing the helicopter around.

by giant Sikorsky Skycranes, helicopters designed for lifting heavy loads.

The tasks performed by the helicopter include the transport of troops and combat equipment (even heavy equipment such as artillery, tanks and trucks), the directing of fire support, rescue work, medical evacuation, reconnaissance, radio relay service, courier services, guard duty and supply services for ships at sea and various other missions. In four years of operations in Vietnam up to the end of 1965, U.S. helicopters flew more than a million sorties, transported more than 1.6 million troops and delivered more than 84 million pounds of cargo. To the 2,000 helicopters now flying in Vietnam the Defense Department has already arranged to add more than 3,500. In the fiscal years 1967 and 1968 the department plans to buy more helicopters than fixed-wing airplanes. The Army has contracted for thousands of new "combat" helicopters to be delivered in the next few years. The first of these is the "Hueycobra," a streamlined craft with a very narrow fuselage that can fly at 200 miles per hour, is protected by armor and can carry considerable firepower, including a rapid-fire gun, a grenade launcher and aerial rockets. Later additions will be of the compound type, capable of higher flying speeds.



STALLING is a problem for helicopters at high forward speeds, rather than at low speeds as in the case of an airplane. The reason is that the faster the helicopter moves, the slower the retreating blade tips move through the air and the steeper their angle in relation to the airflow ("angle of attack") must be to provide lift. The stall angle is about 12 degrees.

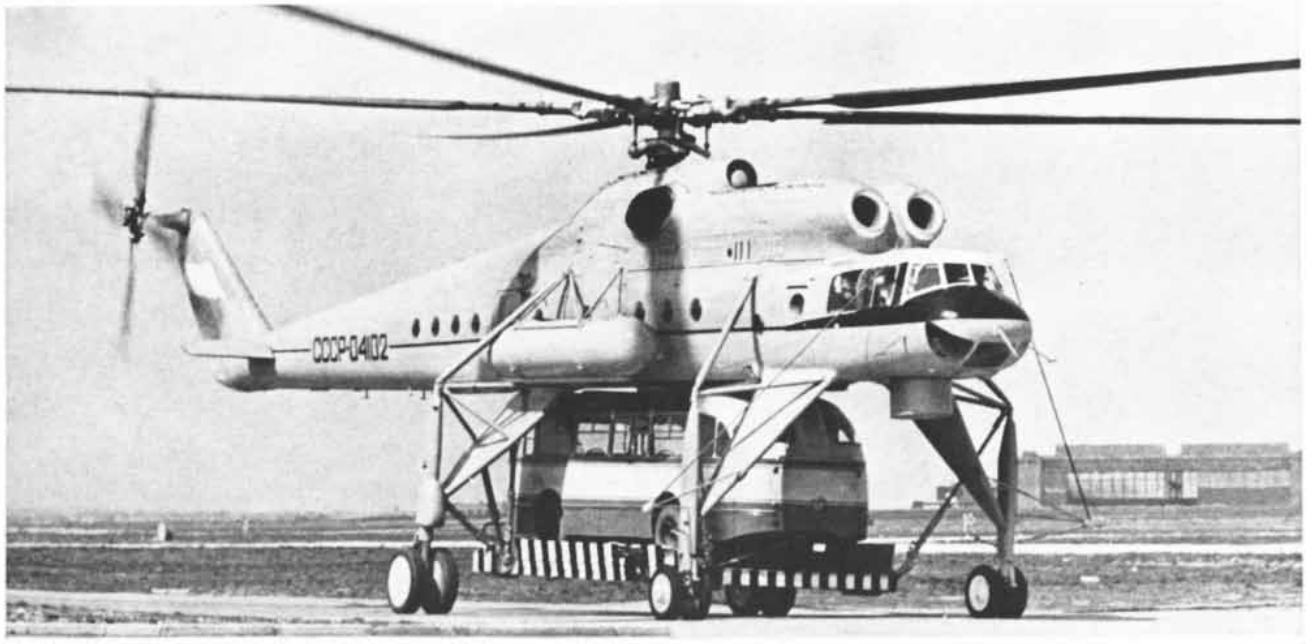


MACH-NUMBER EFFECTS are also a problem for helicopters at high speeds, affecting rotor performance primarily on the advancing side of the disk swept out by the blades. In this diagram the black contour lines give the local angle of attack in degrees and the colored lines give the Mach number (the ratio of blade velocity to the speed of sound) of the blade. Stalling is a problem in the area hatched in black, Mach effects in the area hatched in color.

Compared with the military employment of helicopters, civilian use of the craft is still on a small scale. Of the total of 1,929 helicopters manufactured by the seven major U.S. producers in 1965, for example, more than three-quarters went to the military. Although limited in scale, however, the peaceful uses of the machine are not small in importance. Helicopters have rescued thousands of flood victims, mountain climbers, shipwrecked people and people and animals stranded in snowstorms. The helicopter has proved itself invaluable in large-scale agriculture; used for crop-dusting, spraying and seeding, it spreads the sprays effectively by means of its downwash, can fly slow, close to the ground and in precise patterns, and is much safer for this kind of work than the fixed-wing airplane. Helicopters are also employed to excellent effect for picking up astronauts and their capsules at splashdown, for aerial inspection of electric power lines and overland pipelines, for geophysical surveys and for fire spotting and fire fighting. Rush-hour service to motorists, informing them of tie-ups and advising them of alternate routes, is now provided by helicopters in 22 metropolitan areas in the U.S.

One of the most valuable commercial uses of the helicopter is the transportation of workers and construction materials to remote locations in mountains, jungles and elsewhere that would take weeks or months to reach by other means or that would be otherwise inaccessible. In Canada a company called Okanagan Helicopter, Ltd., now operates a fleet of some 60 helicopters laying electrical cables and hauling poles, powerline towers, prefabricated housing units and other equipment to difficult-to-reach sites. This kind of performance can sometimes be as valuable in a city as in remote, rugged terrain. In one recent operation, for example, a Boeing tandem helicopter was employed to

PASSENGER TRAFFIC has so far proved economically feasible in the U.S. only as a subsidized service to ferry people from airports to city-center terminals. This Boeing Vertol 107 operated by New York Airways carries up to 25 passengers on scheduled flights.



CARGO-CARRYING HELICOPTERS have been developed in a number of countries. This Soviet helicopter, the MI-10, is fitted with long legs to enable it to carry bulky loads such as a bus. Helicopters of the future can be expected to carry even heavier loads.

place heavy air-conditioning units on the rooftops of tall buildings. The helicopter installed 50 units, weighing more than two tons apiece, in four days; it had been estimated that the job would take more than 10 weeks by other means.

In the final analysis the largest potential use for the helicopter, as for other types of aircraft, is in the transportation of passengers, on a regular, scheduled, airline basis. So far this form of service has not succeeded in establishing its economic viability. The only helicopter lines in regular operation are local: between neighboring airports, from airports to downtown, or between neighboring cities. All these lines are subsidized. When Congress cut off funds for helicopter-airline subsidies in 1965, a line serving the Chicago region had to suspend its regular service. The three large metropolitan helicopter services now operating—Los Angeles Airways, New York Airways and San Francisco and Oakland Helicopter Airlines—depend on financial support from major long-distance airlines; a fourth that is now being considered to serve the Washington-Baltimore area will likewise need such support.

These services are technically successful: they reduce a typical express-

way trip time of 45 minutes, for example, to 12 minutes, and they can deliver passengers to the center of the city at terminals such as the "helipad" atop the PanAm Building in New York City or, preferably, in river-edge clearings or similar open spaces. The cost, however, is three times that by bus or limousine—a price most passengers are not willing to pay for the time saved. It appears that if helicopter passenger transport is to become popular, it must reduce its cost and expand the range of its operations. Studies have shown that the total time for a trip from one city center to another would be shorter by helicopter than by high-speed airplane for cities up to several hundred miles apart.

The helicopter costs per pound of payload can certainly be whittled down to some extent by improvements in the design and maintenance requirements of the present versions of the vehicle and by mass-production economies. But radical advances also are required. The helicopter needs a breakthrough that would do for it what jet propulsion did for the long-distance airlines, which were ailing financially before the jet engine replaced the internal-combustion engine and propeller.

Many helicopters now are powered by the gas turbine instead of the internal-combustion engine, thus enjoying the advantages of high power, low weight and lower vibration and noise levels. A further major advance, it is hoped, will be the application of the driving power to the individual rotor blades rather than to the rotor assembly. Experimental helicopters have been built with various forms of drive applied at the blade tips: pulse jets, ramjets and even rockets. So far the devices that have been tried have proved to be too costly in fuel consumption and too noisy, but the continuing research may develop a practicable system of jet propulsion through the blade tips, either from a central engine or from small jet engines located in the blades themselves. This approach, by eliminating the rotor drive shaft, gearboxes and torque-correcting tail rotor, should make the helicopter lighter, simpler and more efficient.

The evolution of the transport helicopter appears to be pointing toward a craft that will be giant-sized (compared with the present machine), will carry 100 passengers or more and will be of the compound type (using auxiliary devices for lift and propulsion) so that it can travel at more than 300 miles per hour. Such a craft, with its vertical-flight capabilities, could compete economically with fixed-wing aircraft for trips up to several hundred miles. It will also have competition, of course, from improved ground transportation of the future, notably high-speed railroads. Our complex society, however, seems to have an appetite for variety in its services. In the field of mechanical devices for entertainment the radio, the phonograph, the television set and the cinema all continue to thrive in symbiotic coexistence, and in transportation we have trains, trucks, passenger cars, buses, subways and aircraft, each occupying an enduring niche in the total system. Unquestionably the unique characteristics of the helicopter assure it a place in the transportation picture.

EXECUTIVE HELICOPTERS are a recent development. The Fairchild Hiller FH-1100 (*left*) carries a pilot and five passengers. It has a two-blade teetering rotor. The Hughes 500 (*right*) has a range up to 500 miles. Both helicopters are powered by gas turbines.

NEW MODELS are built for increased speed. The Bell "Huey-cobra" (*left*), a military model, is aerodynamically clean and has retractable landing gear and stub wings for speed. The Lockheed XH-51A "compound" helicopter has a hingeless rotor for maneuverability. With a jet engine and stub wings to relieve the rotor of some propulsion and lift functions, it has flown 272 miles per hour.

The hope of doing each other some good prompts these advertisements

Two Indians

At a station in Montana two members of the Blackfeet Tribe boarded a train we were riding. The soft-voiced young men were leaving home and parents for a distant city where one could learn to be an x-ray technician, they told us as the coniferous forests clicked past.

Coniferous forests today are grown and processed by firms like Weyerhaeuser Company. The game that the forests support makes excellent sport, but for sustaining human life a regular paycheck proves far more convenient. People trained in handling x-ray film serve Weyerhaeuser, for example, in:

- Showing why the cones of noble fir must not be picked and immediately processed in an attempt to cut loss of viable seed.
- Selecting seed reasonably unriddled by larvae.
- Saving vast amounts of tedious dissection of bark samples in studies of Douglas-fir beetle populations and behavior.
- Finding an effective systemic insecticide that is translocated into the growth and needles of Sitka spruce and grand fir seedlings.

The big market for our radiographic products is not in the forest products industry but in the healing arts, in certain routine procedures in structural safety assurance, and in industrial quality control. Otherwise x-ray technique is easy to shove off into a seldom frequented corner of the technical mind. Too bad.

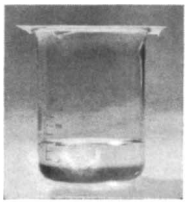
Weyerhaeuser Company's address is Tacoma, Wash. 98401. Ours is Eastman Kodak Company, Dept. 740, Rochester, N. Y. 14650, in case you care to propose a suitable audience for a new informational film of ours—an audience of Indians or other people willing to open their minds to x-ray. It's called "More Than Meets the Eye."

Adventure in TLC

In the interests of further extending TLC on precoated scissorable media, our French affiliate Kodak-Pathé has sent us a modest quantity of a new EASTMAN CHROMAGRAM Sheet to let Americans try. Our colleagues at Vincennes have produced a thin, microporous layer of polyamide with a structure that eludes the optical microscope but is shown by electron microscopy to be a sponge of filaments and membranes with globular chambers and connecting canals. In the large it looks about as chalky white as the now familiar silica gel- or alumina-coated CHROMAGRAM Sheet, but in chromatographic behavior it differs greatly from them and from glass plates coated with polyamide powder. Whether different means better depends on what you are trying to do. Those who discover its great worth will have no cause to share glory, for they will have done it with little help from us, beyond a hint that the medium seems particularly promising for the separation of phenolic compounds, low-MW aromatic nitro compounds, and 2,4-dinitrophenylhydrazones of aldehydes and ketones.

The material on the poly(ethylene terephthalate) support is a sorbent for partition chromatography. It requires no activation. A liquid stationary phase of water, aqueous buffer solution, a complexing solution, or dimethylformamide can be introduced before spotting. This leads to the possibility of combining partition TLC in one dimension with electrophoresis in the other.

The very special feature appears when after migration the coating is exposed to ethanol vapor. The porous polymeric structure thereupon collapses and becomes a strong, strippable transparent film—transparent down to 240mμ for transmission spectrophotometry.



There are a few more facts we can and should send you about the new material, but not many more. The facts are of little value without a box of the sheet: $25.30 for twenty sheets, 20 x 20cm. Please specify Type K541V for this adventure. (EASTMAN CHROMAGRAM *Developing Apparatus is priced $35.50.) From Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company).*

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Photofabrication is wonderful, essential, and growing very fast. It requires no big investment in fancy machinery. It permits either the removal of metal, glass, ceramics, or plastics or the building up of metal to any pattern a draftsman can draw, with speed and economy that are independent of the complexity of the pattern.

It's a reversal of what artists have always done in representing objects seen in the material world. Photofabrication starts with drawings and by chemistry and optics transforms them into the objects, usually with a reduction in linear scale.

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You see, then, that creating and distributing a large body of reliable technical knowledge about photofabrication is a marketing operation with us. Photofabrication is supposed to be the customers' business, whereas our business is to manufacture light-sensitive materials. Nevertheless, one of our marketing men who has had much to do with making photofabrication as indispensable as it is drifted into the marketing game from one of our production departments, where he was an expert on electroplating the big wheels on which we cast film base.

Which merely illustrates that

1) when joining us one can never really be sure where one's technical interests will eventually lead;

2) we have plenty of significant and challenging work for technical people willing to start right out as marketers.

Technical people could have some personally beneficial discussions along these lines with Eastman Kodak Company, Business and Technical Personnel Department, Rochester, N.Y. 14650.

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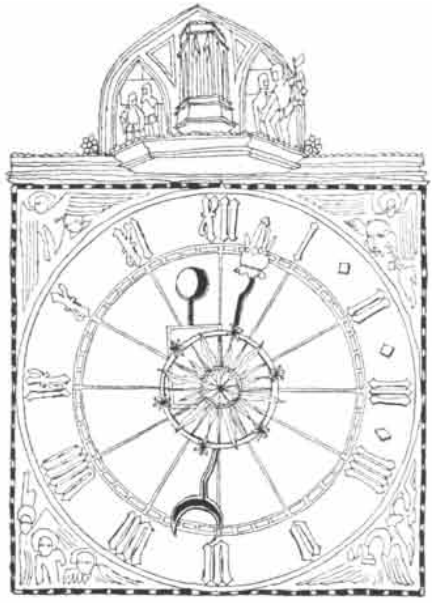

More against Chemical Warfare

A petition calling for a review of U.S. policy on chemical and biological weapons has been signed by more than 5,000 U.S. scientists and forwarded to President Johnson. The petition had been made public last fall over the names of the first 22 signers (see "Science and the Citizen," November, 1966) and was then circulated to the members of the Federation of American Scientists. The list of signers now includes 17 winners of the Nobel prize and 127 members of the National Academy of Sciences.

The petition calls attention to the potential destructiveness of chemical and biological weapons, warns that the employment of any such weapon "weakens the barriers to the use of others" and notes that U.S. forces have directed chemical weapons against crops and people in Vietnam. It calls on the President to institute a Government study of U.S. policy on chemical and biological weapons, order an end to the use of antipersonnel and anticrop chemical weapons in Vietnam and "reestablish and categorically declare" that the U.S. intends to refrain from initiating the use of chemical and biological weapons.

Revised Patent System?

President Johnson has sent Congress a Patent Reform Act that would make the first basic changes in the U.S. patent system since 1836. His recommendations include (1) awarding patents on a "first to file" basis, (2) disclosing patent applications within two years instead of keeping them secret indefinitely and (3) changing the term of a patent.

"Modernization of the patent system is long overdue," the President said. He pointed out that the average time required to obtain a patent is two and a half years and that many inventors have to wait much longer. He also said that under the system of keeping patent applications secret until the patent is granted "public disclosure of new technology is delayed" and "businessmen are unaware of new inventions and may invest substantial sums in developing a product that has already been patented by a competitor." He added: "One of the most burdensome aspects of the present patent system lies in resolving the dispute between two persons who claim that they have invented the same product or process.... Most nations resolve those disputes by a simple and clear standard: 'the first to file.' Under this system the inventor who first recognizes the worth of the invention and files a patent application is awarded a patent." The President proposed making the term of a patent 20 years from the date of application; the present term is 17 years from the date on which the patent is granted.

Common Code

The cells of the colon bacillus, the cells of the South African clawed toad and the cells of the guinea pig all translate the genetic code in essentially the same way. There are, however, slight differences in emphasis, which might be regarded as "dialects" in a common genetic language. These findings, representing the most comprehensive evidence yet published that the genetic code is the same in all organisms, are reported in *Science* by Richard E. Marshall, C. Thomas Caskey and Marshall Nirenberg of the National Institutes of Health.

The genetic code is the "dictionary" used by the cell to translate from the four-letter language of nucleic acid, in which the genetic message of each organism is written, to the 20-letter language of protein. The nucleic acid most directly involved in protein synthesis, ribonucleic acid (RNA), is a threadlike molecule in which four bases—uracil (U), cytosine (C), adenine (A) and gua-

THE CITIZEN

nine (G)—serve as the four-letter language. A group of three of these bases, known as a codon, is sufficient to specify one of the 20 amino acids that, arranged in various sequences, form the many thousands of different protein molecules synthesized by the living cell. Four bases will produce 64 unique codons, with the consequence that more than one codon will specify a particular amino acid. Thus the amino acid alanine can be specified by four codons: GCU, GCC, GCA and GCG. In response to any of these codons the colon bacillus (*Escherichia coli*) will insert a unit of alanine in the growing chain of a protein molecule. Laboratory studies carried out by Nirenberg and his colleagues and by other workers (notably H. Gobind Khorana and his group at the University of Wisconsin) have previously shown, however, that *E. coli* responds three or four times more actively to GCG than to GCC.

A typical finding of the new report from Nirenberg's laboratory is that cells of the South African clawed toad (*Xenopus laevis*) and of the guinea pig also translate GCU, GCC, GCA and GCG as alanine, but with different levels of response. *Xenopus* responds almost equally well to the first three codons but only very weakly to GCG, the codon to which *E. coli* responds most strongly. Guinea pig cells respond about equally well to GCU and GCA, less well to GCC and resemble *Xenopus* cells in responding least well to GCG.

Xenopus, an amphibian, was selected for this investigation because of the possibility that the striking physical changes that occur in an amphibian organism during its life cycle may be related to changes in the response to different codons at different times or in different organs. This possibility was given a limited test by comparing skeletal-muscle cells of *Xenopus* with liver cells. Nirenberg and his co-workers found no difference in the response of the two types of cell to RNA codons.

The hypothesis supported by these experiments is "that the [genetic] code became frozen by the time that organisms as complex as bacteria had evolved," which may have been more than three billion years ago. Nirenberg and his colleagues suggest that the differences found in the way bacterial, am-

phibian and mammalian cells respond to various codons "may reflect changes in the codon recognition apparatus, acquired after cells had evolved, which may enable cells to store additional genetic information and become more highly differentiated."

After Apollo, What?

The continuation of a substantial space program in the decade or so following the landing of men on the moon is recommended in a report of the President's Science Advisory Committee. The report, which was prepared by the committee's panels on space science and space technology, presents alternate proposals that at a maximum foresee a goal of a manned landing on another planet by about 1985 and at a minimum envision a continuation of manned and unmanned earth-satellite programs and exploration of the moon plus a more ambitious program of exploring other planets with unmanned vehicles. The maximum program would require a space budget of $7 billion in 1972, compared with the present outlay of $6.7 billion. The minimum program would call for expenditures of $3.5 billion in 1972.

"We see the objectives of the U.S. activities in space for the next decade as falling into two major categories," the committee said. The first involves practical uses of space. In the nonmilitary field the uses include communication and weather prediction. Justification of practical programs "should still be based directly on material benefits to our society."

The second objective of the space program is exploration. The major rationale for the pursuit of this objective will continue to be "the challenge of exploring the unknown," the committee said, adding that the challenge touches on three "fundamental scientific questions of considerable philosophical content." Does life exist in places other than the earth? What can be learned about the origin, evolution and ultimate destiny of the universe? What are the physical conditions on the moon and on the other planets?

"An attractive long-term objective for space exploration is a program directed ultimately at the exploration of the planets by man," the committee said. Although the committee did not call for the establishment of a definite planetary goal, its maximum program would be capable of supporting a decision to put men on a planet—probably Mars or Venus. "Such a decision," the committee noted, "could provide a sense of urgency for supporting more liberally objectives such as the qualification of man for long-duration flight, the development of advanced nuclear, electric or chemical propulsion systems, or preliminary unmanned planetary exploration."

For the time being the committee recommends "a balanced program based on the expectation of eventual manned planetary exploration." The program would integrate manned and unmanned efforts and would have five major objectives. They are lunar exploration; "a strongly upgraded program of early unmanned exploration of the nearby planets"; ascertaining the capacity of man for space flights of long duration; vigorous exploitation of space applications, and "the exploitation of our capability to carry out complex technical operations in near Earth orbit (and on the Moon) for the advance of science, particularly astronomy."

New Moons

A French astronomer has tentatively added a 10th moon to the nine that circle the planet Saturn and an American investigator has confirmed Polish astronomical observations of a decade ago that first showed two ghostly dust-cloud "moons" in orbit around the earth. The French discovery is contained in photographs made by Audouin Dollfus of the Meudon Observatory in December, 1966, and in January of this year, when Saturn's rings were edge-on and their obscuring light was minimized. The moon is a 14th-magnitude object, estimated to be some 300 miles in diameter, that circles the planet every 18 hours in an orbit just outside the rings. It has been named Janus, but its discoverer is referring to it only as "a probable satellite" until further observations establish its existence beyond doubt. Astronomers have not forgotten that in 1905 W. H. Pickering of the Harvard College Observatory claimed the discovery of a 10th moon of Saturn, which he named Themis. The existence of Themis has never been confirmed.

The existence of the earth's two dust-cloud moons had been suspected since 1906, when astronomers observing the two "Lagrange areas" (points of dynamic equilibrium) associated with the sun and Jupiter found them to be occupied by a number of asteroids. In 1951 Kazimierz Kordylewski of Poland's Cracow Observatory began a search of the two Lagrange areas, known as L/4 and L/5, associated with the earth-moon system. As long as Kordylewski looked for solid bodies at the two points of equilibrium his quest was fruitless. In 1956, however, he began to search instead for luminous patches such as might be formed by the accumulation of tiny particles. Soon thereafter he located first one faint cloud and then another. He announced their existence in 1961.

Writing in *Physics Today,* J. Wesley Simpson of the Lockheed Aircraft Corporation reports that between January, 1964, and November, 1966, he and his fellow workers observed the L/4 and L/5 moons a number of times and also duplicated Kordylewski's feat of capturing their images on high-speed film. Even on the fastest film the clouds, which have a brightness of about the sixth magnitude (near the point of invisibility for unaided-eye observation), make an image that is too faint to reproduce. Simpson proposes direct sampling of the two areas to determine the extent to which they are "reservoirs of interesting cosmic rubble."

Electric Chemical Plants

Electrolytic processes, long employed to manufacture chlorine, sodium hydroxide and other inorganic chemicals, have recently been introduced for making in one step organic compounds that had previously required complex organic syntheses. The new technology is known as synthetic electroorganic chemistry. During the past year the Monsanto Company placed "on stream" a major electrolytic plant for making adiponitrile, an important starting material in the manufacture of nylon. In the same period the Nalco Chemical Company began large-scale electrolytic production of tetraethyl lead and tetramethyl lead, widely used as antiknock compounds in motor fuel.

In a recent review of synthetic electroorganic chemistry in *Science* Stanley Wawzonek of the University of Iowa ascribed the past neglect of the field "to general ignorance of the method, the disorganized condition of the electroorganic literature, and industry's reluctance to undertake long-range studies of the method's potential." He attributed the recent interest in electrolytic methods to several factors, including the development of new solvents and new kinds of electrodes, and to "the realization that the cost of electric power has changed very little over the years while the costs of chemicals and labor have mounted considerably."

The Monsanto process for making adiponitrile uses acrylonitrile, made at low cost from propylene and ammonia, as a starting material. By the use of a spe-

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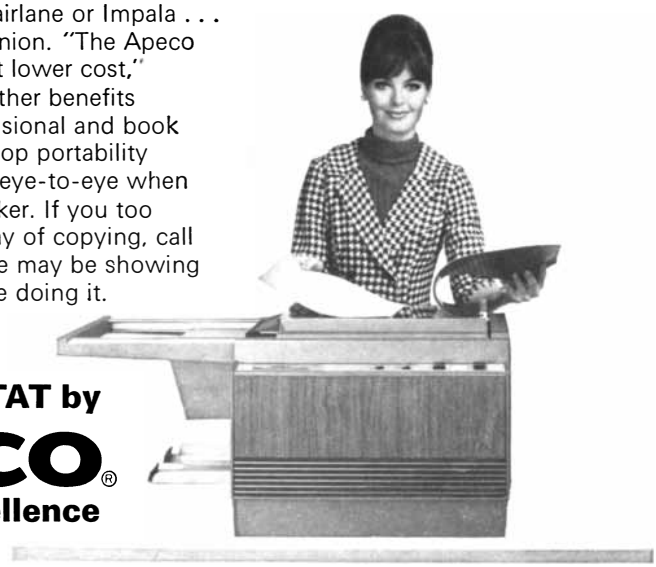

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cial solubilizing agent an electrolytic solution of about 40 percent acrylonitrile is obtained. With the passage of an electric current two molecules of acrylonitrile join together and acquire two atoms of hydrogen to form one molecule of adiponitrile. The yield is reported to be upward of 95 percent.

The Nalco process for making tetraethyl lead depends on the electrolysis of ethyl magnesium chloride in ether solvents. With the passage of an electric current the ethyl magnesium chloride dissociates into negatively charged ethyl ions and positively charged magnesium chloride ions. Ethyl ions migrate to a lead anode and combine directly with it to form tetraethyl lead. Tetramethyl lead is produced by substituting methyl compounds for ethyl compounds.

Yes, We Have No Foundations

Since late in the 19th century mathematics has been widely regarded as a way of describing relations among "sets" of "mathematical objects," for example the set of prime numbers or the set of smooth surfaces. In recent years, however, many philosophers have come to regard the notion of a set as being essentially unclear and have expressed concern about the shakiness of set theory as a basis for supporting mathematical superstructures. The validity of the view that there is therefore a "crisis" in the foundations of mathematics has been challenged in *The Journal of Philosophy* by Hilary Putnam of Harvard University. Writes Putnam: "The much-touted problems in the philosophy of mathematics seem to me, without exception, to be problems internal to the thought of various system builders." He suggests that the various systems of mathematical philosophy "need not be taken seriously" and adds: "I don't think mathematics is unclear; I don't think mathematics has a crisis in its foundations; indeed, I do not believe mathematics either has or needs 'foundations.' "

Putnam argues that there are many possible "equivalent descriptions" of the realm of mathematical facts. By way of analogy he cites quantum physics, which is built on two apparently incompatible descriptions of the physical world: a system of particles and a system of waves. Putnam points out that the two physical theories are "not merely compatible but equivalent: the primitive terms of each [theory] admit of definition by means of the primitive terms of the other theory, and then each theory is a deductive consequence of the other. Moreover, there is no particular advantage to taking one of the two theories as fundamental and regarding the other one as *derived*. The two theories are, so to speak, on the same explanatory level. Any fact that can be explained by means of one can equally well be explained by means of the other." He concludes: "In short, what has happened is that the systematic equivalences between the sentences of the two theories have become so well known that they *function* virtually as synonymies in the actual practice of science."

In mathematics, Putnam goes on to say, "the different equivalent formulations of a given mathematical proposition do not call to mind apparently *incompatible* pictures as do the different equivalent formulations of the quantum theory, but they do sometimes call to mind radically different pictures, and I think that the way in which a given philosopher of mathematics proceeds is often determined by which of these pictures he has in mind, and this in turn is often determined by which of the equivalent formulations of the mathematical propositions with which he deals he takes as primary."

Of the many possible ways of looking at mathematics, Putnam regards two as having special importance. He refers to these two pictures by the loose titles "Mathematics as Set Theory" and "Mathematics as Modal Logic." According to the second view mathematics has no special objects of its own but simply states what follows from what. Putnam suggests that in recent years the philosophy of mathematics has been "too much in the grip" of the set-theory view at the expense of the equivalent modal-logic view. He proposes extending an "objects-modalities duality"—analogous to the wave-particle duality of quantum physics—to the whole of mathematics.

Putnam cautions that his purpose is not "to start a *new* school in the foundations of mathematics (say 'modalism'). Even if in some contexts the modal-logic picture is more helpful than the mathematical-objects picture, in other contexts the reverse is the case. Sometimes we have a clearer notion of what 'possible' means than of what 'set' means; in other cases the reverse is true; and in many, many cases both notions seem as clear as notions ever get in science."

The Warm-hearted City

It is well known that cities are warmer than the countryside around them, but it is not generally realized that the contours of urban temperature form a distinct "heat island." Recently a group of faculty members and students at Oregon State University undertook to map the heat island of Corvallis, the city in which the university is located. Moving through the city in automobiles (with one man at the wheel, a second holding a mercury thermometer out the window and a third keeping a record), they found that the temperature increased as much as 13 degrees Fahrenheit in a distance as short as 2.4 miles.

The measurements were made under conditions that were known to favor the highest heat island: a clear night with no wind. Under such conditions cooling by conduction is at a minimum, and the greater amount of heat in the city takes longer to radiate away than the lesser amount in the countryside. The source of the heat in the heat island is human activities and the absorption of solar energy by pavement and buildings during the day. The contours of the maximum heat island coincide with the most heavily populated area of the city.

Writing in *Bulletin of the American Meteorological Society,* five members of the Oregon State group point out that, given a clear night with no wind, the temperature difference represented by the heat island is much the same under quite different large-scale weather conditions. They measured the heat island on two nights: during the winter on January 31 of last year and in the spring on April 18. Their maximum heat island of 13 degrees F. was observed in January; the heat island in April was an almost equally warm 10 degrees.

Arsenic and Old Bronze

Bronze is defined as copper alloyed with tin; it might be supposed that this held as true in the Bronze Age as it does today. A recent analysis of early Bronze Age tools and weapons from the area of the Aegean Sea shows, on the contrary, that for a 400-year period beginning about 2500 B.C. the commonest form of bronze was copper alloyed with arsenic. Writing in the *American Journal of Archaeology,* J. A. Charles of the Metallurgical Laboratory of the University of Cambridge notes that, although arsenical bronze is seldom made today, it is superior to the tin alloy in a number of ways; among them is that it has better casting characteristics and is much easier to work hot. The reason tin bronze eventually took its place, Charles suggests, is that molten arsenical bronze gives off highly toxic fumes. Many early Bronze Age metalworkers must have been sickened or fatally poisoned. Presumably the hazard was recognized and tin was welcomed as a substitute for arsenic.

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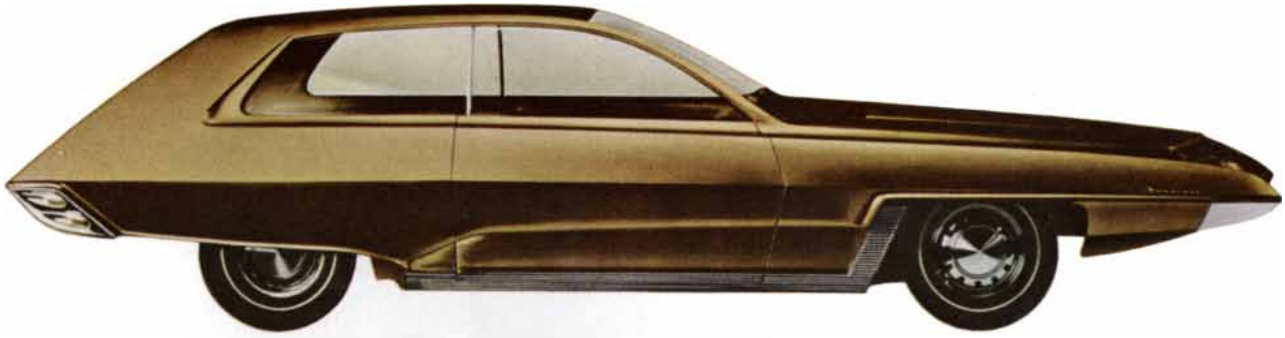

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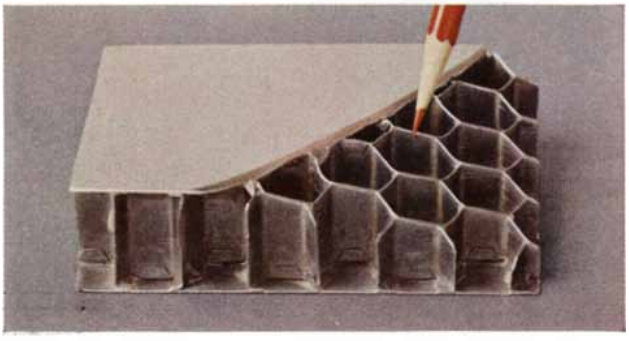

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The Antiquity of Human Walking

Man's unique striding gait may be the most significant ability that sets him apart from his ancestors. A big-toe bone found in Tanzania is evidence that this ability dates back more than a million years

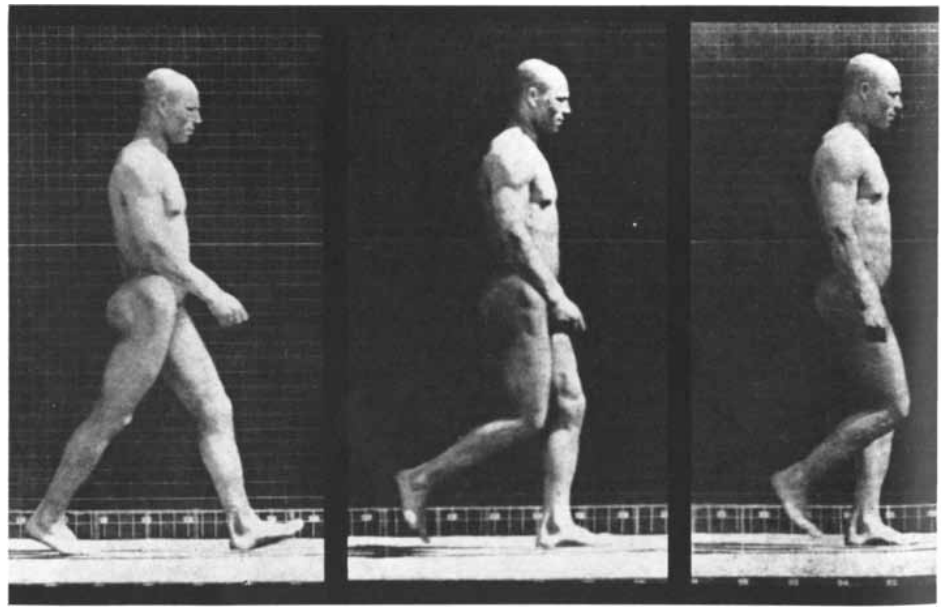
by John Napier

Human walking is a unique activity during which the body, step by step, teeters on the edge of catastrophe. The fact that man has used this form of locomotion for more than a million years has only recently been demonstrated by fossil evidence. The antiquity of this human trait is particularly noteworthy because walking with a striding gait is probably the most significant of the many evolved capacities that separate men from more primitive hominids. The fossil evidence—the terminal bone of a right big toe discovered in 1961 in Olduvai Gorge in Tanzania—sets up a new signpost that not only clarifies the course of human evolution but also helps to guide those who speculate on the forces that converted predominantly quadrupedal animals into habitual bipeds.

Man's bipedal mode of walking seems potentially catastrophic because only the rhythmic forward movement of first one leg and then the other keeps him from falling flat on his face. Consider the sequence of events whenever a man sets out in pursuit of his center of gravity. A stride begins when the muscles of the calf relax and the walker's body sways forward (gravity supplying the energy needed to overcome the body's inertia). The sway places the center of body weight in front of the supporting pedestal normally formed by the two feet. As a result one or the other of the walker's legs must swing forward so that when his foot makes contact with the ground, the area of the supporting pedestal has been widened and the center of body weight once again rests safely within it. The pelvis plays an important role in this action: its degree of rotation determines the distance the swinging leg can move forward, and its muscles help to keep the body balanced while the leg is swinging.

At this point the "stance" leg—the leg still to the rear of the body's center of gravity—provides the propulsive force that drives the body forward. The walker applies this force by using muscular energy, pushing against the ground first with the ball of his foot and then with his big toe. The action constitutes the "push-off," which terminates the stance phase of the walking cycle. Once the stance foot leaves the ground, the walker's leg enters the starting, or "swing," phase of the cycle. As the leg swings forward it is able to clear the ground because it is bent at the hip, knee and ankle. This high-stepping action substantially reduces the leg's moment of inertia. Before making contact with the ground and ending the swing phase the leg straightens at the knee but remains bent at the ankle. As a result it is the heel that strikes the ground first. The "heel strike" concludes the swing phase; as the body continues to move forward the leg once again enters the stance phase, during which the point of contact between foot and ground moves progressively nearer the toes. At the extreme end of the stance phase, as before, all the walker's propulsive thrust is delivered by the robust terminal bone of his big toe.

A complete walking cycle is considered to extend from the heel strike of one leg to the next heel strike of the same leg; it consists of the stance phase followed by the swing phase. The relative duration of the two phases depends on the cadence or speed of the walk. During normal walking the stance phase constitutes about 60 percent of the cycle and the swing phase 40 percent. Although



WALKING MAN, photographed by Eadweard Muybridge in 1884 during his studies of human and animal motion, exhibits the characteristic striding gait of the modern human.

the action of only one leg has been described in this account, the opposite leg obviously moves in a reciprocal fashion; when one leg is moving in the swing phase, the other leg is in its stance phase and keeps the body poised. Actually during normal walking the two phases overlap, so that both feet are on the ground at the same time for about 25 percent of the cycle. As walking speed increases, this period of double leg-support shortens.

Anyone who has watched other people walking and reflected a little on the process has noticed that the human stride demands both an up-and-down and a side-to-side displacement of the body. When two people walk side by side but out of step, the alternate bobbing of their heads makes it evident that the bodies undergo a vertical displacement with each stride. When two people walk in step but with opposite feet leading, they will sway first toward each other and then away in an equally graphic demonstration of the lateral displacement at each stride. When both displacements are plotted sequentially, a pair of low-amplitude sinusoidal curves appear, one in the vertical plane and the other in the horizontal [*see illustrations on next page*]. General observations of this kind were reduced to precise measurements during World War II when a group at the University of California at Berkeley led by H. D. Eberhart conducted a fundamental investigation of human walking in connection with requirements for the design of artificial legs. Eberhart and his colleagues found that a number of functional determinants interacted to move the human body's center of gravity through space with a minimum expenditure of energy. In all they isolated six major elements related to hip, knee and foot movement that, working together, reduced both the amplitude of the two sine curves and the abruptness with which vertical and lateral changes in direction took place. If any one of these six elements was disturbed, an irregularity was injected into the normally smooth, undulating flow of walking, thereby producing a limp. What is more important, the irregularity brought about a measurable increase in the body's energy output during each step.

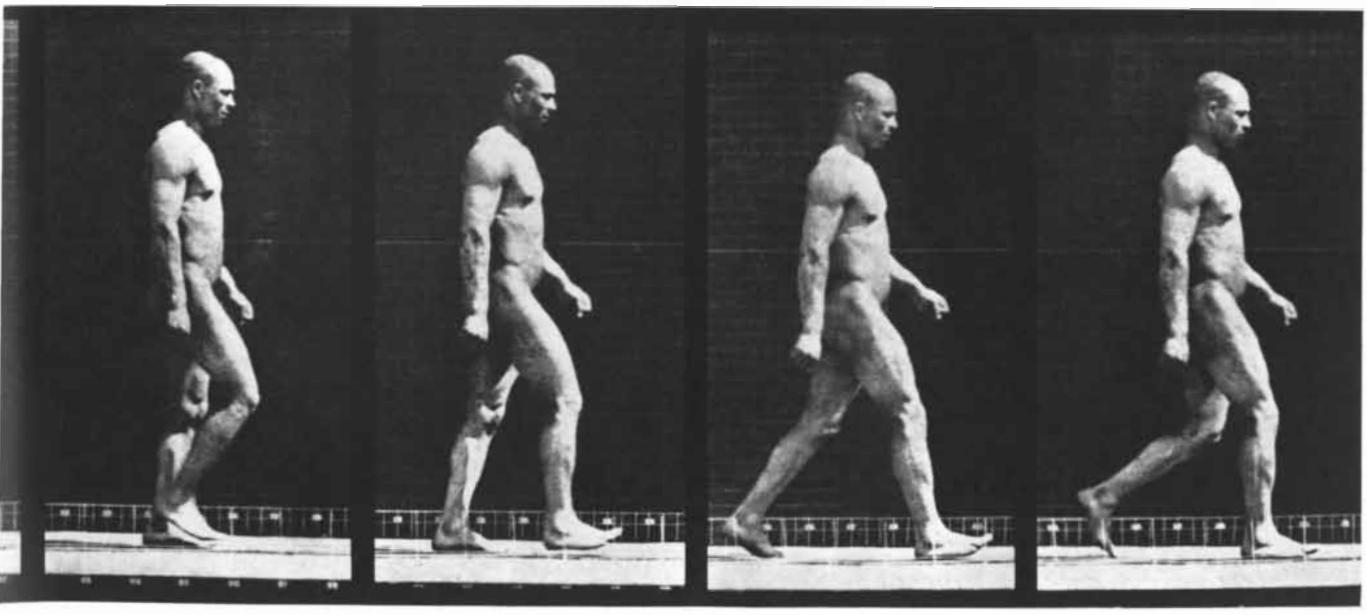
The Evidence of the Bones

What I have described in general and Eberhart's group studied in detail is the form of walking known as striding. It is characterized by the heel strike at the start of the stance phase and the push-off at its conclusion. Not all human walking is striding; when a man moves about slowly or walks on a slippery surface, he may take short steps in which both push-off and heel strike are absent. The foot is simply lifted from the ground at the end of the stance phase and set down flat at the end of the swing phase. The stride, however, is the essence of human bipedalism and the criterion by which the evolutionary status of a hominid walker must be judged. This being the case, it is illuminating to consider how the act of striding leaves its distinctive marks on the bones of the strider.

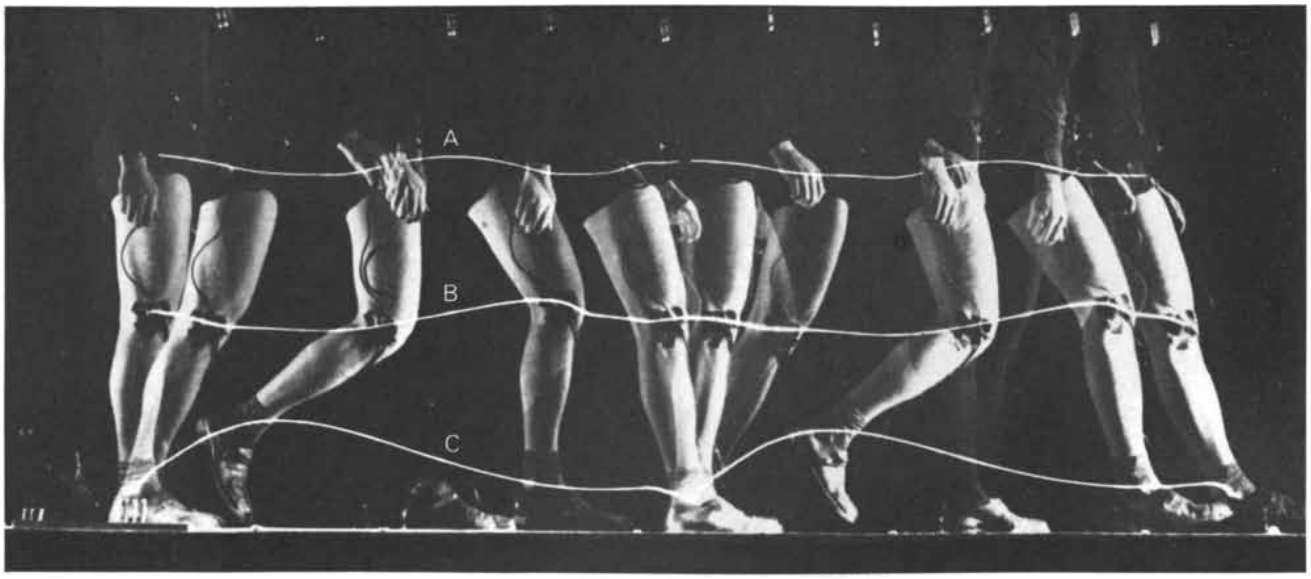
To take the pelvis first, there is a well-known clinical manifestation called Trendelenburg's sign that is regarded as evidence of hip disease in children. When a normal child stands on one leg, two muscles connecting that leg and the pelvis—the gluteus medius and the gluteus minimus—contract; this contraction, pulling on the pelvis, tilts it and holds it poised over the stance leg. When the hip is diseased, this mechanism fails to operate and the child shows a positive Trendelenburg's sign: the body tends to fall toward the unsupported side.

The same mechanism operates in walking, although not to the same degree. During the stance phase of the walking cycle, the same two gluteal muscles on the stance side brace the pelvis by cantilever action. Although actual tilting toward the stance side does not occur in normal walking, the action of the muscles in stabilizing the walker's hip is an essential component of the striding gait. Without this action the stride would become a slow, ungainly shuffle.

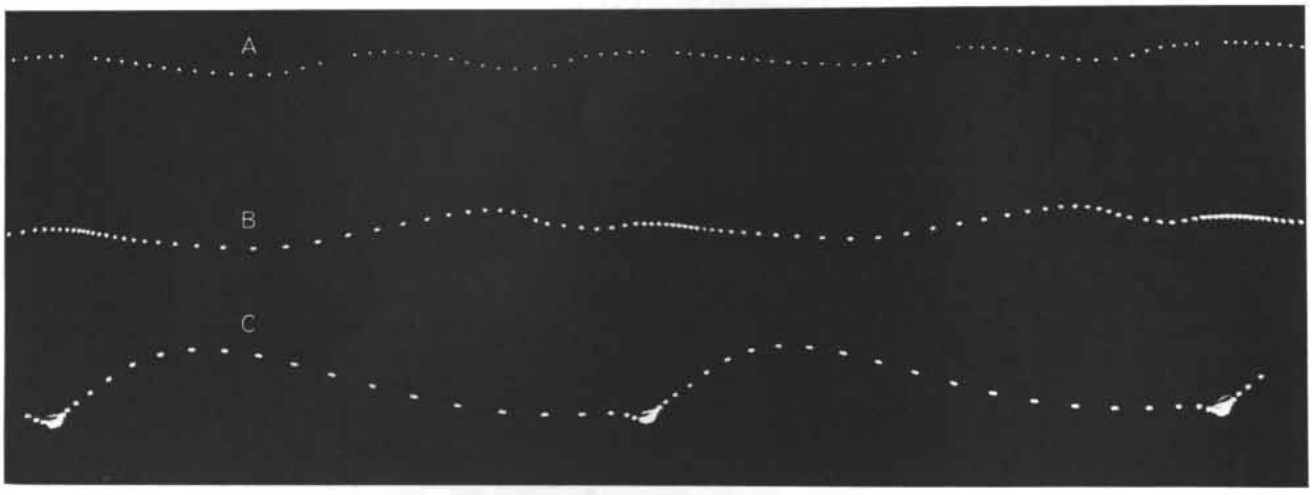
At the same time that the pelvis is stabilized in relation to the stance leg it also rotates to the unsupported side. This rotation, although small, has the effect of increasing the length of the stride. A familiar feature of the way women walk arises from this bit of anatomical mechanics. The difference in the proportions of the male and the female pelvis has the effect of slightly diminishing the range through which the female hip can move forward and back. Thus for a given length of stride women are obliged to rotate the pelvis through a greater



The free foot strikes the ground heel first and the body's weight is gradually transferred from heel to ball of foot as the opposite leg lifts and swings forward. Finally the heel of the stance foot rises and the leg's last contact with the ground is made with the big toe.



WALKING CYCLE extends from the heel strike of one leg to the next heel strike by the same leg. In the photograph, made by Gjon Mili in the course of a study aimed at improvement of artificial legs that he conducted for the U.S. Army, multiple exposures trace the progress of the right leg in the course of two strides. The ribbons of light allow analysis of the movement (*see illustration below*).



SINE CURVE described by the hip of a walking man was recorded on film by means of the experimental system illustrated above. An interrupter blade, passing in front of the camera lens at constant speed, broke the light from lamps attached to the walker into the three rows of dots. The speed of hip (*a*), knee (*b*) or ankle (*c*) during the stride is determined by measuring between the dots.

angle than men do. This secondary sexual characteristic has not lacked exploitation; at least in our culture female pelvic rotation has considerable erotogenic significance. What is more to the point in terms of human evolution is that both the rotation and the balancing of the pelvis leave unmistakable signs on the pelvic bone and on the femur: the leg bone that is joined to it. It is by a study of such signs that the walking capability of a fossil hominid can be judged.

Similar considerations apply to the foot. One way the role of the foot in walking can be studied is to record the vertical forces acting on each part of the foot while it is in contact with the ground during the stance phase of the walking cycle. Many devices have been built for this purpose; one of them is the plastic pedograph. When the subject walks across the surface of the pedograph, a motion-picture camera simultaneously records the exact position of the foot in profile and the pattern of pressures on the surface. Pedograph analyses show that the initial contact between the striding leg and the ground is the heel strike. Because the foot is normally turned out slightly at the end of the swing phase of the walking cycle, the outer side of the back of the heel takes the brunt of the initial contact [*see illustration on opposite page*]. The outer side of the foot continues to support most of the pressure of the stance until a point about three-fifths of the way along the sole is reached. The weight of the body is then transferred to the ball of the foot and then to the big toe. In the penultimate stage of push-off the brunt of the pressure is under the toes, particularly the big toe. Finally, at the end of the stance phase, only the big toe is involved; it progressively loses contact with the ground and the final push-off is applied through its broad terminal bone.

The use of pedographs and similar apparatus provides precise evidence about the function of the foot in walking, but every physician knows that much the

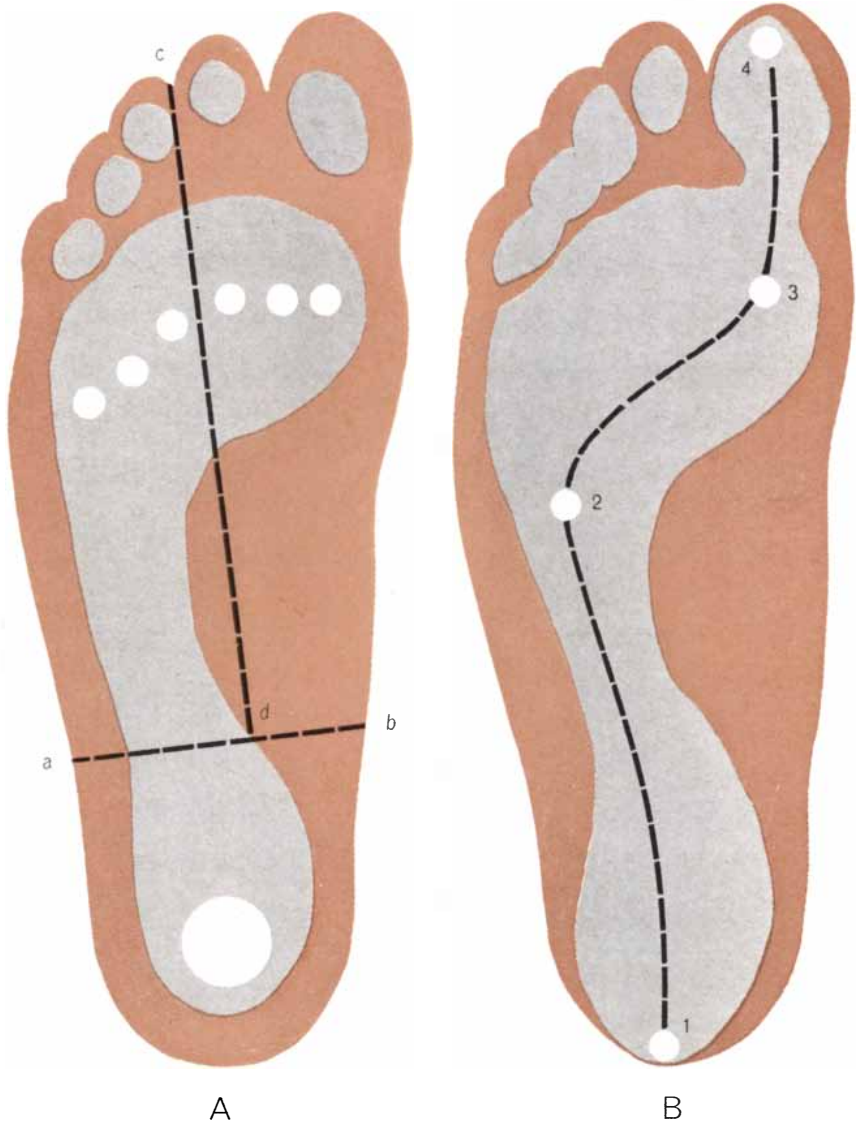
same information is recorded on the soles of everyone's shoes. Assuming that the shoes fit, their pattern of wear is a true record of the individual's habitual gait. The wear pattern will reveal a limp that one man is trying to hide, or unmask one that another man is trying to feign, perhaps to provide evidence for an insurance claim. In any case, just as the form of the pelvis and the femur can disclose the presence or absence of a striding gait, so can the form of the foot bones, particularly the form and proportions of the big-toe bones.

The Origins of Primate Bipedalism

Almost all primates can stand on their hind limbs, and many occasionally walk in this way. But our primate relatives are all, in a manner of speaking, amateurs; only man has taken up the business of bipedalism intensively. This raises two major questions. First, how did the basic postural adaptations that permit walking—occasional or habitual—arise among the primates? Second, what advantages did habitual bipedalism bestow on early man?

With regard to the first question, I have been concerned for some time with the anatomical proportions of all primates, not only man and the apes but also the monkeys and lower primate forms. Such consideration makes it possible to place the primates in natural groups according to their mode of locomotion. Not long ago I suggested a new group, and it is the only one that will concern us here. The group comprises primates with very long hind limbs and very short forelimbs. At about the same time my colleague Alan C. Walker, now at Makerere University College in Uganda, had begun a special study of the locomotion of living and fossil lemurs. Lemurs are among the most primitive offshoots of the basic primate stock. Early in Walker's studies he was struck by the frequency with which a posture best described as "vertical clinging" appeared in the day-to-day behavior of living lemurs. All the animals whose propensity for vertical clinging had been observed by Walker showed the same proportions—that is, long hind limbs and short forelimbs—I had proposed as forming a distinct locomotor group.

When Walker and I compared notes, we decided to define a hitherto unrecognized locomotor category among the primates that we named "vertical clinging and leaping," a term that includes both the animal's typical resting posture and the essential leaping component in its locomotion. Since proposing this category a most interesting and important extension of the hypothesis has become apparent to us. Some of the earliest primate fossils known, preserved in sediments laid down during Eocene times and therefore as much as 50 million years old, are represented not only by skulls and jaws but also by a few limb bones. In their proportions and details most of these limb bones show the same characteristics that are displayed by the living members of our vertical-clinging-and-leaping group today. Not long ago Elwyn L. Simons of Yale University presented a reconstruction of the lemur-like North American Eocene primate *Smilodectes* walking along a tree branch in a quadrupedal position [see "The Early Relatives of Man," by Elwyn L. Simons; SCIENTIFIC AMERICAN, July, 1964]. Walker and I would prefer to see *Smilodectes* portrayed in the vertical clinging posture its anatomy unequivocally indicates. The fossil evidence, as far as it goes, suggests to us that vertical clinging and leaping was a major primate locomotor adaptation that took place some 50 million years ago. It may even have been the initial dynamic adaptation to tree life from which the subsequent locomotor patterns of all the living pri-

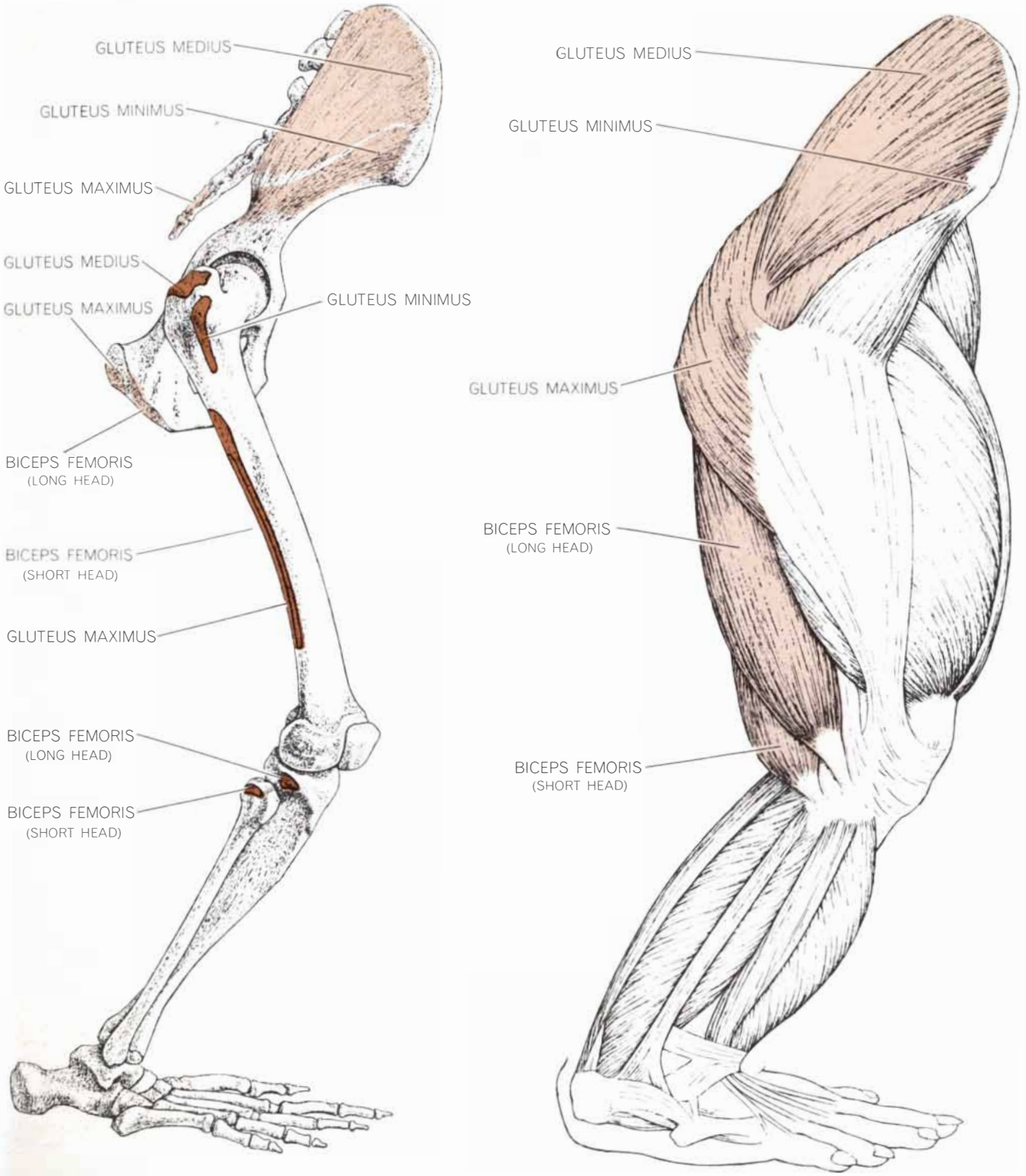


DISTRIBUTION OF WEIGHT in the human foot alters radically as action takes the place of rest. When motionless (*A*), the foot divides its static load (half of the body's total weight) between its heel and its ball along the axis *a–b*. The load on the ball of the foot is further divided equally on each side of the axis *c–d*. When striding (*B*), the load (all of the body's weight during part of each stride) is distributed dynamically from the first point of contact (*1, heel strike*) in a smooth flow via the first and fifth metatarsal bones (*2, 3*) that ends with a propulsive thrust (*4, push-off*) delivered by the terminal bone of the big toe.

mates, including man, have stemmed.

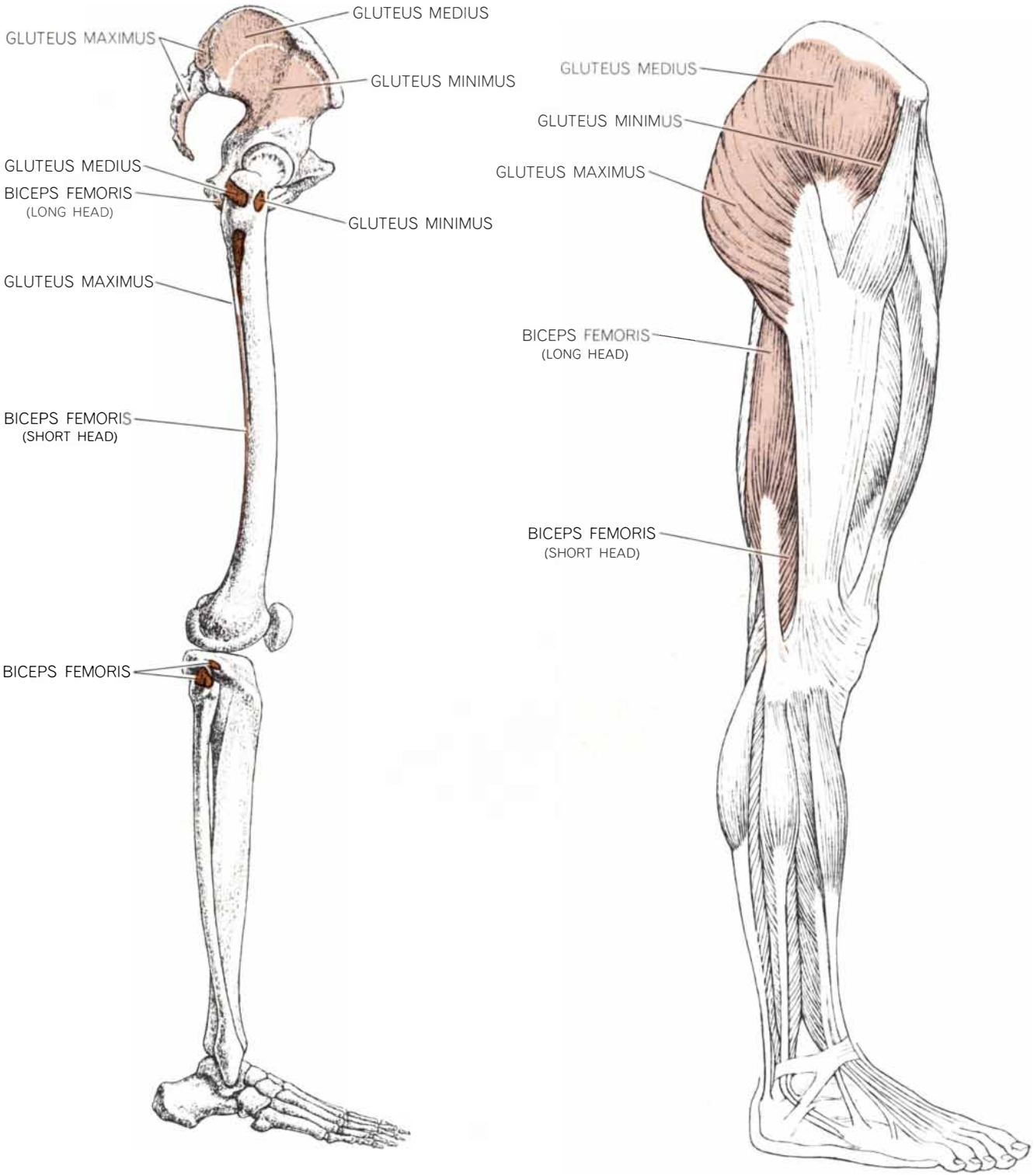
Walker and I are not alone in this view. In 1962 W. L. Straus, Jr., of Johns Hopkins University declared: "It can safely be assumed that primates early developed the mechanisms permitting maintenance of the trunk in the upright position.... Indeed, this tendency toward truncal erectness can be regarded as an essentially basic primate character." The central adaptations for erectness of the body, which have been retained in the majority of living primates, seem to have provided the necessary anatomical basis for the occasional bipedal behavior exhibited by today's monkeys and apes.

What we are concerned with here is the transition from a distant, hypothetical vertical-clinging ancestor to modern, bipedal man. The transition was almost

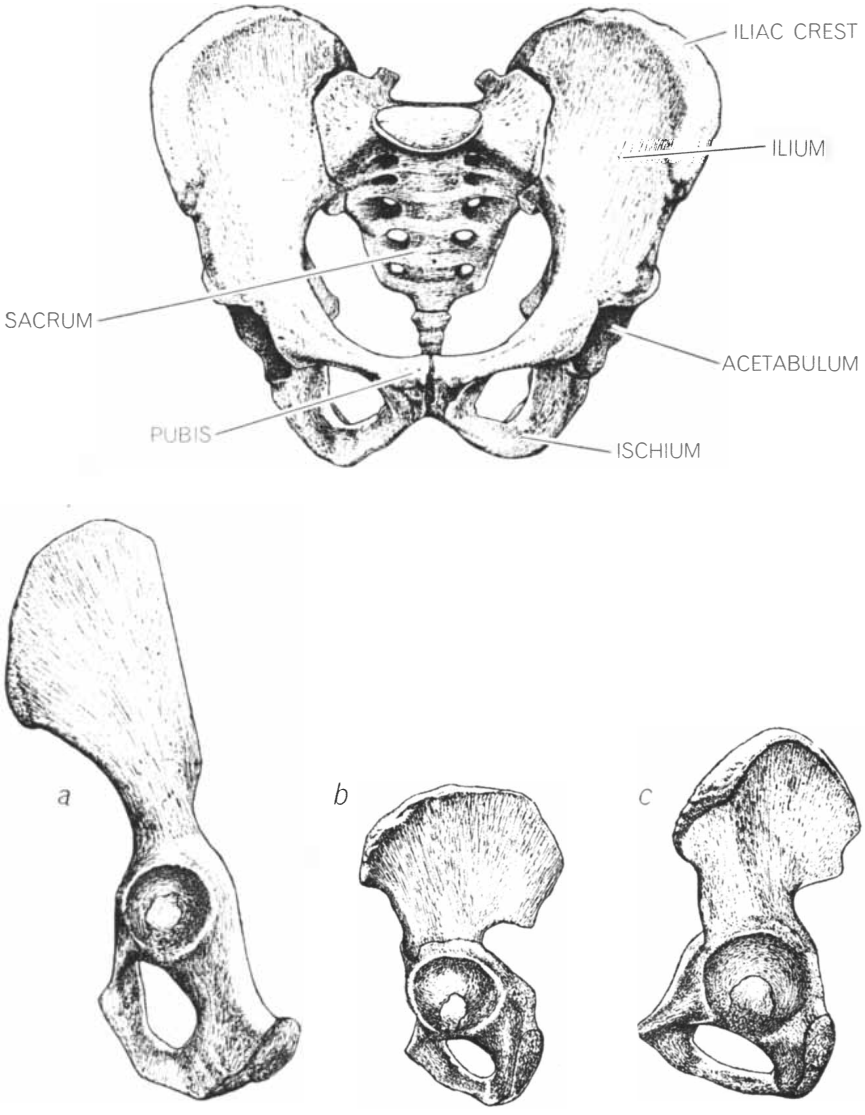


QUADRUPEDAL POSTURE needs two sets of muscles to act as the principal extensors of the hip. These are the gluteal group (the gluteus medius and minimus in particular), which connects the pelvis to the upper part of the femur, and the hamstring group, which connects the femur and the lower leg bones. Of these only the biceps femoris is shown in the gorilla musculature at right. The skeletal regions to which these muscles attach are shown in color at left. In most primates the gluteus maximus is quite small.

certainly marked by an intermediate quadrupedal stage. Possibly such Miocene fossil forms as *Proconsul*, a chimpanzee-like early primate from East Africa, represent such a stage. The structural adaptations necessary to convert a quadrupedal ape into a bipedal hominid are centered on the pelvis, the femur, the foot and the musculature associated with these bones. Among the nonhuman primates living today the pelvis and femur are adapted for four-footed walking; the functional relations between hipbones and thigh muscles are such that, when the animal attempts to assume a bipedal stance, the hip joint is subjected to a stress and the hip must be bent. To compensate for the resulting forward shift of the center of gravity, the knees must also be bent. In order to alter a bent-hip, bent-knee gait into



BIPEDAL POSTURE brings a reversal in the roles played by the same pelvic and femoral muscles. Gluteus medius and gluteus minimus have changed from extensors to abductors and the function of extending the trunk, required when a biped runs or climbs, has been assumed by the gluteus maximus. The hamstring muscles, in turn, now act mainly as stabilizers and extensors of the hip. At right are the muscles as they appear in man; the skeletal regions to which their upper and lower ends attach are shown in color at left.



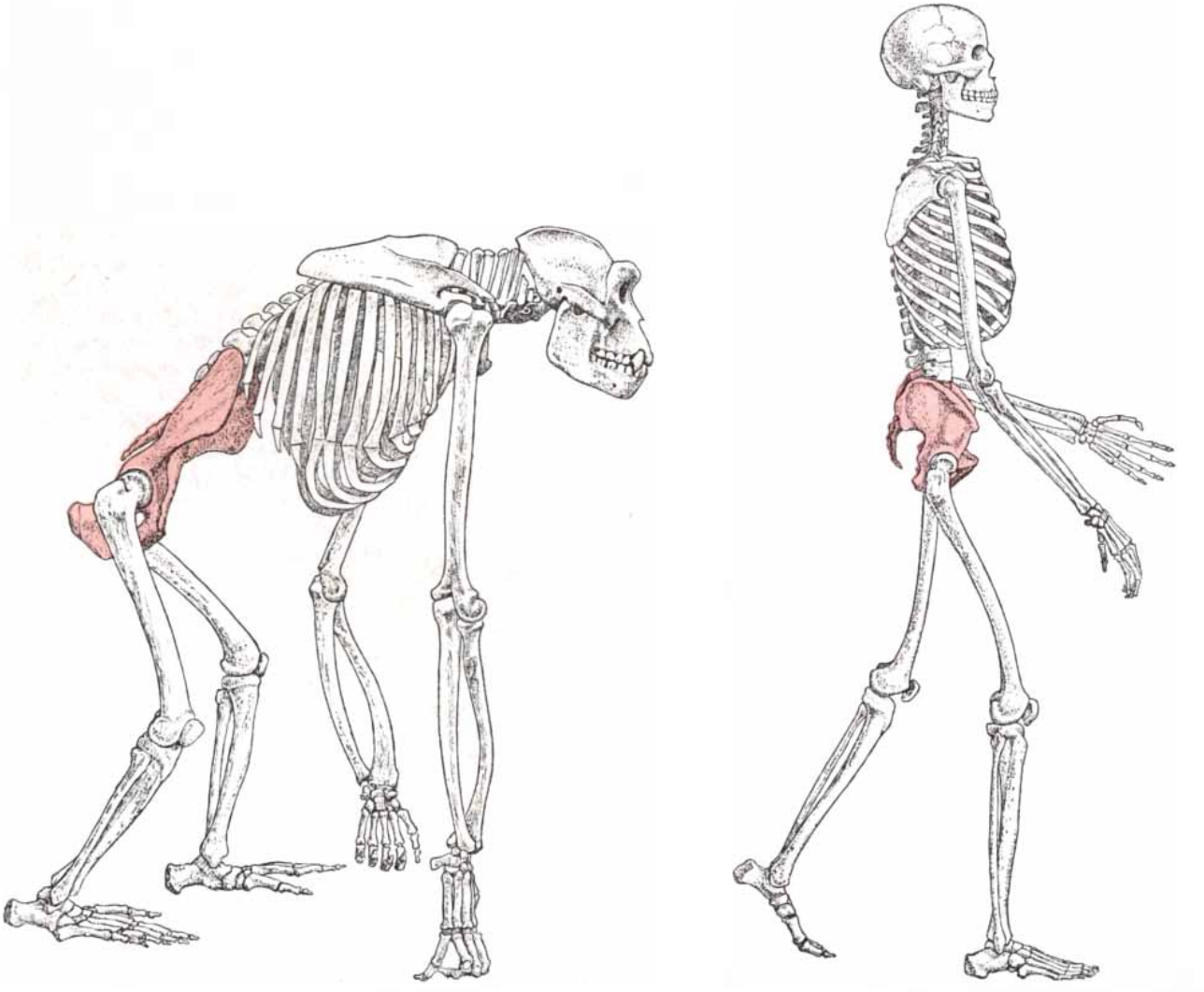
COMPONENTS OF THE PELVIS are identified at top; the bones are those of the human pelvis. Below, ilium and ischium of a gorilla (*a*), of *Australopithecus* (*b*) and of modern man (*c*) are seen from the side (the front is to the left in each instance). The ischium of *Australopithecus* is longer than man's; this almost certainly kept the early hominid from striding in the manner of *Homo sapiens*. Instead the gait was probably a kind of jog trot.

man's erect, striding walk, a number of anatomical changes must occur. These include an elongation of the hind limbs with respect to the forelimbs, a shortening and broadening of the pelvis, adjustments of the musculature of the hip (in order to stabilize the trunk during the act of walking upright), a straightening of both hip and knee and considerable reshaping of the foot.

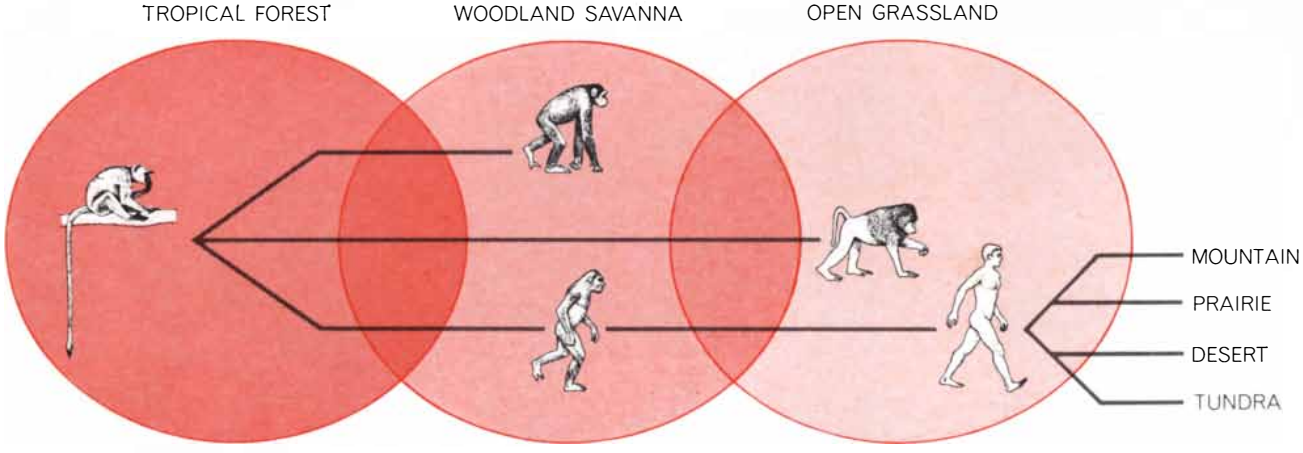
Which of these changes can be considered to be primary and which secondary is still a matter that needs elucidation. Sherwood L. Washburn of the University of California at Berkeley has expressed the view that the change from four-footed to two-footed posture was initiated by a modification in the form and function of the gluteus maximus, a thigh muscle that is powerfully developed in man but weakly developed in monkeys and apes [*see illustrations on preceding two pages*]. In a quadrupedal primate the principal extensors of the trunk are the "hamstring" muscles and the two upper-leg muscles I have already mentioned: the gluteus medius and gluteus minimus. In man these two muscles bear a different relation to the pelvis, in terms of both position and function. In technical terms they have become abductor muscles of the trunk rather than extensor muscles of the leg. It is this that enables them to play a critical part in stabilizing the pelvis in the course of striding. In man the extensor function of these two gluteal muscles has been taken over by a third, the gluteus maximus. This muscle, insignificant in other primates, plays a surprisingly unimportant role in man's ability to stand, or even to walk on a level surface. In standing, for example, the principal stabilizing and extending agents are the muscles of the hamstring group. In walking on the level the gluteus maximus is so little involved that even when it is paralyzed a man's stride is virtually unimpaired. The gluteus maximus comes into its own in man when power is needed to give the hip joint more play for such activities as running, walking up a steep slope or climbing stairs [*see illustration on page 64*]. Its chief function in these circumstances is to correct any tendency for the human trunk to jackknife on the legs.

Because the gluteus maximus has such a specialized role I believe, in contrast to Washburn's view, that it did not assume its present form until late in the evolution of the striding gait. Rather than being the initial adaptation, this muscle's enlargement and present function appear to me far more likely to have been one of the ultimate refinements of human walking. I am in agreement with Washburn, however, when he states that changes in the ilium, or upper pelvis, would have preceded changes in the ischium, or lower pelvis [see "Tools and Human Evolution," by Sherwood L. Washburn; SCIENTIFIC AMERICAN, September, 1960]. The primary adaptation would probably have involved a forward curvature of the vertebral column in the lumbar region. Accompanying this change would have been a broadening and a forward rotation of the iliac portions of the pelvis. Together these early adaptations provide the structural basis for improving the posture of the trunk.

Assuming that we have now given at least a tentative answer to the question of how man's bipedal posture evolved, there remains to be answered the question of why. What were the advantages of habitual bipedalism? Noting the comparative energy demands of various gaits, Washburn points out that human walking is primarily an adaptation for covering long distances economically. To go a long way with a minimum of effort is an asset to a hunter; it seems plausible that evolutionary selection for hunting behavior in man was responsible for the rapid development of striding anatomy. Gordon W. Hewes of the University of Colorado suggests a possible incentive that, acting as an agent of natural selection, could have prompted the quadrupedal ancestors of man to adopt a two-footed gait. In Hewes's view the principal advantage of bipedalism over quadrupedalism would be the free-



SHAPE AND ORIENTATION of the pelvis in the gorilla and in man reflect the postural differences between quadrupedal and bipedal locomotion. The ischium in the gorilla is long, the ilium extends to the side and the whole pelvis is tilted toward the horizontal (*see illustration on opposite page*). In man the ischium is much shorter, the broad ilium extends forward and the pelvis is vertical.



ECOLOGICAL PATHWAY to man's eventual mastery of all environments begins (*left*) with a quadrupedal primate ancestor living in tropical forest more than 20 million years ago. During Miocene times mountain-building produced new environments. One, a transition zone between forest and grassland, has been exploited by three groups of primates. Some, for example the chimpanzees, have only recently entered this woodland savanna. Both the newly bipedal hominids and some ground-living quadrupedal monkeys, however, moved beyond the transition zone into open grassland. The quadrupeds, for example the baboons, remained there. On the other hand, the forces of natural selection in the new setting favored the bipedal hominid hunters' adaptation of the striding gait typical of man. Once this adaptation developed, man went on to conquer most of the earth's environments.

ing of the hands, so that food could be carried readily from one place to another for later consumption. To assess the significance of such factors as survival mechanisms it behooves us to review briefly the ecological situation in which our prehuman ancestors found themselves in Miocene times, between 15 and 25 million years ago.

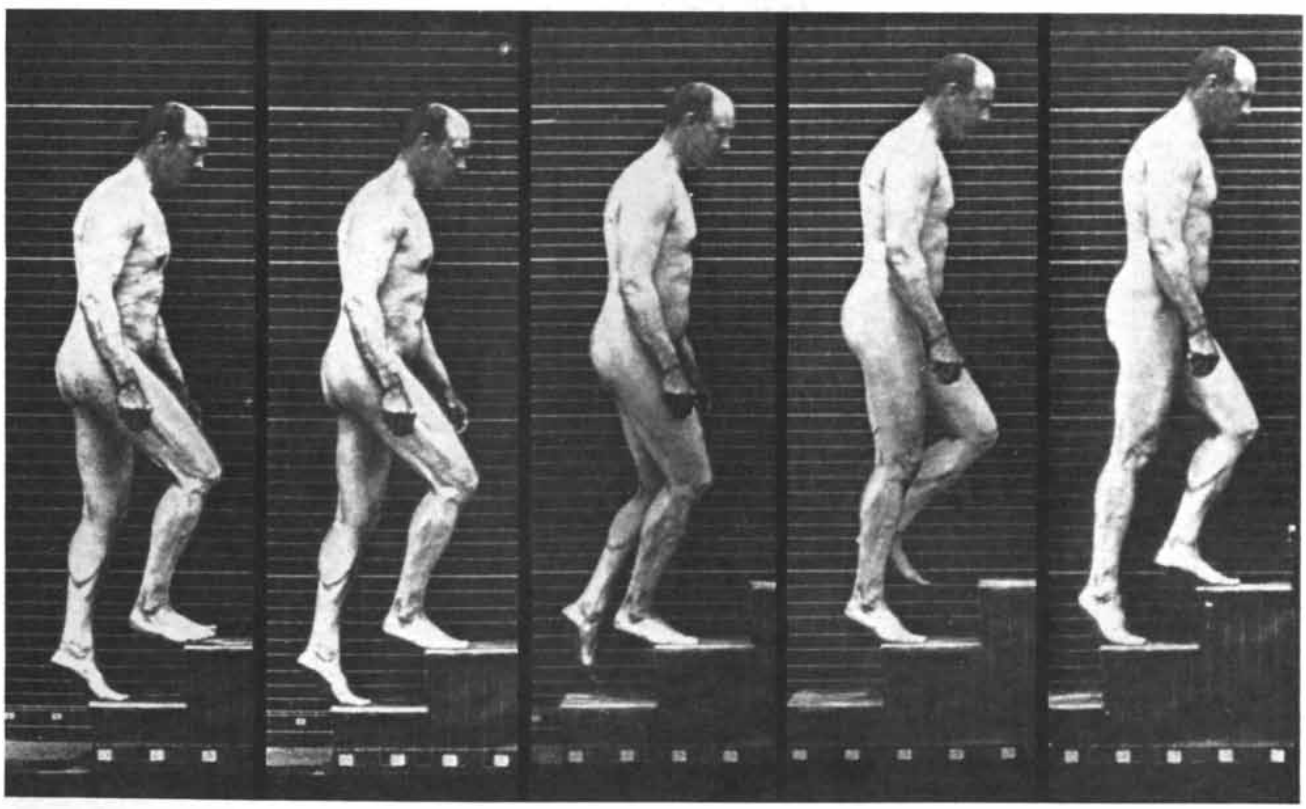
The Miocene Environment

During the Miocene epoch the worldwide mountain-building activity of middle Tertiary times was in full swing. Many parts of the earth, including the region of East Africa where primates of the genus *Proconsul* were living, were being faulted and uplifted to form such mountain zones as the Alps, the Himalayas, the Andes and the Rockies. Massive faulting in Africa gave rise to one of the earth's major geological features: the Rift Valley, which extends 5,000 miles from Tanzania across East Africa to Israel and the Dead Sea. A string of lakes lies along the floor of the Rift Valley like giant stepping-stones. On their shores in Miocene times lived a fantastically rich fauna, inhabitants of the forest and of a new ecological niche—the grassy savanna.

These grasslands of the Miocene were the domain of new forms of vegetation that in many parts of the world had taken the place of rain forest, the dominant form of vegetation in the Eocene and the Oligocene. The savanna offered new evolutionary opportunities to a variety of mammals, including the expanding population of primates in the rapidly shrinking forest. A few primates—the ancestors of man and probably also the ancestors of the living baboons—evidently reacted to the challenge of the new environment.

The savanna, however, was no Eldorado. The problems facing the early hominids in the open grassland were immense. The forest foods to which they were accustomed were hard to come by; the danger of attack by predators was immeasurably increased. If, on top of everything else, the ancestral hominids of Miocene times were in the process of converting from quadrupedalism to bipedalism, it is difficult to conceive of any advantage in bipedalism that could have compensated for the added hazards of life in the open grassland. Consideration of the drawbacks of savanna living has led me to a conclusion contrary to the one generally accepted: I doubt that the advent of bipedalism took place in this environment. An environment neglected by scholars but one far better suited for the origin of man is the woodland-savanna, which is neither high forest nor open grassland. Today this halfway-house niche is occupied by many primates, for example the vervet monkey and some chimpanzees. It has enough trees to provide forest foods and ready escape from predators. At the same time its open grassy spaces are arenas in which new locomotor adaptations can be practiced and new foods can be sampled. In short, the woodland-savanna provides an ideal nursery for evolving hominids, combining the challenge and incentive of the open grassland with much of the security of the forest. It was probably in this transitional environment that man's ancestors learned to walk on two legs. In all likelihood, however, they only learned to stride when they later moved into the open savanna.

Moving forward many millions of years from Miocene to Pleistocene times, we come to man's most immediate hominid precursor: *Australopithecus*. A large consortium of authorities agrees that the shape of the pelvis in *Australopithecus* fossils indicates that these hominids were habitually bipedal, although not to the degree of perfection exhibited by modern man. A few anatomists, fighting a rearguard action, contend that on the contrary the pelvis of *Australopithecus*



STAIR-CLIMBING, like running, is a movement that brings the human gluteus maximus into play. Acting as an extensor of the trunk, the muscle counteracts any tendency for the body to jackknife over the legs. Photographs are from Muybridge's collection.

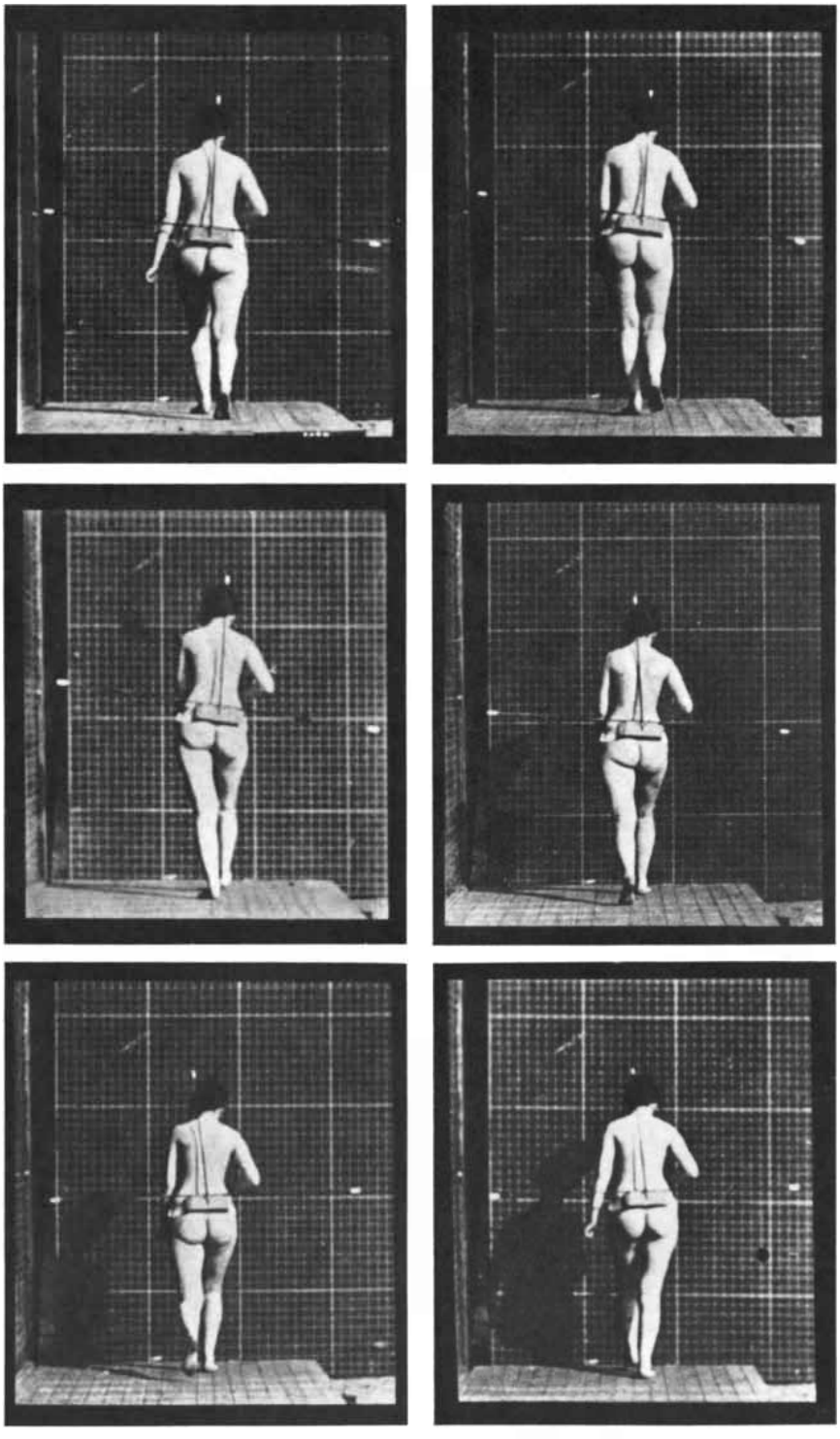
shows that these hominids were predominantly quadrupedal. I belong to the first school but, as I have been at some pains to emphasize in the past, the kind of upright walking practiced by *Australopithecus* should not be equated with man's heel-and-toe, striding gait.

From Bipedalist to Strider

The stride, although it was not necessarily habitual among the earliest true men, is nevertheless the quintessence of the human locomotor achievement. Among other things, striding involves extension of the leg to a position behind the vertical axis of the spinal column. The degree of extension needed can only be achieved if the ischium of the pelvis is short. But the ischium of *Australopithecus* is long, almost as long as the ischium of an ape [*see illustration on page 62*]. Moreover, it has been shown that in man the gluteus medius and the gluteus minimus are prime movers in stabilizing the pelvis during each stride; in *Australopithecus* this stabilizing mechanism is imperfectly evolved. The combination of both deficiencies almost entirely precludes the possibility that these hominids possessed a striding gait. For *Australopithecus* walking was something of a jog trot. These hominids must have covered the ground with quick, rather short steps, with their knees and hips slightly bent; the prolonged stance phase of the fully human gait must surely have been absent.

Compared with man's stride, therefore, the gait of *Australopithecus* is physiologically inefficient. It calls for a disproportionately high output of energy; indeed, *Australopithecus* probably found long-distance bipedal travel impossible. A natural question arises in this connection. Could the greater energy requirement have led these early representatives of the human family to alter their diet in the direction of an increased reliance on high-energy foodstuffs, such as the flesh of other animals?

The pelvis of *Australopithecus* bears evidence that this hominid walker could scarcely have been a strider. Let us now turn to the foot of what many of us believe is a more advanced hominid. In 1960 L. S. B. Leakey and his wife Mary unearthed most of the bones of this foot in the lower strata at Olduvai Gorge known collectively as Bed I, which are about 1.75 million years old. The bones formed part of a fossil assemblage that has been designated by the Leakeys, by Philip Tobias of the University of the Witwatersrand and by me as possibly the earliest-known species of man: *Homo habilis*. The foot was complete except for the back of the heel and the terminal bones of the toes; its surviving components were assembled and studied by me and Michael Day, one of my colleagues at the Unit of Primatology and Human Evolution of the Royal Free Hospital School of Medicine in London. On the basis of functional analysis the resemblance to the foot of modern man is close, although differing in a few minor particulars. Perhaps the most significant point of resemblance is that the stout basal bone of the big toe lies alongside the other toes [*see upper illustration on next page*]. This is an essentially human characteristic; in apes and monkeys the big toe is not exceptionally robust and



PELVIC ROTATION of the human female is exaggerated compared with that of a male taking a stride of equal length because the two sexes differ in pelvic anatomy. Muybridge noted the phenomenon, using a pole with whitened ends to record the pelvic oscillations.

PRIMITIVE FOOT, complete except for the back of the heel and the tips of the toes, was unearthed from the lower level at Olduvai Gorge in Tanzania. Attributed to a very early hominid, *Homo habilis,* by its discoverer, L. S. B. Leakey, it is about 1.75 million years old. Its appearance suggests that the possessor was a habitual biped. Absence of the terminal bones of the toes, however, leaves open the question of whether the possessor walked with a stride.

BIG-TOE BONE, also discovered at Olduvai Gorge, is considerably younger than the foot bones in the top illustration but still probably more than a million years old. It is the toe's terminal bone (*bottom view at left, top view at right*) and bore the thrust of its possessor's push-off with each swing of the right leg. The tilting and twisting of the head of the bone in relation to the shaft is unequivocal evidence that its possessor walked with a modern stride.

diverges widely from the other toes. The foot bones, therefore, give evidence that this early hominid species was habitually bipedal. In the absence of the terminal bones of the toes, however, there was no certainty that *Homo habilis* walked with a striding gait.

Then in 1961, in a somewhat higher stratum at Olduvai Gorge (and thus in a slightly younger geological formation), a single bone came to light in an area otherwise barren of human bones. This fossil is the big-toe bone I mentioned at the beginning of this article [*see lower illustration above*]. Its head is both tilted and twisted with respect to its shaft, characteristics that are found only in modern man and that can with assurance be correlated with a striding gait. Day has recently completed a dimensional analysis of the bone, using a multivariate statistical technique. He is able to show that the fossil is unquestionably human in form.

There is no evidence to link the big-toe bone specifically to either of the two recognized hominids whose fossil remains have been recovered from Bed I at Olduvai: *Homo habilis* and *Zinjanthropus boisei*. Thus the owner of the toe remains unknown, at least for the present. Nonetheless, one thing is made certain by the discovery. We now know that in East Africa more than a million years ago there existed a creature whose mode of locomotion was essentially human.

NEUTRON-ACTIVATION ANALYSIS

This powerful analytic tool is now routinely used in a wide range of disciplines to measure the concentrations of trace elements, often in amounts less than a billionth of a gram

by Werner H. Wahl and Henry H. Kramer

In most physical or chemical investigations impurities are regarded as a nuisance. In recent years, however, experiments in a wide range of fields have been devoted to the painstaking analysis of just such "trace elements." Part of the impetus of this trend has come from the growing realization that minute amounts of certain elements are essential to the metabolism of all living organisms. Accordingly the identification and measurement of trace elements have become indispensable aids to the understanding of many biological processes. The analysis of trace elements also plays an important role in such diverse disciplines as geology, medicine, archaeology, electronics, metallurgy, art history and criminology. Among the techniques devised for measuring the concentration of trace elements perhaps the most sensitive and versatile is neutron-activation analysis.

Reduced to its simplest terms, this method of analysis consists of the following main operations. First a sample of material is bombarded by an intense beam of neutrons. The neutrons interact with the nuclei of atoms in the sample, in many cases to form radioactive nuclei. The sample is then removed from the path of the neutron beam, whereupon the radioactivity of the sample can be measured. The radiation emitted by such "radionuclides" has a characteristic spectrum that can be analyzed to deduce both the elemental constituents of the sample and their respective concentrations. So far variations of this basic technique have been used to detect the presence of some 70 different elements, sometimes in amounts as small as a trillionth (10^{-12}) of a gram! In our laboratory at the Sterling Forest Research Center of the Union Carbide Corporation we have been working for the past few years to improve the sensitivity and extend the usefulness of this powerful analytic tool.

Neutron-activation analysis is one of the many unanticipated dividends of basic research into the nature of the atomic nucleus. The phenomenon of radioactivity—the spontaneous decay of a nucleus accompanied by the emission of radiation—was identified in some natural substances as early as 1898, but it was not until 1933 that Irène and Frédéric Joliot-Curie noted that when they placed pieces of aluminum next to a sample of naturally radioactive polonium, radiation was emitted that did not come from the polonium; moreover, the samples remained radioactive even after the polonium was removed. Chemical analysis showed that the "induced" radioactivity came from a radioisotope, or radioactive species, of phosphorus produced by the disintegration of the aluminum nuclei. The phosphorus decayed at a rate not previously observed for any naturally radioactive substance. This was the first reported observation of an artificial radioisotope.

A few years later the noted chemist Georg von Hevesy, "without having a special reason to do so," exposed a purified salt of the element dysprosium to a stream of neutrons emitted by a radioactive mixture of radium, radon and beryllium. He observed that the irradiated salt displayed "the most intense artificial radioactivity.... This observation induced me to determine the dysprosium content of an yttrium sample by exposing it to a neutron stream." Thus, on an impulse, von Hevesy discovered the principle of neutron-activation analysis.

The hiatus between the discovery of activation analysis and its routine application resulted from the lack of sufficiently intense neutron sources and the inability of early detection devices to resolve the various kinds of radiation produced by the activated samples. During World War II the development of the atomic bomb removed the first of these two obstacles. Essential to the making of the bomb were large nuclear reactors, which generate enormous quantities of neutrons. With the early reactors built at Oak Ridge and Hanford investigators were able to analyze at least 60 trace elements in amounts as small as a millionth (10^{-6}) of a gram.

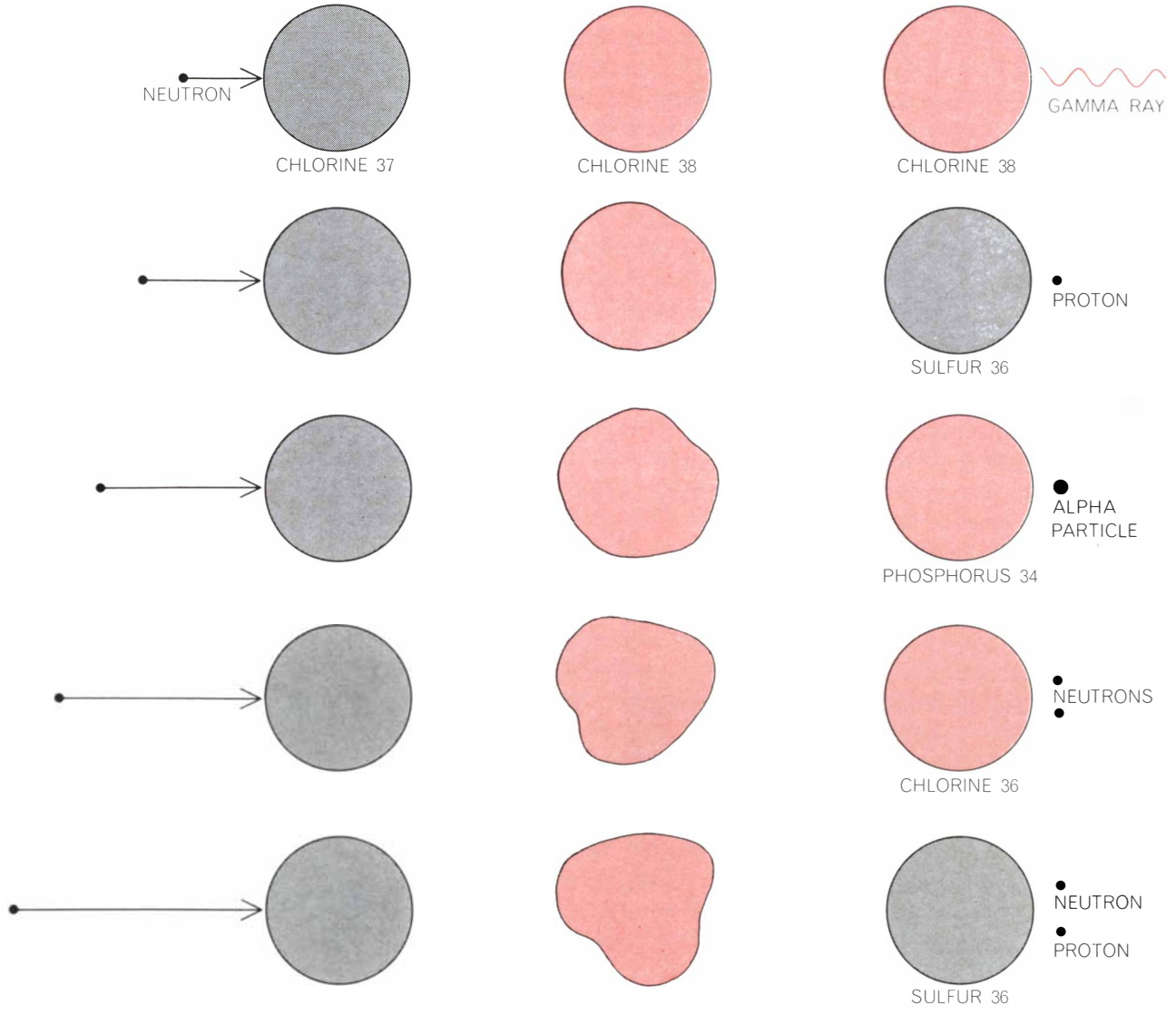
Only a few workers were able to use these facilities for conducting neutron-activation analyses; radiation-detection equipment was still crude, and many hours were required for processing the huge volume of data needed to make a single analysis. As a result neutron-activation analysis remained for many years more of a demonstrated capability than a useful analytic tool. By the middle 1950's improvements in instrumentation had significantly reduced the time required for recording and processing large quantities of data. With this final obstacle removed neutron-activation analysis can now be employed for analyzing trace elements wherever an intense source of neutrons is available.

The first step in the technique, in which the sample is exposed to the neutron beam, is called the activation step. The instability of the "compound nuclei" produced in this step arises from the immense amount of energy that is transferred to a target nucleus whenever it absorbs a neutron. Almost immediately after a compound nucleus is formed it releases its excess energy by emitting "prompt radiation"; in the process it is transformed into a nucleus that can be

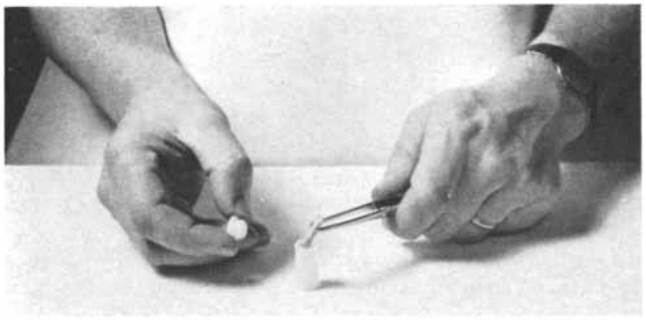
either stable or radioactive. A radioactive nucleus in turn decays and emits radiation. It is this last emission of radiation that is detected and measured in neutron-activation analysis. In addition, the prompt radiation emitted by the compound nucleus is sometimes measured to provide information about the particular reaction that takes place when a compound nucleus disintegrates.

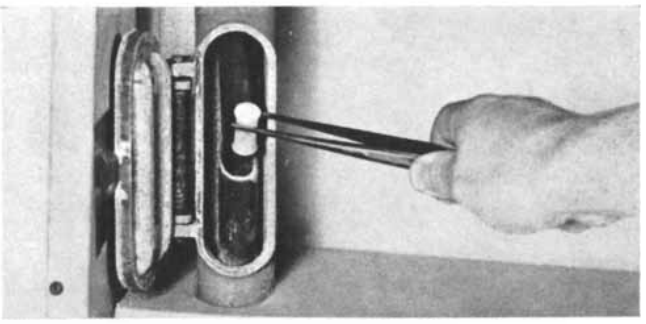
The type of nuclear reaction that will occur in this situation depends largely on the energy of the absorbed neutron. The greater the energy of the neutron, the harder it will hit the nucleus and the greater the probability is that the prompt emission will be in the form of a nuclear particle rather than an electromagnetic wave such as a gamma ray. For example, when a neutron is absorbed by a nucleus of chlorine 37 (a stable isotope of chlorine whose nucleus contains 20 neutrons and 17 protons), a highly unstable form of chlorine 38 is produced. This unstable compound nucleus decays to a more stable state by emitting either a gamma ray or one (or more) of a variety of nuclear particles, such as neutrons, protons or alpha particles [*see illustration below*].

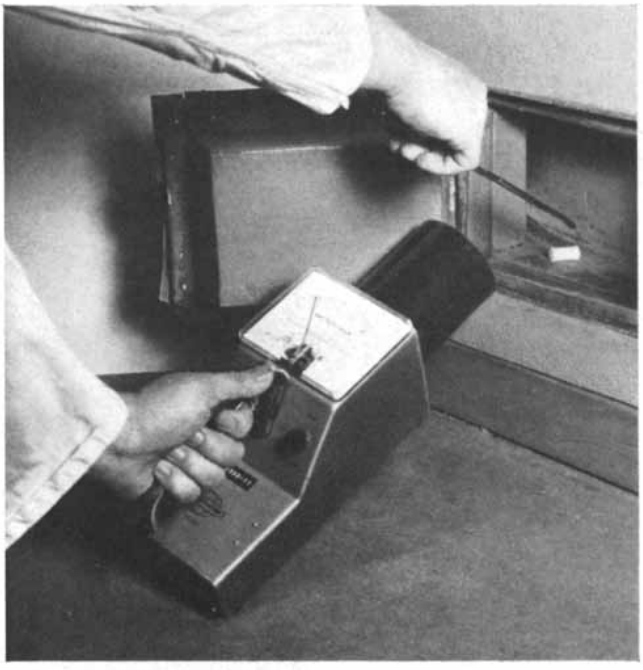
Accordingly the particular radionuclide that is produced when a sample is bombarded by neutrons depends on both the stable nucleus that absorbs the neutron and the energy of the absorbed neutron. Since a sample normally contains many different elements—and hence many more different isotopes—a profusion of radionuclides will be produced by neutron bombardment. The analyst is usually not interested in the total amount of radioactivity that is induced; he is primarily concerned with the activity of a particular radionuclide, since it is the quantitative indicator of the

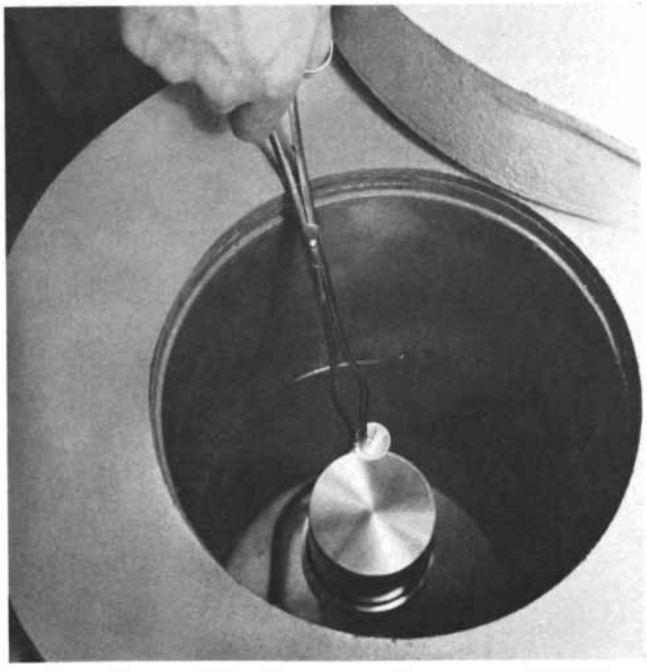


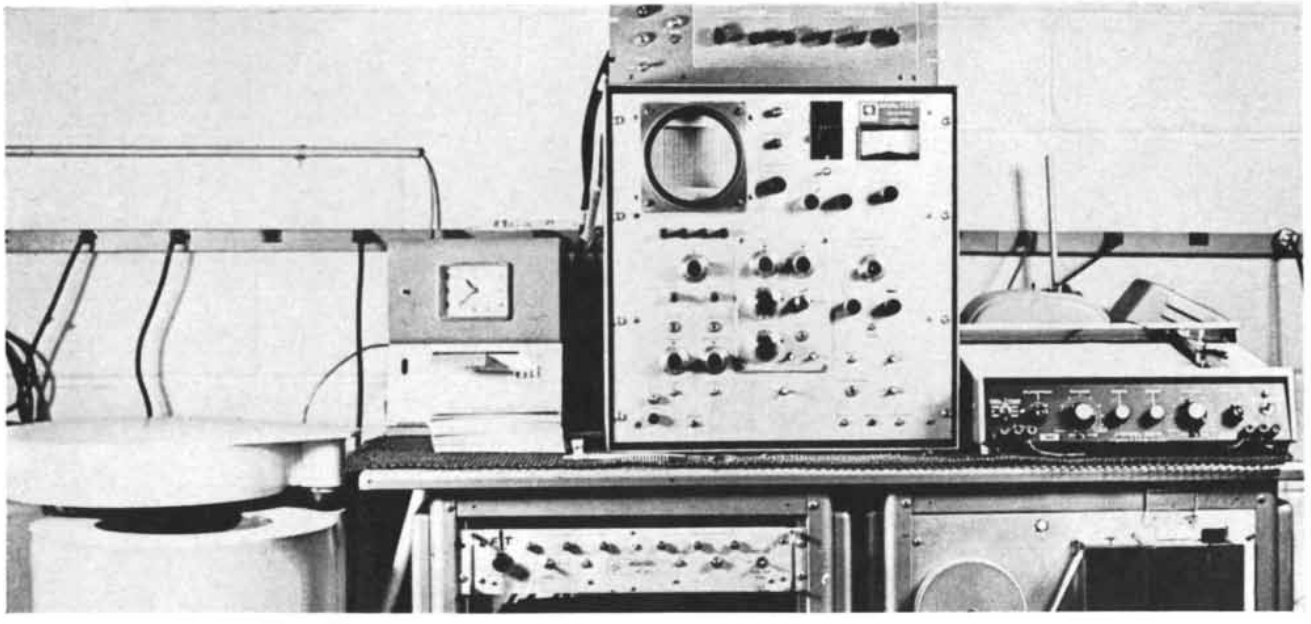
NEUTRON-ACTIVATION ANALYSIS of chlorine 37 (a stable isotope of chlorine whose nucleus contains 20 neutrons and 17 protons) begins when a chlorine 37 nucleus absorbs an extra neutron (*column 1*), producing a highly unstable "compound nucleus" of chlorine 38 (*column 2*). Almost immediately after a compound nucleus is formed it releases its excess energy by emitting "prompt radiation"; in the process it is transformed into a nucleus that can be either stable or radioactive (*column 3*). Radiation from the radioactive nuclei (*color*) can be measured. The type of nuclear reaction that will take place when a compound nucleus disintegrates depends largely on the energy of the absorbed neutron. The greater the energy of the neutron, the greater the probability that a nuclear particle rather than an electromagnetic wave will be emitted. Energy of the neutrons increases from top to bottom.











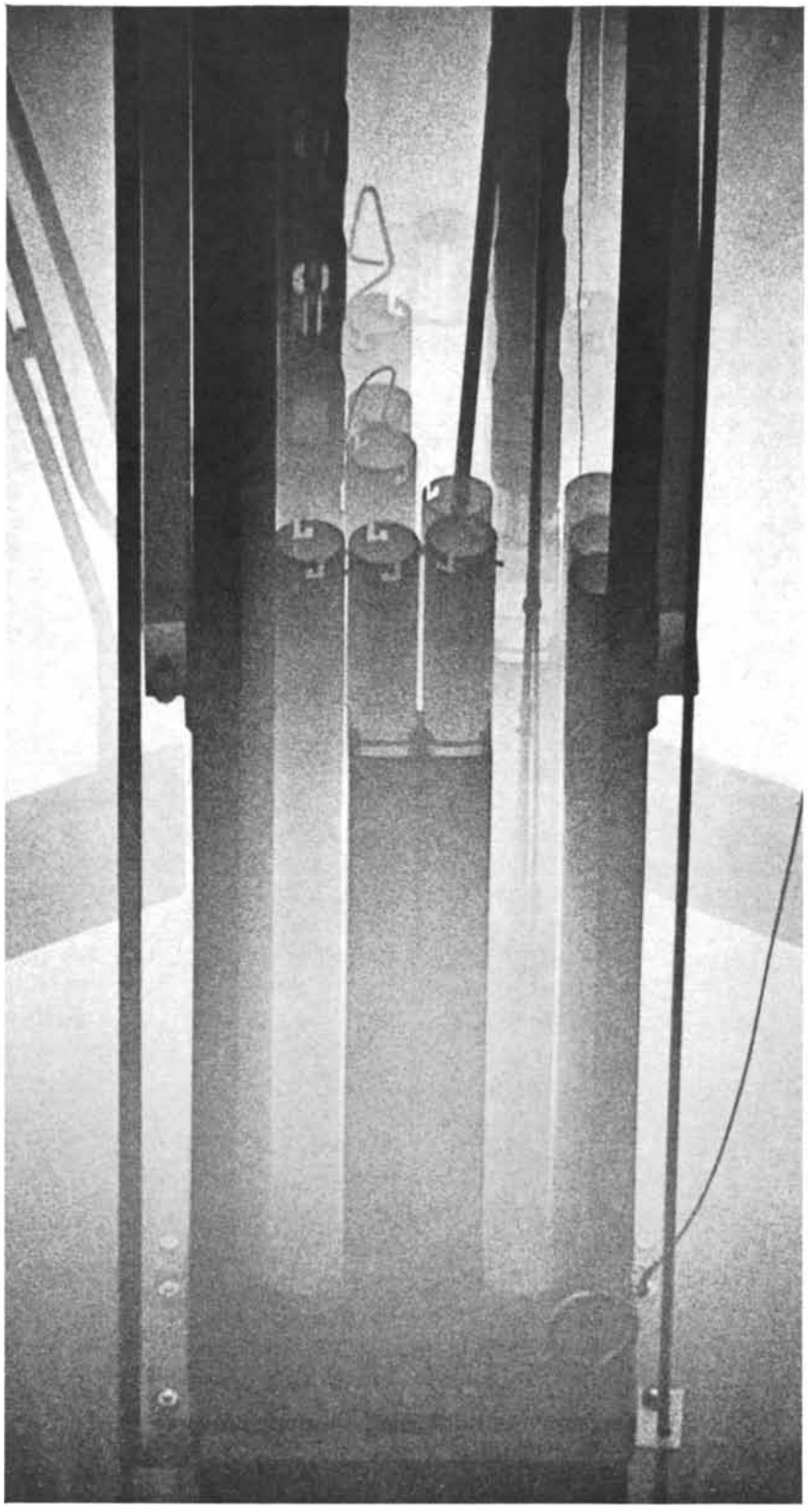
PROCEDURE followed in performing a typical neutron-activation analysis is illustrated by the sequence of photographs on this page, which were made in the authors' laboratory at the Sterling Forest Research Center of the Union Carbide Corporation. A small sample of the material to be analyzed is first inserted in a plastic irradiation container (*top left*). The container is then placed in a pneumatic transfer tube (*top right*), which leads to the core of a nuclear reactor where the sample is bombarded with neutrons. After a certain irradiation period the activated sample is returned to the laboratory (*middle left*) and placed inside a massive lead radiation shield (*middle right*). Scintillation detectors located inside the shield measure the radioactivity of the sample and transfer this information to an array of instruments (*bottom*), which analyze and record the characteristic energy spectrum of the induced radioactivity.

concentration of a particular stable isotope in the original sample.

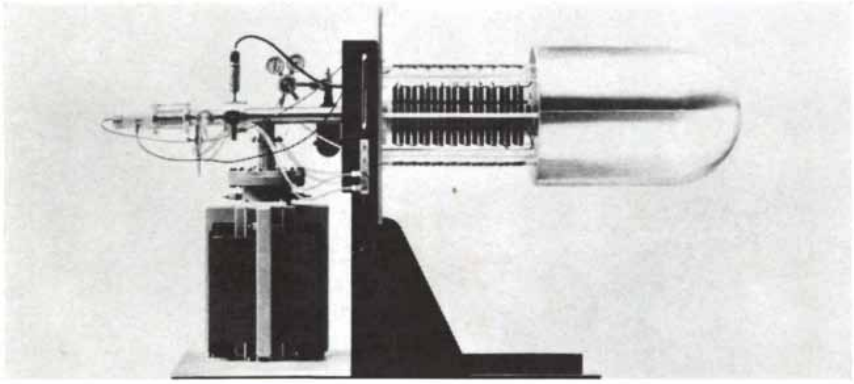
For each radionuclide the amount of radioactivity induced is proportional to the number of nuclei of the original stable isotope, the number of neutrons that are available to interact with the nuclei (the neutron flux) and the probability that a neutron will interact with a target nucleus. Every neutron that enters the sample does not interact with a nucleus, of course; the spacing between the nuclei is so large compared with both the size of the nuclei and the size of the neutrons that most of the neutrons will pass right through the sample. Only when a neutron comes fairly close to a nucleus does it have a chance to be absorbed. In somewhat oversimplified terms, the probability of an interaction between an incoming particle and a target nucleus is proportional to the apparent cross-sectional area presented by the target. According to this analogy the probability of a neutron-nucleus interaction is called the cross section of the interaction and has the dimensions of an area.

The number of radioactive nuclei in an irradiated sample also depends on how long the sample was exposed to the neutrons and on the characteristic decay rate of the radioactive nuclei, which begin to decay as soon as they are produced. The net rate of production of a radionuclide is equal to its gross production rate minus its decay rate. The radionuclide to be measured is usually not present in the original sample; consequently during irradiation the gross production rate initially far exceeds the decay rate. These two rates approach each other at an exponential rate that depends on the half-life of the radionuclide. (The half-life is the characteristic time required for half of the nuclei in a population of radioactive atoms to decay.) In time the net rate of production will be zero, and no more radioactivity will be produced. This phenomenon is called saturation.

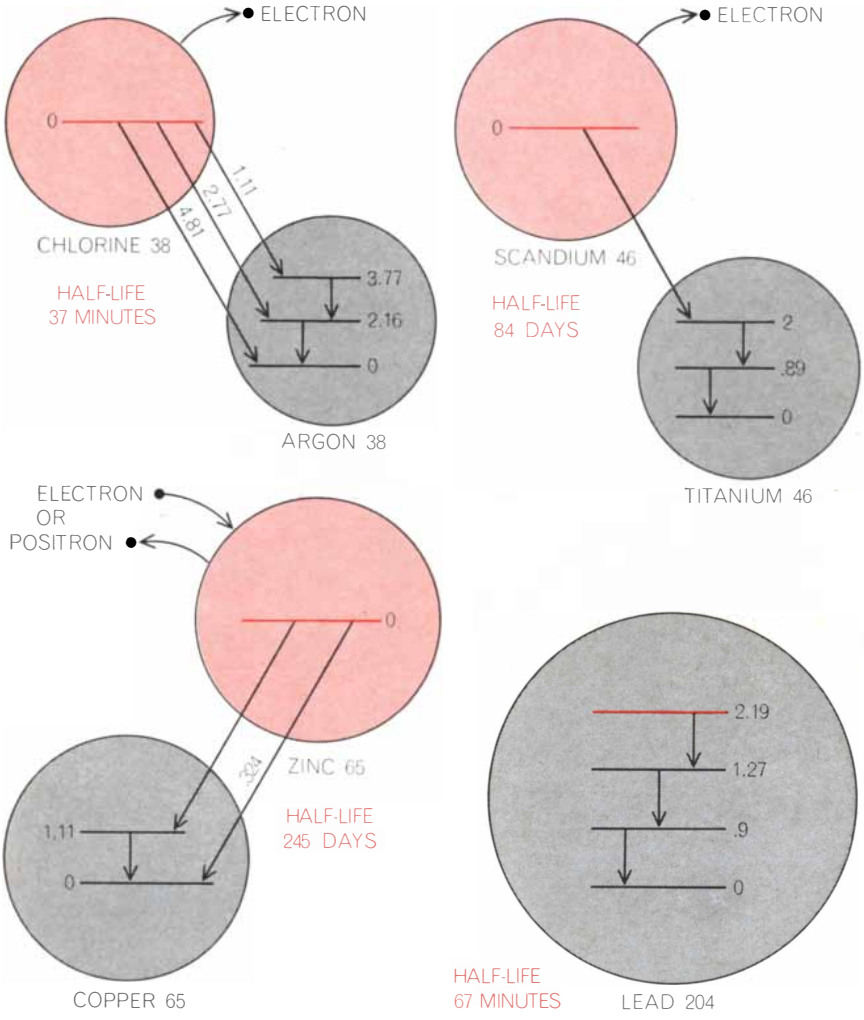
In practice the sample is exposed to neutrons long enough to produce a measurable activity of the particular "indicator" radionuclide formed by the element that is being assayed; then the sample is removed from the irradiation zone and its induced radioactivity is measured. Activation ceases when the sample is removed, and in time all the induced radioactivity will decay. Thus the amount of each radionuclide present at any time after neutron bombardment is influenced by those factors that are fixed for a given sample (the number of



NUCLEAR REACTOR is used by the authors and their colleagues as a source of neutrons for activating samples of various materials. The neutrons are emitted as a by-product of the fission of uranium 235, which takes place in the vertical pipelike fuel elements visible in the center of the photograph. The entire reactor is immersed in a large tank of water in order to slow down the energetic neutrons emitted by the fission reaction. The sample to be activated is transferred into the reactor in the vicinity of the fuel elements. The glow surrounding the fuel elements is called Cerenkov radiation; it is produced by the passage of fast electrons through the water. The photograph was made solely by the light of the Cerenkov radiation.



COCKCROFT-WALTON GENERATOR produces neutrons by bombarding a target (*inside end of tube at left*) with accelerated charged particles. The sample is placed in the path of the neutrons, which are emitted in all directions. Neutron generators produce a usable neutron flux about 10,000 times smaller than flux available from a nuclear reactor.



DECAY PROPERTIES of every radionuclide are unique to that particular nuclear species. An artificial radioactive nucleus usually decays by emitting electrons, positrons or gamma rays, or by absorbing an orbital electron. In each case the radioactive nucleus (*color*) loses internal energy, forming a more stable nucleus (*gray*), which can have the same atomic number (*arrows pointing straight down*), a higher atomic number (*arrows pointing to lower right*) or a lower atomic number (*arrows pointing to lower left*). A radioactive species can decay by a number of routes, sometimes producing a more stable species that is in an excited state. When the excited species decays to its ground state, it emits a gamma ray, which is usually associated with the decay processes of the parent radionuclide. Black numbers denote energy in millions of electron volts (MeV). Half-lives are indicated in color.

reacting isotopes, the cross section of the production reaction and the half-life of the radionuclide) and those factors that can be varied by the analyst (the neutron flux, the period of irradiation and the decay time prior to measurement of the induced activity). All these factors are expressed in a single mathematical equation called the activation equation.

There are three types of neutron source used for activating samples: nuclear reactors, neutron generators and isotopic sources. The neutron flux available in nuclear reactors allows analyses of most elements in concentrations from 10^{-12} to 10^{-6} gram. Neutron generators, such as the Cockcroft-Walton generator and the Van de Graaff generator, produce a usable flux about 10,000 times smaller than the flux available from a nuclear reactor, and this reduction in flux is accompanied by a comparable reduction in the sensitivity of measurement. The neutron yield of the isotopic sources is still lower, and they are used mainly to demonstrate the principles of the activation technique.

Since many different radionuclides are produced in a particular irradiated sample, the problem is to measure the activity of the indicator radionuclide in the presence of all the other induced radionuclides. This task is not as difficult as it sounds. It happens that every radionuclide disintegrates in a manner unique to itself. There are 66 natural radionuclides and 1,095 known radionuclides that can be artificially produced. No two of these 1,161 nuclei have exactly the same decay properties. Accordingly by measuring the decay properties of the radiation from a sample one can sometimes effectively isolate one radionuclide from all the others in the sample. When the decay properties cannot be measured directly, the radionuclides can be separated chemically. Therefore by one method or another all the activated nuclei in a sample can be identified and measured.

The radionuclides most frequently encountered in neutron-activation analysis decay by the emission of beta particles (electrons and positrons) and gamma rays. Because it is difficult to resolve beta-particle spectra resulting from mixtures of radionuclides, beta particles are not used for analysis unless they are the only emission from the indicator isotope, or unless the element can be conveniently isolated in a pure form. Gamma rays, on the other hand, are emitted with distinct energies that can be resolved by the standard technique known as scintilla-

Basic Research at Honeywell
Research Center
Hopkins, Minnesota

Measurements of the Micropulsations of the Earth's Magnetic Field

Micropulsations are now being measured on a long term continuous basis in a previously unmonitored section of the Midwestern United States, hopefully leading to further correlations between these magnetic variations and geophysical disturbances.

For a long time scientists have known that solar activity has repercussions within the magnetosphere of the earth. The plasma clouds from the sun generate magneto-hydrodynamic waves which are observed on the earth as micropulsations of the earth's magnetic field. Since about 1936 scientists have been measuring these micropulsations at various locations on the earth's surface and have attempted to correlate them with observed geophysical phenomena. By so doing they have determined the origins of some disturbances but the causes of many others remain unknown.

The micropulsations normally being measured are in the extremely low frequencies under 5 cycles per second and have amplitudes ranging from several 10's of gammas to milligammas. The shape, amplitude, frequency and nature (whether impulsive or continuous) of the micropulsations imply different causes. Correlation is attempted with observed data on physical occurrences obtained in many ways including information from instrumented balloons, rockets and satellites.

A problem in correlating data is that although many measuring stations exist, vast areas of the earth are not adequately covered as yet. The Midwest region of the United States from the Great Lakes to Colorado has been such an area. The Honeywell Research Center is now establishing a station in this region.

All such stations must be located in an area of unusually low electrical noise and also must be near a research base for equipment maintenance and data gathering. Fortunately the University of Minnesota has maintained a virgin forest about 35 miles north of Minneapolis for natural history research. The University has now permitted Honeywell to locate its station in the center of this unique forest.

Housed in a trailer furnished by the U. S. Bureau of Standards, the present Honeywell facility consists of signal conditioning equipment, a low noise amplifier, a magnetic recorder and a multi-channel strip chart recorder. Current work is directed toward the establishment of a 3-axis system.

Of particular interest to Honeywell scientists is the micropulsation known as a "pearl", so called because its signal, when charted, resembles a pearl necklace. (See Fig. 1.) Less is known about the "pearl" than other low-frequency signals and although many hypotheses have been set forth regarding its origin and nature, none have been proven.

Honeywell scientists are using a standard speed-up technique to study the "pearls". The taped low-frequency signals are played back at higher speeds, enabling the scientist to hear when a disturbance occurs. A 30-minute "pearl" pulsation is then condensed into short blips. Interesting portions of the tape identified by the blip are fed into a sonograph which displays the signal's frequency, time and intensity. The scientist using an XY plotter will play different channels simultaneously to determine the polarization and temporal variation of the field.

The visual trace (Fig. 1) helps to determine the interesting portions in order to concentrate the analysis. It also provides a visual record which can be published for correlation with other stations.

Many "pearls" have now been recorded at the Honeywell station. It is hoped that some new understanding of the causes of phenomena in the earth's upper atmosphere will result.

If you are engaged in research on micropulsations and wish further information concerning Honeywell's plans for work in this area, you are invited to correspond with Mr. Van Kardashian, Honeywell Research Center, Hopkins, Minnesota. If you are interested in a career at Honeywell's Research Center and hold an advanced degree, write to Dr. John Dempsey, Vice President of Research at this same address. Several important new staff positions are unfilled at the present time.

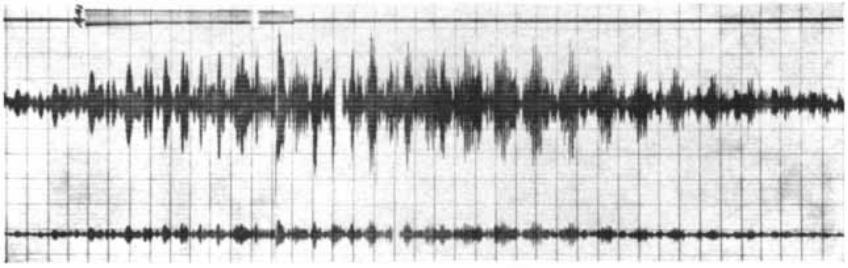


FIG. 1. Segment of micropulsation record showing high- and low-sensitivity traces. Recorded at 25 inches per hour at Honeywell's Cedar Creek Station.

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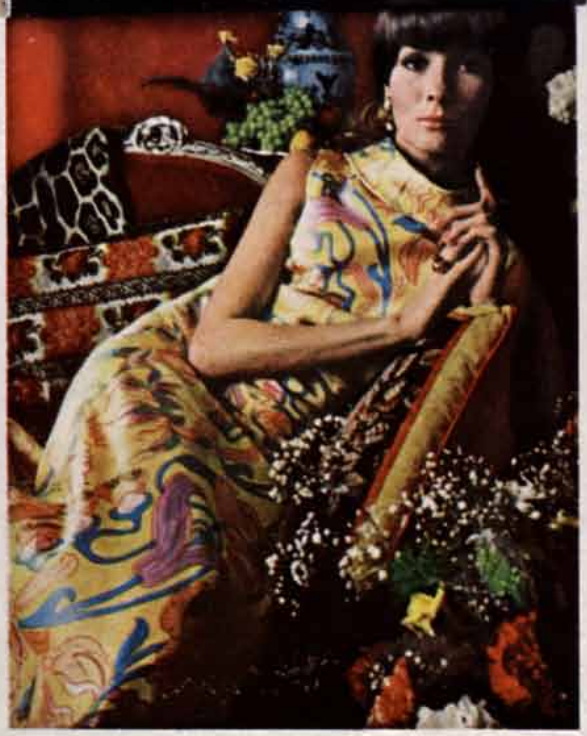

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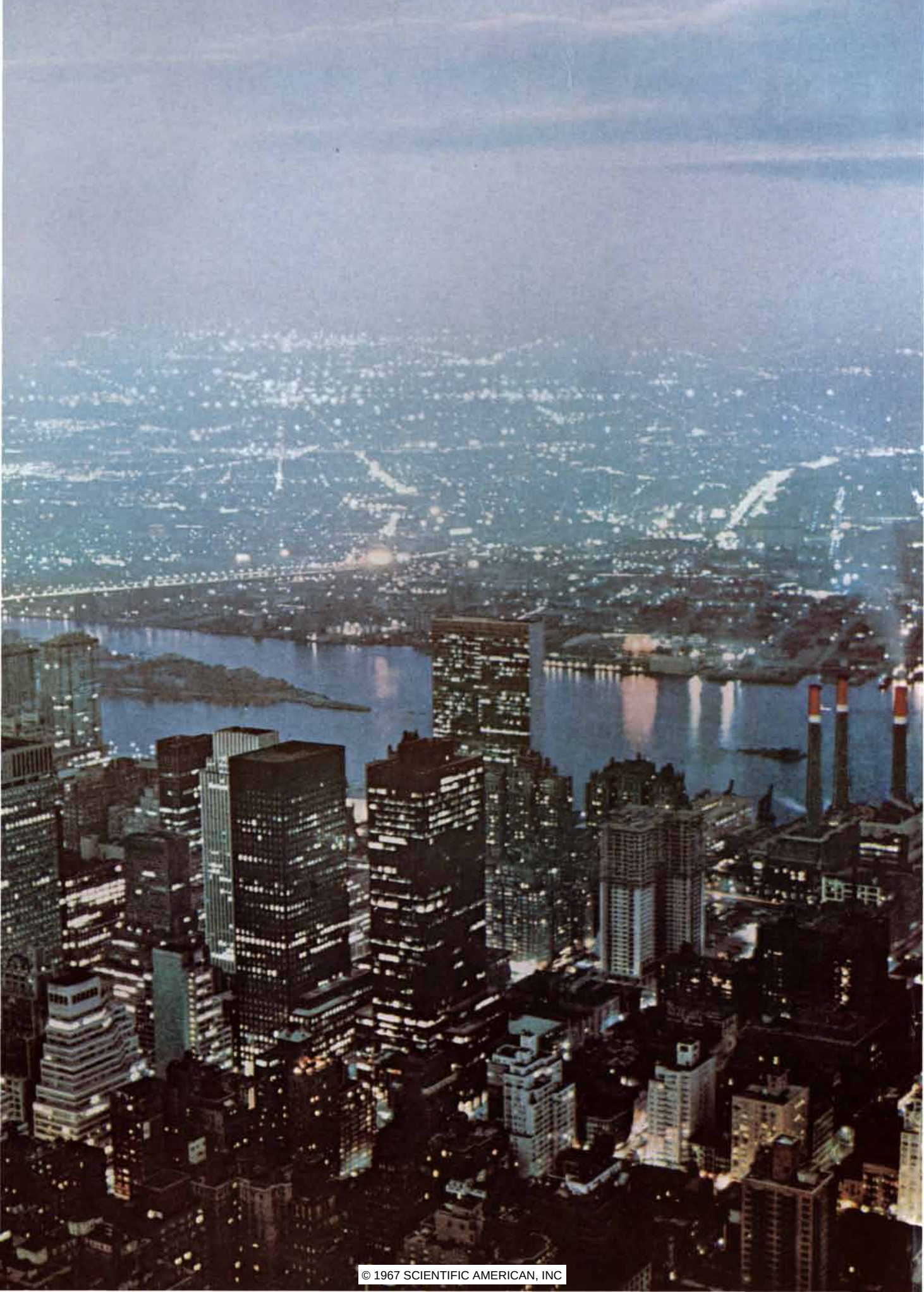

3500 feet down, people could travel 500 miles per hour–through solid rock

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Although the automobile will continue to be the basic means of American travel, high-speed mass transportation will soon be needed through thickly populated intercity areas.

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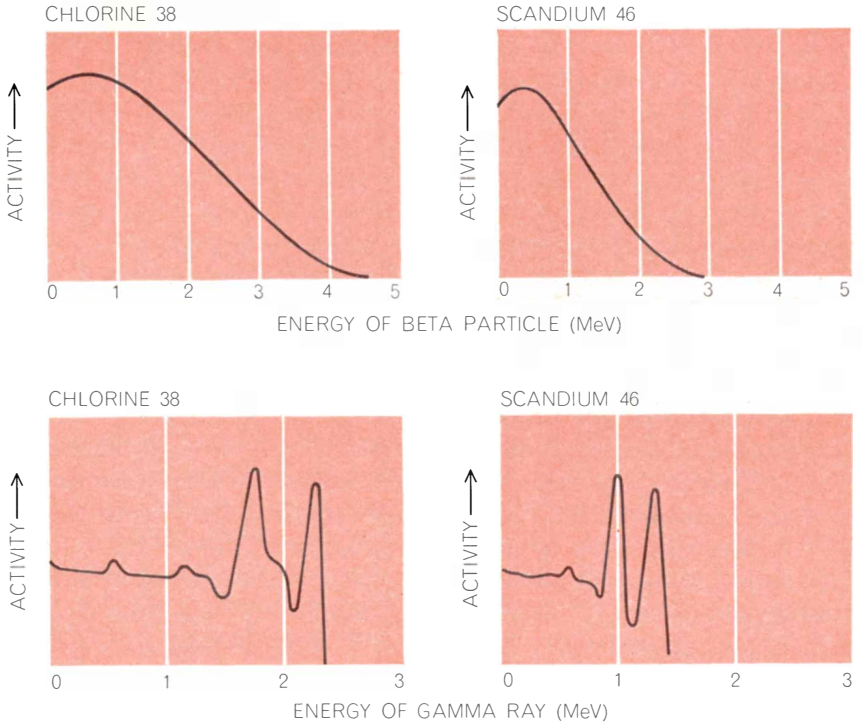
tion spectrometry; as a result most neutron-activation analyses are based on gamma ray data.

In scintillation spectrometry gamma rays are detected by causing them to interact with a material that responds to the interaction by scintillating, that is, by emitting photons of visible light whose intensity is directly proportional to the energy of the absorbed gamma ray. The most widely used scintillating material is a single crystal of sodium iodide "doped" with a small amount of the element thallium. The crystal is coupled to a photomultiplier tube, which detects the light emissions and converts them into electronic pulses. These pulses are fed into a multichannel pulse-height analyzer, which sorts them according to amplitude and counts the number of pulses in each amplitude range during a given counting period. The result is a record of the energy distribution of the gamma rays emitted by the radioactive nuclei in the sample.

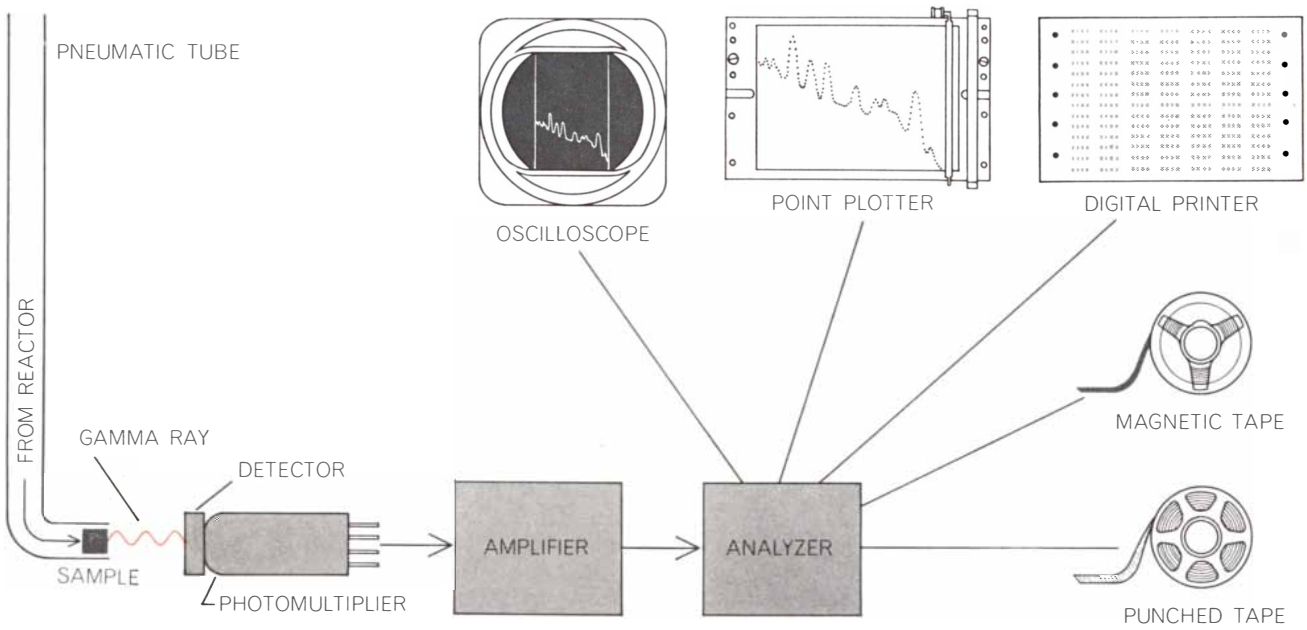
In some cases the gamma rays emitted by different radionuclides are so similar in energy that they cannot be adequately resolved in the gamma ray spectrum. In these instances the different characteristic decay rates of the individual radionuclides can be used to isolate one isotope from another. It is often possible to maximize or minimize the activity of one radionuclide with respect to another in an activated sample by properly adjusting the duration of the irradiation period and the decay period. The use of time as an independent variable is unique to the neutron-activation technique, giving the analyst two additional factors to manipulate to his advantage. The ability to discriminate in this manner depends primarily on the difference in the half-lives of the radionuclides induced in the samples. Short irradiation periods are used to maximize the ratio of short-lived nuclei with respect to longer-lived nuclei when the longer-lived ones may give rise to interfering radiations. By the same token longer irradiation periods are employed to maximize the long-lived nuclei, and the analyses for these nuclei are completed after the short-lived nuclei have been allowed to decay.

When the radioactivity of the indicator nuclide cannot be accurately measured in the presence of other radionuclides, even after the time variables are taken into account, chemical methods are used to isolate the individual radionuclides. This situation usually obtains when the radiations from the desired indicator nuclide are effectively masked by more abundant radiations from longer-lived nuclei and cannot be resolved by spectral analysis. Even though the element of interest may be present in extremely small quantity, the methods of chemical separation are the same as those used in normal quantitative analyses. Instead of the separations' being carried out on a microscale, however, they are facilitated by the addition of a known amount (approximately 10 to 50 milligrams) of the element of interest to the sample after it has been irradiated, and then the chemical isolation of a mixture containing the radionuclide induced in the sample and the added stable element. The analysis is completed by the measurement of the radioactivity in the isolated mixture. Since the quantity of the added element is known, the efficiency of the chemical separation is easily determined, and the radioactivity measurements can be corrected for any losses caused by chemical processing after irradiation. Since the radiochemical separation need not be quantitative, the separation procedures can be shortened and the tedious work frequently required for quantitative analysis can be minimized.

Once the radiations of the indicator nuclide are isolated, quantitative measurements of the induced activity can be made. In principle the activation technique is an absolute analytic method, and the weight of an element can be determined directly from the measured activity and a knowledge of the nuclear constants and experimental conditions. But since it is difficult to make an absolute measurement of radioactivity, and because reaction cross section and neutron flux are seldom known precisely, activation analyses are not normally completed by the absolute method. Instead a comparative method is almost always used. A standard sample containing a known amount of the element to be analyzed is irradiated and processed in the same way as the sample being analyzed. Since all the terms in the activation equation except for the number of target atoms and the induced activity are the same for the control and the test sample, the activity of the indicator nuclide in the test sample can be directly compared with the activity of the control to obtain the weight ratio of the desired element in two samples. Analyses by this method can be completed with an accuracy of about 2 percent of the actual



MOST RADIONUCLIDES DECAY by emitting beta particles (electrons and positrons) or gamma rays. The beta-particle spectra of low-energy beta-particle emitters (*top*) are difficult to resolve in the presence of high-energy emitters; as a consequence beta particles are rarely used for neutron-activation analysis. Gamma rays, on the other hand, are emitted with distinct energies that can be readily resolved by scintillation spectrometry (*see illustration on opposite page*); as a result most neutron-activation analyses use gamma ray data.



GAMMA RAYS from an activated sample are measured by allowing them to fall on a scintillation detector, which emits photons of visible light whose intensity is directly proportional to the energy of the absorbed gamma ray. The detector is coupled to a photomultiplier tube, which detects the light emissions and converts them into electronic pulses. The pulses are amplified before being fed into a multichannel pulse-height analyzer, which sorts them into a record of the energy distribution of the original gamma rays. The gamma ray data can be "read out" of the analyzer in a number of ways, some of which are represented schematically in illustration.

concentration at levels down to as little as 10 times the lower limit of detection. Analyses with an accuracy of better than 1 percent of the actual value are possible but extremely difficult to attain by this technique. As a result the neutron-activation technique is most widely used for trace-element analysis where an accuracy of from 2 to 5 percent is permissible.

One of the most fascinating applications of neutron-activation analysis in recent years was undertaken in 1961 by two Swedish physicians, Sten Forshufvud and Anders Wassén, in collaboration with Hamilton Smith of the Department of Forensic Medicine at the University of Glasgow. For a long time medical writers have doubted the official diagnosis of cancer as the cause of Napoleon's death in exile on the island of St. Helena in 1821. On the basis of the recorded symptoms a number of alternative diagnoses have been proposed, including peptic ulcer, malaria, dysentery, syphilis and gonorrhea. In order to test the hypothesis that Napoleon had in reality been poisoned, Forshufvud and his co-workers obtained well-documented samples of Napoleon's hair, which was shaved from his head the night after he died, apparently to provide as much hair as possible for distribution as souvenirs and to facilitate the making of a death mask. Several of the samples were irradiated with neutrons in a nuclear reactor. Consecutive half-millimeter lengths of rather long hairs were then analyzed for the presence of arsenic. The concentration of arsenic in the segments was found to be much higher than that in normal human hair, indicating that Napoleon may have suffered from chronic arsenic intoxication. Moreover, the arsenic content of the consecutive lengths of hair was not uniform, indicating that he was probably exposed to arsenic intermittently. Considering that the average growth of hair on the scalp is about .35 millimeter per day, it was possible to infer that periods of higher arsenic concentration in the hair coincide with days on which Napoleon was reported to be sicker during his captivity. Hence, judging by the arsenic concentration in hair found in healthy people today, it seems likely that Napoleon died from arsenic poisoning, the arsenic being administered at intervals during his illness.

Neutron-activation analysis has also been used in an attempt to date and authenticate old paintings. One method is to measure the concentrations of various trace elements in white lead paint, which has been used as a primer and white pigment since the Middle Ages. The purity of white lead is directly related to the purity of the lead used to make the paint. Since the metallurgical techniques for purifying lead have been modified several times during the past five centuries, the trace-element content of the white lead in a particular painting can be used to estimate the age of the painting. Using the neutron-activation technique, Jan Houtman and J. Turkstra of the Reactor Instituut at Delft in the Netherlands have analyzed tiny samples of white lead removed from a number of authentic "old masters" at museums in Belgium and the Netherlands [*see illustration on page 82*].

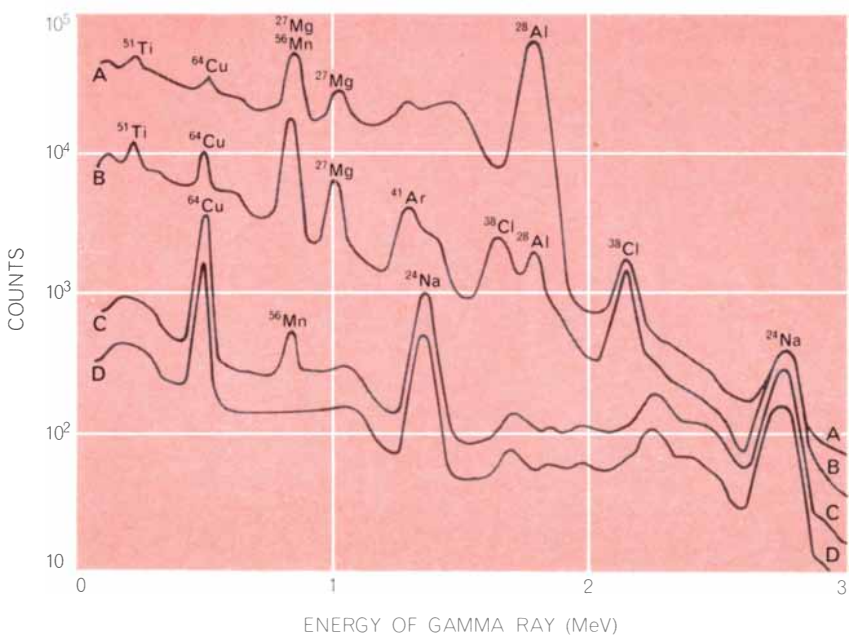
They have found that the concentrations of copper, silver, mercury and manganese were fairly high and constant in white lead made between 1500 and about 1850; after 1850 these concentrations dropped to about a tenth of their earlier values and have remained low and constant ever since. Similarly, the concentration of chromium was found to be high before 1650 and much lower since 1650. On the other hand, the concentrations of zinc and antimony, which were quite low before 1940, have increased considerably in recent years. The great sensitivity of the neutron-activation technique makes possible a complete analysis using less than a milligram sample of the white lead, which can be obtained from the edge of the painting without causing any noticeable damage. Data obtained by the neutron-activation technique can be used not only to date a painting but also in some cases to determine the identity of the artist by com-

paring the paint with the paint of authenticated works.

Most of the trace-element analyses performed by the neutron-activation technique are of course more mundane than the ones just described. Nonetheless, the technique has played a key role in solving many important technological problems. For example, it has been used in the development of purer materials for manufacturing transistors, high-strength metal alloys and plastics. One noteworthy problem that was solved had to do with certain epoxy resins, which originally had a short and unpredictable shelf life. A neutron-activation analysis of these resins revealed the presence of very small amounts of a number of metals. When these trace contaminants were removed, the shelf life of the resins was extended considerably. Apparently the trace contaminants had catalyzed the fixing of the resin.

Neutron-activation techniques are also used to characterize raw materials by their trace-element content. In one of our studies at Union Carbide we discovered that the trace-element content of the mineral chromite in ore deposits is constant within a given deposit but is quite different from that found in other deposits. This information is useful for measuring the extent of a given deposit and for determining why one source of ore gives rise to a better product than another. Petroleum geologists, using a similar approach, employ trace-metal analysis to determine the extent of oil reserves, the stratigraphic position of oil traps, the age of crude oils and the fundamental principles governing the origin, migration and alteration of petroleum. Soils from widely separated locations also show large variations in trace-element concentrations; as a result vegetation exhibits trace-element characteristics peculiar to the area in which it grows. Such information is used by geologists to locate new ore deposits, by ecologists to study the relation between the growth of certain trees and shrubs and their environment, and by official investigators to identify the original source of raw opium that has been confiscated.

The neutron-activation technique has developed into one of the most sensitive,



RADIONUCLIDE	HALF-LIFE	RADIONUCLIDE	HALF-LIFE
ALUMINUM 28 (^{28}Al)	2.3 MINUTES	ARGON 41 (^{41}Ar)	1.83 HOURS
TITANIUM 51 (^{51}Ti)	5.8 MINUTES	MANGANESE 56 (^{56}Mn)	2.58 HOURS
MAGNESIUM 27 (^{27}Mg)	9.5 MINUTES	COPPER 64 (^{64}Cu)	12.9 HOURS
CHLORINE 38 (^{38}Cl)	37.3 MINUTES	SODIUM 24 (^{24}Na)	15 HOURS

SIMULTANEOUS ANALYSIS of a number of elements in a sample is possible using their gamma ray spectra. The spectra shown here were recorded for a neutron-irradiated piece of paper after decay periods of three minutes (*A*), 10 minutes (*B*), four hours (*C*) and 24 hours (*D*). The peaks in the spectra can be identified by referring to the key at bottom. Because of the different half-lives of the elements, the analysis of a particular element can be facilitated by choosing a decay time when the emissions from the "indicator" radionuclide are least interfered with by the emissions from other radionuclides in the sample.

SCIENCE/SCOPE

Round-the-clock commercial communications with the Far East was inaugurated January 26 over COMSAT's Intelsat II. Hovering in synchronous orbit 22,300 miles above the Pacific, new satellite is relaying telephone, Teletype, data, and television between the U.S. and Hawaii, Japan, and Australia. It will also be used by NASA to support the Apollo moon-landing program. Intelsat II has three times more transmitter power, five times greater bandwidth, and substantially broader antenna-beam coverage than COMSAT's Early Bird, also built by Hughes.

Air defense umbrellas for major U.S. metropolitan areas are now being maintained by the Army's new Missile Mentor computer systems, developed by Hughes. The Mentors detect and track all aircraft in the defense areas, give commanders more data for split-second battle decisions than ever before, and coordinate the firing of Nike Hercules and Hawk missiles. With their solid-state circuitry, the Mentors cost only 1/10 as much as the tube-circuitry systems they replaced, and can be operated and maintained by 50 men instead of 200.

Hughes has completed ground terminals for the Defense Communications Agency's satellite network in Hawaii, the Philippines, Southeast Asia, Ethiopia, West Germany, and Fort Monmouth, N.J. These ground stations, linked by 15 satellites dispersed in random 21,000-mile orbits around the equator, comprise the first military satellite communications network and insure uninterrupted two-way radio between U.S. forces anywhere in the world.

Several advanced programs at Hughes have important and immediate opportunities for engineers: electro-optical, microcircuit, space systems, information processing, circuit design, communication and radar system. Requirements: at least two years of applicable experience, an accredited engineering or scientific degree, U.S. citizenship. Please send your resume to: Mr. J. C. Cox, Hughes Aircraft Company, Culver City, California. Hughes is an equal opportunity employer.

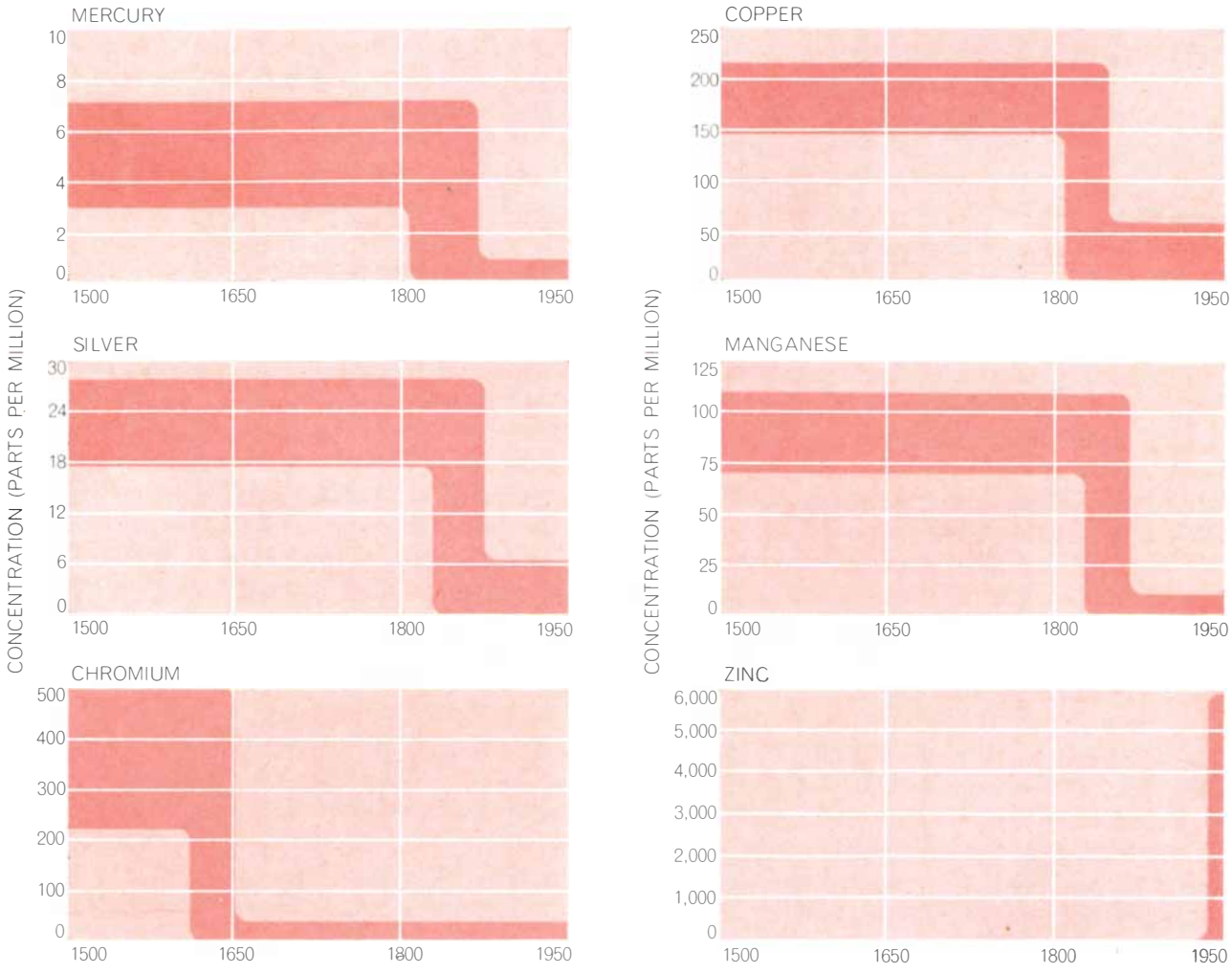
Full-color photos of the Atlantic cloud cover will be taken by a new camera being developed by Santa Barbara Research Center for NASA's ATS-C satellite, scheduled for launch in December. SBRC, a Hughes subsidiary, also built the camera that is sending back black-and-white photos of the earth's cloud cover from ATS-1, now in geostationary orbit over the Pacific. New color camera will transmit simultaneous blue, green, and red video channels, from which full-color photos will be made.

A computer that "learns" in much the same way an animal does has been built by Hughes as part of a long-range research program in artificial intelligence. It has already learned to recognize letters and numerals and to differentiate between sounds. Its ability to search photographs for structures of a particular kind, now being applied under a NASA contract, may lead to an automatic method of classifying the visual appearance of other planets.

Creating a new world with electronics

HUGHES

HUGHES AIRCRAFT COMPANY



PAINTINGS CAN BE DATED by measuring the concentrations of various trace elements in white lead paint, which has been used as a primer and white pigment since the Middle Ages. The changes in trace-element content are related to changes in the metallurgical techniques used to purify lead. The neutron-activation technique requires less than a milligram of white lead to perform a complete analysis. Graphs are based on data obtained by Jan Houtman and J. Turkstra of the Reactor Instituut at Delft in the Netherlands.

accurate and broadly applicable methods for the measurement of minor and trace elements in biological specimens. It is being used to elucidate the role of trace elements in normal and abnormal physiological functions. Typical subjects of study include selenium in "white muscle" disease, manganese in heart disease, arsenic and molybdenum in uremia, copper and manganese in leukemia and zinc in the formation of kidney stones. Cadmium, mercury and uranium (in addition to arsenic) are analyzed in biological samples to evaluate evidence of poisoning. Chronic poisoning is distinguished from acute poisoning by analyzing blood, urine, stomach fluids, fingernail clippings and hair. Abnormal concentrations of poisons in all these substances indicate chronic, or long-term, exposure; abnormal concentrations in all but the fingernails and hair indicate acute exposure, since it takes time for the hair and fingernails to grow.

Although the neutron-activation technique is used almost exclusively to detect various chemical elements and measure their quantity, it is basically an isotopic method; it is the particular isotopic nucleus that interacts with the neutron to produce a given radioisotope of an element. The technique is applicable to elements only when the isotopic abundances of a sample are known. This is the case in most samples, because the elements are present in their natural isotopic abundance. The technique is now being used with increasing frequency, however, as an isotopic method of analysis, especially in studies of human metabolism. Radioisotopes are routinely used in diagnostic studies of the changes in normal body functions caused by disease. Nonradioactive isotopes can also be used, and indeed they have certain advantages. An enriched nonradioactive isotope of iron has already been used for studies of the function of iron in blood plasma and a stable isotope of calcium has been used to determine the metabolic pathway of calcium in children. In general the method involves the administration of a nonradioactive salt enriched in a specific isotope. Measurement of the change in the concentration of the administered isotope over a period of time provides useful information about its metabolic role. The major advantage of using a nonradioactive isotope as a tracer is that the patient is not subjected to radiation, a consideration that is particularly important in studies of children and pregnant women.

We have described here only a few of the many applications of the neutron-activation technique. Because it can be used to analyze samples of virtually any size for their content of at least 70 elements, and to do so to within, on the average, a billionth of a gram, this product of basic nuclear research will be an increasingly useful tool.

What in the world is Raytheon doing in the North Sea?

For one thing — seeking untapped oil reserves for major oil companies through the efforts of Seismograph Service Corporation — Raytheon's new subsidiary. On land as well as sea, in over fifty countries SSC has proved its leadership in the field of seismic exploration. Off Nigeria, SSC crews are pioneering with a new shallow-water technique for seismic profiling through the surf in previously inaccessible inshore waters. Here at home, SSC engineers are developing sonic techniques for seismic exploration that will eliminate the expense, danger and fish-kill problems inherent in the use of dynamite. Raytheon's Submarine Signal Division has long been a leader in underwater sound. Application of this technology to seismic exploration is typical of the many opportunities that now exist for matching SSC and Raytheon capabilities for further expansion into oceanography and the exploration for other natural resources.

RAYTHEON

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Rivers in the Making

In various parts of the world water drains from the land not in distinct streams and rivers but in strangely interlaced channels. It seems that such drainage is a stage in the evolution of rivers

by H. F. Garner

For people who live in North America and Europe a river is a body of water flowing in an orderly way along a well-defined channel. In somewhat more technical terms such a river is a system of drainage in which tributary channels join a trunk channel and thus deliver water from higher levels to lower levels (ultimately the sea). Even in flood this kind of river remains within the valleys through which the channels run. Outside North America and Europe there are regions where the form of drainage is quite different; it can best be described as disorderly and unstable. In such a region the water typically runs simultaneously in several channels or submerges large areas of land. Viewed from the air, the flow can be seen to consist of diverging and converging runoff in sheets, multiple channels, rapids and falls. Indeed, the water may even flow across a system of hills or mountains that in a more stable situation would be a drainage divide.

On first consideration this kind of drainage might seem accidental. The geological evidence suggests, however, that it is a normal stage in the evolution of an even more random pattern of drainage into clearly defined channels. The mechanism of the evolutionary process is of course erosion: the water carves channels and keeps them clear by the abrasive action of the sediment it has picked up from the breakdown of rock. Interference with the erosional mechanism can reverse the process, causing the river's channels to become less distinct and creating a situation in which the river may again flood randomly across the land. Paradoxically that may prove to be precisely the long-range effect of man-made dams, many of which were built with flood control as a primary objective. A dam impounds the sediment that would normally be eroding the channel of the river. Moreover, evaporation from the lake behind the dam reduces the amount of water available for erosional activity downstream. Eventually a dam built to control floods could give rise to more severe floods.

A remarkable fossil record of a transitional form of drainage appears in the deeply carved rocks of the region known as the Channeled Scabland on the Columbia Plateau in the state of Washington. The region is now arid, but the landscape tells the story of a sprawling system of channels that in prehistoric times drained more than 10,000 square miles. An example of a similar situation in which the waters are still at work is the Caroní River in Venezuela.

The significance of the Channeled Scabland was first perceived some 45 years ago by J. Harlen Bretz of the University of Chicago. In the course of geological work on the Columbia Plateau he became interested in some unusual deposits and eroded features that were clearly the work of running water. Further investigation showed that over a vast area of what is now a desert water had carved a complex network of deep channels and basins, leaving the scars of some impressive waterfalls 400 to 900 feet high and up to a mile wide [*see illustration on page 90*]. It was evident that water had simultaneously eroded several more or less parallel channels, often spilling not only out of them but also out of valleys and even across drainage divides.

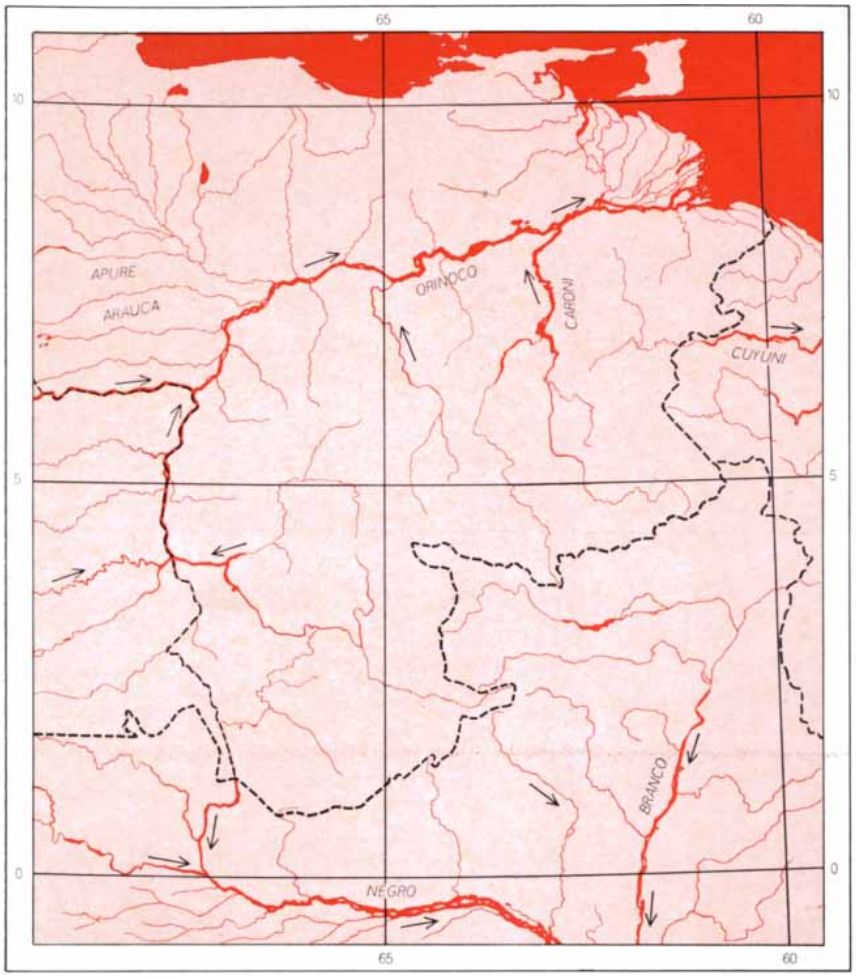
Bretz recognized that the geological record testified to the flow of huge quantities of water over a region that was not prepared to receive it. He called this prehistoric catastrophe the Spokane Flood. At first he attributed the phenomenon to the rupture of a natural dam consisting of glacial ice. After further investigation he concluded that the amount of erosion involved required not one event but prolonged or repeated flooding. What released water in such quantities over such a long time remains in doubt; various hypotheses relate the phenomenon to the melting of glaciers, to the diversion of streams from valleys blocked by ice and to the draining of a large lake.

No flooding of this character is now to be found in North America. Floods occur, of course, and many are destructive, but none exhibit the wild, far-flung cascading represented by the fossil record in the Channeled Scabland. The floods that occur are well-behaved in the sense that channels in valleys merely overflow. In rare cases the water extends as far as the sharply rising wall of the valley, but it never spills out of the valley entirely.

I had read Bretz's early account of the Channeled Scabland shortly before I joined a group of geologists on a trip in Venezuela in the fall of 1951. Therefore I was somewhat prepared for what we saw as we flew south across the Orinoco River toward an area of older rocks drained by the Caroní River. Still, it took me a while to realize that we were seeing a reenactment of Bretz's flood in another place and time.

The Caroní is not really a river. Over much of its course it has no trunk channel. What we saw was palm-studded clumps of savanna forest and patches of

CARONÍ RIVER in Venezuela is a drainage system in the making, as indicated by the multiple channels in the aerial photograph on the opposite page. The channels, in which the flow is toward the bottom of the page, represent a transitional pattern of flow in which the water is slowly carving a trunk channel through a region that was once arid and had indistinct drainage routes.



DRAINAGE PATTERNS of the region through which the Caroní flows include several unstable rivers that cross obscure divides. A major natural divide is the boundary between Venezuela and Brazil, represented by broken line below the center of map. In general rivers above boundary flow toward the Orinoco; those below, toward the Negro and the Amazon.

saw grass standing in an expanse of swirling, greenish water that in some areas oozed sluggishly into heavily forested tracts and elsewhere poured swiftly in turbulent cataracts. In several places the torrent surged through gaps in low ranges of hills. When confronted by the western extensions of the Sierra de Imataca, 500 to 800 feet high, the water simultaneously occupied several more or less parallel mountain passes, forming islands some miles in width and length. The overall pattern was one of a complex maze of channels that was five to 20 miles wide and was interrupted every few hundred yards by rapids and waterfalls [*see illustration on preceding page*].

My subsequent study of aerial photographs of the Caroní region and of the geological literature has suggested a few generalizations. One is that the kind of flow we saw in the Caroní prevails during most of the year and therefore can be regarded as normal for that drainage system. Another is that eastern South America has several similar networks of channels now carrying water, whereas North America has none except in parts of Canada where erosion by glacial ice destroyed preglacial drainage systems. Since neither the Channeled Scabland nor eastern South America has recently been glaciated, the Canadian pattern could not account for the kind of flooding that had occurred in the Scabland and is seen now in the Caroní. It did seem, however, that a close comparison of the Scabland setting and that of the Caroní, together with a search for similar drainage patterns in other nonglacial regions, might clarify the matter.

The comparison of the Scabland and the Caroní has revealed several similarities. In both regions the era of flooding had been preceded by the extensive deposition of coarse gravel across each drainage area. In the Caroní region, at least, the deposits buried drainage channels that had existed earlier. The Caroní's exotic patterns of sheetflood runoff and network channels are found in the lowland reaches, where the gravel deposits are concentrated. In contrast, the soil of the Caroní's headwater regions is fine-grained, of the type created by chemical weathering rather than by the mechanical processes that form gravel, and the headwater plateaus are traversed by tributary streams in the branching pattern regarded as normal.

A second similarity of the Scabland and Caroní regions is that preflood processes created many randomly oriented slopes, which often are inclined toward undrained depressions. Such a depression, usually covering several square miles, will exhibit a centripetal pattern of drainage channels when water enters it in moderate amounts: the water drains toward the center in several small streams. If water enters the depression in large amounts, a lake will form and will grow until overflow from it erodes an outlet channel. Then the depression has exterior drainage and the lake shrinks or disappears, while the other streams in the depression retain their centripetal pattern. Several such patterns are found in the Caroní region, and the fossil record suggests that the Scabland had them too.

A third similarity of the two regions is that preflood processes reduced by erosion many bedrock uplands, including some drainage divides. As a result some divides became so indistinct that running water could cross them. The Orinoco River provides a striking example of divide-crossing: it splits to give rise to the Casequiare River, which joins the Rio Negro and the Amazon in Brazil. Hence the Orinoco has two mouths on the Atlantic about 1,000 miles apart. The Spokane Flood had several outlets; the Apure-Arauca drainage system near the Caroní has four, and the Caroní would have three or four mouths except that a network of channels merges into a single channel just below Caroní Falls, six miles above the point where the Caroní flows into the Orinoco.

All these facts, considered in conjunction with the work of several investigators of erosion, clearly point toward the causes that account for the remarkable drainage patterns of the Scabland and the Caroní. The key cause is a major change of climate from arid conditions to humid ones. In nonglacial environments, particularly those in which there is no freezing, only the essentially mechanical breakdown of rocks that occurs

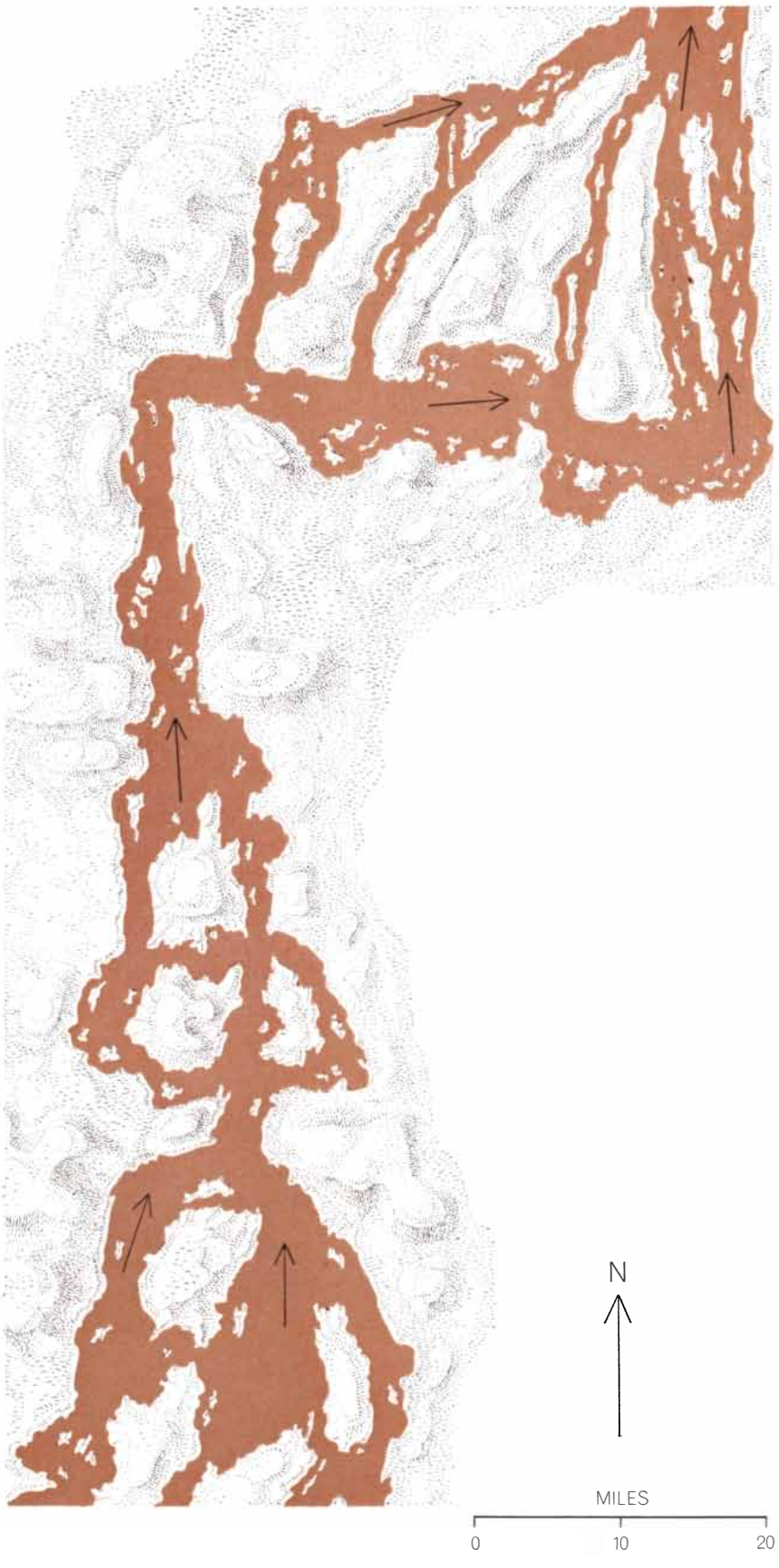
in deserts (by such means as stresses arising from alternate extremes of heat and cold) could provide an expanse of coarse gravel like that found in the Scabland and Caroní regions. Only under arid conditions is the land surface bare of vegetation so that rock fragments can be picked up by water almost anywhere and spread more or less everywhere. Hence the water flowing over the land after a heavy rain in a desert quickly acquires a full load of sediment.

Ordinarily desert runoff will not carry sediment far, because in an arid environment water both evaporates rapidly and sinks into the ground. Therefore the gravel, sand, silt and clay are quickly redeposited. The effect of such redeposition is slowly to plane, or smooth, the land by filling channels and valleys and beveling drainage divides. At the same time the effect of wind on bare terrain is to strongly erode fine sediment and to create deflation depressions: low areas lacking outlets for drainage.

Finally, it is only under arid conditions that running water consistently acquires a maximum load of debris. This has a curious result. Flowing water loaded to capacity with debris expends its energy in keeping the material in suspension; there is no surplus energy for cutting and maintaining channels. Indeed, in a dry environment flowing water rarely reaches the sea. A desert has no surplus of water requiring systems of channels extending to the sea or to other environments. Deserts are essentially undrained.

If the climate becomes more humid, the situation changes in several ways. Water is present in excess of the amounts that evaporate, soak in or are utilized by the plants that now flourish. Moreover, the growth of a widespread plant cover reduces the amount of sediment available for the water to pick up. The surplus water therefore has erosional energy. Without clearly defined channels on the smooth landscape of the former desert, the water is forced to spread widely across the land in perennial floods. Eventually, where the flow is deepest and fastest, channels begin to form. Gradually they deepen and lengthen, and the network of channels becomes more clearly defined, as is evident now in the Caroní. Over still longer periods of time the familiar river pattern of a trunk channel with tributaries develops.

In the Scabland region the evolutionary process apparently went from start to finish. Bretz has recorded evidence of an early general flooding, followed by the development of network chan-



PATTERN OF FLOW of the Caroní River is mapped on the basis of aerial photographs. The river has a network of channels with varying directions of flow, which are indicated by the arrows. The pattern is actually more complex than shown here because much water flows under vegetation and the boundaries of flow cannot be seen clearly in the photographs.

nels and ending with the establishment of a trunk stream (the Columbia River) and a tributary system, of which the Snake River and its drainage basin are a part.

Support for the concept that a multichannel drainage pattern is inherently unstable and represents a transitional stage is provided by work done some 75 years ago by William Morris Davis of Harvard University. He pointed out that water flowing through multiple channels in networks favors the routes of least erosional resistance. Channels in the weaker rocks are thus deepened more actively than channels elsewhere. Eventually a trunk channel is established and alternate channels are abandoned. A multichannel network such as the Caroní thus implies that the drainage system is one of recent origin.

Many South American rivers, including the Amazon and the Paraguay, share with the Caroní evidence that their pattern is attributable to a change of climate from arid to humid conditions. It is interesting to note that independent studies of plants and land forms in the region confirm the fact that such a change of climate has taken place. The llanos, or plains, of Venezuela and the pampas of Argentina are half-dry remnants of a once vast desert.

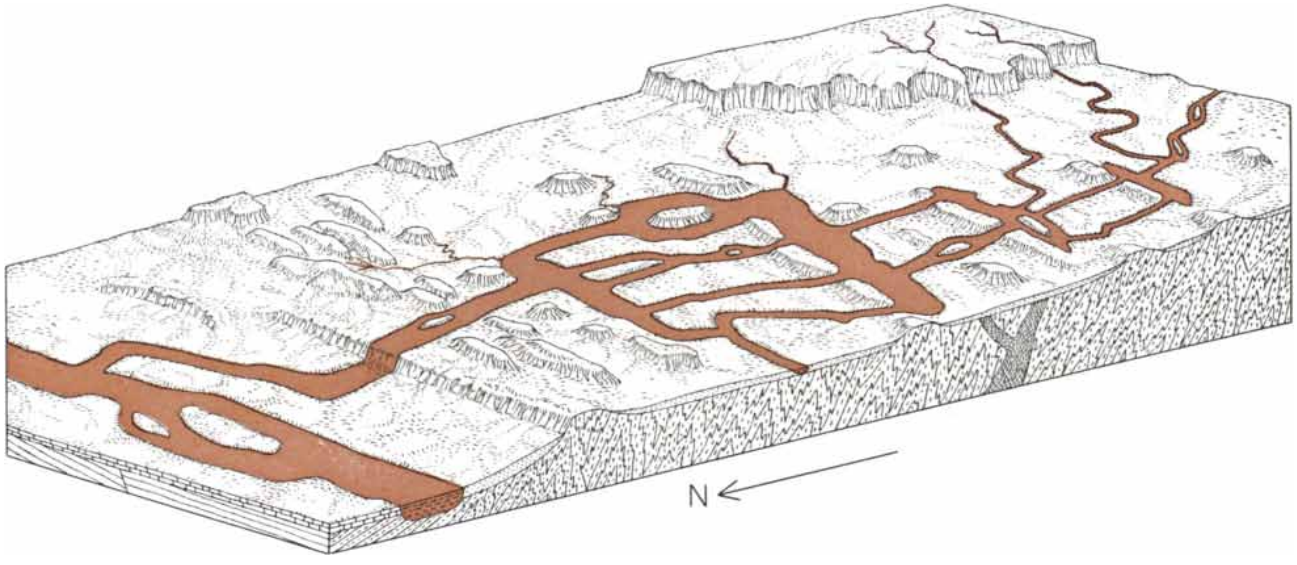
The mechanism that seems most plausibly to account for the change of climate is a warming of the seas following the last glaciation. In most areas air must travel upward and inland from the sea before the moisture it carries as a result of evaporation from the sea can fall as rain. The distance the air must travel and the amount of rain that will fall depend on the relative temperatures of the surface water and the air at sea level.

Water has a higher latent heat than air: more calories are needed to warm a given amount of water than are needed to warm an equal amount of air. Hence the temperature of the sea generally determines the temperature of the air above it. Only in the equatorial seas, however, are currents warm enough to induce by evaporation a relative humidity of 100 percent in the warm air at sea level. That level of humidity is the point of condensation at which precipitation can take place. Since the quantity of water in such warm air is high, precipitation occurs readily. Thus near the Equator heavy vegetation in the form of rain forest is found right at the water's edge.

To the north and south of the Equator ocean currents are cooler, and the relative humidity of the cool air above this cooler water is less than 100 percent at sea level. The rate of evaporation is lower, so that the air carries a lower absolute amount of moisture. The 100 percent relative humidity necessary for rainfall must thus be achieved by cooling of the air. In most cases the cooling is accomplished by expansion of the air as it rises to cross the land.

The need for the air to rise before rain can fall creates coastal deserts of varying width on most lands within 35 degrees of the Equator. The coast of Ecuador, for example, where air must rise about 35 feet above sea level before moisture can condense, has a fairly narrow band of desert. Farther south, in northern Peru, air masses have to rise about 3,500 feet before condensation occurs, and the coastal deserts are broader. At Lima the air must rise 5,000 or 6,000 feet to yield moisture. Beyond 35 degrees from the Equator the air temperature is low enough so that the cooling that will give rise to 100 percent relative humidity is found nearer sea level. Thus the opportunity exists again for precipitation near the coast, and one finds cold coastal rain forests such as those in Chile, Oregon and Washington.

The mechanism relevant to this discussion is the one that operates within the regions about 35 degrees north or south of the Equator, that is to say, over about two-thirds of the earth's surface. The colder the sea is, the farther the air has to rise to produce rain. Therefore when the seas are cold, as they are in a time of extensive glaciation, rain may bypass the coastal lowlands and fall only when the clouds reach high ground inland. In cases where coastal deserts become so large that upland areas catching moisture are significantly reduced, the flow of established rivers to the sea ceases. Moreover, the slopes between the upland and the sea should then undergo the leveling (by erosion of divides and burial of drainage channels) that I have described as adjuncts of prolonged arid-



GEOLOGICAL DIAGRAM of the Caroní drainage basin indicates schematically the features that account for the river's instability. A key feature is the blanket of gravel spread over the land by water that ran in sheets after the rare rains when the region was arid. Another feature is the number of hills made islands by present runoff. They are of bedrock, which means that they were preexisting obstacles the river had to skirt in carving channels. The Orinoco (*left*) is a more stable river but has similar features.

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ity. Movement of water in such deserts becomes more unsystematic as the drainage system is destroyed.

When glaciation subsides and seas grow warmer, precipitation can occur closer to the sea. Thus the upland areas that catch moisture grow in size, and channels lengthen as the runoff water again has enough volume to reach lowlands and eventually the sea. It is in circumstances of this kind that a transitional drainage system such as that of the Caroní will develop. In sum, the pattern over long periods of time is an alternation between the expansion of coastal aridity inland *from* the sea and the expansion of upland humidity seaward *toward* the shore [*see illustration on page* 92].

The classical explanation of how a river grows is "headward erosion": the gradual lengthening of the channel upstream. The evolution of rivers is more comprehensively explained by the erosional extension of channels downslope that takes place when an increase of rainfall sends perennial runoff over formerly arid terrain. Headward erosion is in most instances concentrated in dominantly humid divide areas and mainly affects soil or very weak rocks. Indeed, it is doubtful that such a mechanism has accounted for the entire growth of a major river.

All the continents have many drainage regions that appear to be of the Scabland and Caroní type. Some, like the Caroní, carry water and are gradually evolving into rivers. Others, like the Channeled Scabland, formed rivers long ago. Still others dried up before the evolution was completed.

It is also possible for the processes characteristic of an arid environment to be arrested by a return to humidity. In such a case the normal river form of a trunk stream with tributaries may be retained through several arid periods. If the channels and valley bottoms have been partly filled by sediment, a resumption of channel erosion will create what is generally known as a floodplain: a channeled, sedimented valley flatland that is periodically flooded. Most of the established rivers in North America have valleys of this kind.

In Africa, where various workers have documented a comparatively recent change of equatorial climate from aridity to humidity, the Niger, Chad and Nile drainages along the southern margin of the Sahara Desert resemble the drainage systems in the Caroní region. Their form is indicative of increased precipitation in their headwaters. These drainage systems have large networks of channels. They have indistinct drainage divides; the Chari flows into Lake Chad by way of a channel maze and also into the Atlantic by way of the Benue and Niger rivers. These North African regions are also characterized by patterns of centripetal flow into closed depressions (some of which, like Lake Chad, are still closed) and by numerous swamps (such as the Egyptian Sudd on the Nile). Like the South American rivers, their flow diverges locally around

CHANNELED SCABLAND in the state of Washington shows many marks of running water although the region is now arid. An extensive prehistoric drainage created the main valley, probably by retreat of a waterfall. The bowl-shaped cliffs at upper left are also thought to be the work of waterfalls. Several networks of channels, some shallow and some deep, are visible. Hills of bedrock, such as the one at right center, were islands. Eventually the water carved a trunk channel, which is the Columbia River.

large bedrock islands or dunes deposited long before by the wind. The evolutionary significance of such islands is that they are preexisting obstructions around which the developing river had to make its way; they could not have been formed by deposition or headward erosion.

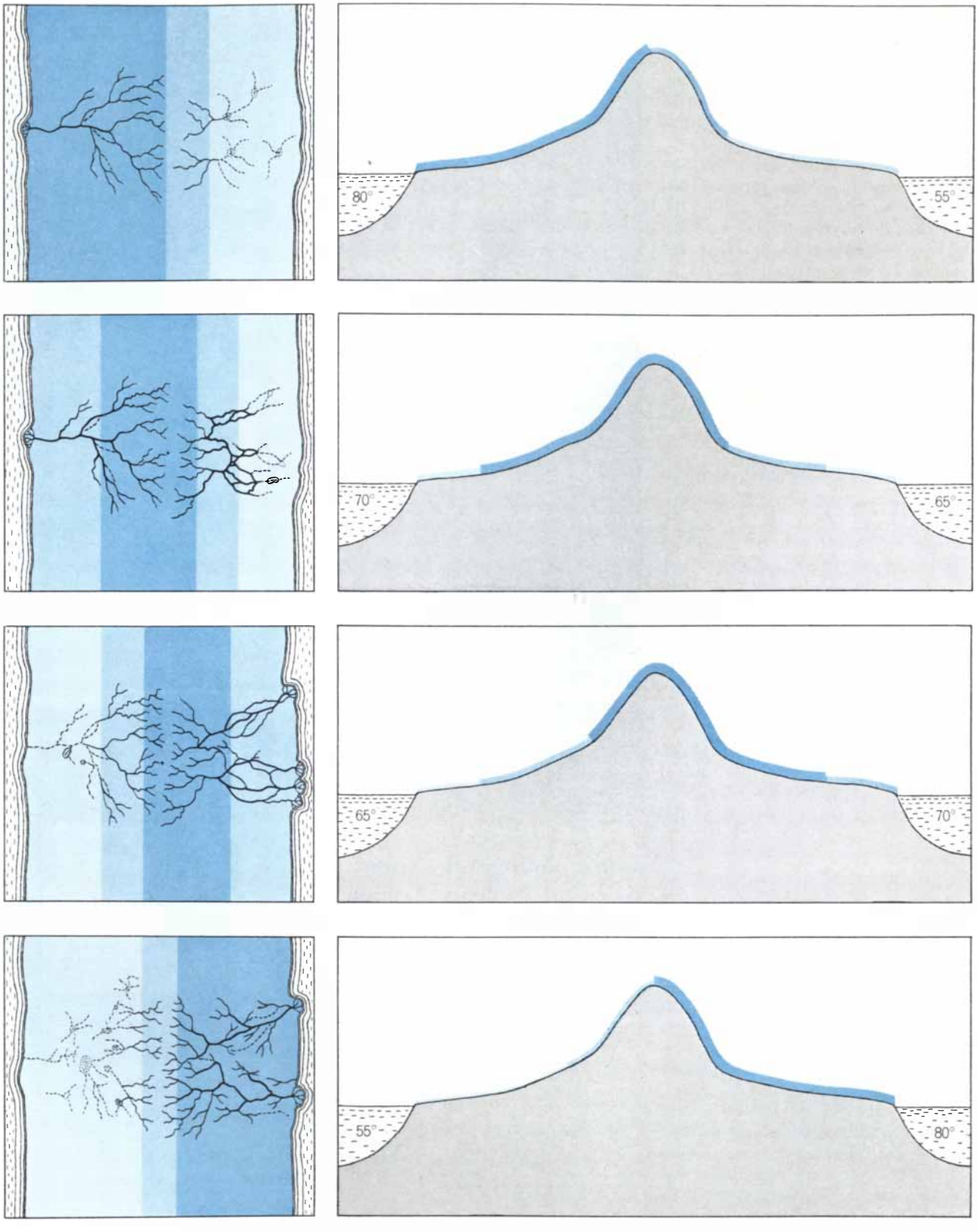
The Zambezi River, which skirts the Kalahari Desert in South Africa, displays similar phenomena. In 1963 the first rains in 29 years fell on the Kalahari. The reader will appreciate the significance of the fact that after the rains an area of more than 10,000 square miles was flooded because the original drainage—the Molopo River—had its course obliterated by giant sand dunes and gravel deposits that had been emplaced under arid conditions.

A dried-up channel maze much like the Channeled Scabland can be seen in the Chad District of the central Sahara, between Lake Chad and Tibesti. In West Pakistan the Indus River develops a channel network where it crosses a desert lowland; the network has been extensively modified by irrigation works of man. There is a channel maze with bedrock islands at the confluence of the Ganges and Brahmaputra rivers to the east; several workers attribute the maze to rock faulting, but it may owe some of its form to the grading processes that operate under arid conditions.

Several examples of climatically disrupted drainage can be found in eastern Australia, where the Thomson, Murray and Darling rivers flow from the humid Great Dividing Range westward into the lowlands of the interior desert. The Hwang Ho River in China developed several channel networks where it enters the Ordos Desert and later abandoned them. In this case there also appears to have been some modification by man.

North America has several fossil channel mazes in areas where unstable drainage systems have long since been shaped into normal rivers. These mazes are far less spectacular than the Channeled Scabland and the Caroní River, because they are older and time has obscured the evidence of flooding, but they are just as interesting. A notable example can be seen in the region traversed by the lower part of the Ohio River. In this region a series of channel networks up to 10 miles in width has been described by Nevin M. Fenneman of the University of Cincinnati. A conspicuous feature of the region is a series of bedrock obstructions similar to the islands of the Caroní.

A related drainage network of similar



CHANGE OF CLIMATE over thousands of years alters the patterns of drainage and vegetation of a hypothetical landmass that is somewhat north or south of the Equator. The region is shown in plan views (*left*) and in corresponding sections (*right*). The alterations of climate reflect changes in the surface temperatures of the oceans adjoining the continent. At top the land near the warm ocean receives ample rain and forests begin at the water's edge; the opposite ocean is cold, so that clouds have to rise before rain can fall, and there is a coastal desert. As the temperature of one ocean falls and that of the other rises, the situation is slowly reversed.

form—indeed, a continuation of the one in the lower Ohio River region—is found at the head of the Mississippi Embayment near the confluence of the Mississippi and Ohio rivers. There the lowland is interrupted by an elongated series of bedrock hills called Crowley's Ridge. The ridge is crossed by a number of ancient channels, and others lie to the north, east and west. F. E. Mathes of the U.S. Geological Survey long ago postulated that widespread flooding simultaneously eroded the channels after the terrain had been spread with alluvial deposits. His account could easily be substituted for portions of Bretz's description of the Channeled Scabland.

The Mississippi-Ohio maze, like the others, is readily explained by the mechanisms I have described: a large and persisting runoff crossing formerly arid terrain as a result of the onset of a humid climate, probably connected with the development of glaciers. In this case it seems certain that some of the gravels are glacial. Here as elsewhere, however, the classical explanation of rivers as features of considerable permanence created by headward erosion can account for neither the channel networks nor the fact that bedrock obstructions lie within drainage lines.

What the mechanisms do show is a connection between flooding and the origin of rivers. The most extreme flooding is the kind found in many drainage systems outside of North America and Europe. In fact, most such floods now appear to be closely related to the gigantic one that Bretz deduced from the Channeled Scabland.

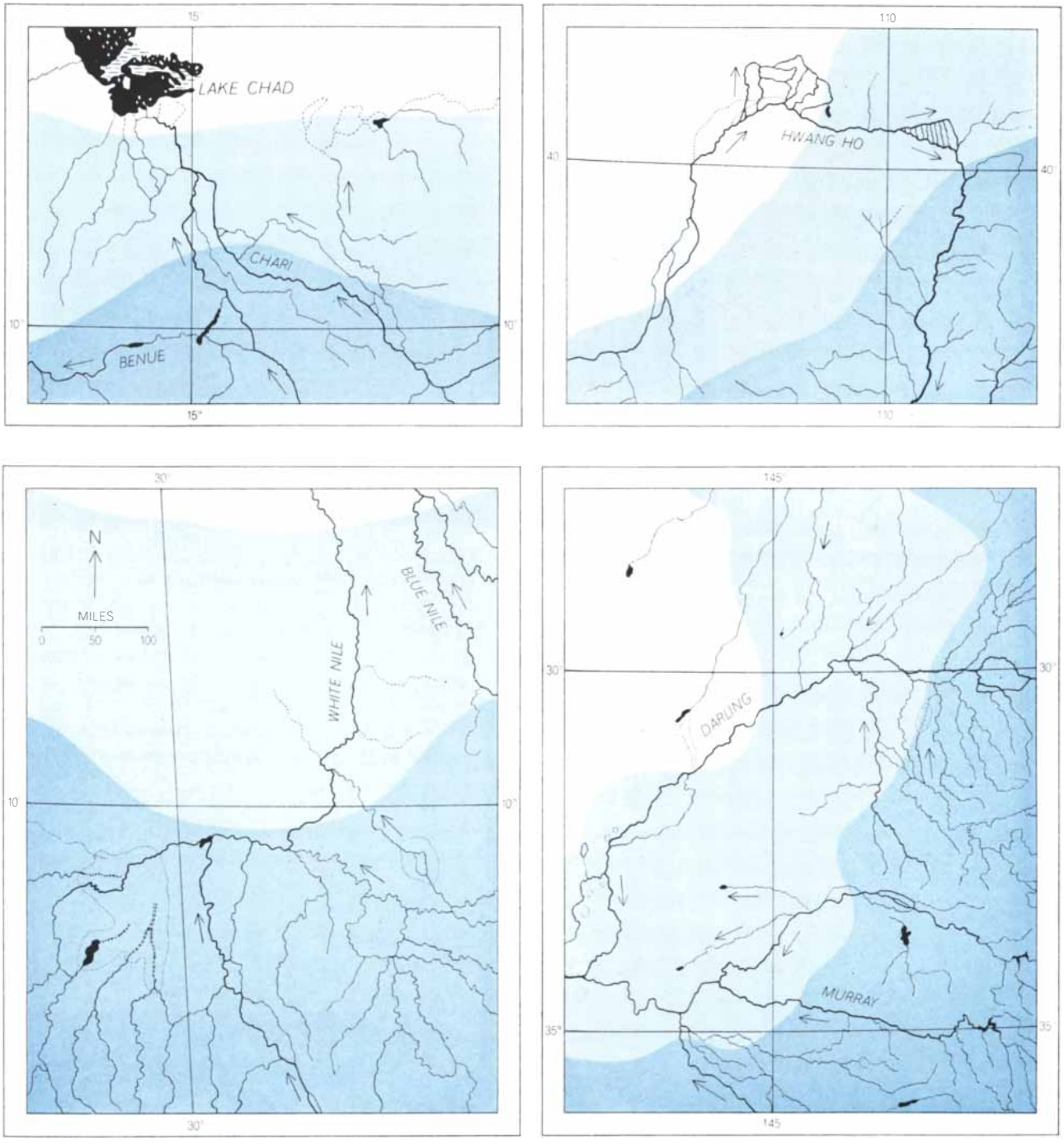
Indeed, the human inhabitants of North America and Europe have been fortunate in the comparative mildness of the floods those continents have seen in historic times. The apparent reason for the mildness of the floods in North America is that the Southwest, which is the part of the continent that has been most arid over a long period, does not lie directly downslope from the predominantly humid East. The most consistently flooded part of the Middle West does lie between those areas, and so do the fossil channel mazes of the midlands.

I mentioned at the beginning the inhibiting effect man-made dams have on a river's natural tendency to deepen and keep its channel clear by erosion. In reality this is only one of the problems created by dams. Another is that as the reservoirs behind dams slowly fill with sediment they correspondingly lose their capacity for storing water. The U.S. has

hundreds of reservoirs that are losing storage capacity in this way at the very time that the pressure of increasing water needs demands the maintenance of maximum supplies.

Here one encounters another paradox. The effectiveness of the nation's reservoir system in controlling floods depends largely on letting water levels fall during periods of dry weather. Usually the drop in water level is due to the use of water for the generation of electric power. With the increasing demand for maximum supplies of water, however, the reservoirs may have to be kept full; if so, they could neither produce electricity nor contain excess water to prevent floods.

One might think that the answer to the problems created by dams would be to flush the sediment out of the reservoirs and let it run downstream. The trouble is that no sediment-flushing system yet devised has proved effective. Moreover, few dams have any provision for flushing sediment. It seems probable that in the fairly near future the nation will have to take measures to control floods developing because of the dams built to control floods.



DRAINAGE PATTERNS similar to that of the Caroní and the prehistoric flow of the Channeled Scabland are found in several parts of the world. Among the examples are the Lake Chad region in North Africa; the Hwang Ho, or Yellow River, in China; the Nile, and the Darling River in Australia. In each case water flows over desert terrain from uplands that are now humid (*dark color*) or semiarid (*medium color*) as a result of changes of climate. In each system the water passes into arid (*light*) regions.

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THE EVOLUTION OF BEE LANGUAGE

Different species of bees communicate in different ways. When primitive bees are compared with more advanced ones, it seems that communication by sound preceded communication by dancing

by Harald Esch

There can be no doubt that many members of the animal kingdom "talk" to their own kind, but it is a curious fact that of all the communicating animals the only one whose language man has been able to translate in much detail is the bee. We owe this breakthrough into animal language to the sharp observation and dedicated curiosity of the Austrian zoologist Karl von Frisch. Studying color vision in bees many years ago, von Frisch placed a color-marked dish of sugar sirup near a beehive. He noted that once a bee discovered this rich deposit of food many other bees from the same hive promptly began to visit it. Clearly the discoverer must have informed its hivemates. How had it told them? Von Frisch investigated the matter by a series of ingenious experiments. He set out sugar dishes at various locations, sometimes miles away from the hive, and observed the behavior of the discoverers of these food sources when they returned to the hive. He found that the scouts "spoke" to the hive by means of a dance that told the direction and distance of the food dish.

After pursuing these experiments for many years alone von Frisch began to publish summaries of his findings in the late 1940's, and they piqued the interest of eminent scientists [see "The Language of the Bees," by August Krogh; SCIENTIFIC AMERICAN, August, 1948]. Captivated by the explicitness of the bees' systematic language, many investigators (linguists as well as biologists) have been drawn to the study. It offers leads concerning not only the mysteries of animal communication but also the origin and evolution of language itself.

Intensive investigations over the past two decades have shown that the language of the bees is more complex than was first supposed. Its "vocabulary" includes sounds and scents as well as the movements of the dances. By examining these elements and studying bees of various species we are now beginning to develop some conception of how the bee language probably evolved. Let us review the investigations and see where they have led.

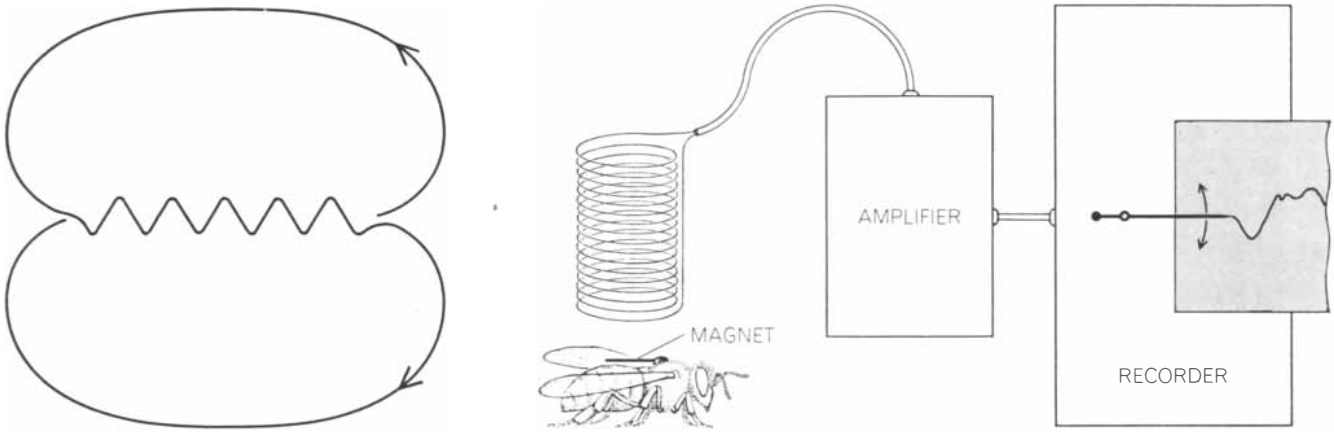
Von Frisch, who started his observations on the honeybee, discovered that when the food site was at an appreciable distance from the hive, the returning forager used a "wagging" dance to give the location to its hivemates. The dancer, wagging its abdomen, performs a short, straight run in a certain direction, then runs back in a semicircle to the starting point and makes the straight run again in the same direction, and it repeats this performance again and again, sometimes as many as 200 times. Von Frisch learned that the direction of the straight run shows the direction of the food site. The direction is related to the position of the sun in the sky. When the dance is performed within the hive, the dancer makes its runs on the vertical combs. A run straight upward means that the direction of the food site is toward the sun; straight downward, away from the sun; any other direction is indicated by angling the run from the vertical line.

How does the dancer indicate the distance to the food site? Von Frisch deduced that this information resided in the tempo of the dance: the number of runs per minute [see "Dialects in the Language of the Bees," by Karl von Frisch; SCIENTIFIC AMERICAN, August, 1962]. The slower the tempo, the greater the distance. Von Frisch's measurements showed a correlation between the distance and the dance tempo. For example, when the food dish was 1,000 feet from the hive, the forager bee performed the wagging dance at the rate of 30 runs per minute; when the dish was 2,000 feet away, the dancer's rate was 22 runs per minute.

Still, there were several puzzling questions. In the total darkness of the hive how could the bees observe and interpret the dance? Furthermore, how could one be sure that the supposed relation between the dance tempo and the distance was actually meaningful to the bees? A human observer with a stopwatch could plot and translate this information, but what reason was there to believe the bees possessed the same ability? Indeed, it turned out on further investigation that at least half a dozen other elements in the dancing bee's ritual could be correlated similarly with the distance to the food site.

In the summer of 1955 I took a job in the bee research laboratory at the University of Bonn (during a vacation from the study of physics), and I was introduced into the fascinating world of bee language by Wolfgang Steche, a former student of von Frisch's. Prompted by questions Steche raised about the bees' method of giving distance information, I undertook some new experiments. Perhaps the distance information lay in the wagging part of the dance

BEES OF TWO SPECIES visit a feeding station set up by the author during his investigation of bee communication. The big bee is *Apis mellifera*, the common honeybee. The small ones are *Trigona varia*, one of the six stingless Brazilian species chosen for study. Painted "petals" provide visual cues that help the bees to find the station; red paint contains a reflector of ultraviolet so that the bees, blind to red, can see it.



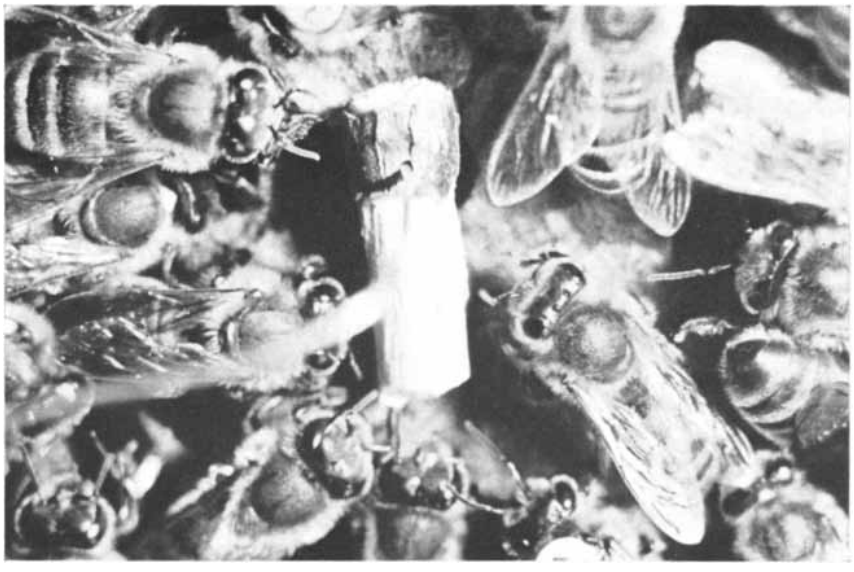
HONEYBEE'S DANCE (*figure-eight pattern at left*) **was recorded by means of a magnet attached to the bee. The wagging movements produced voltage changes in a sensing coil. These changes, after amplification, were reproduced on an oscillograph** (*right*)**, reveal-**

rather than in the tempo of the entire dance. This hypothesis promised to be difficult to investigate, because the bee's wagging movements are so rapid that they are barely detectable by the unaided eye. I was able to bring them within the scope of measurement, however, by attaching a tiny magnet to the bee's abdomen and holding a coil over the bee during its dance; the motions of the magnet produced fluctuations of electric voltage in the coil, and these fluctuations, recorded with an oscillograph, gave a detailed account of the wagging movements [*see illustration at top of these two pages*].

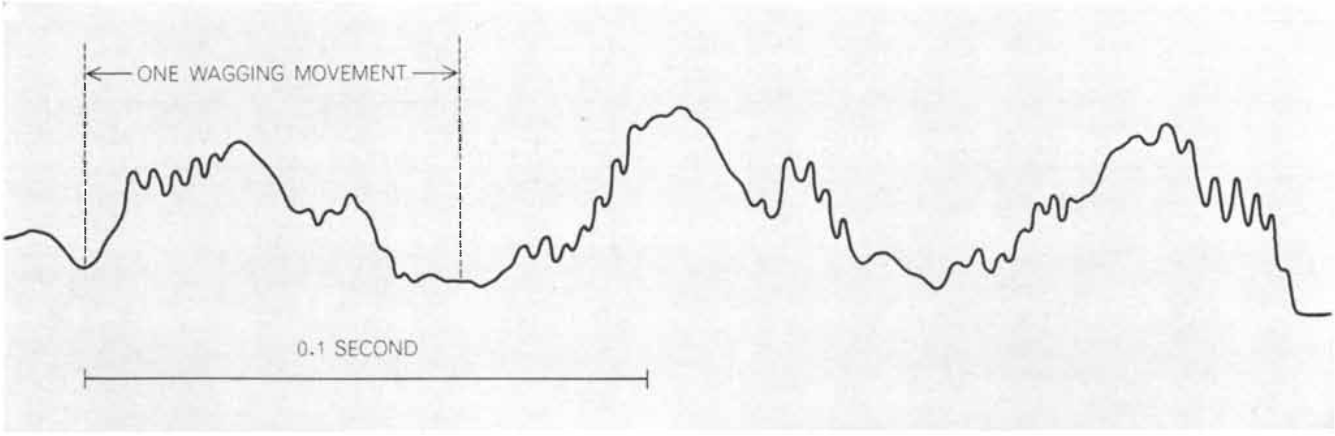
The oscillograms showed that the wagging of the dancing bee generally has a constant frequency of about 15 wags per second. The duration of the wagging during a run varies, however. It turned out that the wagging time, or the total number of wags in a run, was correlated with the distance to the food site: the greater the distance, the more wagging movements per run. Further analysis of the oscillograms, however, introduced confusion into the picture. The length of the time interval between the successive wagging runs (or, as we might say, the nonwagging time) also was closely correlated with the distance to the food site! Which, then, was the actual cue, the wagging time or the nonwagging time?

I became so intrigued with the problem that in 1960 I joined von Frisch in his laboratory, and this time we set up a more elaborate experiment. I built an artificial bee that performed a wagging dance like a live bee. My dummy's dance was controlled by tape recordings of the dances of the real bees, and apparently it mimicked their dances faithfully [*see illustration at bottom of these two pages*]. The bees in a hive followed my dummy's dance and showed great interest in it. Nevertheless, it did not move them to go forth into the field to look for the food source. Evidently some crucial feature of the bee language was missing in the dummy.

I reexamined the tape recordings of the live bees' dance closely and found that during their wagging the bees produced some kind of vibration at a frequency of about 250 cycles per second—a vibration my dummy could not match. This frequency is in the range of the sound spectrum. I therefore placed a microphone in the hive to catch any sounds the dancing bees might be emitting. Sure enough, the microphone re-



ANIMATED DUMMY (*center of photograph at left*)**, made of wood but identical in odor with the hive's inhabitants, was driven by a motor** (*far right*) **in mimicry of a returned forager's actions** (*bee in motion in second photograph*)**. The honeybees clustered**



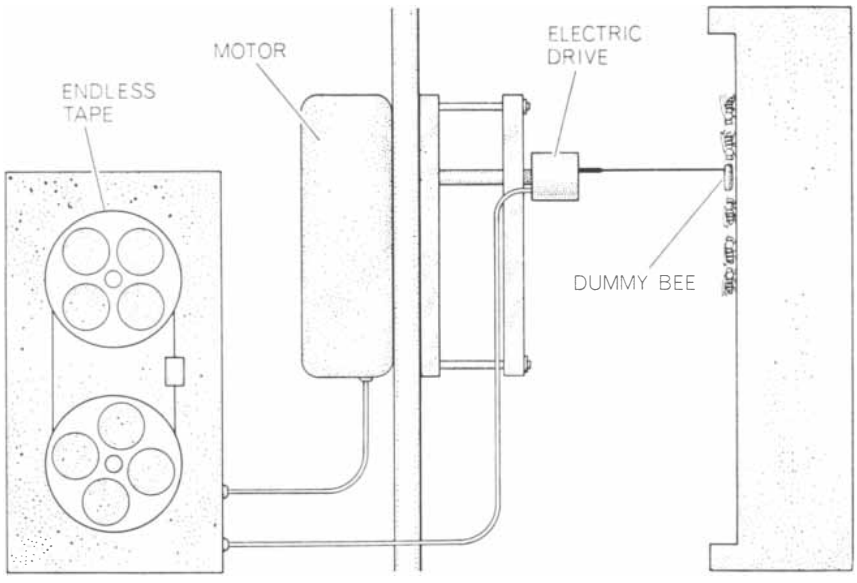
ing motions too rapid for the unaided eye to detect. On the oscillograph tracing the .07-second distance from trough to trough is the duration of one wag; the briefer, low-amplitude oscillations imposed on the wag curve record the noises made by the bee's wings.

vealed that during its wagging a bee gave forth strong sound signals, generated by vibrations of its wings. The period of sound emission coincided exactly with the duration of the wagging run. Since the length of a bee's wagging run had already been found to be closely correlated with the distance to the food site it had visited, we now had to consider the possibility that the bees used sound as the cue to distance. In other words, the language of the bees might be based not only on kinetics but also on phonetics!

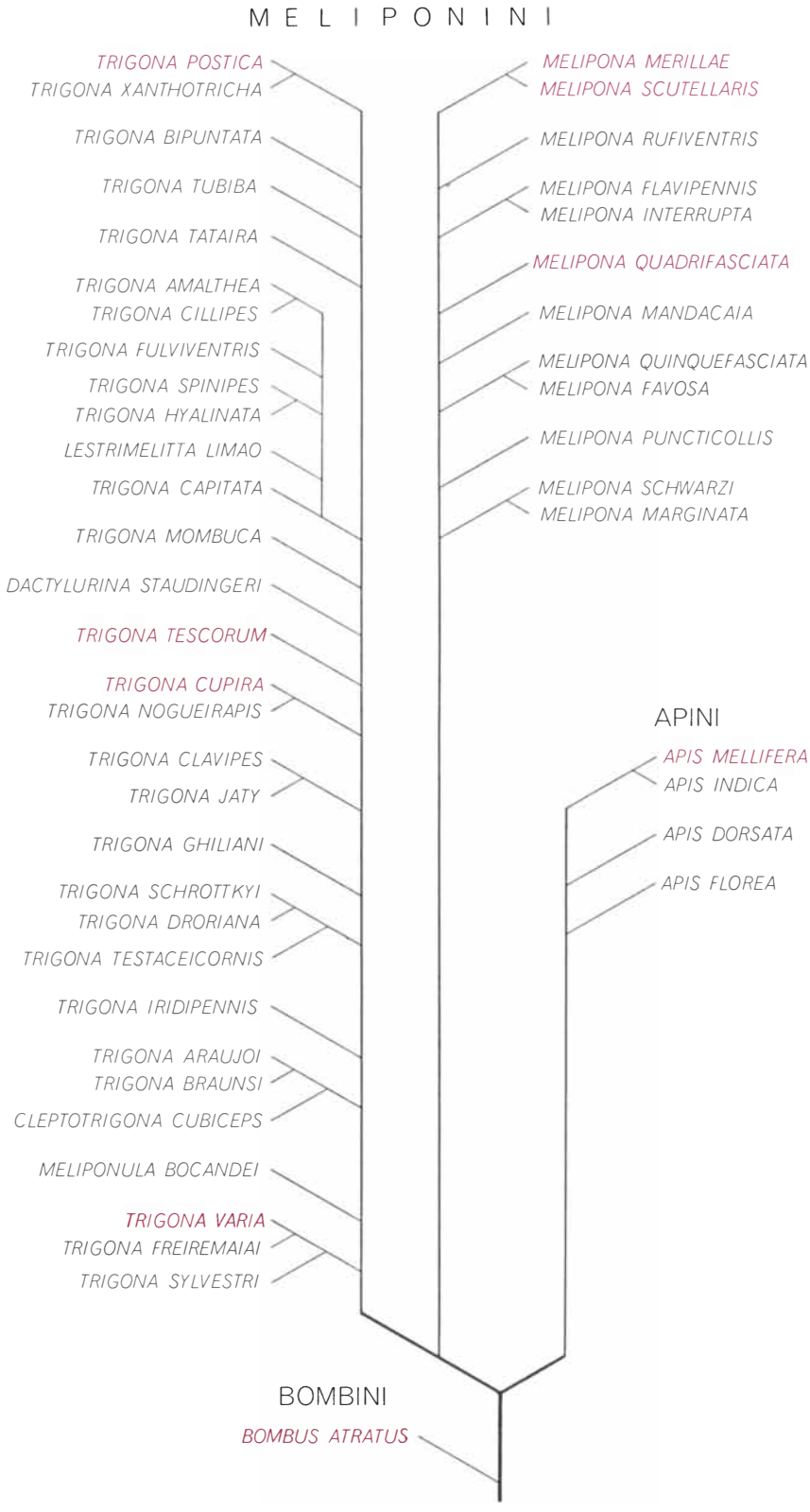
At about the same time that I came on these findings Adrian M. Wenner of the University of California at Santa Barbara, working independently, also discovered the audible "talk" of bees [see "Sound Communication in Honeybees," by Adrian M. Wenner; SCIENTIFIC AMERICAN, April, 1964]. That sounds constitute part of the language of the bees seems quite plausible. The bee, as everyone knows, is by nature a noisy animal. Its use of sound for communication would help to explain the ability of the bees to receive the messages of foragers in the dark of the hive. Moreover, linguists have pointed out that it would be strange indeed if a language as well developed as that of the honeybee were entirely devoid of sound elements or vocalization.

Nevertheless, some investigators are unwilling to accept the idea of bee "speech," on the ground that there is no evidence bees can hear sounds. It must be said that definitive proof of specific hearing ability has not been established. There is plenty of indirect evidence, however, that bees do perceive and respond to sound.

By the use of electrophysiological methods Hans Joachim Autrum of Germany showed many years ago that a bee can detect sound through its legs. Bees standing on a vibrating surface were able to sense very slight vibrations with an amplitude as small as 13 millimicrons. In effect the surface on which the bee stands serves as an "eardrum." However, skepticism about the hearing ability of bees, or at least their ability to interpret sounds, arose from the fact that attempts to elicit meaningful responses to sounds in bees were invariably unsuccessful. It was found that bees could not be guided to a feeding place by sound cues alone. I made a similar finding with some recent experiments of my own. At the entrance to a hive I



around both the dummy and the genuine forager, stimulated by their dancing. No bees, however, left the hive to search for food proclaimed by the dummy's dance. The author concluded that bee communication involves more than the wagging dance alone.



THREE TRIBES of social bees within the family Apidae are arrayed according to their social complexity. Lowest on the tree, the bumblebee *Bombus,* lacks communication of any kind. The social behavior of various genera in the tribe Meliponini shows increasing complexity. Some bees of the genus *Trigona,* for example, have foragers that make scent trails and alert the hive after finding food. Foragers of the genus *Melipona* vary their sound signals to indicate the distance from the hive to the food source. Most advanced are honeybees of the genus *Apis.* They dance to announce both the distance and the direction of a food source. Species whose names appear in color were studied by the author.

built three runways leading to three feeding dishes. I would place food in one of the three dishes and then cause the runway to that station to vibrate, as a cue to the location of the food. Even after extensive periods of training the bees did not learn to use the vibration as a significant signal (although tests beforehand had shown that they could perceive the vibration). The bees never solved the "maze" but continued to visit all three dishes at random, ignoring the vibration cue. A visual cue, however, proved quite effective. When I put a blue mark on the runway to the food, it took the bees only three or four trials to discover that the marking meant food, and thereafter they invariably chose the correct runway.

Almost by accident I happened on observations of another kind that revealed that, although sounds or similar vibrations per se may not be meaningful stimuli for the bees, the sounds associated with the wagging dance certainly play a crucially significant role in communication. I noticed that often a returning forager performed its wagging dance in the hive silently; for some unknown reason these dancers failed or were unable to produce any sound, although in all other respects their dance followed the normal pattern. What particularly interested me was that in every such case, although the bees in the hive followed the dance, not a single bee went to the feeding station the dancer had discovered! I observed more than 15,000 of these silent dances, and all of them uniformly failed to guide bees to the food site.

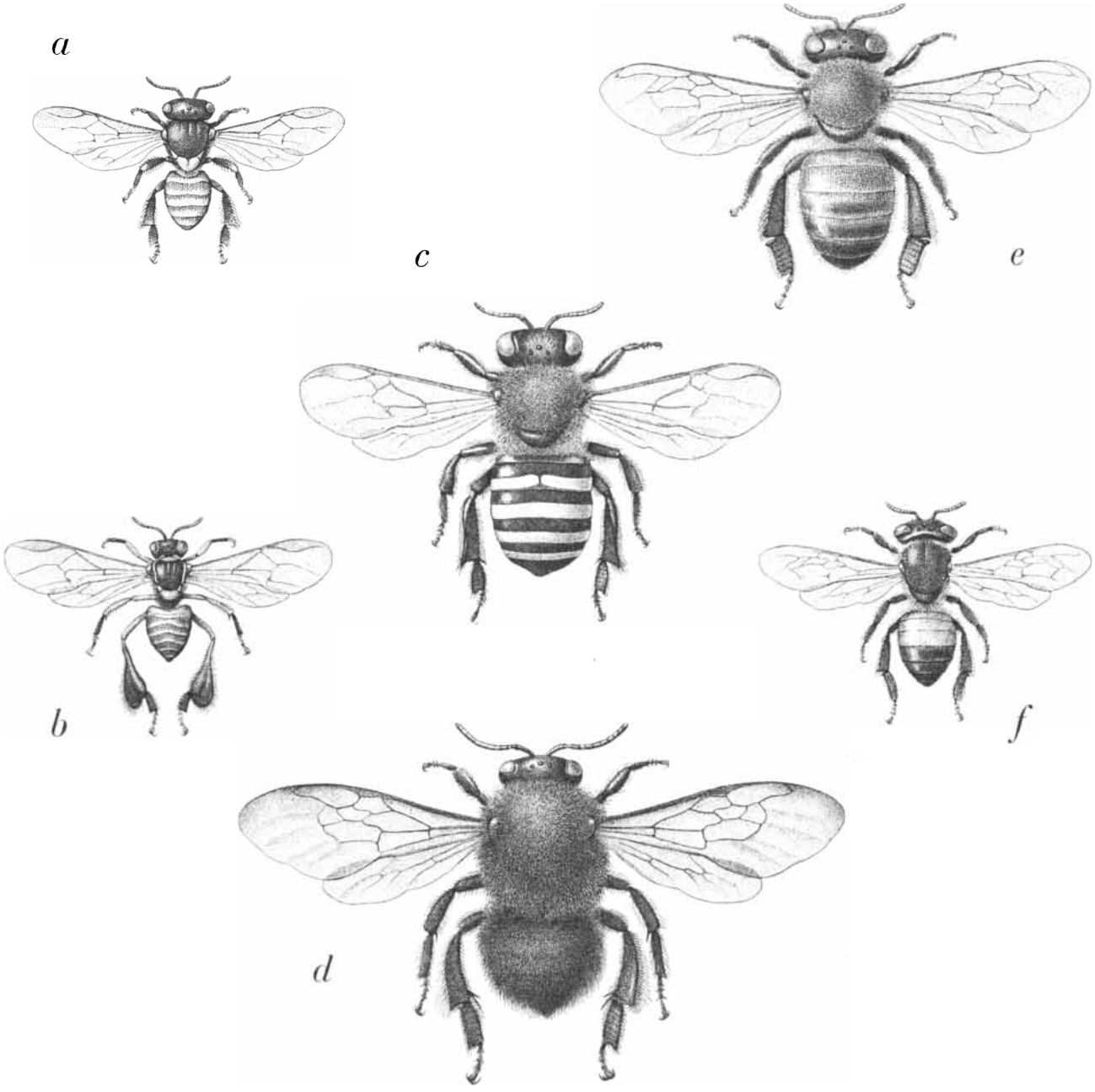
Surely, then, sound must be an important part of the bee language. With that fact reasonably well established, we are in a position to make some plausible conjectures about the evolution of the language.

Some time ago a former student of von Frisch's, Martin Lindauer, working with Warwick E. Kerr in Kerr's laboratory in Rio Claro in Brazil, began to investigate the communication system of a family of tropical bees known as stingless bees, of which there are about 200 species in Brazil. These insects, distant relatives of the honeybee, do not dance; they communicate with their fellows primarily by means of sound. A forager returning to the hive buzzes to its hivemates with its vibrating wings, gives them samples of the food it has collected and by the scent clinging to its body lets them know the odor of the food source. The excited bees soon set off to seek it.

I had the opportunity of working with Kerr's group in Rio Claro in 1964, and we analyzed recordings of the sounds made by foraging stingless bees. The analysis showed that some of these bees (of the genus *Melipona*) use a kind of Morse code to indicate the distance to the food site: a series of short dashes (sounds of short duration) to show that the site is nearby, a series of longer-drawn-out sounds to indicate longer distances. The length of each single sound signal, like the length of the honeybee's wagging run and its accompanying sound, corresponds to the relative distance to the site. The stingless bees' sound language enables hive members to find food sites as much as several hundred yards away from the hive.

How do the recruited bees learn the direction of the site? This, we found, is a rather primitive and complex process. The forager, followed by the recruited group, starts off in the general direction of the site and for the first 20 to 30 yards flies an erratic, zigzag course. The leader then goes into straight flight and leaves the followers behind. They return to the hive and wait near the entrance for the forager to return. When it does, it passes around new samples of the food and again takes off for the site with the group following for a short distance. After several repetitions of this partway guidance, some members of the group, as if they have suddenly understood the message concerning direction, take off and make their own way to the food site.

From these clues and certain other



FIVE BEE SPECIES studied by the author not only differed in modes of communication but also made different kinds of nests. The bumblebee (*d*) and *Trigona viria* (*b*) both construct horizontal nests with individual "pots" where food or eggs are stored. *Trigona postica* (*a*) and *Melipona quadrifasciata* (*c*) also build horizontal nests and store their food in pots but raise their broods in cells like the honeybees. The European honeybee (*e*) and its dwarf relative *Apis florea* (*f*) store both food and brood in vertical cell arrays.

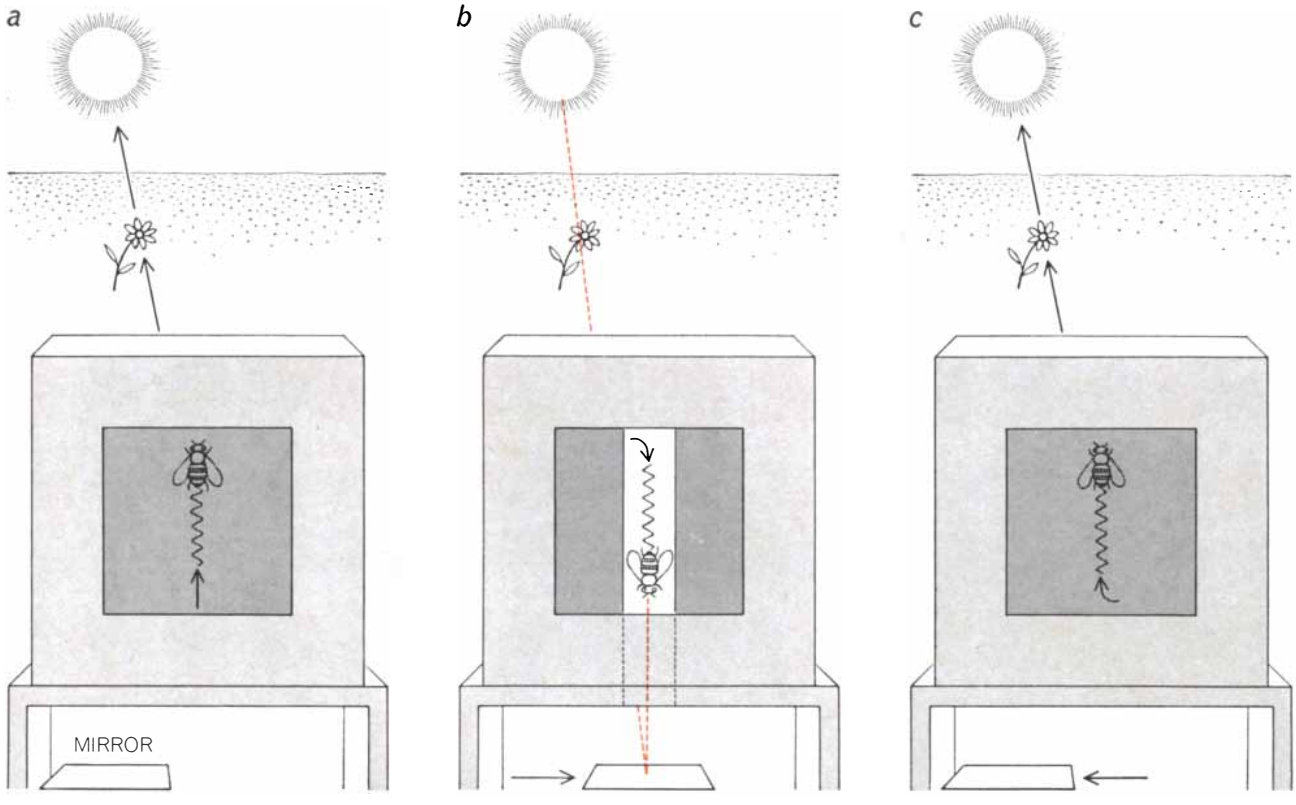
known facts about the behavior of insects we can begin to draw a hypothesis about the origins and evolution of the bee language. In the first place, the rhythmic noisemaking and dancing activities of the foragers on their return to the hive have well-known antecedents in primitive insect behavior. A moth alighting from a flight rocks back and forth rhythmically on its feet for a time, and the duration of this rocking tends to be related to the length of the flight it has just completed. In the moth the rhythmic aftermath seems to answer some basic physiological need; it takes place even when the head and much of the upper body is cut away. We can surmise that in the highly social bee this inherent behavior, potentially so useful for conveying information about the preceding flight, could easily have evolved into the distance-indicating code of the bee language.

The indication of direction also has precedents in insect evolution. At the most primitive, straightforward level an insect forager personally leads the group to the food. An ant scout, for instance, escorts its fellows to a food source it has found, following a trail of scent spots it has laid down on its way back to the colony. Lindauer and Kerr discovered the same behavior in a primitive species of stingless bee (*Trigona postica*). The forager of this species, in its flight back to the hive, stops every two or three yards to mark a stone, a tree or a bush with a strong scent that it secretes from its mandibular glands. When it reaches the hive, it runs noisily about in great excitement, bumps its hivemates, passes out samples of the food and finally, when it has collected a group of followers, guides them along its scented trail to the food.

In the more advanced species of stingless bees the guidance is abbreviated. The forager indicates the distance by means of a sound code and the direction by means of its zigzag flight. In the honeybee the entire language has become symbolic. Instead of the zigzag flight it performs a wagging dance within the hive, representing the direction in terms of abstract geometry and gravity, with the vertical, symbolically pointing to the sun, as the reference line. The straight run of the dance, with the sun represented as to the right or to the left or ahead of the line of flight, simulates the actual flight to the food. The run also tells the distance in symbolic terms, presumably making the duration of the emitted sound correspond to the distance.

There are variations—apparent throwbacks—in the behavior of honeybees that tend to support this evolutionary hypothesis. For instance, on a sunny day a honeybee forager will often revert to direct rather than symbolic guidance for its hivemates. It performs its wagging dance on a horizontal surface in front of the hive, pointing its run in the actual direction of the food site and buzzing its wings repeatedly as if to take off on a flight in that direction. Lindauer has observed that this kind of behavior belongs to a more primitive stage than the performance of the honeybee in the hive does. There is a dwarf bee (*Apis florea*), closely related to the European honeybee, that lives in the open, never in a hollow tree, cave or other dark place. This bee always performs its wagging dance on a horizontal surface and only if it can see the sky; deprived of a view of the sun's location, it stops dancing.

I found that, by eliminating the hive conditions that require the honeybee to resort to symbolic language, I could make the honeybee revert to the primi-



USE OF THE SUN as a direction indicator was induced experimentally in honeybees by the author. When food was placed along a line between hive and sun, a returning forager pointed the way to the food in the usual gravity-oriented manner by making runs straight up the face of the hive (*a*). The author then reflected sunlight into the bottom of the dark hive with a mirror (*b*). The forager stopped running upward and instead showed the way to the food by running toward the sun's image. With darkness restored (*c*), the forager resumed its upward runs. Turning the sun "on" and "off" caused repeated reversals and altered the tempo of the dance.

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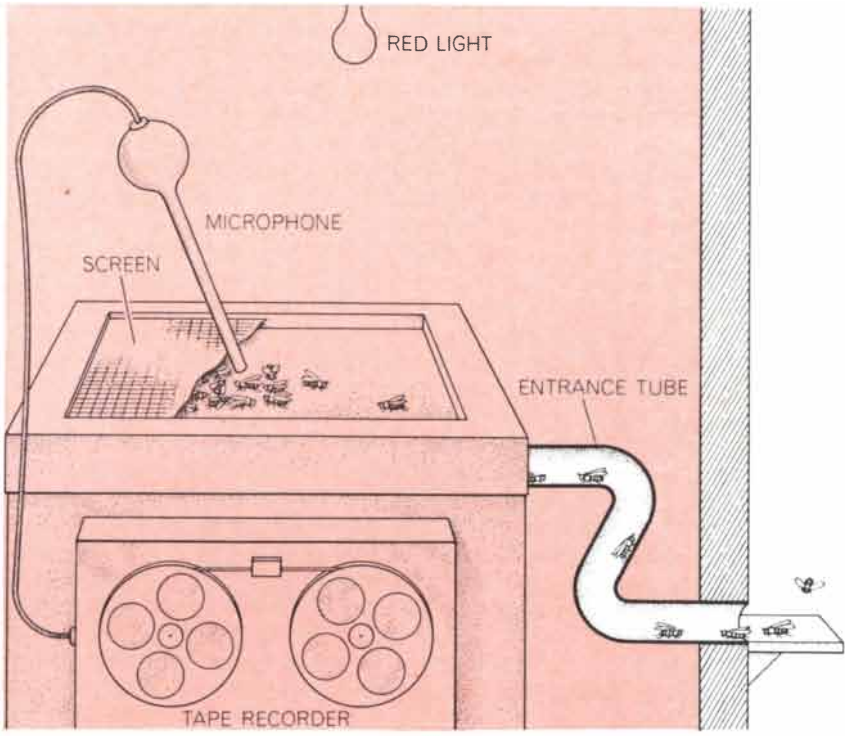


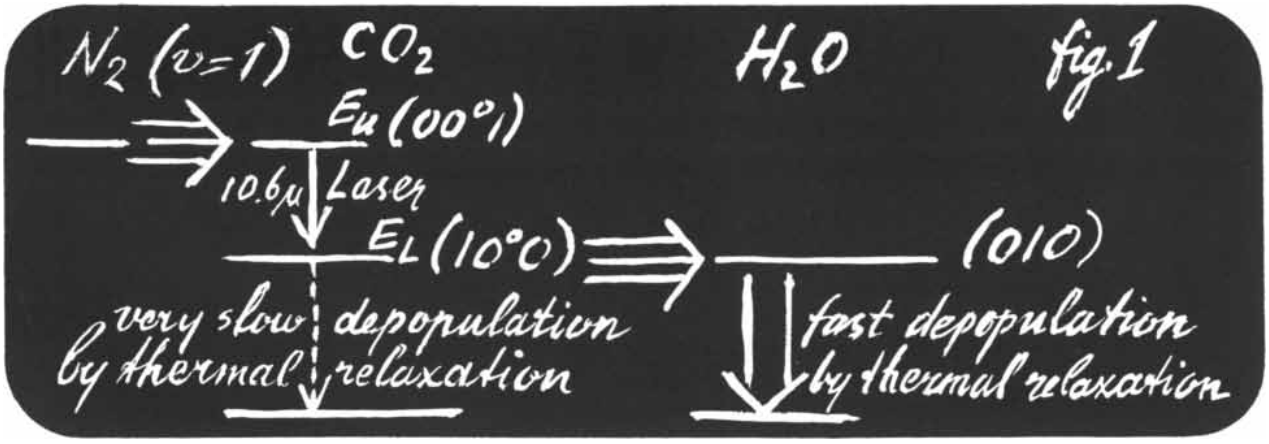
REVERSION to primitive behavior was forced on honeybees by an experiment in which the author tipped the vertical hive into a horizontal position and covered the formerly vertical face with screening so that the sounds made by returning foragers could be recorded. Coming back to a dark hive with no vertical surface to run on, the foragers did not dance. They did emit sounds indicating the distance to the food source, as stingless bee foragers do.

tive behavior of stingless bees. I laid the hive horizontally, so that there were no vertical surfaces on which the bees could dance, and then observed the dark hive under red light (which bees cannot see). In these circumstances returning foragers did not dance, presumably because in the dark the wagging-dance language requires a vertical, gravitational reference line to indicate direction. The scouts did, however, emit sound signals that told the distance to the food site [*see illustration above*]. In short, the honeybee under these conditions behaved very much like a *Melipona* stingless bee: no dance in the hive but a chatter of sound telling the hivemates that food had been found and how far away it was.

Experiments show that the honeybee prefers to use the sun, rather than the symbolic upward line in the hive, as the reference for indicating the direction of a food site to its hivemates. As we have noted, when the food source is in the direction of the sun, the forager makes its wagging run straight upward in the darkness of the hive. In some of my experiments I put a mirror at the bottom of the hive so that the sun's image appeared in the mirror. The dancer then turned about and made its run straight down toward the sun's image! That is to say, it gave up its artificial mode of representing the sun's direction and went for the sun itself. When I moved the mirror away, the dancer returned to its conventional upward wagging run [*see illustration on page 102*].

(Incidentally, by turning the sun "on" and "off" rapidly in this way I caused the dancer to speed up the tempo of its dance greatly. The amount of wagging in each run remained the same, however. This experiment showed conclusively that the wagging time, rather than the number of runs per minute, is the significant indicator of the distance to the food site.)

Taken together, all the information gained from observation and experiment suggests that (1) the language of the bees had its origin in some automatic, rhythmic behavior of flying insects at the end of a flight; (2) at the most primitive stage of development the social bees obtained information primarily from sounds emitted by the foragers; (3) the language gradually evolved into the precise ritual of the honeybees' wagging dance and its accompaniment of sound. We plan to extend the research to many more species of bees, hoping to learn in detail just how the language developed.



Why would you need water vapour in high-power CO_2 lasers?

(From a laboratory lecture by Dr. W. J. Witteman)

For a laser to operate there must be a certain amount of inversion between the upper and lower levels, i.e. the upper level must have a higher population than the lower. To achieve in addition a high radiation output, the upper level must be efficiently pumped and the lower one quickly depopulated by relaxation. One of the basic problems for the optimalisation of laser operation lies in finding out which energy transfer process restricts radiation production.

Now if you look at fig. 1 you will see a schematic drawing of the upper and lower laser levels of the carbon dioxide molecule (E_U and E_L, respectively). Excitation of the upper laser level occurs during collision with vibrationally excited nitrogen molecules. Since the vibrational energy quanta of nitrogen are practically equal to those of the upper laser level, the energy transfer is extremely fast. Now as a result of the laser process, the lower level (10° 0) will be populated. The population density will be very high in the absence of other gases because it can only then be depopulated by thermal collisions with CO_2 and N_2 molecules. It can be estimated that, on average, 5.10^4 collisions are needed to transfer one vibrational energy quantum of the lower level to the translational motion of the molecules. This number of collisions is too high for depopulation to follow the possible pumping rate of the upper level.

Fortunately, this depopulation process can be considerably accelerated by adding small amounts of water vapour*). Since the lowest vibrational energy quanta of the water molecule are close to those of the lower level, a carbon dioxide molecule with an excited lower level needs only a few collisions with water molecules for its energy to be transferred. In turn, the vibrationally excited water molecule rapidly converts its vibrational energy into translational energy by colliding with other water molecules. This fast conversion is due to the strong attractive forces from the dipole-dipole interaction between a colliding pair.

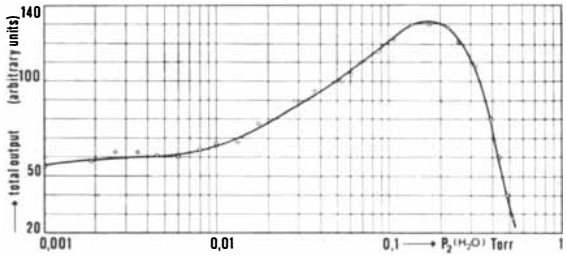
We have shown that the relaxation equation can be expressed to include the serial de-excitation through water vapour in the following form**).

$$\frac{dE}{dt} = -p_1 \left[\frac{1}{\tau_{11}} + \frac{1}{\tau_{22}} \left(\frac{p_2}{p_1} \right)^2 \right] \cdot \left[E(T) - E(T_0) \right]$$

where τ_{11} and τ_{22} are the vibrational-translational relaxation times of carbon dioxide and water vapour, respectively, and p_1 and p_2 are their partial pressures. $E(T)$ is related to the vibrational energy of the lower laser level and $E(T_0)$ its value when fully depopulated by thermal collisions. Fig. 2 shows how the experimentally observed radiation increases as a function of the added water vapour pressure. It can be shown theoretically that in the presence of 0.2 torr water vapour, the depopulation of the lower laser level is so fast that it no longer restricts the radiation production .

Its influence on the relaxation mechanism is not the only function performed by the water vapour in our system. Via an intricate chain of chemical reactions, it has been shown to perform a vital function in the continuous regeneration of the desired gas mixture. This enables us to construct high power CO_2 lasers which are fully sealed off. We have a handy 1.5 m. version of this laser which we regularly farm out to our industrial colleagues. It delivers 55 watt continuously, and with an overall efficiency of 11% and a life in excess of a thousand hours. It may well now enter the workshop as a convenient tool for every day use.

Fig. 2



*) See Physics Letters **18** (15 Aug. '65) page 125-127.

**) See IEEE Journal of Quantum Electronics QE-2 nr. 9 (Sept. 1966) page 375-378.

ANTIMATTER AND COSMOLOGY

Experiments in high-energy physics have demonstrated the complete symmetry between particles and antiparticles. A novel theory of the universe that takes this basic symmetry into account is advocated

by Hannes Alfvén

How shall we save the symmetry of the universe? The discovery of antimatter profoundly disturbed —perhaps I should say excited—physicists, astronomers, cosmologists and philosophers. A simple thought immediately came into everyone's mind: if antimatter exists, for symmetry's sake we must imagine that the universe is composed of equal parts of matter and antimatter. The idea raises, however, all kinds of difficult questions. No system can exist half matter and half antimatter, because the two forms of matter annihilate each other. Even if we suppose there are two systems—the universe and an antiuniverse—how are the systems prevented from meeting and destroying each other? What manner of evolution created and separated the two kinds of matter?

I shall discuss in this article a cosmological theory suggested by the Swedish physicist Oskar Klein. Although he has worked on it for several years, the theory will be new to most readers, because so far it has attracted attention only among specialists. It seems to me a remarkably interesting hypothesis, well founded on physical principles and definitely not to be confused with science fiction.

To present the theory and the problems it seeks to solve, a little background is necessary. Over the past few centuries astronomy and laboratory physics have been involved in an intimate collaboration. The microscopic study of the structure of matter in the laboratory has supported the macroscopic study of the structure of the universe. Isaac Newton's studies of the laws of motion and gravitation led to an accurate description of the solar system and the motions of the planets. The development of spectroscopy enabled astronomers to discover the chemical composition and the physical state of the stars. The physicists' exploration of nuclear reactions disclosed the mechanisms by which the stars generate their energy: it provided a clear and detailed picture of the "thermonuclear reactor" that works in the interiors of the stars (but not yet in our laboratories!).

At the beginning of this century the physicists produced a discovery that was very unsettling for the philosophers and cosmologists who were convinced that nature was ruled by a universal symmetry. The physicists found that whereas the unit of negative electric charge was embodied in the electron, the unit of positive charge was carried by the proton, a particle 1,840 times heavier than the electron. The philosophers wondered: Why should the positive and negative charges be associated with different masses? Should one not expect the equal and opposite charges to be represented by equal and opposite particles?

The champions of symmetry were eventually vindicated. The physicist P. A. M. Dirac predicted on mathematical grounds that the electron should indeed have an opposite with exactly the same mass, and in 1932 the positron was detected and identified in the laboratory. There followed a long, expensive and successful search for other antiparticles. With large accelerators the antiproton was created, and in the range of intermediate particles between the electron and the proton every charged particle was found to have a twin of opposite charge. The symmetry between particles and antiparticles has now become one of the fundamental principles of physics.

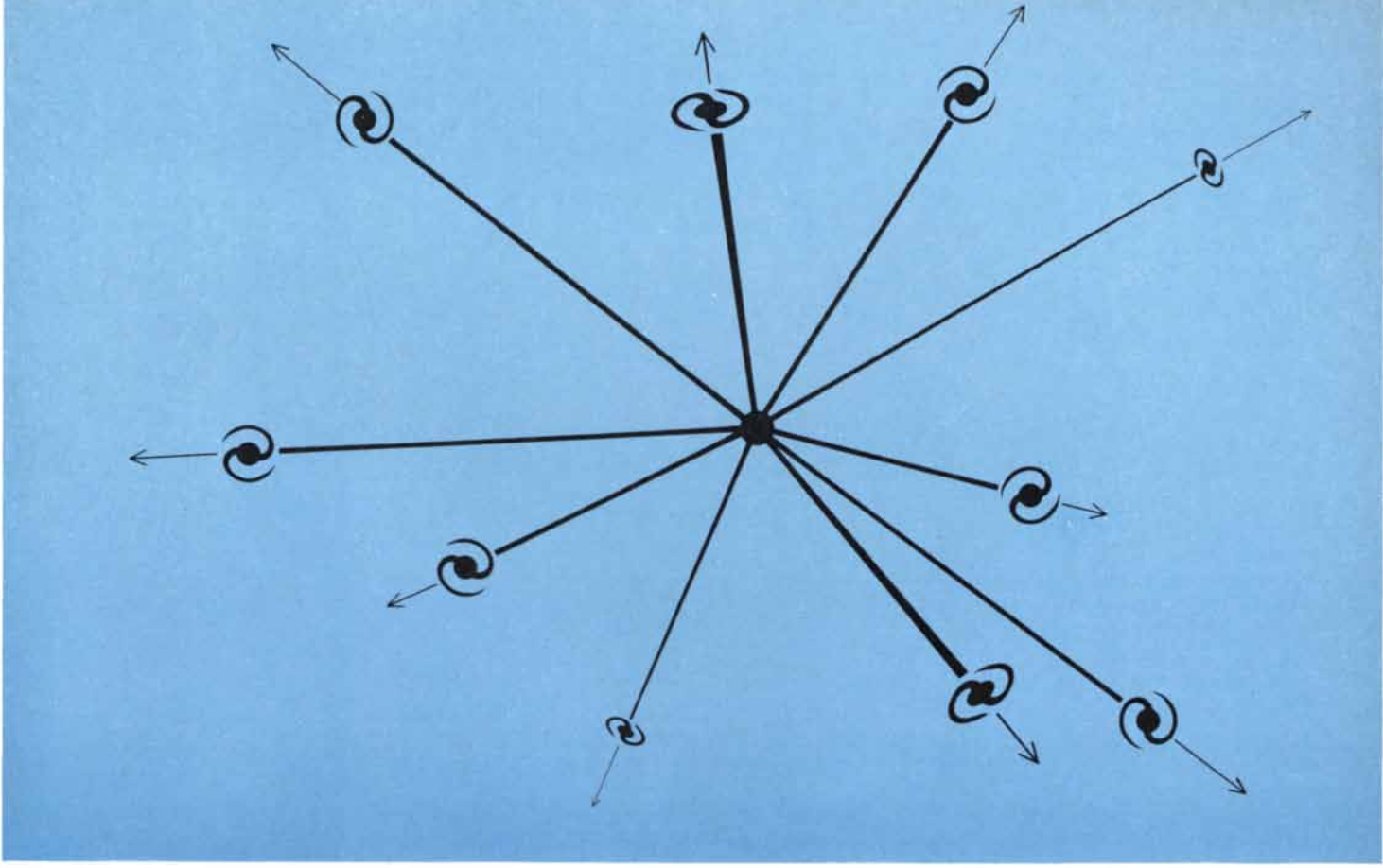
From antiparticles there naturally follow antiatoms. The combination of an antiproton with a positron would form an antihydrogen atom, and quantum mechanics predicts that it would have almost exactly the same properties as the atom of ordinary hydrogen; for instance, it would emit light at the same wavelengths. Antihydrogen atoms in turn would combine into antihydrogen molecules and constitute a gas with the typical properties of ordinary hydrogen: liquefying at 252 degrees below zero centigrade and so on.

Similarly, antiparticles could compose all the heavier elements. Antioxygen, for example, would consist of a nucleus containing eight antiprotons and eight antineutrons with eight positrons surrounding the nucleus. The antielements, all the way up to antiuranium, could build up an "antiworld," including in principle "antilife" itself.

We can be sure that as accelerator technique advances it will be possible to progress from producing antiparticles to building more complex forms of antimatter. More than a year ago physicists at the Brookhaven National Laboratory combined an antiproton and an antineutron into an antideuteron, the counterpart of the nucleus of ordinary heavy hydrogen. The Brookhaven achievement produced some satisfaction among physicists but no surprise.

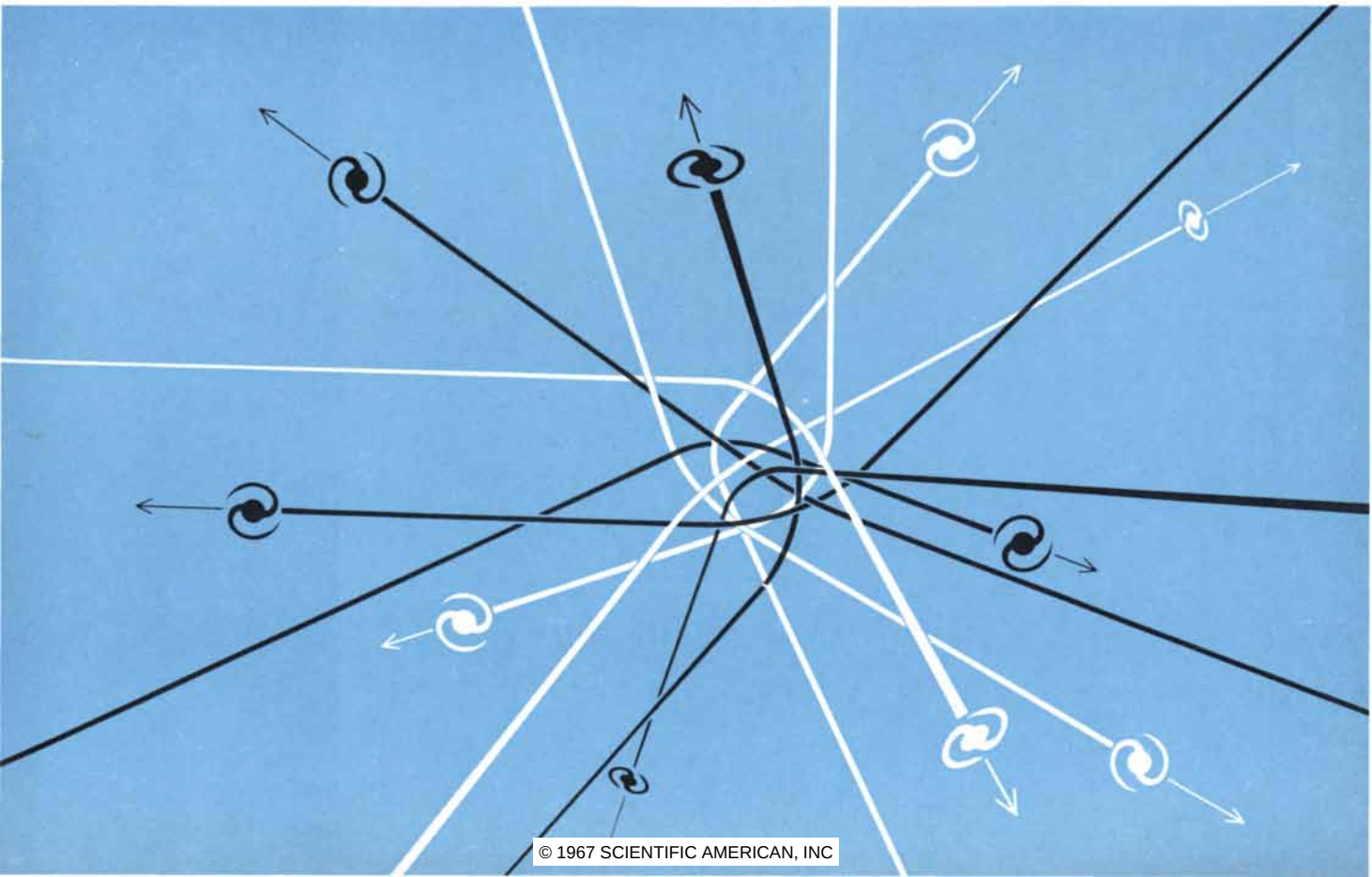
Those interested in cosmology naturally began to examine quite seriously the possibility of the existence of antimatter on a macrocosmic scale. Klein's approach to the question started with two basic premises: that the universe at large is composed of equal quantities of matter and antimatter and that it is governed by known physical laws, that is, a plausible picture of such a universe can be drawn without postulating any new laws of nature.

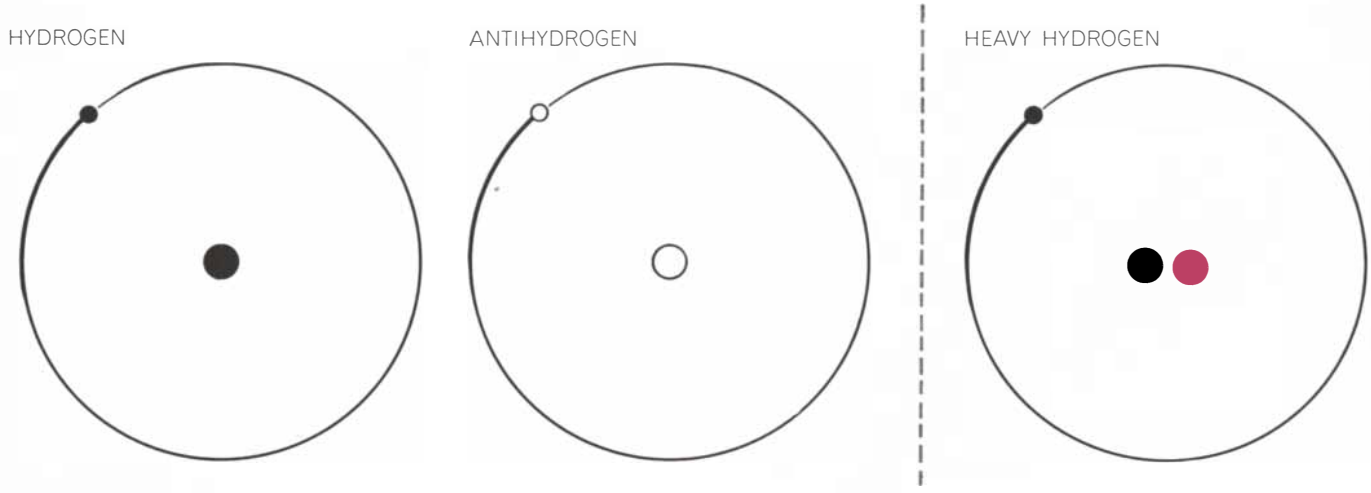
The first question with which one must deal is the nature of the universe's evolution. Obviously if antimatter exists on a large scale, the current theories of



"BIG BANG" THEORY of the origin of the universe (*above*) accounts for the astronomical observation that the galaxies are receding at speeds proportional to their distance from the observer by assuming that the universe was created in the explosion of an extremely dense "ylem" consisting only of ordinary matter. The big-bang theory makes no provision for the existence of antimatter.

ALTERNATIVE POSSIBILITY (*below*) is consistent with the theory suggested by the Swedish physicist Oskar Klein, which assumes that the "initial state" of the universe was a rarefied gas of particles and antiparticles that contracted under the influence of gravitation and later expanded as a result of radiation pressure. This theory allows both galaxies (*black*) and antigalaxies (*white*).

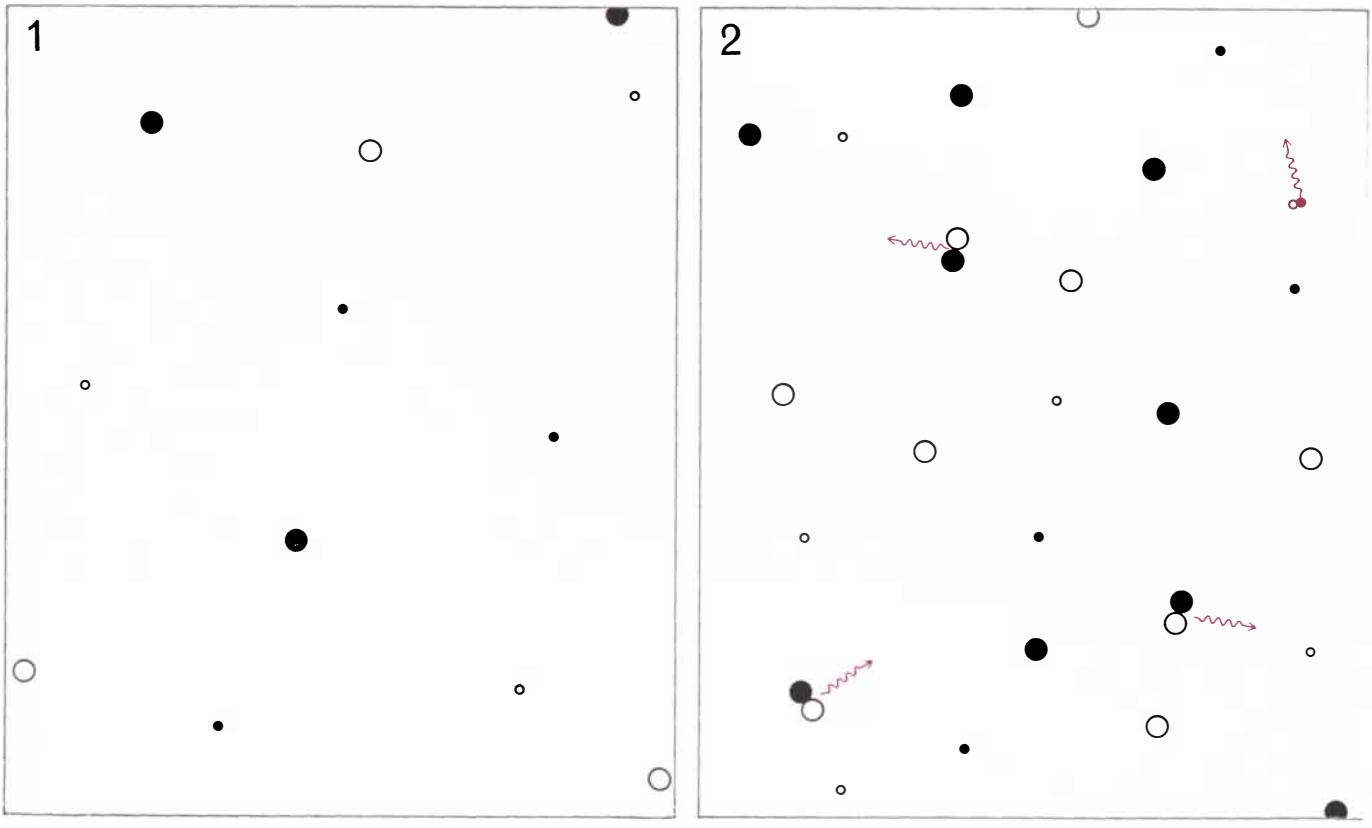




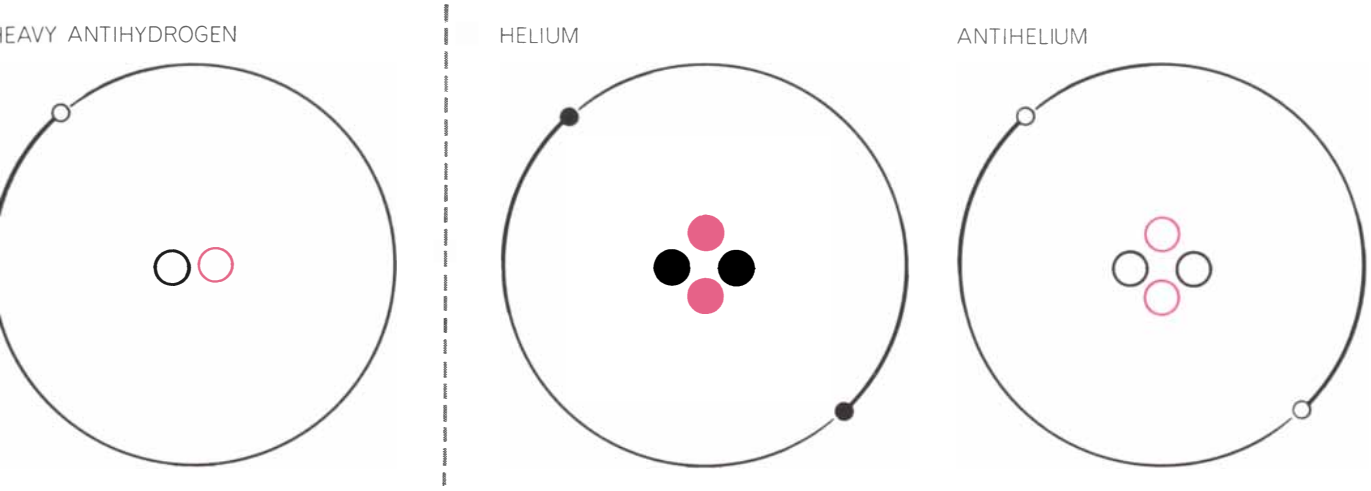
ATOMS AND ANTIATOMS are identical in every respect except charge. Atoms consist of positively charged protons (*large black dots*), negatively charged electrons (*small black dots*) and uncharged neutrons (*colored dots*). Antiatoms consist of negatively

the history of the universe—the "big bang" theory and the "steady state" theory—fall by the wayside. The big-bang theory assumes that the universe started from an "ylem," or extremely dense ball consisting only of what we know as ordinary matter. If the original nucleus had contained antimatter as well as matter, it would have annihilated itself; the big bang would have been a too big bang! As for the steady-state theory, based on the concept of continuous creation of matter, this idea likewise denies the creation of antimatter.

Klein's theory supposes that in its "initial state" the universe consisted of an extremely dilute cloud of gas, or rather a plasma of electrified particles. Let us call it an ambiplasma, because it contained both particles and antiparticles. These may have been only protons and antiprotons, but the primordial cloud might also have included electrons and positrons. We do not venture to



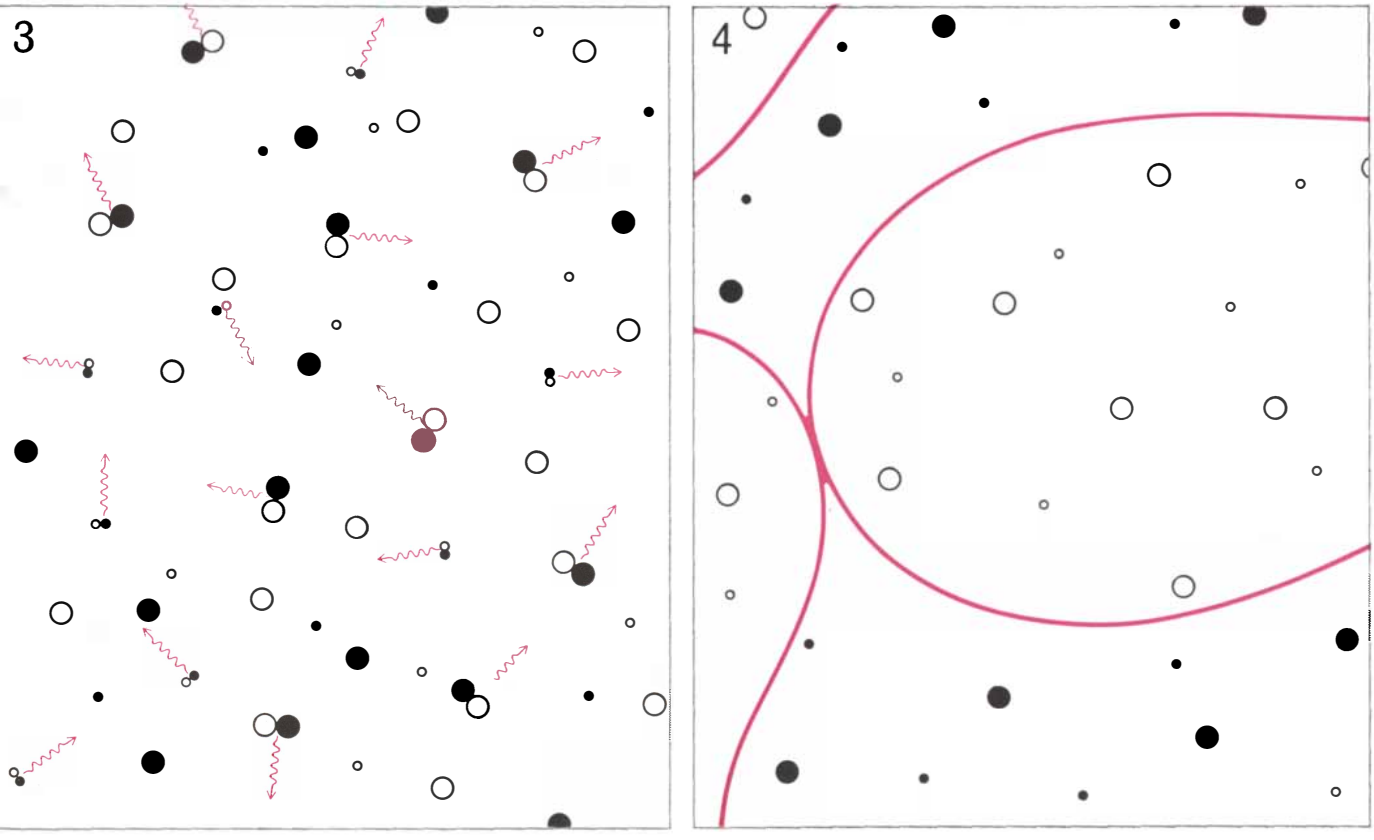
ACCORDING TO KLEIN'S THEORY, the primordial "metagalaxy" was an attenuated plasma containing only protons and antiprotons (and perhaps some electrons and positrons). In this initial state the spherical metagalactic cloud had a radius of about a trillion light-years, and the density was so low that the particles and antiparticles practically never encountered one another (*1*). Gravitation caused the cloud to contract very slowly until it reached a radius of a few billion light-years, at which stage the protons and anti-



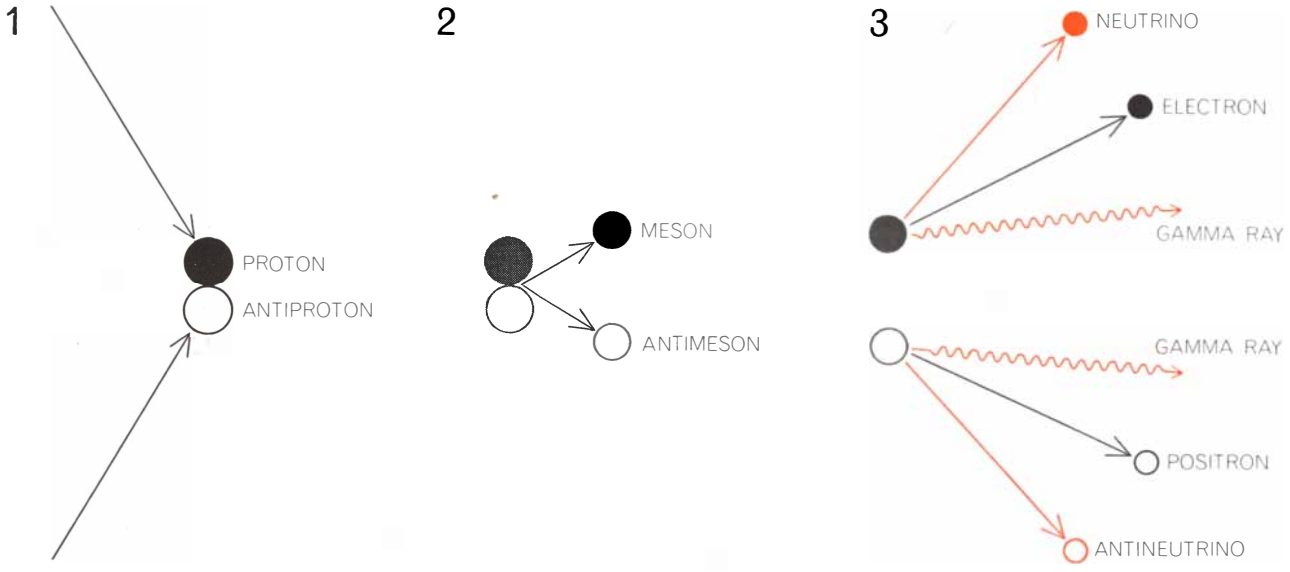
charged antiprotons (*large black circles*), positively charged positrons (*small black circles*) and uncharged antineutrons (*colored circles*). An antideuteron (a nucleus of heavy antihydrogen) was observed in 1965 by workers at Brookhaven National Laboratory.

say how the cloud of ambiplasma originated. (For that matter, the big-bang theory does not attempt to explain how the original ylem came into being.) We simply assume the existence of the cloud and go on to show that by gravitation it would begin to contract very slowly. To simplify the calculations Klein supposed that the cloud has the shape of a sphere and that the particles (ordinary and anti) are distributed throughout it in uniform density. The cloud has a radius of, say, a trillion light-years, and the density of particles is no more than one per million cubic meters.

At this dispersion the particles and antiparticles practically never encounter one another. When the cloud has contracted to a radius of a few billion light-years, the particles are still widely separated, but now and then a proton and an antiproton do collide. Their mutual annihilation releases energy, mainly in the form of radiation. As the contraction



protons began to collide and annihilate each other, producing electromagnetic radiation (*2*). When the radius of the cloud had shrunk to about a billion light-years, the radiation arising from proton-antiproton annihilation was so strong that the radiation pressure overcame the gravitational attraction (*3*). The cloud then began to expand, completing its separation into regions of matter and regions of antimatter (*4*). This kind of "radiation explosion" is more consistent with known physical processes than the big bang is.



COLLISION OF PROTON AND ANTIPROTON (*1*) **results in their mutual annihilation. The particles are transformed into mesons** (*2*)**, which decay rapidly and emit neutrinos and gamma radiation** (*3*)**. Moments later only electrons and positrons remain.**

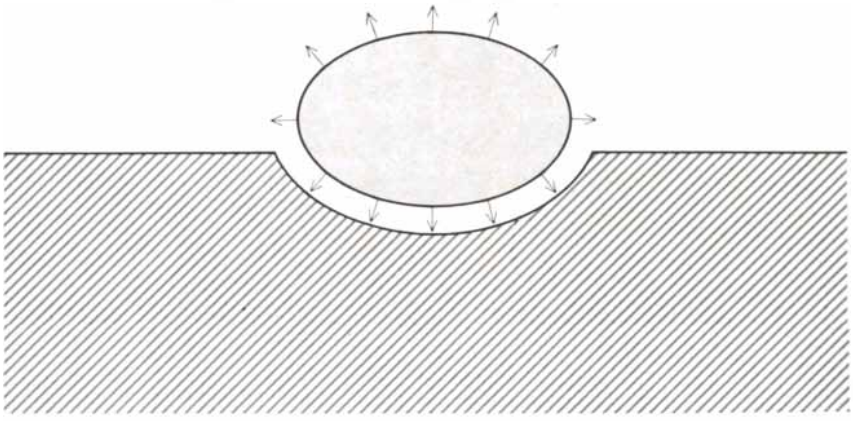
proceeds the collisions become more and more frequent and the radiation pressure grows stronger. When the radius of the cloud has shrunk to about a billion light-years, the radiation arising from particle-antiparticle annihilation is so strong (although the average density is still less than one particle per cubic centimeter) that it overcomes the gravitational attraction. The cloud, including the galaxies that have condensed within it by that time, begins to expand. The result is the expanding universe we now observe with our telescopes.

As in the big-bang theory, the expansion in Klein's theory can be said to arise from an explosion: a kind of radiation explosion issuing from the annihilation of particles. This expansion, however, is more consistent with physical processes as we know them than the big bang is. The big-bang theory calls for a bomb in which matter is packed to inconceivable density by some process that passes understanding. Klein's concept, on the other hand, invokes only the well-known phenomena of gravitation and the production of radiation energy by particle annihilation. Furthermore, calculations based on the Klein theory agree fairly well with certain observed features of our universe, for example the relation of the average density of matter to the rate of expansion in various regions.

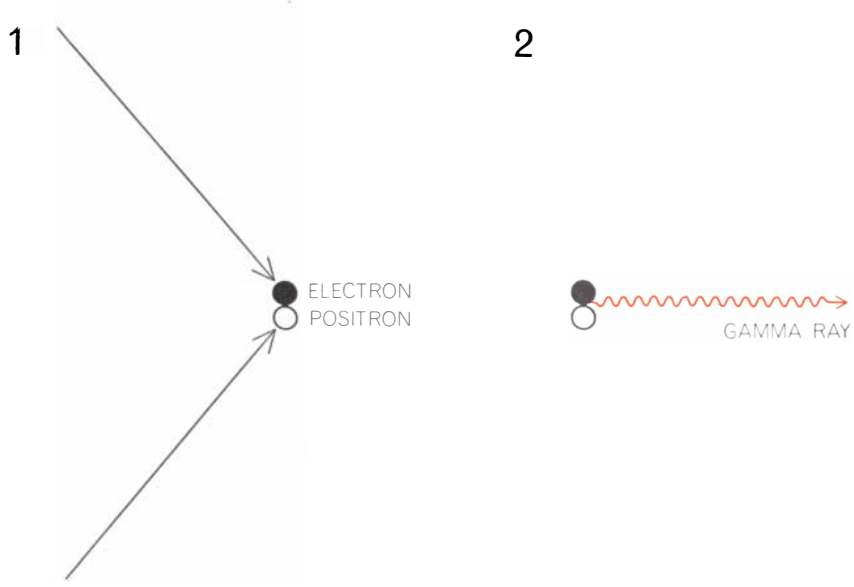
Klein calls the universe in which we live the metagalaxy. It includes all the galaxies that have been detected with our telescopes and no doubt a multitude of other galaxies within the system that are yet to be discovered. According to the big-bang theory this assemblage of galaxies, perhaps 10 billion in number, constitutes the entire universe. Klein suggests, however, that there may be other metagalaxies outside our own.

In its general features the Klein model of the development of the metagalaxy is highly satisfactory, in the sense that it depends only on known physical principles and is consistent with observed facts. We must come now, however, to the crucial and difficult questions of how matter was separated from antimatter and how they are kept apart, as they must be to form stable worlds. To the first of these questions the answer is still far from clear. The theory requires that the ambiplasma have contained magnetic fields, either in the initial state or in the course of development of the cloud. It can be shown that under the combined action of gravitation and electromagnetic forces, by a process essentially similar to electrolysis, protons and electrons might have collected in some regions and antiprotons with positrons in other regions. Much work remains to be done, however, on the details of this process, and I shall not attempt to go further into this still nebulous subject at this time. The second question, however, has been developed in reasonably satisfactory detail.

Analyzing the question, we can soon come to the conclusion that it is entirely possible antiworlds might exist side by side with our own kind of world even within our own galaxy. This conclusion



LEIDENFROST PHENOMENON was invoked in order to account for the separation of matter and antimatter in the universe. Ordinarily this term describes the behavior of a drop of water placed on a hot plate (*left*). If the temperature of the plate is just above the boiling point of water (100 degrees centigrade), the drop will evaporate almost instantly. If, however, the temperature of the plate is several hundred degrees higher and the plate

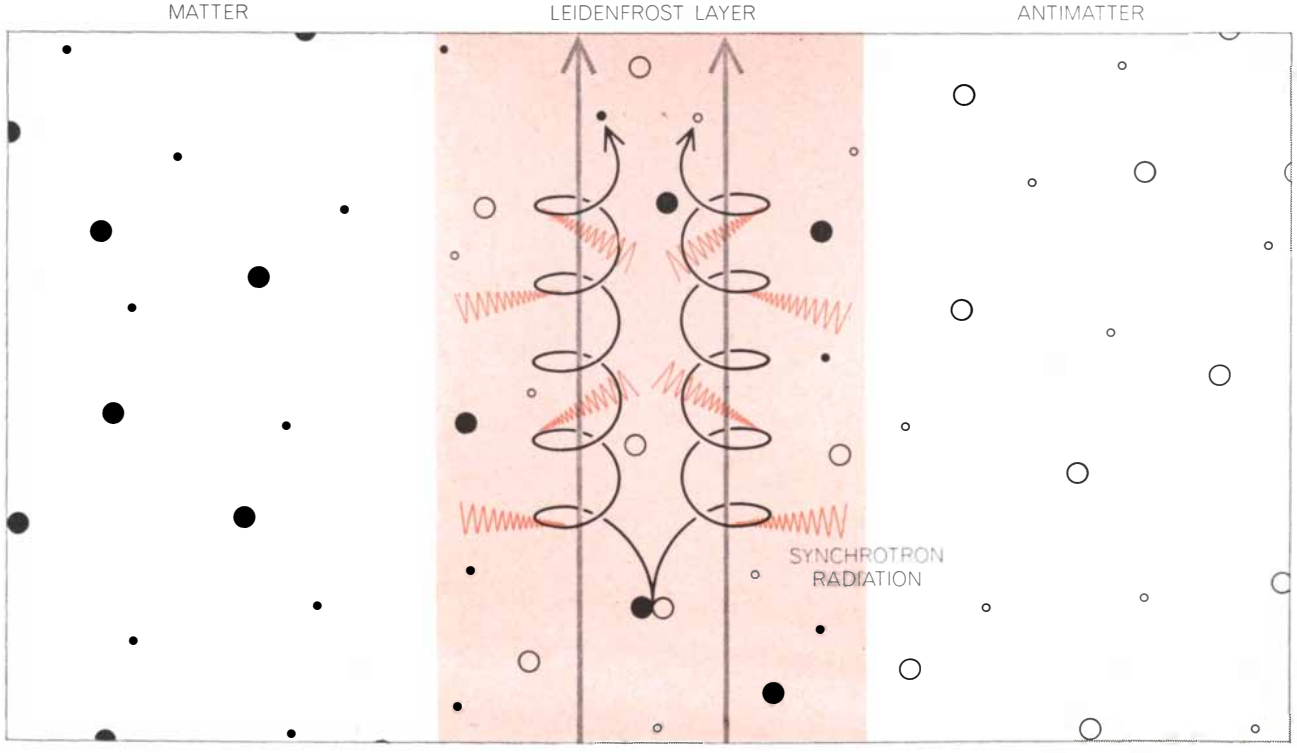


COLLISION OF ELECTRON AND POSITRON (*1*) also results in mutual annihilation and is accompanied by the emission of gamma radiation (*2*). Annihilated particles are gray.

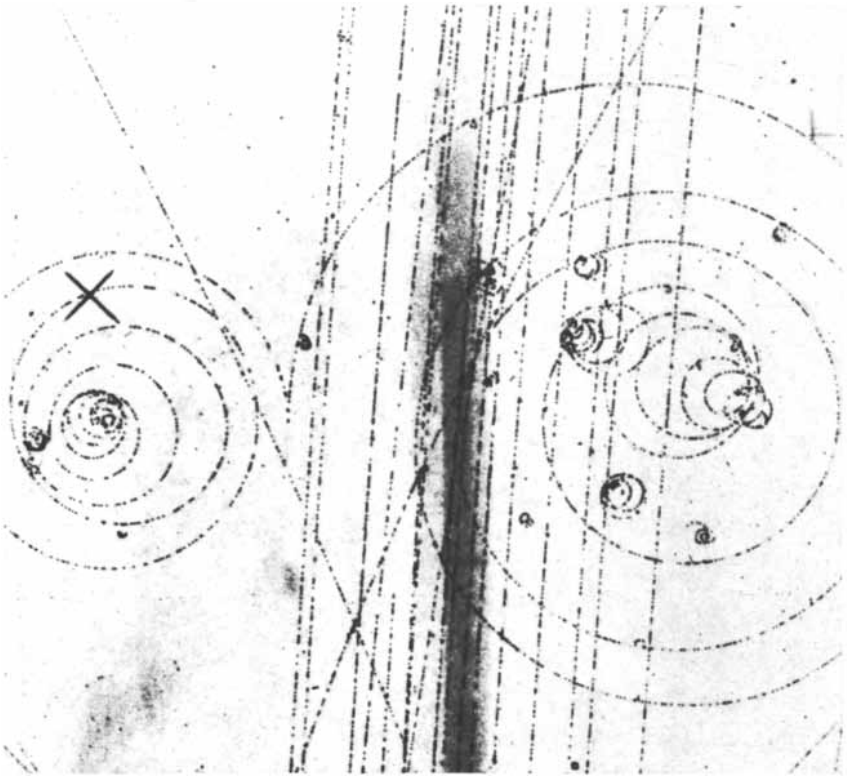
rests on a familiar principle known as the Leidenfrost phenomenon. If water is dropped on a hot plate at a temperature moderately above the boiling point (100 degrees C.), it will evaporate very rapidly. If, however, the temperature of the plate is very much higher and the plate is concave enough to hold water without its rolling off, a teaspoonful of water placed on the plate may lie there without boiling off for as long as 10 minutes. Rapid evaporation of the water at the interface with the hot plate forms a thin layer of vapor that insulates the body of water from the hot plate itself. This Leidenfrost phenomenon is sometimes a nuisance in high-temperature boilers.

In the same way matter and antimatter might be kept apart by a very hot layer at the interface between them. The hot layer would be produced by the annihilation reactions between particles and antiparticles meeting at the interface. We know that the vast reaches of space around the planets of the solar system, around stars and even around galaxies are occupied by thin clouds of plasma subjected to magnetic fields. Let us say that out in space such a plasma, surrounding a body made up of matter, borders on a magnetized antiplasma surrounding a body of antimatter. Collisions between protons and antiprotons will produce, as end products of their mutual annihilation, high-energy electrons and positrons. These particles will spiral around the lines of the magnetic fields and form a very hot layer of ambiplasma in which the electrons and positrons go on annihilating one another. Such a layer could act as a kind of curtain between matter and antimatter and thus insulate the two worlds from each other.

All this brings us face to face with the distinct possibility that antiworlds may



is concave enough to hold the water without its rolling off, the drop will lie there without boiling off for several minutes. A layer of vapor at the interface insulates the drop from the hot plate itself. Similarly, a hot, insulating Leidenfrost layer might be formed at the interface between a world of matter and a world of antimatter (*right*). Such a layer would be produced by the annihilation reactions between particles and antiparticles meeting at the interface. Collisions between protons and antiprotons would produce high-energy electrons and positrons, which would spiral around the magnetic-field lines in the layer, emitting radio waves.



BUBBLE-CHAMBER PATHS of an electron and a positron (*large spirals*) turn in opposite directions in the presence of a magnetic field, which is perpendicular to the plane of the photograph. The electron-positron pair was formed as the end product of a collision between a target proton and an accelerated antiproton produced by the alternating-gradient synchrotron at Brookhaven. The smaller spirals represent lower-energy electrons and positrons.

INTENSE RADIO STAR, designated 3*C* 273, may derive its enormous radio energy from matter-antimatter annihilations in its dense interior. Protruding jet suggests an explosion.

actually be neighbors of ours, astronomically speaking. It cannot be excluded that the Andromeda nebula, the closest galaxy to ours, or even stars within our own galaxy are composed of antimatter. Looking at the stars in the night sky, how can we tell whether they are matter or antimatter? An antimatter body would emit precisely the same spectra as a corresponding body of matter. It is true that in a given magnetic field the two kinds of matter would show different Zeeman effects. The Zeeman effect is a splitting of spectral lines resulting from the action of a magnetic field on the electrons of atoms or molecules. When a magnetic field with the same direction acts on positrons, the splitting has the opposite sense, and in this way antimatter could be distinguished from matter. But suppose the magnetic fields associated with antimatter have the opposite direction from those associated with matter. In that event the Zeeman effect will be exactly the same in both cases. The fact is we must admit we have no conclusive proof that any object in the heavens is composed of matter rather than antimatter. Consider Vega, for instance, the brightest star in the northern sky. If it consisted of antimatter, it would not look different in any respect from the way it does. Aside from the light coming from Vega we may receive some very energetic cosmic rays from the star, but we cannot tell the nature of this matter, because we have no way of knowing whether extremely energetic cosmic particles striking the top of our atmosphere are particles or antiparticles.

Is there, then, no possible means of determining if antimatter exists beyond our world? A possibility does come to mind. We might detect the presence of antimatter in space by discovering certain specific emissions of energy from regions of ambiplasma, where matter is mixed with antimatter. Very likely the Leidenfrost "curtains" of ambiplasma, if they exist, are so thin that their energy radiation is not strong enough to be detectable on the earth. However, since the metagalaxy has developed from an ambiplasma, according to the Klein cosmology, we should expect some regions of space to be in that state. What kinds of energy would be emitted from a magnetized ambiplasma in which particle-antiparticle annihilation was taking place?

When a proton collides with an antiproton, the annihilation process produces a number of mesons that rapidly decay through a complicated series of steps.

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The end result is that within a few microseconds after the collision the original particles have been transformed into energy in the form of gamma rays, neutrinos, one or two electrons and one or two positrons. The original rest-mass energy of the proton and antiproton amounted to 1,800 million electron volts (each possessing 900 million). In the transformation half of the total energy goes into neutrino radiation. This form of energy is very difficult to detect, and we must give up any hope of its significant interception. The gamma rays account for a fourth of the total energy from the transformation. In principle this radiation could be detected by devices such as the scintillation counter, but it would have to be caught in a space laboratory, because gamma rays are scattered and absorbed by the earth's atmosphere, and in any case only an extremely small fraction of the gamma emission from the ambiplasma could be captured and recorded by such a scintillation counter.

We are left, then, with the final fourth of the energy from the transformation, which is carried by the electrons and positrons, mainly in the form of kinetic energy (each electron and positron having a kinetic energy of about 100 million electron volts). The energetic electrons and positrons will spiral in the magnetic field of the ambiplasma, and in so doing they will emit radio waves—the so-called synchrotron radiation. Thus the particles will give up most of their kinetic energy as radio emission. Radio waves can penetrate the earth's atmosphere and can be collected by the huge antennas of radio telescopes. These advantages would make it 10 million times easier to detect radio emission than gamma emission from an ambiplasma.

Hence radio telescopes offer the best chance of detecting an ambiplasma in space, if it exists. They would record such a radiating source as a radio star. Here may be an explanation for the mysterious quasars, which emit enormous amounts of radio energy. It seems quite possible that some, if not all, of the starlike radio objects in the heavens, including quasars, arise from matter-antimatter annihilations. Recent theoretical calculations by B. Bonnevier, A. G. Ekspong and N. K. Yamdagni of Stockholm give strong support to this idea. The spectrum of radio emission from a hypothetical magnetized ambiplasma, they found, agrees reasonably well with the observed spectra of common radio stars.

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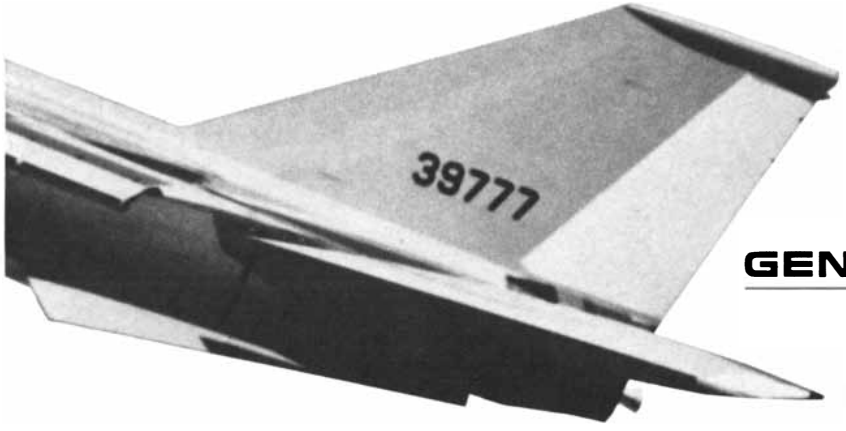


GENERAL DYNAMICS

Fort Worth Division

MATHEMATICAL GAMES

The amazing feats of professional mental calculators, and some tricks of the trade

by Martin Gardner

The ability to do arithmetic rapidly in one's head seems to have only a moderate correlation with general intelligence and even less with mathematical insight and creativity. Some of the most distinguished mathematicians have had trouble making change, and many professional "lightning calculators" (although not the best) have been dullards with respect to all other mental abilities.

Nevertheless, great mathematicians have also been skillful mental calculators. Carl Friedrich Gauss, for example, could perform prodigious feats of arithmetic in his mind. He liked to boast that he knew how to calculate before he could talk. When he was only three years old, his father, a bricklayer, was working on a weekly payroll for his laborers when young Friedrich startled him by saying, "Father, the reckoning is wrong...." The boy gave a different sum, which proved to be correct when the long list of numbers was added again. No one had taught the child any arithmetic.

The late John von Neumann was a mathematical genius who was also gifted with this peculiar power to compute without pencil or paper. In his book *Brighter than a Thousand Suns* Robert Jungk tells of a meeting at Los Alamos during World War II at which ideas were tossed back and forth by von Neumann, Enrico Fermi, Edward Teller and Richard Feynman. Whenever a mathematical calculation was called for, Fermi, Feynman and von Neumann would spring into action. Fermi would do the work on a slide rule, Feynman would punch a desk calculator and von Neumann would do it in his head. "The head," writes Jungk (quoting another physicist), "was usually first, and it is remarkable how close the three answers always checked."

The mental calculating abilities of Gauss, von Neumann and other mathematical lions such as Leonhard Euler and John Wallis may seem miraculous; they pale, however, beside the feats of the professional stage calculators, a curious breed of mental jugglers and acrobats who flourished throughout the 19th century in England, Europe and America. Many began their careers as small boys. Although some wrote about their methods and were studied by psychologists, it seems likely that they held back most of their secrets or perhaps did not themselves fully understand how they did what they did.

The first of the stage calculators, Zerah Colburn, was born in 1804 in Cabot, Vt. Like his father, great-grandmother and at least one brother, he had an extra finger on each hand and an extra toe on each foot. (The extra fingers were amputated when he was about 10. Did they stimulate, one wonders, his first efforts to count and calculate?) The child learned the multiplication table to 100 before he could read or write. His father, a poor farmer, was quick to see the commercial possibilities, and the lad was only six when his father took him on tour. His performances in England, when he was eight, are well documented. He could multiply any two four-digit numbers almost instantly, but he hesitated a moment on five-digit numbers. When told to multiply 21,734 by 543, he at once said 11,801,562. Asked how he had done it, he explained that 543 was equal to 181 times 3. Since it was easier to multiply by 181 than by 543, he had first multiplied 21,734 by 3, then multiplied the result by 181.

Washington Irving and other admirers of the boy raised enough money to send him to school, first in Paris and then in London. Either his calculating powers diminished thereafter or his interest in such feats declined. He returned to America when he was 20, and for about 10 years was a Methodist circuit preacher. His quaint autobiography, *A Memoir of Zerah Colburn: written by himself... with his peculiar methods of calculation*, was published in Springfield, Mass., in 1833. At the time of his death at the age of 35 he was teaching foreign languages at Norwich University in Northfield, Vt.

Colburn's stage career had its parallel in England in the performances of George Parker Bidder, born in 1806 in Devonshire. It is said that his father, a stonemason, taught him no more than how to count and that he acquired the ability to do arithmetic by playing with marbles and buttons. He was nine when he went on tour with his father. Typical of the kind of question put to him by strangers was: If the moon is 123,256 miles from the earth and sound travels four miles a minute, how long would it take for sound to travel (assuming that it could) from the earth to the moon? In less than a minute the boy replied: 21 days 9 hours 34 minutes. When asked (at age 10) for the square root of 119,550,669,121, he answered 345,761 in 30 seconds. In 1818, when he was 12 and Colburn was 14, the two boy wizards crossed paths in Derbyshire and were pitted against each other. Colburn implies in his memoirs that he won the contest, but London newspapers awarded the palm to Bidder.

Professors at the University of Edinburgh persuaded the elder Bidder to let them take over his son's education. The boy did well in college and eventually became one of England's most successful engineers. Most of his work had to do with railroads, but he is perhaps best known today as the man who designed and supervised the construction of the Victoria Docks in London. Bidder's calculating powers did not diminish with age. Shortly before his death in 1878 someone mentioned that there are 36,918 waves of red light per inch. Assum-

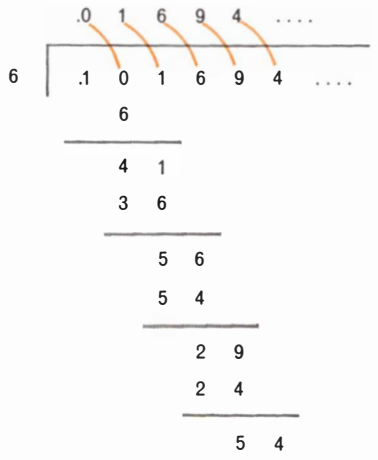
PROBLEM: 236×47

$236 = 200 + 30 + 6$

$47 = 40 + 7$

1. $40 \times 200 = 8{,}000$
2. $8{,}000 + (40 \times 30) = 9{,}200$
3. $9{,}200 + (40 \times 6) = 9{,}440$
4. $9{,}440 + (7 \times 200) = 10{,}840$
5. $10{,}840 + (7 \times 30) = 11{,}050$
6. $11{,}050 + (7 \times 6) = 11{,}092$

Colburn's method of mental multiplication



Aitken's computation of 1/59

ing that light travels at 190,000 miles per second, how many waves of red light, the man wondered, would strike the eye in one second. "You need not work it," Bidder said. "The number of vibrations will be 444,443,651,200,000."

Both Colburn and Bidder multiplied large numbers by breaking them into parts and multiplying from left to right by an algebraic crisscross technique often taught today in elementary schools that stress the "new math." For example, 236×47 is converted to $(200 + 30 + 6)(40 + 7)$ and handled as shown in the illustration on the opposite page. If the reader will close his eyes and try it, he will be surprised to find this method much easier to use in his head than the familiar right-to-left method. "True, the method... requires a much larger number of figures than the common Rule," Colburn wrote in his memoirs, "but it will be remembered that pen, ink and paper cost Zerah very little when engaged in a sum." (Throughout his book Colburn writes in the third person.) Why is this method so much easier to do in the head? Bidder, in a valuable lecture on his methods to the Institute of Civil Engineers in London (published in 1856 in Volume 15 of the institute's *Proceedings*), gives the answer. After each step there is "one fact, and one fact only," that has to be held in the memory until the next step is completed.

Another reason why all stage calculators have preferred this method, although they seldom said so, is that they can start calling out a product while still calculating it. This is usually combined with other dodges to give the impression that computing time is much less than it really is. For example, a calculator will repeat a question, then answer it as though the result came into his mind immediately when actually he began calculating while the person was still calling out the second number. Sometimes he gains even more time by pretending not to hear the question so that it has to be repeated. One must bear these dodges in mind when reading any observer's account that speaks of a lightning calculator's "immediate" answers.

I shall pass quickly over the so-called idiot savants among the calculators. They were not so idiotic as their publicity made them out to be; besides, their speed was considerably less than that of stage performers with more intelligence. Jedediah Buxton, an 18th-century English farmer, was one of the earliest of the breed. He remained a farmer all his life and never gave public exhibitions, but local fame brought him to London to be tested by the Royal Society. Someone took him to the Drury Lane theater to see David Garrick in *Richard III*. Asked how he liked it, Buxton replied that the actors had spoken 14,445 words and taken 5,202 steps. Buxton had a compulsion to count and measure everything. He could walk over a field, it was said, and give an unusually accurate estimate of its area in square inches, which he would then reduce to square hairbreadths, assuming 48 hairs to an inch. He never learned to read, write or work with written figures.

Perhaps the best all-around mental calculator now living is Alexander Craig Aitken, a professor emeritus of mathematics at the University of Edinburgh. He was born in New Zealand in 1895. Unlike most lightning calculators, he did not begin calculating mentally until he was 13, and then it was algebra, not arithmetic, that aroused his interest. In 1954, almost 100 years after Bidder's historic London lecture, Aitken spoke to the Society of Engineers in London on "The Art of Mental Calculation: With Demonstrations." His talk was published in the society's *Transactions* (December, 1954) to provide another valuable firsthand account of what goes on inside the mind of a rapid mental calculator.

A native ability to memorize numbers quickly is the one absolutely essential prerequisite. All the great stage calculators featured memory demonstrations. When Bidder was 10, he would ask someone to write a number of 40 digits and read it to him backward. He would at once repeat it forward. At the end of a performance many calculators could repeat accurately every number that had been involved. There are mnemonic tricks by which numbers can be transformed into words that in turn are memorized by other tricks, but such techniques are much too slow for stage work and there is no question that the masters avoided such aids. "Mnemonics I have never used," Aitken said, "and deeply distrust. They merely perturb with alien and irrelevant association a faculty that should be pure and limpid."

Aitken mentioned in his lecture that he had recently read about how the contemporary French calculator Maurice Dagbert had been guilty of an "appalling waste of time and energy" when he had memorized pi to the 707 decimal places computed in 1873 by William Shanks. "It amused me to think," Aitken said, "that I had done this myself some years before Dagbert, and had found it no trouble whatever. All that had been necessary was to range the digits in rows of fifty each, each fifty being divided into ten groups of five, and to read these off in a particular rhythm. It would have been a reprehensibly useless feat had it not been so easy."

Twenty years later, after modern computers had carried pi to thousands of decimal places, Aitken learned that poor Shanks had gone wrong on his last 180 digits. "I amused myself again," Aitken continued, "by learning the correct value as far as 1,000 places, and once again found it no trouble, except that I needed to 'fix' the join where Shanks's error had occurred. The secret, to my mind, is relaxation, the complete antithesis of concentration as usually understood. Interest is necessary. A random sequence of numbers, of no arithmetical or mathematical significance, would repel me. Were it necessary to memorize them, one might do so, but against the grain."

Aitken interrupted his lecture at this point by reciting pi, in an obviously rhythmic fashion, to 250 digits. Someone asked him to start the run at the 301st decimal. After he had given 50 digits he was asked to skip to the 551st place and give 150 more. He did all this without error, the digits being checked against a table of pi.

Do mental calculators visualize numbers while they work with them? Ap-

PROBLEM: 777×777

$$a^2 = [(a + b) \times (a - b)] + b^2$$

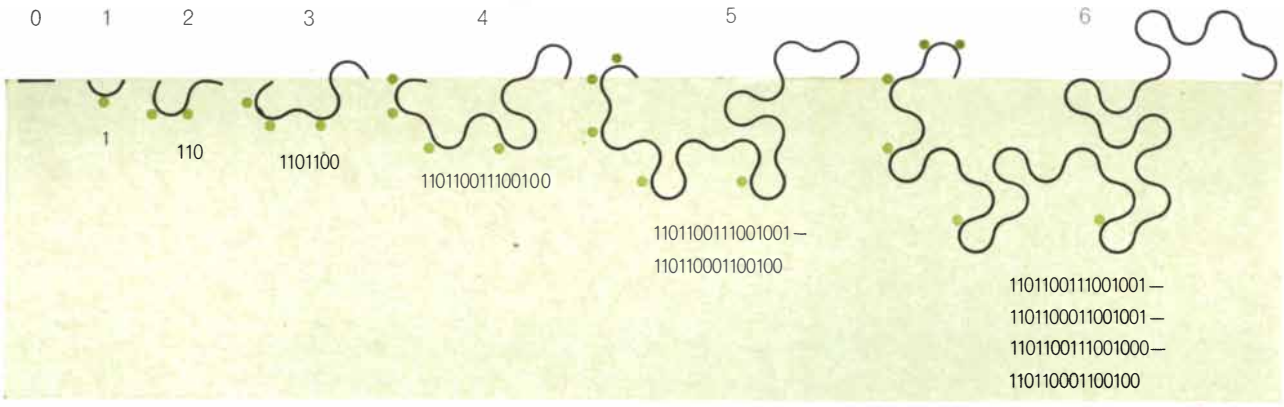
$$777^2 = [(777 + 23) \times (777 - 23)] + 23^2$$

$$777^2 = [800 \times 754] + 529$$

$$777^2 = 603{,}200 + 529$$

$$777^2 = 603{,}729$$

How Aitken squares 777



Sea dragons of orders 0 to 6, with their binary formulas

parently some do and some don't, and some don't know whether they do or don't. The French psychologist Alfred Binet was on a committee of the Académie des Sciences that investigated the mental processes of two famous stage calculators of the late 19th century, a Greek named Pericles Diamandi and Jacques Inaudi, an Italian prodigy. In his 1894 book *Psychologie des grands calculateurs et joueurs d'échecs* Binet reported that Diamandi was a visualizer but that Inaudi, who was six times as fast, was of the auditory-rhythmic type. The visualizers have almost always been slower, although many professionals were of this type, such as Dagbert, the Polish calculator Salo Finkelstein and a remarkable Frenchwoman who took the stage name of Mademoiselle Osaka. The auditory calculators such as Bidder seem to be more rapid. William Klein, a Dutch computer expert who used to perform under the name of Pascal (*Life* did a story about him in its issue of February 18, 1952), is probably the fastest living multiplier, capable of giving the product of two 10-digit numbers in less than two minutes. He too is an auditory calculator; indeed, he is unable to work without muttering rapidly to himself in Dutch. If he makes a mistake, it is usually caused by his confusing two numbers that *sound* alike.

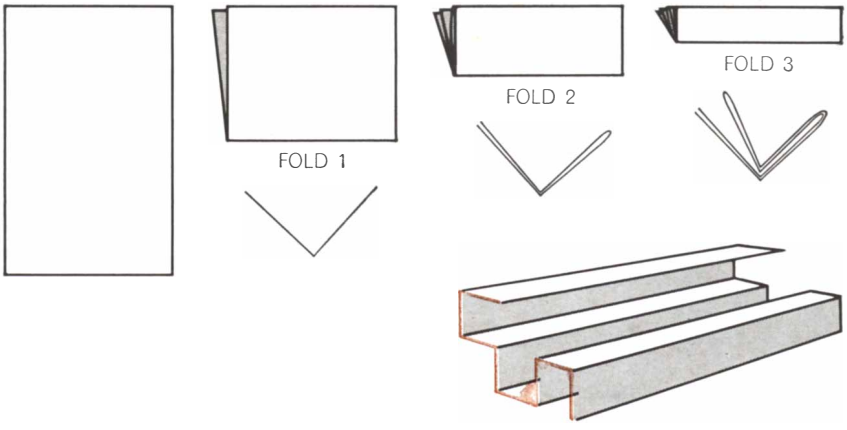
Aitken said in his lecture that he can visualize if he wishes; at various stages of calculation and at the finish the numbers spring into visual focus. "But mostly it is as if they were hidden under some medium, though being moved about with decisive exactness in regard to order and ranging. I am aware in particular that redundant zeros, at the beginning or at the end of numbers, never occur intermediately. But I think that it is neither seeing nor hearing; it is a compound faculty of which I have nowhere seen an adequate description; though for that matter neither musical memorization nor musical composition in the mental sense have been adequately described either. I have noticed also at times that the mind has anticipated the will; I have had an answer before I even wished to do the calculation; I have checked it, and am always surprised that it is correct."

Aitken's skull houses an enormous memory bank of data. This is typical of the lightning calculators; I doubt that there has ever been one who did not know the multiplication table through 100, and some authorities have suspected that Bidder and others knew it to 1,000 but would not admit it. (Larger numbers can then be broken into pairs or triplets to be handled like single digits.) Long tables of squares, cubes, logarithms and so on are stored in the memory along with countless numerical facts—such as the number of seconds in a year or ounces in a ton—that are useful in answering the kind of question audiences like to ask. Since 97 is the largest prime smaller than 100, calculators are often asked to compute the 96-digit recurring period for 1/97. Aitken long ago memorized it, so that if anyone pops *that* question he can rattle off the answer effortlessly.

There are in addition hundreds of shortcut procedures the calculator has learned or worked out for himself. The first step in any complicated calculation, Aitken pointed out, is to decide in a flash on the best strategy. To illustrate, he disclosed a curious shortcut that is not well known. Suppose you were asked for the decimal reciprocal of a number ending in 9, say 59. Instead of dividing 1 by 59, you can add 1 to 59, making 60, then divide .1 by 6 in the manner shown in the top illustration on the preceding page. Note that at each step the digit obtained in the quotient is also entered in the dividend one place later. The result is the decimal for 1/59.

If asked to give the decimal for 5/23, Aitken went on, he sees at once that he can multiply by 3 above and below the line to obtain the equivalent fraction 15/69, which has the desired 9 ending. He then changes 69 to 70, divides 1.5 by 7 according to the procedure just explained and gets his answer. But he can also change the fraction to 65/299 and divide .65 by 3, entering the number *two* places further along in the dividend.

Which strategy is best? A decision has to be made instantly, Aitken said, and then followed by great steadfastness of



Three folds generate an order-3 dragon

purpose. Midway through the calculation it may flash into one's mind that there is a better strategy. "One must resolutely ignore that, and keep on riding the inferior horse."

Aitken squares numbers by the method shown in the bottom illustration on page 117. The b is chosen to be fairly small and such that either $(a + b)$ or $(a - b)$ is a number ending in one or more zeros. In the case illustrated Aitken lets b equal 23. Having memorized a table of lower squares, he knows that 23^2 is 529 without thinking. During his lecture he was given seven three-digit numbers, each of which he squared almost instantly. Two four-digit numbers were squared in about five seconds. Note that Aitken's formula, when applied to any two-digit number ending in 5, leads to a delightfully simple rule that is worth remembering: Multiply the first digit by itself-plus-one and affix 25. For example, 85×85: 8 times 9 is 72, and appending 25 makes 7,225.

Thomas H. O'Beirne, a Glasgow mathematician with whom I correspond, mentioned in a recent letter that he once went with Aitken to an exhibition of desk calculators. "The salesman-type demonstrator said something like 'We'll now multiply 23,586 by 71,283.' Aitken said right off 'And get...' (whatever it was). The salesman was too intent on selling even to notice, but his manager, who was watching, did. When he saw Aitken was right, he nearly threw a fit (and so did I)."

The machines are, of course, discouraging young people with wild talents like Aitken's from developing their skills. Aitken confessed at the close of his lecture that his own abilities began to deteriorate as soon as he acquired his first desk machine and saw how gratuitous his skill had become. "Mental calculators may, like the Tasmanian or the Moriori, be doomed to extinction," he concluded. "Therefore... you may be able to feel an almost anthropological interest in surveying a curious specimen, and some of my auditors here may be able to say in the year A.D. 2000, 'Yes, I knew one such.' "

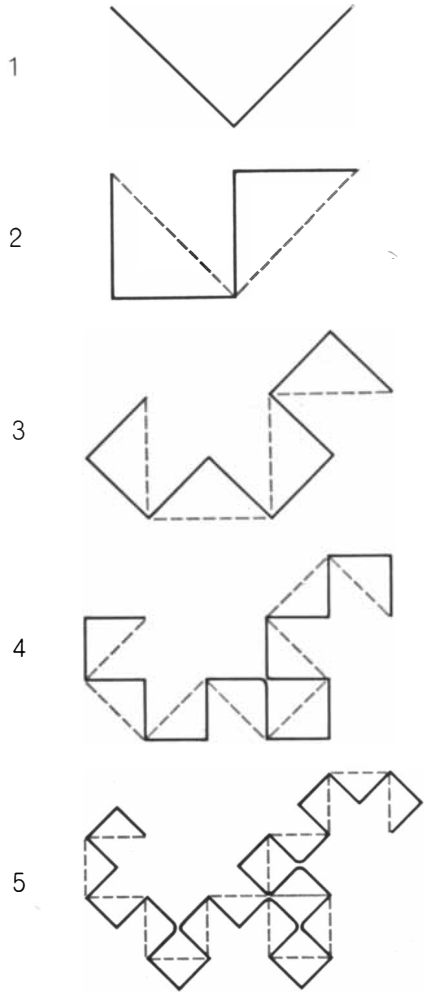
Next month I shall discuss some of the tricks of stage calculators by which even a tyro can obtain impressive results. Even the masters have not been above introducing pseudo-calculations into their stage work, much like an acrobat who gets applause for a showy feat that actually is not difficult at all.

The answers to the set of problems presented here last month follow:

1. (1) False (for example, the square root of 1/4 is 1/2). (2) 1963 pennies are worth $19.63. (3) No. All even numbers (except 2) are composite. Every sequence of composite numbers separating two primes must therefore begin and end with an even number. Consequently the sequence will contain an odd number of composite numbers. Since 10 is even, there cannot be 10 composite numbers between two primes. (4) Alan W. Wolff is a lady. (5) Six. (6) A quarter-inch. The first page of Volume I and the last page of Volume II are separated only by two covers. (7) Let a stand for 1234567890 and write the simple equation $a^2 - (a - 1)(a + 1) = 1$, which reduces to $1 = 1$. (8) Yes. A tetrahedron has four faces, and so the assertion that it has "four or five faces" is correct. (9) 123456789. (10) Zero. (11) He deals the bottom card to himself, then continues dealing from the bottom counterclockwise. (12) Deny.

2. NORA × L = ARON has the unique solution $2178 \times 4 = 8712$. Had Nora's middle initial been A, the unique solution would have been $1089 \times 9 = 9801$. The numbers 2178 and 1089 are the only two smaller than 10,000 with multiples that are reversals of themselves (excluding trivial cases of palindromic numbers such as 3443 multiplied by 1). Any number of 9's can be inserted in the middle of each number to obtain larger (but dull) numbers with the same property; for instance, $21999978 \times 4 = 87999912$. For a recent report on such numbers, in all number systems, see "Integers That Are Multiplied when Their Digits Are Reversed," by Alan Sutcliffe, in *Mathematics Magazine*, Vol. 39, No. 5, November, 1966, pages 282–287.

3. Each dragon curve can be described by a sequence of binary digits, with 1's standing for left turns and 0's for right turns as the curve is traced on graph paper from tail to snout. The formula for each order is obtained from the formula for the next lowest order by the following recursive technique: add 1, then copy all the digits preceding that 1 but change the center digit of the set. The order-1 dragon has the formula 1. In this case, after adding a 1 there is only one digit on the left, and since it is also the "center" digit we change it to 0 to obtain 110 as the order-2 formula. To get the order-3 formula add 1, followed by 110 with the center digit changed: 1101100. Higher-order formulas are obtained in the same way. It is easy to see that each dragon consists of two replicas of dragons of the next lowest order, but joined head to head so that the second is drawn from snout to tail.



Geometric method

The top illustration on the opposite page shows dragon curves of orders 0 to 6. All dragons are drawn from tail to snout and are here turned so that each is swimming to the right, the tips of his snout and tail touching the waterline. If each 1 is taken as a symbol of a right turn instead of a left and each 0 as a left turn, the formula produces dragons that face the opposite way. The colored spots on each curve correspond to the central 1's in the formulas for the successive orders from 1 to the order of the curve. These spots, on a dragon of any order, lie on a logarithmic spiral.

The dragon curve was discovered by physicist John E. Heighway as the result of an entirely different procedure. Fold a sheet of paper in half, then open it so that the halves are at right angles and view the sheet from the edge. You will see an order-1 dragon. Fold the same sheet twice, always folding in the same direction, and open it so that every fold is a right angle. The sheet's opposite edges will have the shapes of order-2 dragons, each a mirror image of the

other. Folding the paper in half three times generates an order-3 dragon, as illustrated at the bottom of page 118. In general n folds produce an order-n dragon.

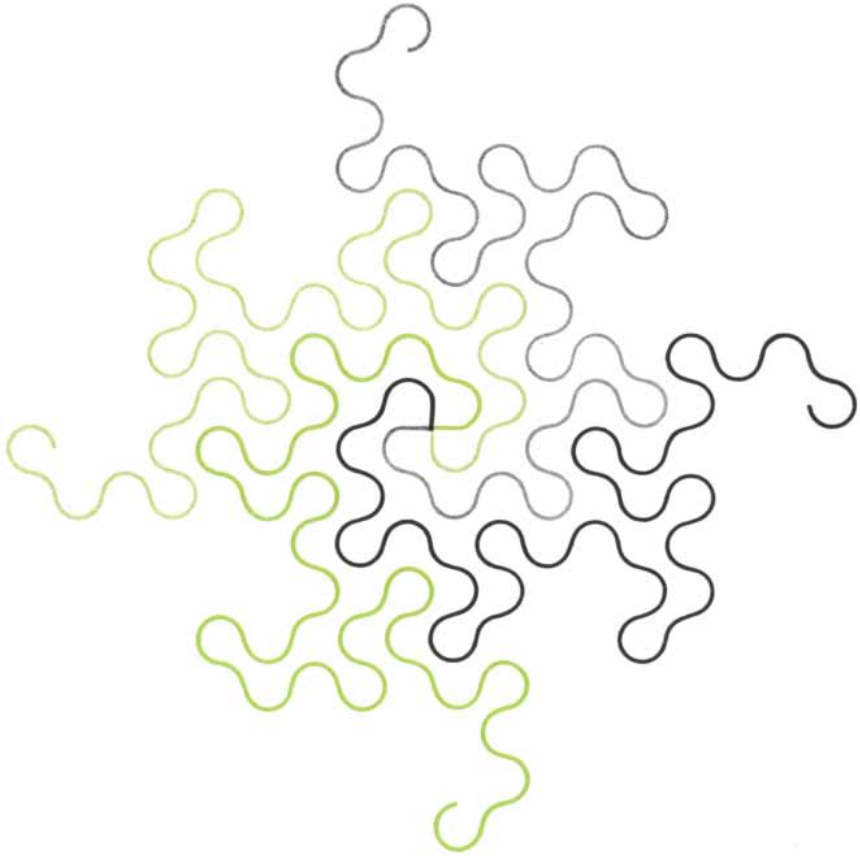
The binary formula can be applied, of course, to the folding of a strip of paper (adding-machine tape works nicely) into models of higher-order dragons. Let each 1 stand for a "mountain fold," each 0 for a "valley fold." Start at one end of the strip, making the folds according to the formula. When the strip is opened until each fold is a right angle, it will have the shape of the dragon corresponding to the formula you used.

Physicist Bruce A. Banks discovered the geometric construction shown on the preceding page. It begins with a large right angle. Then at each step each line segment is replaced by a right angle of smaller segments in the manner illustrated. This is analogous to the construction of the "snowflake curve," as explained in this department in April, 1965. The reader should be able to see why this gives the same result as paper folding.

William G. Harter, the third of the three physicists who first analyzed the dragon curve, has found a variety of fantastic ways in which dragons can be fitted together snugly, like pieces of a jigsaw puzzle, to cover the plane or to form symmetrical patterns. They can be joined snout to snout, tail to tail, snout to tail, back to back, back to abdomen and so on. The illustration below shows a tail-to-tail-to-tail-to-tail arrangement of four right-facing order-6 dragons. If the reader wishes to produce an eye-dazzling pattern, let him fit together in this way four order-12 dragons like the one shown last month. For dragon-joining experiments it is best to draw your dragons on transparent paper that can be overlapped in various ways. I would enjoy hearing from readers who find any unusual properties of this newly discovered curve.

4. The top illustration on page 123 shows how as few as six dominoes can be placed so that if each is given a color, four colors are necessary to prevent two dominoes of the same color from touching along a border.

5. Five spots can be placed on the figure as shown in the bottom illustration on page 123 so that each pair is separated by a distance equal to the square root of 2 or more. There is enough leeway to allow each dot to be shifted slightly and therefore the number of different patterns is infinite. Did the reader



Four order-6 dragons joined at their tails

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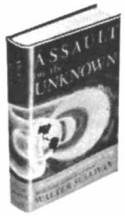
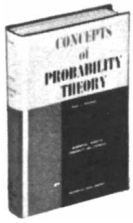


6. Assault on the Unknown—Sullivan *(List Price $8.50, Club Price $7.25)*



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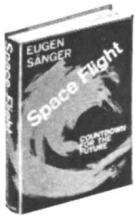

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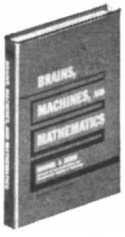

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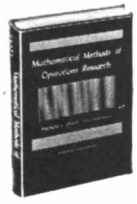

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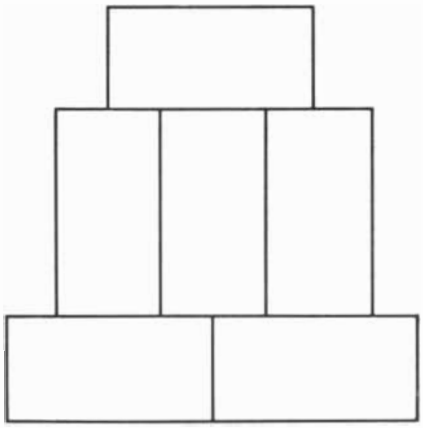
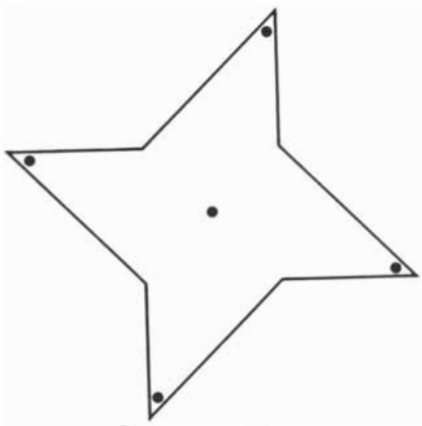


Six dominoes, four colors

fall into the carefully planned trap of thinking each spot had to fall on a vertex?

6. The best way to make the three coins all heads or all tails is to direct that any coin be turned, then any other coin, then the first coin mentioned. The probability of success on the first move is 1/3. If you fail, the probability is 1/2 that your second move will do the trick. It might be supposed that the sum of those two probabilities is the chance of success in two moves or fewer, but this is incorrect. One must examine the effect of the first two moves on each of the six equally possible initial patterns, *HHT*, *HTH*, *HTT*, *THH*, *THT*, *TTH*. The symmetry allows one to pick any two coins for the first two moves. There is success in four cases, so that the chance of success on or before the second move is four out of six, or 2/3.

Seven moves guarantees success if the intent is to make all the coins heads. Of the eight possible starting patterns, only *HHH* is ruled out. You must therefore run through seven pattern variations to make sure you hit *HHH* somewhere along the line. An easily remembered strategy suggested by a reader, Samuel Schwartz, is to label the coins 1, 2, 3 and take them in the order 1, 2, 3, 2, 1, 2, 3. The probability of success on the first move is 1/7, on or before the second move it is 2/7, and so on up to 7/7, or 1, on or before the seventh move.



Solution to spot puzzle

7. If n soldiers of differing height stand in a row, at least p soldiers will be in either ascending or descending order. The number p is the square root of the smallest perfect square that is not less than n.

To prove this, label each soldier with a pair of letters, a and d. Let a be the maximum number of men on the soldier's left, including himself, who are in ascending height order. Let d be the maximum number on his left, including himself, in descending order. It is easy to show (this is left to the reader) that no two soldiers can have the same pair of numbers. Their a numbers or their d numbers may be the same, but not both.

Assume that 10 soldiers are so arranged that their largest subset in ascending or descending order has p members, the lowest possible. No soldier can have an a or a d number greater than p. Since no two soldiers have identical pairs of a and d numbers, p must be large enough to provide at least 10 different pairs of a and d numbers.

Can p equal 3? No, because this provides only $3^2 = 9$ pairs of numbers:

a	1	1	1	2	2	2	3	3	3
d	1	2	3	1	2	3	1	2	3

Any number p will provide p^2 pairs of a and d numbers. Since 3^2 is 9, we do not have enough pairs to associate with the 10 soldiers. But 4^2 is 16, more than enough. We conclude that no matter how 10 soldiers arrange themselves, at least four must be in order. Four remains the p number for sets of soldiers up to and including 16. But 17 soldiers have a p number of 5 because we have to go to the next highest p number to find enough a and d number pairs.

8. The 25 knights cannot simultaneously jump to different squares. This is easily proved by a parity check. A knight's move carries the piece to a square of a different color from that of the square where it started. A five-by-five checkerboard has 13 squares of one color, 12 of another. Thirteen knights obviously cannot leap to 12 squares without two of them landing on the same square. The proof applies to all boards with an odd number of squares.

THE AMATEUR SCIENTIST

Little pendulums that oscillate like big ones

Conducted by C. L. Stong

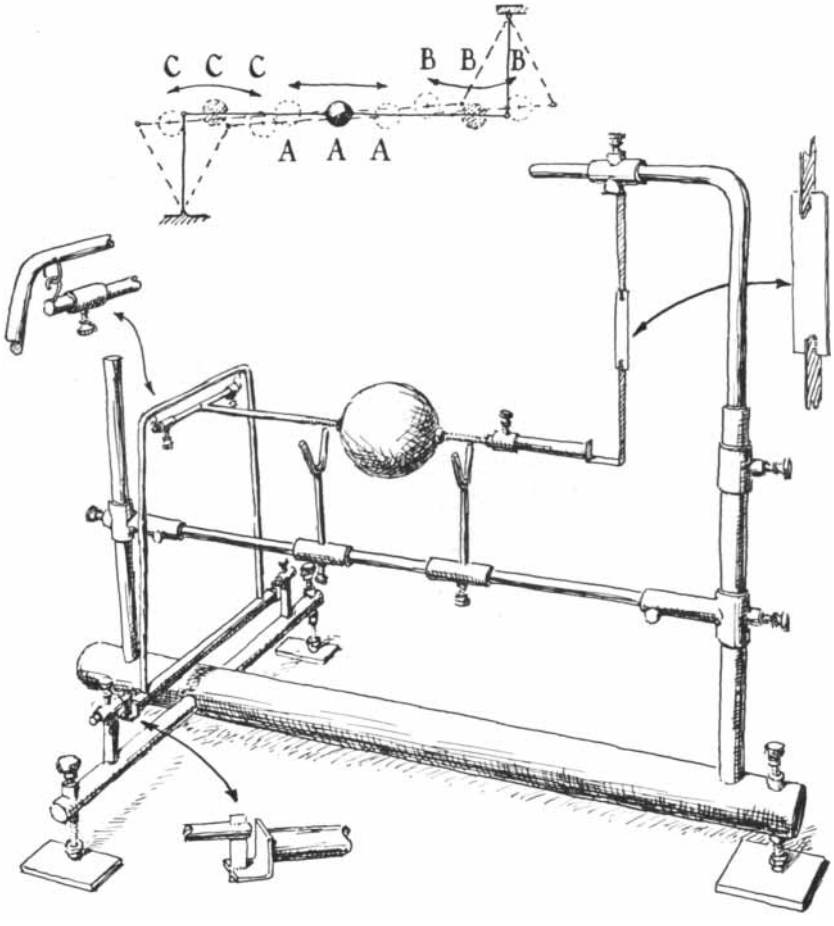
Three properties of the simple pendulum have long fascinated experimenters. The properties are the pendulum's ability to keep time, to sense relative motion and to measure the force of gravity. Although the maser has now outmoded the pendulum as an accurate timekeeper, many experimenters continue to find work with pendulums diverting. Amateurs have recently solved some mechanical problems of long standing that were responsible for variations in the rate at which pendulums swing and have constructed pendulum clocks that keep time to within a thousandth of a second per week.

Other experimenters have been developing new versions of pendulums for sensing the earth's rotation on its axis, vibrations induced in the earth's surface by earthquakes and periodic disturbances in the local gravitational field. One of these is Nils E. Lindenblad of Princeton, N.J., who took up the study of pendulums two years ago at the age of 70 after a career of 45 years as an electronics engineer. Lindenblad writes:

"My experiments with pendulums were undertaken primarily as a means of tapering off work habits that had to be changed as a result of retirement. I first thought of tinkering with seismographs of the kind used for detecting long earthquake waves, but I soon learned that most of the basic problems in the operation of these instruments had been solved electronically by the use of amplification and feedback. Further improvements, I was told, would doubtless entail refinement of circuits—just the kind of work I wanted to avoid.

"Scaling down my ambitions somewhat, I set out to develop a small mechanical pendulum of good quality and long period that could be used as a reference mass: a mass that tends to stand still when neighboring objects move. The pendulum I had in mind would be designed to swing six times per minute, a rate of vibration equivalent to a period of 20 seconds. Simple pendulums, such as those consisting of a weight suspended by a thin wire, vibrate at a rate that varies inversely with the square root of their length. One designed for a period of 20 seconds turns out to be about 330 feet long! My problem, then, was to find ways of reducing the length to the proportions of my basement workshop without introducing frictional or other mechanical losses that would seriously impair the performance of the apparatus.

"Pendulums of long period and small size are not new. A classical design, for example, is the compound pendulum. This apparatus consists of a rod that carries a bob on each end. When the rod is suspended at one end, it vibrates as a simple pendulum. As the pivot point is moved toward the middle of the rod the period increases. If the bobs are of equal mass, the period becomes infinite when the pivot point is shifted to the middle of the rod.



Horizontal pendulum of long period devised by Nils E. Lindenblad

"A compound pendulum, however, cannot be used as a reference mass. When the apparatus is displaced, the resulting forces of inertia developed by the two bobs act in opposition. Hence the bobs move if the object to which the pendulum is attached moves, and no reference effect is achieved.

"Another classical apparatus of long period and small size is the horizontal pendulum, essentially a cantilever hinged at one end to a rigid support. When the axis of the supporting hinge lies in the horizontal plane, the cantilever swings as a simple pendulum of short period. The period increases as the axis departs from the horizontal. The mechanism then swings like a barn door that is more or less out of plumb. Pendulums of this type are commonly used as the reference mass in seismometers. The pendulum senses the horizontal component of earthquake waves even though components of the arc traversed by the bob lie in both the horizontal and the vertical planes. I thought it would be interesting to attempt the development of a reference-mass pendulum that swung only in the vertical plane.

"In examining the essential properties of pendulums I found it helpful to consider their geometry from two points of view. Customarily the period of vibration is calculated in terms of the length of the pendulum. To find the period in seconds divide the length (in centimeters) by the acceleration of gravity (980 centimeters per second per second), take the square root of the quotient and multiply it by twice pi (6.2832). In other words, the period increases as the length increases.

"It is just as valid, and on occasion more helpful, to think of the period as a function of the curvature of the arc through which the bob swings. For a swing of a given distance from the vertical the period of vibration increases as the curvature of the arc becomes flatter. As the curvature approaches a straight line the period increases without limit.

"This relation leads to the explanation of why the sensitivity of pendulums to external forces increases as the period increases. Work must be done to push a pendulum away from the vertical because the bob is then raised by an amount that depends on its excursion from the vertical as determined by the curvature of its path. Work thus done in elevating the bob is stored by the bob as potential energy that subsequently causes the pendulum to swing. If the arc through which the bob swings is relatively flat, the bob rises only slightly when it is pushed from its rest position, and so less work is needed to start it swinging. In other words, the sensitivity of pendulums to external forces varies inversely with the curvature of the arc traversed by the bob.

"With these principles in mind I explored various linkages that have been developed for transforming circular motion into linear motion. For one experiment I selected a straight-line motion similar to one developed by James Watt, the inventor of the steam engine. The linkage, as modified, consists of a horizontal bar supported at one end by a hinged lever and suspended at the other end by a flat ribbon of spring steel [*see illustration on opposite page*]. The ribbon in turn was hinged in the middle by means of a short length of spring stock turned at right angles to give the suspension lateral freedom. If the ribbon and the lever are equal in length, the midpoint on the horizontal bar will move in a straight line when pushed along its axis through a limited distance. A bob that has a hole through its center of gravity and is slid into position at the middle of the bar will move as though it were suspended by a wire of infinite length forming a pendulum of infinite period.

"If the position of the bob on the bar is shifted toward the suspension member

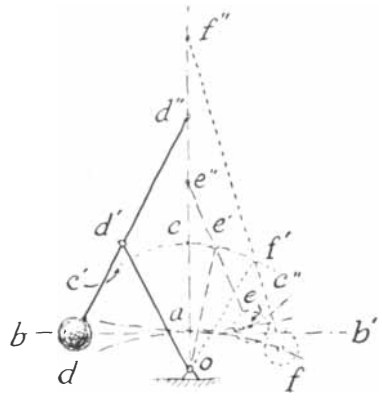
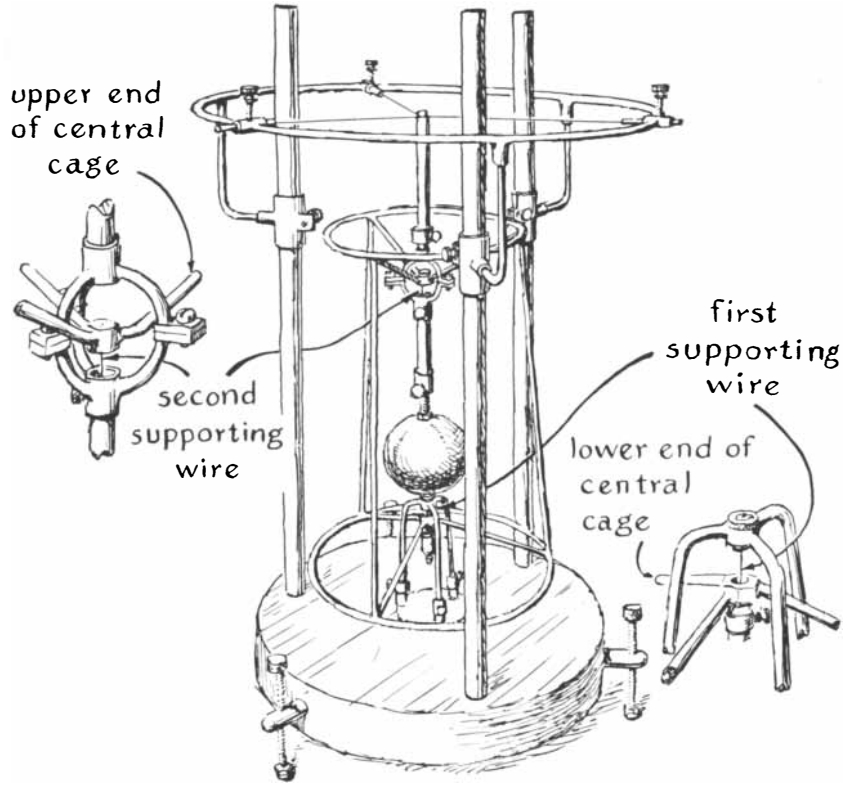


Diagram of properties

and the system is set in motion along the axis of the bar, the bob will move through an arc that curves more or less upward depending on its distance from the midpoint. The bob will oscillate at periods ranging from seconds to minutes. When the bob is shifted in the other direction, from the middle of the bar toward the supporting lever, the system soon becomes unstable because the arc through which the bob moves then curves downward. Accordingly the bob falls and comes to rest at one or the other of its limits of excursion. In the illustration on the opposite page the positions



Demonstration model of free-swinging pendulum

of the bob that result in an infinite period, a short period and the unstable condition are designated respectively *A*, *B* and *C*. The proportions of the structure can be varied, and the performance of the apparatus can be predicted in advance of construction, by making a diagram similar to the one in the upper part of the illustration.

"A demonstration model of the pendulum was assembled on a framework consisting mostly of iron pipe and rod. Iron pipe of small diameter comes in a range of sizes that telescope snugly into each other. The pipe therefore lends itself nicely to making bearings, sliding adjustments and so on. The material is easy to cut and form with ordinary hand tools. I assemble it into rigid structures by brazing or silver-soldering the joints. My facilities are those of the typical amateur. All work is performed on a bench two feet wide and three feet long. My only power tool is a quarter-inch electric drill. The tool I value most, however, is a gas-air torch. I use it for silver soldering and for heating the pipe before making bends.

"The spherical bob of this pendulum and others to be described is made of lead, which can be obtained inexpensively from dealers in plumbing supplies. I made molds for casting the lead by coating plastic balls with copper. After applying the coating, I made a hole in each ball and heated the ball so that the plastic would melt. That left a copper shell into which I poured the molten lead. The copper exterior gives the bob an attractive appearance.

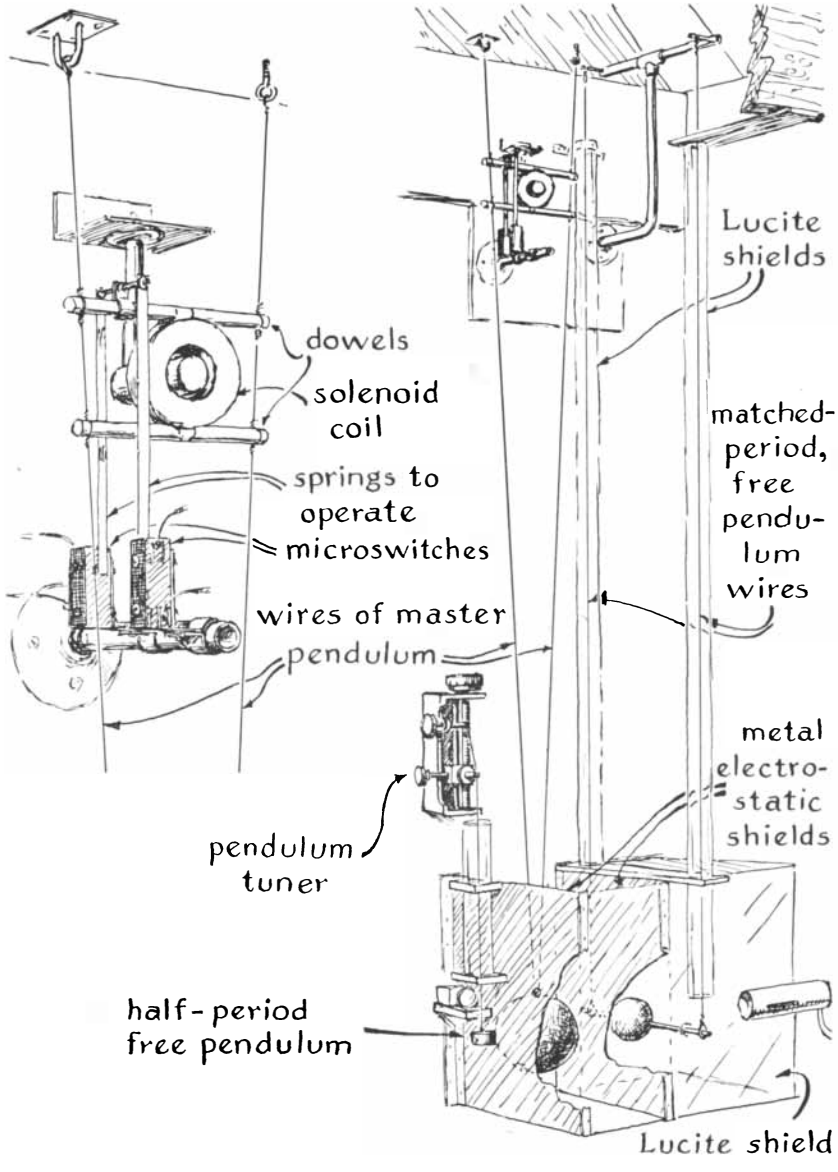
"The plastic balls can be bought in toy stores. To apply the copper plating attach an electrical connection to the surface of the plastic. The connection consists of a disk of thin brass about a quarter-inch in diameter to which a short copper wire has been soldered. The disks were cut from shim stock, which can be bought from dealers in automobile supplies. A disk is attached to the plastic by a film of quick-drying cement.

"The ball and the disk must be washed with a detergent to remove the film of grease that is invariably present; they must also be painted with a thin solution of Aquadag or an equivalent substance that conducts electric current. (Aquadag is a product of the Acheson Colloid Company, Port Huron, Mich. 48060.) When the conducting film has dried, the ball can be plated. (A conducting silver paint is made by E. I. du Pont de Nemours & Co.)

"My plating solution consists of copper sulfate, sulfuric acid and distilled water in the proportions of 32 ounces of copper sulfate and eight ounces of sulfuric acid, by weight, to each gallon of water. Copper flashing, of the kind available from dealers in building supplies, can be used for the anode of the plating bath. The plating current should be limited to about .02 ampere per square inch of surface until a thin film of copper forms over the entire area to be plated. The current can then be increased to .3 ampere per square inch of surface. The direct-current supply must be capable of maintaining a potential of between one and four volts when it is under load. An automobile storage battery can be used as the supply if a suitable rheostat for regulating the current is included in the circuit. An instrument for measuring current is essential.

"Another mechanical linkage, known as Scott-Russell's straight-line motion, was modified to operate as a pendulum of any desired period. It is free to vibrate in any vertical plane. In principle it consists of two rods, one of which is hinged to the other in the form of a distorted *T* [*see top illustration on preceding page*]. The weight of the assembly is supported by the leg of the *T* through an appropriate hinge, such as a pivot or a spring suspension. The bob is carried by one end of the crossbar of the *T*.

"The motion of the opposite end of the crossbar is constrained; that end is free to move up and down but not sideways. The constraint was accomplished by attaching three radial guy wires to



Apparatus for detecting a local gravitational field

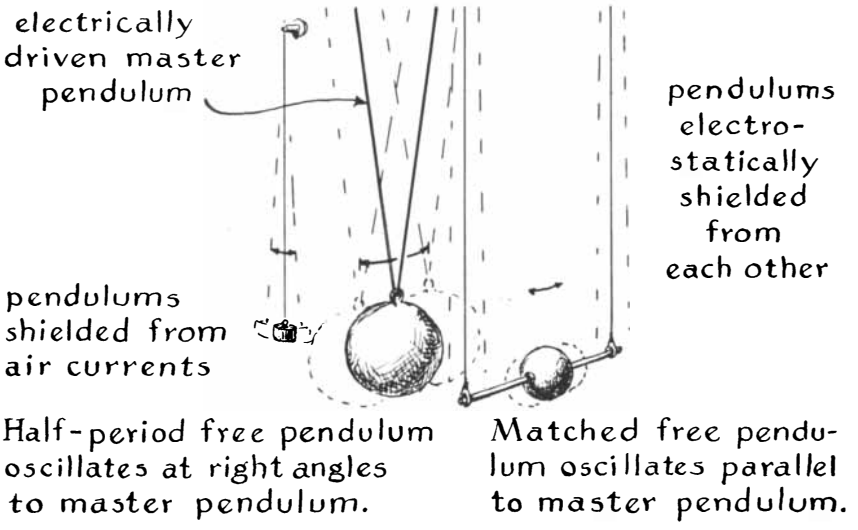
the end of the crossbar and anchoring them to the supporting framework. In the diagram the leg of the *T* is represented by the line *od'* and the crossbar by the line *dd''*. The motion of the *d''* end of the crossbar is restricted to the line *of''*. When the proportions of the rods are made as illustrated by the solid lines *od'*, *dd'* and *d'd''*, the bob will traverse the straight line *bb'* and the period of the pendulum will be infinite. If the length of the portion of the crossbar between *d'* and *d''* is made shorter but all other dimensions are retained as indicated at *e'e''*, the curvature of the arc will increase inversely with the length of *e'e''*. The system will then function as a conventional pendulum. When the length *d'd''* is increased, as at *f'f''*, the path of the bob will bend downward as indicated by the arc *of*. The pendulum will then be unstable and the bob will fall from its center position to one of the limits of excursion.

"The pendulum can be made in other proportions. I always analyze a new structure graphically before attempting construction. First I draw the straight, broken line *of''*, establish point *a* and through it construct the perpendicular *bb'*. I usually make the length *oa* less than 20 percent of the length *oc*. Then with the arbitrary radius *oc* I draw the arc *c'cc''*. Finally I construct the arc through which the bob will swing. This arc fixes the period at which the pendulum will vibrate. It is drawn through *a*, from an appropriate center point on the line *of''*. I next draw the pendulum arm proportioned so that the bob will traverse the arc just drawn through *a*. With an arbitrary point such as *e'* on the arc *cc''* as a center, and with *ac* as a radius, a short arc is drawn to intersect the arc previously drawn through *a*, thus locating point *e*. A straight line that projects from *ee'* intersects *of''* at *e''*, thus establishing the length *e''e'*, which yields the arc *ae* and establishes the desired period of vibration.

"Pendulums of this type can be made to swing in a single plane by constructing the member *od'* in the form of an inverted *U*. The legs are appropriately hinged to a supporting base.

"The remarkable sensitivity of long-period pendulums can be demonstrated by adjusting the rate of vibration to five or fewer swings per minute and setting the apparatus on a heavy workbench. Level the base carefully. Then the pressure of a finger on the bench top will set the bob swinging.

"A demonstration model of the pendulum just described was constructed to



Arrangement of pendulums for the detection of gravitational effects

vibrate freely in all vertical planes. In this version of the basic mechanism the supporting lever takes the form of a circular cage, with radial cross braces attached at 120-degree intervals to the top and bottom rims [*see bottom illustration on page 125*]. The bottom of the cage is flexibly supported at the center, where the cross braces meet, by a short steel wire that extends downward from a small tripod rigidly anchored to the base. The pendulum arm, *dd''*, is similarly flexibly coupled to the radial cross members of the cage at the point where they join at the top. When the pendulum arm is proportioned so that the bob traverses an arc with a radius of 200 feet, the bob vibrates at a period of about eight seconds. It then duplicates within a space of less than two cubic feet the performance of the huge pendulum that was set up more than a century ago by the French physicist Jean Bernard Léon Foucault in Paris to demonstrate the rotation of the earth.

"Pendulums equipped with small bobs swing for a shorter time—given the same amount of inherent loss—than those that have large, heavy bobs because the small bobs store less energy. A good pendulum equipped with a four-pound bob will normally swing for about an hour when it is given an initial push of 10 degrees, if care has been taken to minimize frictional losses at the points of suspension. The duration of the swing could not be extended appreciably, however, even by reducing all frictional losses to zero, because a substantial amount of energy would still escape through the supporting structure. The swing of the bob causes the support to sway from side to side. This vibration is communicated to the bench, the floor and the ground. The loss through the support can be minimized only by anchoring the apparatus to a massive pier. Such piers are costly and cumbersome. A practical solution is to compensate for the loss by driving the pendulum electrically. Several effective driving mechanisms for pendulums of the Foucault type have been described in this department [June, 1958].

"While I was considering the minute quantity of energy required to sustain vibration in a well-made pendulum, it occurred to me that perhaps a pair of pendulums could be used to demonstrate local pulsations in the gravitational field. If the pendulums were closely spaced and tuned to the same period, gravitational attraction between the bobs should cause the pendulum at rest to start swinging when its companion vibrates. To test this assumption I erected two pendulums side by side [*see illustration on opposite page*]. Each of the bobs was suspended by two nonmagnetic wires about five feet long. In the case of the master pendulum, which would be driven electrically, the wires were arranged in the form of a *V* so that the bob would swing in a fixed plane. A lead sphere four inches in diameter and weighing 14 pounds served as the bob. The suspension wires were attached to screw eyes in the ceiling.

"The driving mechanism consisted of a coil, which had several hundred turns of magnet wire and was attached to the suspension wires near the top, and a permanent magnet in the form of a cylinder that occupied the space in the center of the coil. One end of the magnet was anchored to the wall. Limit switches were actuated by the suspension wires

at each end of the swing. One switch, when closed, applied current to a relay equipped with two contact springs. One contact spring, which was connected in parallel with the limit switch, maintained current in the coil of the relay when the switch opened, thus keeping the relay locked down when the suspension wires swung away from the switch. The second contact spring applied current to the driving coil. The magnetic force between the field of the coil and that of the magnet drove the pendulum through one swing. At the end of the swing the second limit switch was operated by the approaching suspension wires. This switch interrupted the current in the coil of the relay, releasing the relay. This action removed power from the coil during the return swing.

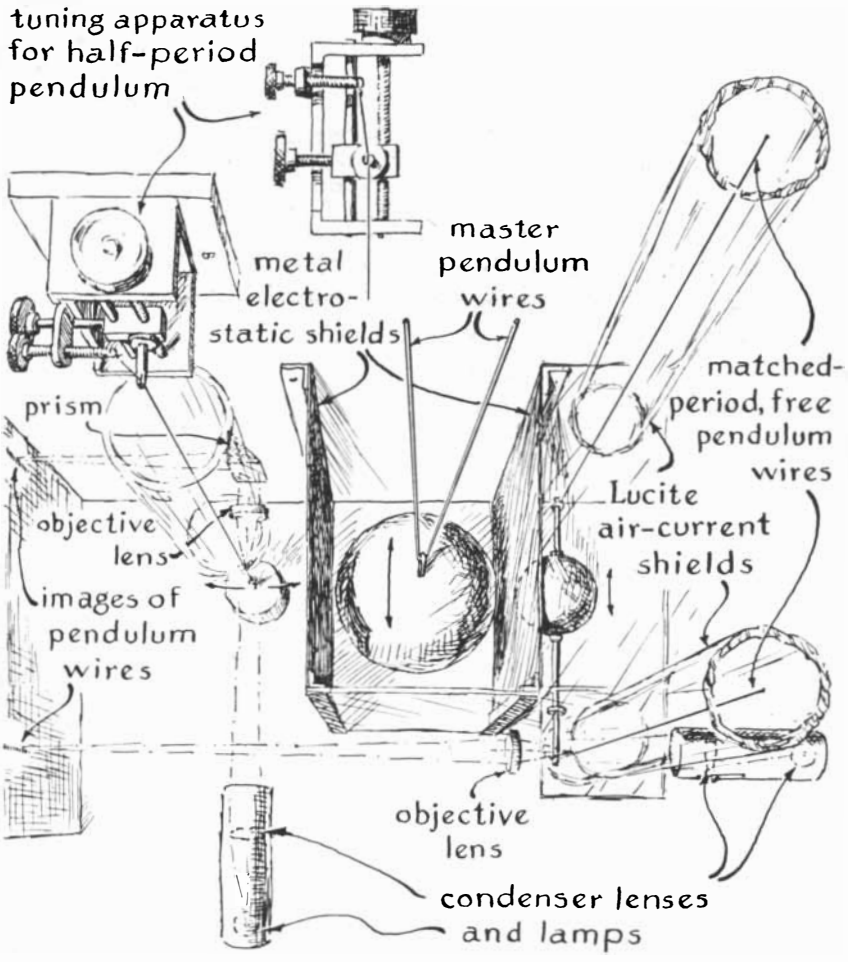
"The second pendulum, which was designed to sense any gravitational effect, consisted of a copper rod 10 inches long suspended at each end by nonmagnetic wires attached at the top to a metal bracket. The bracket was anchored to the cinder-block wall. A three-quarter-inch sphere of lead at the center of the copper rod served as the bob. The rod vibrated in the direction of its axis when the pendulum swung. I tuned the pendulums to resonance by adjusting the length of the master pendulum. The master pendulum was arranged to be in sharp resonance with the sensing pendulum only in the direction of the axis of the rod supporting the bob. A partition of sheet aluminum served as an electrostatic shield between the bobs, and the sensing pendulum was fully enclosed by a housing of transparent plastic to protect it from air currents.

"I assumed that the sensing pendulum would swing through only a small angle, and accordingly I set up an optical system for projecting an enlarged image of one of the suspension wires on a distant screen. The projector consisted of a lamp housing fitted with a condensing lens of 100-millimeter focal length (for concentrating light on the suspension wire) and an achromatic objective lens of 12.4-millimeter focal length for projecting a magnified image of the wire on the screen. (The lenses and other parts of the optical system are available from the Edmund Scientific Co., Barrington, N.J. 08007.)

"When the driven pendulum was set in motion, the sensing pendulum gradually swung into step. Its movement was barely perceptible at the end of two minutes, but within 45 minutes the amplitude of the swing had built up to seven wire diameters, or about .05 inch. Should this response be ascribed to gravitational coupling between the bobs or to mechanical coupling between the supports? To test the latter possibility I suspended a second sensing pendulum on the opposite side of the master pendulum. This one was made a quarter of the length of the other two so that it would vibrate twice as fast. It was suspended by a single wire so that it would be free to vibrate in any plane. The bob and its suspension were nonmagnetic and weighed two pounds.

"I anticipated that if the second pendulum responded to the local gravitational effect, it would vibrate in a plane at right angles to the plane of the master pendulum. Accordingly I set up an optical system to detect vibration in this plane. The system differed from the first one only by the insertion of a 90-degree prism to bend the projected light in the direction of the screen.

"As in the first experiment, the swing of the short pendulum reached perceptible amplitude within two minutes and thereafter continued to increase for about 45 minutes. The fact that the short pendulum vibrates in a plane at 90 degrees to the plane of the master pendulum, and at half the period of the master pendulum, indicates that the response is indeed the result of gravitational coupling. By improving the instrumentation it should be possible to use the experiment for determining the universal constant of gravity. Mathematically the reduction of the data would not be easy. Newton's law, which states that the gravitational attraction between two bodies varies directly in proportion to their masses and inversely in proportion to the square of the distance between them, is valid only for masses so small and widely spaced that they can be regarded as mathematical points. With closely spaced pendulum bobs every point in one bob attracts every point in the other; moreover, the distance between the bobs varies as the bobs swing. The solution of such problems involves some difficult equations in the integral calculus. For this reason I have been content with the simple fun of making the demonstration."



Details of construction of the gravity-sensing pendulum

These Bronx teenagers have found a peaceful way to fight in Vietnam. But they need your help.

Jones Wong, Janet Crawford and Robert Cirkiel are three of the leaders. But there are 2400 more like them at Olinville Junior High School in the Bronx. The youngest is 12. The oldest, 15. All of them are helping a Vietnamese child and his family in their fight against hunger and despair.

Last year, the student council at Olinville voted to share some of its good fortune with a Vietnamese child and family struggling to survive in a refugee camp. Through *Save The Children Federation* they're giving $15 a month to help the Nguyen Huans—a family of five with two sons, eight and four, and a daughter six.

The Huans lost everything in the war and for two years have been sharing a tiny room with another family. There is no privacy, no electricity, no running water, and one daily loaf of bread between them. The father works as a laborer for 50¢ a day. The mother spends her day collecting firewood for cooking and heat. And the eight-year-old son takes care of the two little ones.

The $15 each month provided by the children from Olinville Junior High has already had startling effects. It is providing the Huans with desperately needed clothes and food. With a small loan, the father has been able to start a small store in the family's half room. The money left over, together with money provided by other American sponsors, was borrowed by the refugee camp to help build a community market place and, most important, a school. The Huans are still a long way from winning the battles against hunger and poverty. But despair is giving way to hope.

Peace may one day come to Vietnam. But for hundreds of thousands the eventual solution won't help unless they get food and clothes right now, and a reason to believe that the future will be brighter. Your help is needed to give them a little boost to help them to begin helping themselves.

That's what *Save The Children* is all about. Although your contribution of $15 a month is tax-deductible, it's not charity. The aim is not merely to buy a child a warm coat, a few meals and a new pair of shoes. Instead your funds are used to give a child, his family and a village a chance to permanently increase their income. And hopefully, permanently end their need for charity.

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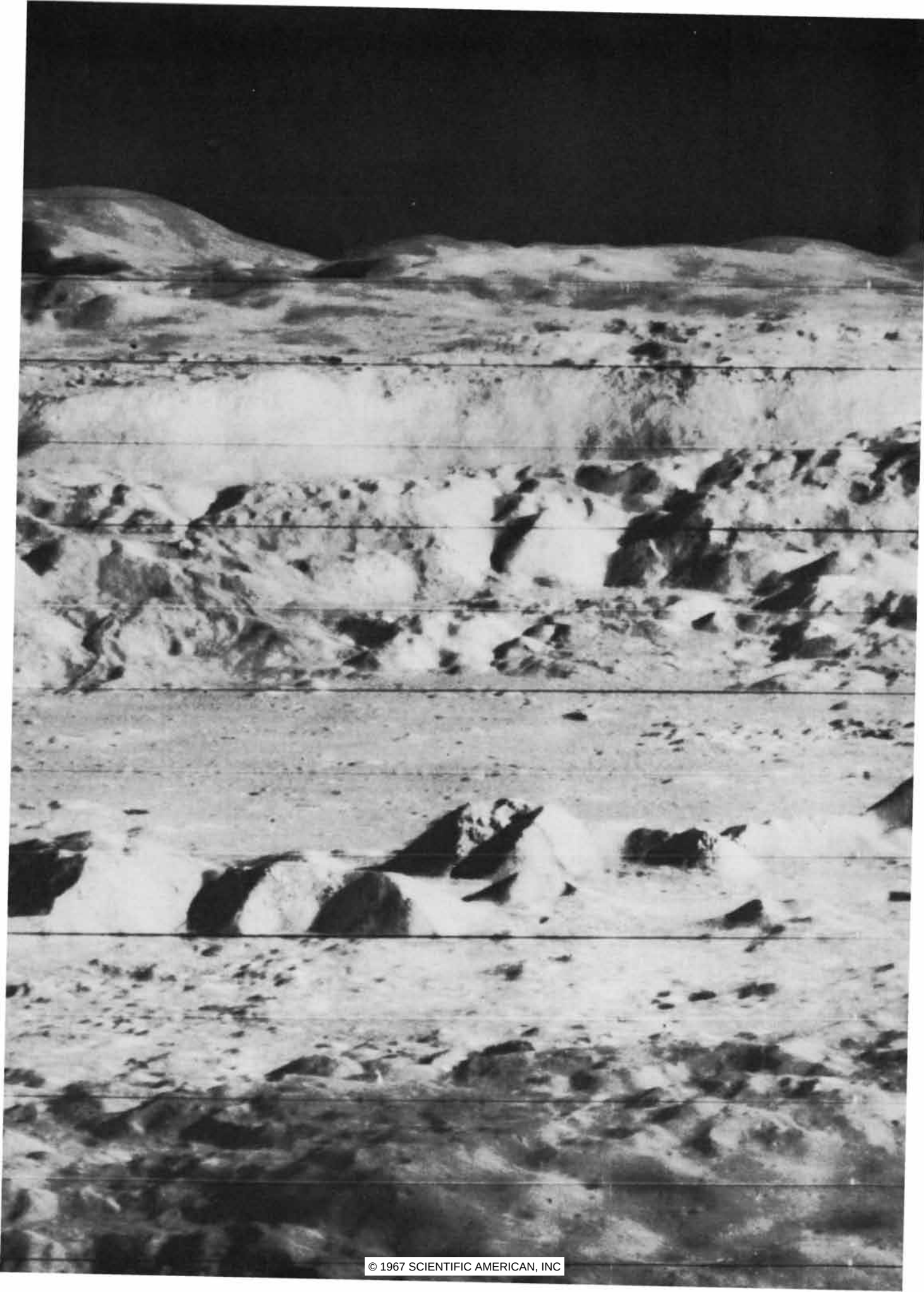

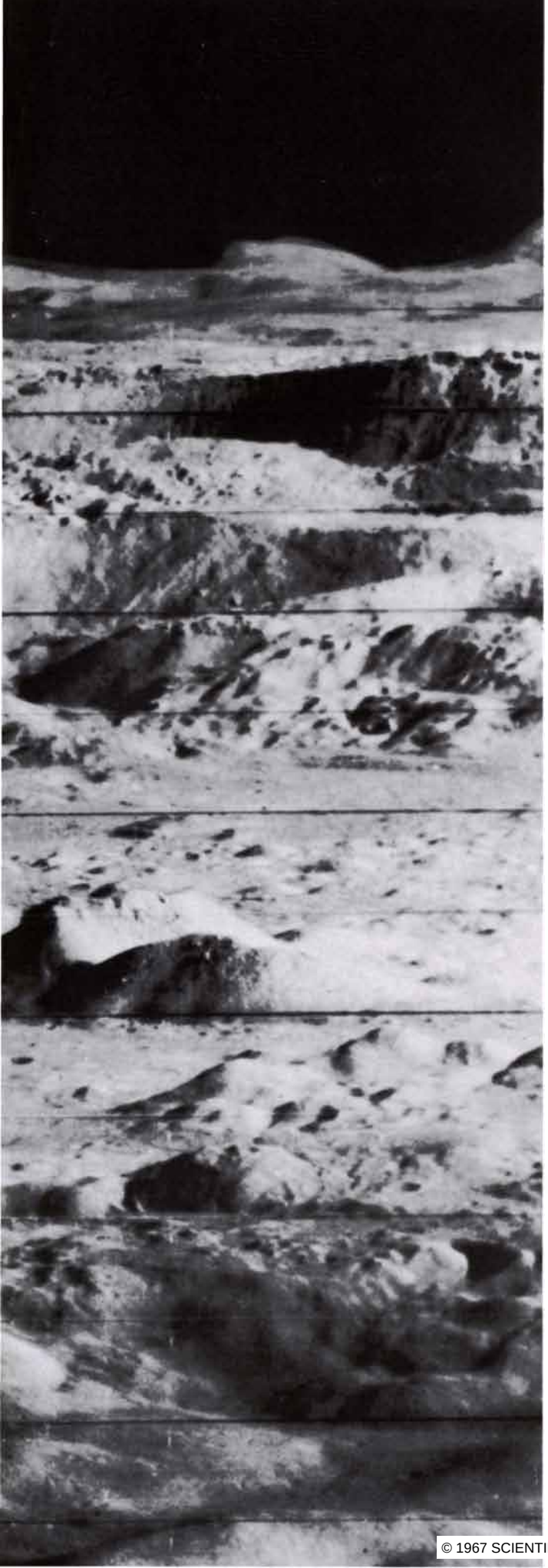

NASA

What kind of jewels will they take to the moon?

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When the Apollo lunar module heads for the moon it will carry jewel bearings manufactured with industrial diamonds. The jewels, some as small as the period at the end of this sentence, are part of Apollo's timekeeping unit.

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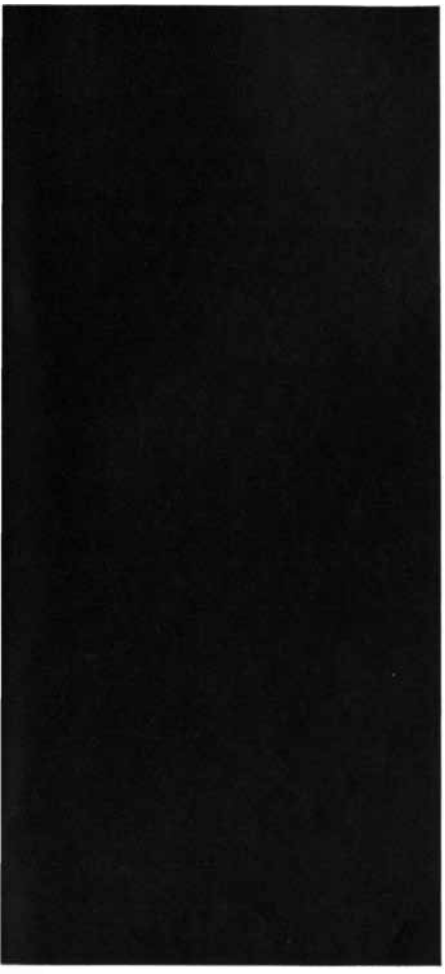

Even now, as the U.S. presses on toward a lunar landing, scientists and engineers are conceiving practical new uses for lunar flight technologies. Martin Marietta is working with NASA to create plans for an orbiting manned space station. It would use components of the Saturn/Apollo system developed to carry man to the moon, but it would have some very down-to-earth functions.

To prepare for Apollo, scientists and engineers have carried technologies to a point undreamed of a few generations ago.

Metallurgy, environmental biology, communications, food processing, electrical power, cryogenic insulation, guidance and propulsion have all been revolutionized to meet the challenge of manned moon flight.

But the benefits derived from these technologies will hardly be limited to the moon project itself.

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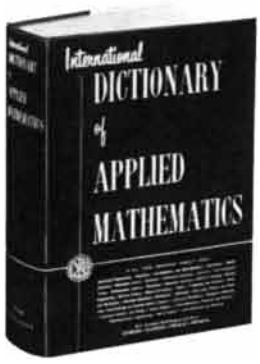

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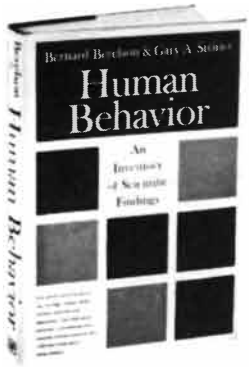

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BOOKS

The origins of experimental embryology: a biological remembrance of things past

by Maxwell H. Braverman

MARCELLO MALPIGHI AND THE EVOLUTION OF EMBRYOLOGY, by Howard B. Adelmann. Cornell University Press ($200).

"The Florentines," writes Mary McCarthy in *The Stones of Florence*, "invented the Renaissance, which is the same as saying they invented the modern world." Her list of innovations attributable to that city is impressive enough to give credence to her lyric claim: the first important literary work in the vulgar tongue; Brunelleschi's massive dome, the first since antiquity; the discovery of perspective; Donatello's freestanding nude, David; the first opera; Petrarch, the first humanist; Machiavelli's study of the mechanism of power in politics; the first chair of Greek; old Cosimo's first public library. It seems appropriate to think of the modern world's arising in Firenze's alleys and the sweet reason of Renaissance science as another reflection of the spirit portrayed by the elegant cathedral and Giotto's bell tower. Yet these apparently rationalist jewels of the 14th century antedated the first signposts (save Leonardo, and one wonders with whom he talked) on the road to modern science—Copernicus' *De revolutionibus orbium coelestium* and Vesalius' *De humani corporis fabrica*—by a century or more. Brunelleschi, Donatello, Uccello, Verrocchio and Botticelli cluster in the years between 1400 and 1500. Galileo, Bacon and Descartes were between 1550 and 1650, and the Renaissance biology of the first microscopists—Malpighi, Grew, Leeuwenhoek, Hooke and Swammerdam—ran from 1625 to 1725.

One might think that the Renaissance change in focus from the hereafter to the here and now, the appreciation of man for himself and not merely as an element in the divine plan, had stimulated simultaneous interest in the objective world, but such was not the case. Painters and sculptors may have carefully scrutinized beasts and flowers in 1400, but the physician was still discoursing on Galen's dissections rather than dissecting for himself. Jakob Burckhardt puts forward professional soldiers, the *condottieri*, as characteristic of Renaissance freedom and of the Renaissance as a cultural discontinuity. These mercenaries could rise by virtue of their talents, regardless of their origin, to the position of independent rulers. In so doing, however, they operated outside the rules of the church, outside the moral framework of their time, in ethical anarchy. "Only the most perfect goodness," says Burckhardt, "could save them from the most monstrous iniquity." The Scholastics of the 15th century must have anticipated a similar intellectual anarchy awaiting them as the security of Aristotle's world was invaded by the microscope, the telescope and the gauche pertinence of experiment. Giordano Bruno threatened finite Scholasticism with infinity; Galileo's telescope showed that the celestial realm was not unlike the mundane one, and his microscope revealed tiny beasts and fine structure that demanded a new level of explanation. Beginning in 1550 the completely defined world of St. Thomas and the Council of Trent gave way to an age of variety and complexity.

Joseph Needham, in his *History of Embryology*, speaks of Galen as having welded together in A.D. 180 the biology of all the antique schools—Crotona, Acragas, Cos, Cnidus, Athens, Alexandria, Rome—and "depositing it at the entrance into the sanctuary of Christendom." He describes the long line of experimentalists beginning in the sixth century B.C. as coming to an end with Galen, and continues: "But so it was to be, and thenceforward experimental research and biological speculation were alike to cease, except for a few stray mutations, born out of due time, until in 1453 the city of Byzantium should burst like a ripe pod and distributing her scholars all over the West help to bring all the fruits of the Renaissance, as if by a fertilising process, into being."

Perhaps the problem of the 1,200-year darkness is epitomized by the replacement of experimental science with scholastic disputation. So also did the arts languish until in the 14th century Petrarch catalyzed a revised interest in Latin literature as a guidepost to life and insisted on the importance of reading Greek manuscripts in the original. It is to Petrarch that we are indebted for the proposal that the vicissitudes of this life take precedence over the anticipated rewards in the hereafter.

What forces made the Western intellect so rigid that for a millennium it marked time—regarding, examining, disputing its former accomplishments—it is not easy to say. Nor can the influences that overcame this intellectual inertia be simply explained. Whatever the stimuli, the 14th century did see a renewed interest in antiquity. Thereupon not only were the pronouncements of classical authors revered but also some attention was given their recommendations concerning method. In science this meant a revival of experiment.

Marcello Malpighi, the subject of Howard Adelmann's five-volume biography and disputation on the early evolution of descriptive embryology, was a physician and teacher at the medical school of Bologna, the city of his birth. Throughout his life (1628–1694) he supported the good fight against Scholasticism in medicine, and by virtue of his investigations on the microanatomy of the lung, the kidney, plant tissues and the chick embryo he found himself embroiled in a wrangle with the medical practitioners of his day; they could no more see the use of microanatomy to the practice of medicine than some medical people today can understand the relevance of all that DNA-RNA jazz to the treatment of cancer. Medicine was then an empirical art. One knew what to do largely through trial and error, through observations of gross symptoms. Whether or not the physicians of the time saw the relation between microanatomy and function, and thus to treatment, their response was to defend the *status quo*.

That the biological renaissance lagged

200 years behind the rebirth of art and literature is at first surprising. On the other hand, it is not inconsistent with what we know of artists and writers, scientists and physicians. After all, the 20th-century thing was invented by the likes of Picasso and Gertrude Stein, and was only later taken over by such as Norbert Wiener, Claude Shannon and Warren McCulloch. And we have yet to see public health measures consistent with the economics, technology and sociology of our time. Perhaps we can regard Freud and Max Weber as our premature geniuses—our Leonardos. In any case, my point is that we would consider a free-speech strike by the students of a medical school unlikely, and we should not be surprised at a similar conservatism in the medical-biological profession of Renaissance Italy.

Trained in the usual Peripatetic style (Aristotle as interpreted by St. Thomas), Malpighi turned to the study of medicine in 1650. At the studium in Bologna he came under the influence of Bartolommeo Massari and Andrea Mariani. He writes in his *Opera posthuma:* "Since at that time the circulation of the blood and the growing new knowledge of anatomy were beginning to become widely known, Dr. Massari, whose interest had been aroused, assembled at his home a *Coro Anatomico* of nine members among whom I had the honor of being enrolled." The *coro anatomico* came together to conduct dissections on living animals or, when the bodies of criminals were available, human corpses. Vesalius had published his anatomical studies 100 years earlier, but the practice of dissecting for oneself was only just becoming known. This small group was a minority among the lecturers at the Bolognese studium, most of whom were concerned only with holding fast to what they had learned from the ancient authorities. One of the lecturers, Paolo Mini, was to maintain even 30 years later that the study of Galen's *De usu partem* made dissection a useless ceremony.

Malpighi says in the *Opera posthuma:* "These anatomical studies and the healing practices instituted by the most learned Mariani, following the doctrine set forth in Hippocrates' *De victus ratione* (*On Regimen*) aroused the animosity of almost all the other professors, who revered the method of the Arabs and the barbaric authors; and from this I suffered not a few insults." In 1653 he successfully defended his thesis, and three years later he was given a chair at Bologna as a lecturer in logic. In the same year Grand Duke Ferdinand II offered him the chair of theoretical medicine at Pisa, which he accepted. At Pisa he came under the second important influence directing him toward the new experimentalism.

In 1610 Cosimo II, of the Florentine Medici family that had ruled Pisa since 1406 and reestablished her university as an equal of those of Bologna and Padua, had brought his old teacher Galileo back from Padua to Florence. There Galileo exerted a major influence on the direction of experimental science, with time out for battles with the Inquisition, until his death in 1642. Both Ferdinand and his younger brother Prince Leopold were intrigued by the new experimental science. Lorenzo the Magnificent, a product of the early Renaissance, we picture strolling down a Florentine street reciting poetry. Two hundred years later the Medicis still underwrite the accomplishments of their time but now in the laboratory. Leopold supported the organization of the Accademia del Cimento, a small group dedicated to experimentation and description. This academy was apparently a more formal phase of a Tuscan academy that had begun under the guidance of Evangelista Torricelli just after the death of Galileo.

In Pisa, Malpighi met Giovanni Alfonso Borelli, mathematician to the court at Florence and a driving force behind the Accademia del Cimento. A schoolfellow of Torricelli's and protégé and admirer of Galileo's, although not formally a student of the master's, Borelli is known in physics primarily for his work on optics and for his writings in support of Copernicus (which cleverly avoided, by trivial subterfuge, the censure that descended on Galileo). Borelli's *magnum opus,* however, is the biological treatise *De motu animalium,* in which he attempted to find an explanation for all physiological phenomena in the fundamental laws of mechanics and statics. Unlike Descartes, who proposed a similar natural philosophy, Borelli was thoroughly familiar with animal dissection, which he conducted with biological collaborators, first among whom was Malpighi.

De motu animalium is defined by some as the true starting point of experimental biology. Although Borelli's attempt to explain physiology in mechanical and mathematical terms was doomed to failure, if only because it outstripped available biological knowledge, his attempt was a heroic one. It presaged future concerns of biology and opened a path trod only by the late D'Arcy Wentworth Thompson and a few others. "God, the geometer," Borelli declares in his dedication, "employs geometry in constructing the organs of animals." We must embarrassedly admit that this says as much as we know today about the control of form, the *shape* of tissues and organs and of animals. The intellectual descendants of the iatrochemist (doctor-chemist) Paracelsus have inherited the modern world of biology; it is only now that the iatromathematicians and engineers, continuing Borelli's practice, are beginning to find the path to their inheritance.

Little of Malpighi's personality comes through in Adelmann's 726-page biography, other than a tendency toward paranoiac responses to his scientific detractors. (It might have been possible to extract more insight from the many letters that are presented in verbatim translation.) Accordingly it is difficult to say how much of Malpighi's interest in investigation, and the invention of new techniques for investigation, was the result of his own proclivities and how much represented the influence of Borelli, that last student of Galileo's.

What influence Borelli had on Malpighi is best demonstrated by the 320 letters from Borelli that Malpighi received between 1659, when Malpighi left Pisa to return to Bologna, and 1668, when the friendship had deteriorated. (Malpighi's letters to Borelli apparently have been lost.) Adelmann includes only two short paragraphs of "generalization" on this large body of material. An analysis of the influence of Borelli is clearly a job for scholarly research. Unfortunately the majority of these letters are translated in paraphrase, not direct quotation, making them an unlikely source for such work. Some idea of the nature of the relationship can be gained from the letter of February 4, 1661, in which Borelli speaks of having received the results of an experiment he had directed Malpighi to perform involving the injection of water into the pulmonary artery. He thanks Malpighi, pointing out two things he wishes Malpighi had done. He then goes on in great detail telling Malpighi how to prepare two colorless solutions that turn black when mixed, one of which is to be injected into the pulmonary vein and the other into the trachea in order to determine if air entering the trachea mixes with blood from the pulmonary vein. He gives many precise and detailed instructions, adding: "But I myself ought to be present, for I think I would have a good many ideas." He goes on: "Since you believe it advisable to write an epistle about this matter, that will be all right." Clearly

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Borelli was no subtle manipulator of men, but if this letter is any indication, Malpighi's debt to him was profound.

Along with Borelli and his precocious influence on mathematical biology I am constrained to mention Sir Kenelm Digby, a contemporary of Malpighi's although he was probably unknown to him. Sir Kenelm examined, as did Malpighi, the developing chick egg. His biology was far ahead of his time, and he was no slouch in using the English language. He is invoked by Adelmann regarding the preformation-epigenesis controversy, in which he was on the side of the angels. He says:

"Take a beane, or any other seede, and putt it into the earth, and lett water fall upon it; can it then choose but that the beane must swell? The beane swelling, can it choose but breake the skinne? The skinne broken can it choose (by reason of the heate that is in it) but push out more matter, and do that action which we may call germinating? Can these germes choose but pierce the earth in small stringes, as they are able to make their way? Can these stringes choose but be hardened, by the compression of the earth, and by their owne nature, they being the heavyest partes of the fermented beane? And can all this be any thing else but a roote? Afterwardes the heate that is in the roote, mingling it selfe with more moysture, and according to its nature, springing upwardes; will it not follow necessarily, that a tender greene substance (which we call a budd, or leafe) must appeare a litle above the earth; since tendernesse, greenenesse, and ascent, are the effects of those two principles, heate and moysture? And must not this greene substance change from what it was att the first, by the sunne and ayre working upon it, as it groweth higher; till att the length it hardeneth into a stalke? All this while, the heate in the roote sublimeth up more moysture, which maketh the stalke att the first grow ranke and encrease in length. But when the more volatile part of that warme iuice, is sufficiently depured and sublimed, will it not attempt to thrust it selfe out beyond the stalke with much vigour and smartnesse? And as soone as it meeteth with the cold ayre in its eruption, will it not be stopped and thickned? And new partes flocking still from the roote, must they not clogge that issue, and grow into a button, which will be a budd? This budde being hardened att the sides, by the same causes which hardened the stalke, and all the while the inward heate still streaming up, and not enduring to be long enclosed, (especially when by its being stopped, it multiplyeth it selfe) will it not follow necessarily that the tender budde must cleave, and give way to that spirituall juice; which being purer then the rest (through its great sublimation) sheweth it selfe in a purer and nobler substance then any that is yet made; and so becometh a flower? From hence, if we proceed as we have begunne, and do weigh all circumstances; we shall see evidently, that an other substance must needes succeed the flower, which must be hollow and containe a fruite in it: and that this fruite must grow bigger and harder. And so, to the last periode of the generation of new beanes."

The preformation-epigenesis controversy of the 17th century had to do with whether the embryo existed preformed in the egg or the parts appeared in sequence. This old chestnut is still dragged out in undergraduate embryology courses today. It seems of little consequence that Adelmann finds Malpighi to be an epigenesist (good guy) or Needham makes him out a preformationist (bad guy). The problem can, however, be translated into present concerns. Is there a one-to-one relation between a set of genes and the characteristics of the adult organism, or do these characteristics represent the interaction of genes fewer in number than the characteristics themselves? Or do both things hold true? One-to-one correspondence is preformation; characteristics generated by a smaller number of genes is epigenesis.

Malpighi published two epistles on the lungs, as Borelli had suggested. At that time William Harvey had already discovered the circulation of the blood. It was known that there were arteries and veins and that the blood moved away from the heart in one and toward the heart in the other. The nature of the connection between them, however, was still mysterious; that is, the capillaries were unknown. Similarly, it was known that air enters the lung through the trachea, but neither the structure of the lung nor its function was perceived. One can appreciate Malpighi's problem. Here was this mass of tissue, the lungs. They swelled with air like a sponge. Blood entered the lungs from the heart and returned to the heart from the lungs. What were they? What did they do? How did they do it?

Malpighi's first experiments presented him with a contradiction. A cat's lungs were removed and the trachea was pinched shut; when the lungs were squeezed, air did not come out of the severed blood vessels, as it would have if the trachea were connected to the blood vessels. In another experiment the lungs were filled with water through the trachea; when they were squeezed, some of the water appeared in the left ventricle, having got there through the pulmonary vein. The second experiment corroborates the notion that the arteries, the veins and the trachea are connected; the first contradicts it. The breakdown of capillaries that must have occurred in the second experiment was to confuse Malpighi almost to the end of his researches on the lung.

Next, looking at the same question in another way, he injected black water into the pulmonary artery of a sheep and observed that the sheep's lungs swelled. The outside of the lungs was blackened, but he does not describe water coming out of the trachea, as it would have if there had been a connection between the blood vessels and the trachea. Reading Borelli's replies to Malpighi's letters, one cannot help but cheer his somewhat cantankerous impatience with Malpighi's inappropriate conclusions from his own research. Malpighi apparently still held at this time that the pulmonary artery, the pulmonary vein and the trachea were interconnected.

Malpighi's observations led him to conclude that, contrary to the going belief, the lungs are not homogeneous flesh but consist of inflatable membranous vesicles. He publishes this conclusion in his first epistle on the lungs. He adds that there is free access to these vesicles from the trachea, and that they can be demonstrated by removing the lungs from a frog, washing the blood out of them by injecting water into the pulmonary artery, inflating them by blowing into the trachea and tying them so that they remain inflated as they dry. Having done this, he says, one can observe the profusion of extremely thin membranes and also the wonderful network of vessels around them, which he supposes to be nerves. He further describes the branchings of the trachea, of the pulmonary artery and pulmonary vein to their finest visible subdivisions. He leaves unsettled the relations among the three vessels. In closing he suggests that the function of the lungs is to mix the liquid and solid parts of the blood and so effect their liquefaction. Borelli writes: "The more I think about this mixing, the greater the difficulty I find with it.... I should like you to investigate further how bodies can be kept fluid."

In his second epistle Malpighi clears up two points that were left in doubt by the first. He is able to explain the nature of the network that binds the thin membranes of the lung together, and to solve

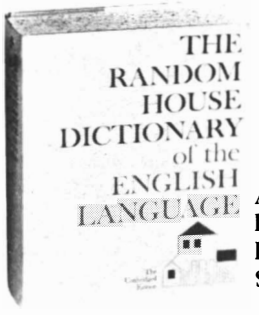
We have the last word on Scientific American.

sci·en·tif·ic (sī′ən tif′ik), *adj.* **1.** of or pertaining to science or the sciences: *scientific studies.* **2.** occupied or concerned with science: *scientific men.* **3.** regulated by or conforming to the principles of exact science: *scientific procedures.* **4.** systematic or accurate in the manner of an exact science. [< LL *scientific(us)*. See SCIENCE, -FIC] —**sci′en·tif′i·cal·ly,** *adv.*

A·mer·i·can (ə mer′i kən), *adj.* **1.** of or pertaining to the United States of America or its inhabitants: *an American citizen.* **2.** of or pertaining to North or South America: *the American continents.* **3.** of or pertaining to the aboriginal Indians of North and South America, usually excluding the Eskimos, regarded as being a subdivision of the Mongolians, and marked generally by reddish to brownish skin, black hair, dark eyes, and prominent cheekbones. —*n.* **4.** a citizen of the United States of America. **5.** a native or an inhabitant of the western hemisphere. **6.** an Indian of North or South America. **7.** a steam locomotive having a four-wheeled front truck, four driving wheels, and no rear truck. [AMERIC(A) + -AN] —**A·mer′i·can·ly,** *adv.*

Just as you had some amusing words about us:

"All the words in the new *Random House Dictionary of the English Language* had been stored in the computer's memory along with rules for combining them in ways derived from an intensive study of the work of 10 contemporary poets."—*From one of Dr. Matrix's ingenious adventures described in Martin Gardner's Department, "Mathematical Games." SA 1/67*



Always has the last word. $25.

the problem of whether or not these vessels open onto common sinuses of blood. He is thus able to identify the network as the capillary connection between the arteries and the veins. It is perhaps typical that although much energy was spent by Malpighi and by Borelli in devising ways to remove all blood from vessels of the lung, the capillaries were first seen in a preparation in which the vessels had remained red because of inadequate washing. Malpighi describes them: "With a sharper lens I saw . . . small vessels so interconnected as to form rings, and so great is the divarication of these vessels proceeding from a vein on one side and an artery on the other that the condition of a vessel is no longer retained and a rete [network] appears. . . . From this I could clearly see that the blood is divided and flows through tortuous vessels and that it is not poured out into spaces, but is always driven through tubules and distributed by the manifold bendings of the vessels."

He then recommends to his readers that these capillaries can be viewed in a frog's lung if the frog is opened up and the lungs are tied at the point where they enter the heart. When the lungs have been dried, the blood vessels can be seen with a single-lens microscope. Finally Malpighi takes that important step beyond his data. "From these considerations," he says, "it is highly probable that the question about the mutual union and anastomosis [joining] of vessels can be solved; for if Nature once circulates the blood within vessels and combines their ends in a network, it is probable that they are joined by anastomosis at other times too [Bravo Malpighi!], and this is plainly to be seen in the frog's bladder distended with urine, for there the blood is observed to move in the way I have described through diaphanous vessels joined together by anastomosis."

Over the next 20 years Malpighi turned his microscope on many portions of the body that were of legitimate concern to the physician, and on many things that were not so obviously connected with practical medicine. He looked at the structure of the tongue and the skin, identifying there the germinal layer that bears his name and also correlating the tongue and skin papillae as both being organs of sense. He investigated the structure of the brain, of the body's fat reserves and of the kidneys. In the kidneys he identified the corpuscles named after him and asserted that they play a principal role in the excretion of urine. One wonders if he saw an analogy between the capillaries of the lung and those of the kidney. It was at this time that Malpighi recognized that "Nature has but one plan of operation, invariably the same whether she is dealing with *minima* the smallest or *maxima*, the very larger, and she delights in using these *minima* in constructing even the largest masses. Indeed all of nature's efforts are directed toward joining together the very smallest parts of our bodies so that all these *minima*, however diverse, composing the structure of living things, construct the parts by means of a kind of compendium."

He produced in 1669, in response to a request by the Royal Society of London, a monograph on the anatomy of the silkworm that stood, apparently unequaled and unexcelled, for more than 100 years. Then he began his studies on the anatomy of plants, which were finally published in 1678. These, along with Nehemiah Grew's *The Anatomy of Vegetables Begun*, are said to have been the first step in divesting botany of its identification with medicinal herbs and making it a science.

Malpighi's two dissertations on the development of the chick in the egg had been published six years earlier. These two papers, in the original totaling 27 pages and 11 plates of drawings, are the core around which are built these five volumes of some 2,500 pages. Adelmann has included full-size facsimile reproductions of the original illustrations in red and black. The two papers are presented in the original Latin, with Adelmann's translation on the facing pages.

I do not know how to respond to the two papers. They represent no great fruits of intellectual achievement, no heroic logical rationale other than that which had informed all of science since the time of Galileo and Harvey. They represent simply the union of two things: a willingness to observe for oneself and the availability of the microscope. The same thing strikes me as being true of Adelmann's "excersuses," some 1,500 pages of explication on the evolution of knowledge of each of a number of organ systems from the Greeks up to the end of the 19th century, that is, up to the arrival on the scene of experimental embryology.

There is much to be learned by reflecting on changing hypotheses in science and much to be gained by analyzing the logical structure of a completed body of scientific knowledge. The history of descriptive embryology, however, is not a history of changing hypotheses but a history of improved description—description aided by greater or lesser advances in technique. Malpighi skimmed the cream. After all, no one before him had looked at such things with a microscope. His achievements would therefore not seem deserving of careful analysis. Yet there is something characteristic of all biology in this skimming. Once the blinders of Scholasticism were off and the microscope was available the entire world was fair game for the biologists. The game became one of exploring the world, seeing new things, naming new animals, investigating the life histories—each one slightly different—of all the animals. The nature of the biological world seems to have encouraged the exploration of diversity without the strong tendency toward unifying theories that characterizes the physical sciences.

Of course, biology does have its unifying theories: the cell theory, Darwinian evolution, Mendelian genetics, the central dogma of DNA-RNA-protein. It would seem fair to say, and it has been said by Needham (a historian-philosopher of embryology who really *was* in a position to generalize about the field), that embryology is a science sadly suffering from the lack of theory. The major theories of biology differ from those of physics in that they do not so much replace earlier theories as fill a void. The older men passing out of the biological arena, as the current dogma achieves the status of theory, leave not because their ideas are being replaced but because mechanism is being considered where description had at one time been sufficient. The change is not so much a change in the nature of the explanation as a change in our notion of what satisfies the question: How does it work?

The texture of biology appears to be quite different from that of physics. Physics has progressed much as Thomas Kuhn describes it in *The Structure of Scientific Revolutions:* anomalies—phenomena for which the investigator's theory had not prepared him—accrue until the old theory becomes awkward by virtue of *ad hoc* patching; then a new theory, supported by a new generation of investigators, is constructed. In biology, however, such signposts to the decay of generalization have been hard to recognize because of the tremendous variety of the material. We can probably expect molecular biology to bring about a belated meeting on common ground, that is, to reduce the assorted facts of biology to a level where identity of mechanism must obtain.

If Malpighi can be called the first of the descriptive embryologists, then Adelmann is probably the last. These volumes may well be the Swann song of a dying breed. As history of science they

are too much in and of what they describe. Their dullness, their exhaustiveness, their emphasis on scholarship for its own sake, their 10-by-13-inch two-hundred-dollar pomposity, their meticulous attention to trivial detail (on page 77 Adelmann details to whom Taddeo, a scholar who died in 1303, left his library, book by book) coupled with their lack of interpretation—all of these are characteristic of descriptive embryology. Yet as a curriculum descriptive embryology has had the redeeming feature that no matter how much the students were programmed with nonsense about the three germ layers of the embryo, or fed mnemonics for memorizing the 12 cranial nerves, nothing stood between them and their embryos. No persiflage could obscure what they saw; there is always sufficient variety among embryos to cause, every now and again, that revolution in learning when the student says: "The book is wrong. That isn't how my embryo is." At that point he suddenly comes to realize the primacy of the material—the embryo—over the book, over his classmates' conclusions, over the teacher's pronouncements.

If libraries gave each other presents, these volumes would certainly be great Christmas sellers—the biological counterpart of sumptuous art books. In all fairness I should mention that the exhaustive bibliography is said to be unique. The volumes have been highly recommended by other reviewers, notably Everett Mendelsohn and Max Fish; perhaps they are valuable for feeding the incestuous flames of scholarship. Professor Fish points out the need for more histories of biology written by "scientists turned historians, who know at first hand the present stage of advancement of the sciences in question."

These volumes, rather than reflecting the concerns of contemporary biology, have about them the aura of a time gone by. The elegant large type, the luxurious broad margins are redolent of the library of an English country gentleman and scholar—the book-lined walls reflecting firelight from rare and ancient works. The five volumes are advertised as "a treasured addition to the finest personal collections." *Marcello Malpighi and the Evolution of Embryology* is a 19th-century book written about 19th-century concerns.

Short Reviews

GIANT METEORITES, by E. L. Krinov. Translated by J. S. Romankiewicz and edited by M. M. Beynon. Pergamon Press ($15). At 7:17 local

time on the morning of June 30, 1908, in the remote Yenisei taiga, not far from the fur-trading post of Vanovara, a gigantic meteorite fell. A couple of hundred miles to the southeast toward Lake Baikal a boy in the forest heard "in the northwest what sounded like gunfire repeated at intervals at least ten times," and wondered. This book is the work of that boy, become a lifelong student of meteoritics and sometime Scientific Secretary of the Committee on Meteorites of the Academy of Sciences of the U.S.S.R. His book tells the story of the great Tunguska fall, of the Arizona meteor crater, of the Sikhote-Aline shower in 1947 in the Soviet Far East, and briefly describes a dozen other known or suspected starwounds on the earth. Krinov is more at home with mineral analysis and orbit calculations than he is with the hydrodynamics of shock, and his volume is therefore not the final word on the ancient craters and their formation, but on what he reports in full there can hardly be a more helpful or detailed treatise.

Krinov tells of the Arizona crater, where in 1876 a cowboy named Mathias Armijo found the first fragment of iron. The mineralogist A. E. Foote analyzed samples of the iron later, and after a visit in 1891 plainly concluded, but did not publish, that this was a meteor crater. The point came into dispute; in 1903 Daniel M. Barringer bought the land in the belief that it was in fact a meteor crater, and that the huge metal mass might still be there. Half a century of scientific work has made it all but certain that Barringer was correct about the initial fall, some 20,000 years ago, yet wrong about the residual mass. There is not much metal left in the crater; most of it went up as vapor in the fall and came down in the thousands of tons of tiny magnetic particles that lie in the Arizona desert for miles around.

The Tunguska fall is even more elusive. Since it knocked down the forest of larch and hemlock for 20 kilometers, was heard 800 miles away, marked seismic records half a world away and made barographic disturbances to be followed twice around the world, it might be expected to have left a fine large crater. There is no such crater, in spite of early false reports. The whole story points more and more clearly, as Krinov recounts it, to an object exploding kilometers above the ground, with a burst of radiant heat and a gigantic bang, but no crater. No one was killed; perhaps some flour stores of the Evenki hunters were burned, and some reindeer were certainly frightened. No radioactivity is known, and no large fragments, although again some microscopic globules of iron and silicate bear their witness. The night skies after the fall were extraordinarily bright from Edinburgh to the Crimea; one could read small print at midnight. The story points to the fall of something like a small comet, all ices and dust, with a tail stretching out toward the North Atlantic. Such is Krinov's view.

The history of knowledge of the Tunguska fall is the history of Russia and the U.S.S.R. in this century. No expedition to the site was mounted until the mineralogist L. A. Kulik managed to travel there in 1927, after the long travail of Czarist Russia and the final establishment of the Soviet state. He led several expeditions, poorly equipped, brave, earnest. On the second expedition the men were troubled by food shortages and scurvy. They had to wire back to Leningrad for more funds. No air photography was attempted until 1930; the first successful air mapping was done in 1938, by a flier named Petrov. Both Petrov and Kulik died at the hands of the Germans in the first year of the war.

The 1947 expedition was different. While the Sikote-Aline fall was less energetic than the Tunguska by a couple of orders of magnitude, the search could be mounted now with real power. Four expeditions went to the scene in as many years; they included air photography and magnetic surveying and even the making of a documentary film, and this time a detachment of engineer troops helped with logistics and earth-moving. There is change on earth as well as in the heavens.

If one estimates the energy release of the Arizona fall, or of the Tunguska event, they come out by chance remarkably similar, in the neighborhood of 10 or 20 megatons TNT equivalent, to use a unit familiar in other contexts. Both artificial craters and airbursts are well known.

This book is a real contribution to the literature of the science; its firsthand quality, its sense of time-spanning and of human growth give it a special interest. A few missing scales and an occasional mishap, such as the statement that Meteor Crater lies just south of "railway line 66," attest to its remarkable history: it was written in Russian by its distinguished senior author and first published in English in this translation.

HELL'S ANGELS: A STRANGE AND TERRIBLE SAGA, by Hunter S. Thompson. Random House ($4.95). It is Labor Day weekend, the ocean fog is still in the West Coast streets, and 100 men roll along "tense for the action, long hair in the wind, ... chain whips, swastikas and stripped-down Harleys flashing chrome as traffic on 101 moves over, nervous, to let the formation pass like a burst of dirty thunder."

A writer once said the most important product of the British coal mines was the British miner. It remains for us to look squarely at this unusual product of the internal-combustion, freeway, mass-media and mortgage culture of California. This book is the perceptive, fluent and humane account of the motorcycle outlaws by a young novelist who lived and rode with them until six of them stomped his ribs in on Labor Day, 1966. These outlaws are not the casual sporting cyclists who ride a million little Japanese bikes, nor the racing set, marked by a mixture of daring and meticulousness, nor the leather cultists hanging around some homosexual bar. They are a small band of losers, poor men and the sons of poor men, lacking and disdaining steady jobs, credit and home addresses. Around them is a cloud of girls: steady companions and wives, "mamas" who are compliant and passive targets of a diffuse sexual license, and occasional chicks and babes of all sorts looking for thrills, often too successfully. These are the fully alienated, but they are men who have found their kindred, who in concert exploit the interstitial freedoms of the highway, the beer joint and the defiant motorcycle.

The outlaw bike is almost always a Harley 74, stripped of 30 percent of its 700-pound factory weight by removing every unessential accessory down to the front brake. A fanatic can satisfy the legal requirement for a rearview mirror with a three-quarter-inch dentist's mirror! What is left is a heavy frame, a tiny seat and a 1,200-cubic-centimeter engine. The engine is rebored and fitted with a lighter flywheel, hot cams and bigger valves. Chrome and flame-paint trim display the flair of the owner, who may spend half a year and $3,000 to complete his "chopper." Only the police and the outlaws favor these large, overdesigned American "hogs." But the chopped hog can outrun the heavy police standard Harley. This is true particularly because an Angel is quite capable of sliding full throttle off tangent to a curve he knows is underbanked. "We've all been over the high side, baby. ... She slides toward the high side ... until she hits a curb or a rail or whatever's there, and then she flips." Every active Hell's Angel has seen the emergency ward as a patient in shock. Violence dwells in their world; they are marked by casts, bandages, lumpy faces,

gonorrhea and rotting teeth. Yet the mortality is not very high, perhaps 4 percent per year. And such violence prepares them for brawls with the outsiders who shun damage. Barbiturates, mixed drugs and finally LSD, in doses as unrestrained as the rest of their lives, are outlaw commonplaces. Sexual relations of all levels and kinds play a major part in both the dream and the reality of outlaw life. But it is clear from Thompson's candid account that rape and wanton violence against innocents and strangers, while by no means unknown among bands such as Hell's Angels and Satan's Slaves (the Los Angeles counterpart), is not at all the norm. It is the thrill-seeker on the fringe, or the outlaw himself, who is the usual victim. He is always there.

Finally, the outlaws are not at all like the bearded, drug-using, rebellious, poetic Bohemian circle of Berkeley and North Beach. Those share alienation only in part; it has not been bred in the bone. Their education and their philosophical width of view sets them apart. The outlaws support the war in Vietnam, or any war; they carry Nazi emblems, and with their latent sadism and their visibly self-limiting powers of revenge they are in essence Fascist. They know they are losers, active losers, even when they deny it. They seek death before order. "Yeah, I guess I am, but you're looking at one loser who's going to make a hell of a scene on the way out." When the power of the state is put on their side, Fascism has been born, and it too has made a hell of a scene on the way out.

This is a sociology of potential; it deserves attention far from the cheap bar El Adobe in East Oakland. The epigraph to the book is from Villon's entry in the ballad contest of Blaise:

In my own country I am in a far-off land
I am strong but have no force or power
I win all yet remain a loser
At break of day I say goodnight
When I lie down I have a great fear of falling.

The motorcycle outlaws are not Villons, yet their ugly tale is a portent for us all. Their claim will be pressed not by hundreds but by millions who deserve and must receive better from an industrial society.

NOBEL LECTURES, PHYSICS: VOLUME I, 1901–1921; VOLUME II, 1922–1941; VOLUME III, 1942–1962. American Elsevier Publishing Company, Inc. ($30 per volume, $85 for the set). For the whole of this century the men who year by year have been awarded the Nobel prize in physics have traveled to Stockholm, there to speak briefly in a nearly popular vein about the meaning of their work. Here are all those talks, printed for the first time in a single language, each led by a page or two of graceful introduction and followed by one more of useful biography. These three well-made (if costly) volumes present the talks with their original illustrations. Not all the winners came: Röntgen, Gustaf Dalén and L. D. Landau were too ill, and Einstein, in Japan, "being too remote from Sweden, ... could not attend the ceremony." One or two of them missed out because of wartime.

All the other talks are here, historically and pedagogically interesting but not always strikingly good. Error occurs in a most instructive way: C. G. Barkla of Edinburgh thinks he has found a J series of X rays, not predicted by Bohr; Marconi, speaking in 1909, is puzzled by the skip of radio waves, although he himself has shown the straight-line theorists to be wrong and has come to believe in surface waves bending over the earth; Enrico Fermi alludes to his transuranium elements modestly enough, saying, "We, in Rome, used to call the elements 93 and 94 ausonium and hesperium respectively." Fritz Zernike tells of bringing his phase-contrast idea to a rather stuffy Zeiss expert at Jena, to be told "if this had any practical value, we ourselves would have invented it long ago." Donald Glaser found most thermodynamics texts wrong on the vapor pressure inside bubbles, and Igor Tamm that everyone forgot the shock-wave radiation at superlight speed in material media, the "singing electrons."

Historically the most valuable talk is perhaps the one by Max Born, who lays out those two magical years from early 1925. Werner Heisenberg's matrix ideas were followed at once by the Born-Jordan quantum mechanics, complete with the commutation laws. Heisenberg had left Göttingen for the seashore to gain respite from hay fever. By the end of the year first P. A. M. Dirac and Wolfgang Pauli, then finally Erwin Schrödinger and his wave mechanics, had joined the Göttingen current, still in flood today. Born's famous statistical interpretation followed before the end of 1926. *Wunderjahren!*

There is no statement in all the pages more convincingly precise than the poetic opening paragraph of Edward Pur-

cell's 1952 lecture: "Professor Bloch has told you how one can detect the precession of the magnetic nuclei in a drop of water. Commonplace as such experiments have become in our laboratories, I have not yet lost a feeling of wonder, and of delight, that this delicate motion should reside in all the ordinary things around us, revealing itself only to him who looks for it. I remember, in the winter of our first experiments, just seven years ago, looking on snow with new eyes. There the snow lay around my doorstep—great heaps of protons quietly precessing in the earth's magnetic field. To see the world for a moment as something rich and strange is the private reward of many a discovery."

SÉMINAIRE BOURBAKI, 1948–1965. W. A. Benjamin, Inc. ($150). Those brilliant and indefatigable mathematicians of Paris who created a system of mathematics under the code name Bourbaki manage of course to keep up with the literature. Characteristically they plan this in a rational and effective way. During three specific periods each year they have presented six expository and deeply appraising discussions of topics in contemporary research, given by mathematicians almost all speaking in French and close in thought to the Bourbakistes. For each talk the speaker prepares mimeographed notes in advance, including a brief and timely bibliography, which are distributed to his hearers at the Institut Henri Poincaré. These 12 large clothbound volumes contain photo-offset reprints of the edited version of those notes, collected over the years mentioned. (The publishers plan to continue annually.)

The exposés are of the highest quality; they are signed by the most illustrious names in mathematics. They are austerely general; no diagrams are to be seen, and neither lightheartedness nor concrete examples manage very often to modify the style. These are invaluable and durable references for serious workers in modern mathematics; they are not for amateurs or for scientists from other fields. Beauty here is bare indeed. A helpful author index has been added to the original notes.

A GEOLOGIST'S VIEW OF CAPE COD, by Arthur N. Strahler. The Natural History Press ($4.95). Geomorphology is a subject that treats of the earth on a scale of a few miles. Too often it is studied in a kind of paper museum of maps and photographs, bringing the classic examples—a granite mountain in New Hampshire, a sand dune in North Africa—from the geological landscape of the world. Here is an intimate little book on the topic, taking this genuinely accessible and varied portion of the world, centered around the new National Seashore, and using it as the entire stage. In a thin volume with some 60 excellent photographs, charts and maps Professor Strahler points out the work of the ancient ice and of the tides, the wind and the waves. His is not an extinct geology, either; he is pleased to show us the motion and flux of the dunes and to map the drift of the sands along Cape Cod beaches. The long spit at Monomoy is being built year by year as the nor'easters waste away the high scarp at Wellfleet. He shows us the water table, exposed in pleasant ponds that occupy the great pots that once held melting blocks of ice left behind by the retreating glacier. The ponds themselves changed, becoming rounded and also dividing as bars were formed by wave action. Finally some filled with water plants and in the end turned to soggy bogs of peat, now often drained and planted in cranberries.

This fine little book is not complete in itself; to make real use of it one must also have some of the splendid topographic maps of the U.S. Geological Survey. The author provides a guide to the maps and detailed instructions on how to get them by mail; they are also stocked by some local stores. Don't wait too long to make the trip; on the basis of present rates the sea will part the Cape near South Wellfleet in about 2,000 years.

MEN AND APES, by Ramona and Desmond Morris. McGraw-Hill Book Company ($7.95). An out-of-the-way work, grotesquely and richly illustrated, that tells of the long-standing half-war and half-alliance between men of many cultures and their distant cousins, the monkeys and apes. Here is Candide's disappointing rescue of the two naked girls pursued by monkeys. Here is King Kong, and also Congo, the hard-edged abstractionist chimpanzee of London. Hanuman and Great Monkey appear, rather too briefly among the sacred apes, and other chapters treat of the beasts as fools, as lovers, as amusements and as experimental subjects. That chimponauts have orbited is well known; less familiar is the hardworking signalman baboon of Port Elizabeth in South Africa, who pulled signal and switch levers for his master, a legless veteran who pointed out the right lever and drew the pay. The baboon "grew very fond of Boer brandy and tobacco, in fact it would get beastly drunk." A curious way to run a railroad.

So the volume goes, wry and a little strained but always readable. There is a good account of the latest work of the primatologists Harry Harlow, Jane Goodall and George Schaller, and a fine list of the primates, to add a soberer tone. Best of all are the drawings, from *Punch* and *The New Yorker* to Picasso and the Luttrell psalter.

TRITIUM AND ITS COMPOUNDS, by E. Anthony Evans. D. Van Nostrand Company, Inc. ($15). Hydrogen has two isotopes heavier than the proton: deuterium and the radioactive tritium, H^3. The remarkable sensitivity of radioactive tracing techniques, by which a molecule that comprises an active atom can be followed through a set of reactions and diffusion processes, is possible for hydrogen only with the use of tritium, whose beta electrons are too weak to be counted through normal counter windows. Over the past 10 years, however, the use of photomultipliers to watch for photons coming from the passage of the beta electrons from the sample, dissolved directly in a scintillating liquid "cocktail," has become commonplace. Tritium is now a dominant tracer isotope.

Tritium activity is infectious, in the sense that almost any hydrogen compound kept in contact with radioactive hydrogen gas exchanges some of its protons with active tritium atoms, becoming labeled at a rate of about 1 percent per day of exposure. The exchange is aided by the recoil energy of the decaying tritium atoms. Many indirect methods of labeling have also been worked out. All of this demands large amounts of tritium, in the range of hundreds of curies, available nowadays because of the once presumed (and now diminished) importance of tritium for thermonuclear weapons.

This book is a detailed account of the preparation of tritium-labeled compounds, of their use as tracers, of the results and of the pitfalls of this subtle kind of chemistry. It is written by the preparator of these labeled molecules in the Radiochemical Center at Amersham, the British national center for such work, which can claim a justly earned international reputation for originality and precision. The book is a treatise at the working level, with more than 1,000 references and an index to 700 labeled compounds. One can read about such clever tricks, now standard, as the use of the euphonious POPOP (2-p-phenylene-bis-5-phenyloxazole) to increase counting efficiency by shifting the color of the

scintillation flashes. Autoradiography, used for tracing materials at the cell level, is compactly but completely handled. Here is a steady look at a powerful part of contemporary chemistry.

THE USES OF AIR PHOTOGRAPHY: NATURE AND MAN IN A NEW PERSPECTIVE, edited by J. K. S. St. Joseph. The John Day Company ($15). Most mapping is now done by air—vertical shots from high altitude. The world is displayed at a scale of one to some tens of thousands. But in the power of 10 below that—say a foot or two to the mile—sidewise air photography from low, slow, small aircraft has a new power to offer. That is the burden of this book, a set of expert chapters mostly by members of the Cambridge University Committee for Aerial Photography. The university has had such a committee for nearly 20 years, and for eight years it has used its own light plane instead of the R.A.F. aircraft, now mostly too fast and high to be useful. Here large halftone plates display strata in oblique photographs, soil creep, mixed deciduous woods (each species displaying a distinct tone and shape of crown), centers of potato blight staining the fields, elephants at a gallop, 4,031 wildebeests and 62 zebras in Serengeti, a buried Roman fort outlined magically, and the tree-lined avenue of Blenheim Palace, stretching two miles out from the great house, looking for all the world like the site of a linear accelerator of Queen Anne's time. The essays go with these photographs to explain and to admire. This book shows what skill and insight can do without much expense on a scale almost intimate for modern aviation.

ATLAS OF PROTEIN SEQUENCE AND STRUCTURE 1966, by Richard V. Eck and Margaret O. Dayhoff. National Biomedical Research Foundation ($3.50). This large paperback, casually presented in computer-output style, is a spelling book of the language of life. Here are carefully spelled out the protein "words," formed of amino acid letters, for the few dozen enzymes, hormones and virus proteins for which the delicate and prodigious labor had been completed by July 1, 1966. Here, for example, are the oxidative enzymes of man and monkey, snake and tuna, moth and mold. Their unity is striking; most of these forms use biochemical dialects with differences less marked than those between English and Dutch. Fascinating, concise, timely and clear, if specialized.

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APRIL 1967

BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

THE SOCIAL POWER OF THE NEGRO

BLACK BOURGEOISIE. Franklin Frazier. The Free Press of Glencoe, 1957.

BLACK CARGOES: A HISTORY OF THE ATLANTIC SLAVE TRADE. Daniel P. Mannix and Malcolm Cowley. The Viking Press, 1962.

LAY MY BURDEN DOWN: A FOLK HISTORY OF SLAVERY. Benjamin A. Botkin. The University of Chicago Press, 1945.

NORTH OF SLAVERY. Leon P. Litwack. The University of Chicago Press, 1961.

SLAVERY. Stanley M. Elkins. The University of Chicago Press, 1959.

THE STRANGE CAREER OF JIM CROW. C. Vann Woodward. Oxford University Press, 1958.

THE INDUCTION OF CANCER BY VIRUSES

CELL TRANSFORMATION BY DIFFERENT FORMS OF POLYOMA VIRUS DNA. Lionel Crawford, Renato Dulbecco, Mike Fried, Luc Montagnier and Michael Stoker in *Proceedings of the National Academy of Sciences,* Vol. 52, No. 1, pages 148–152; July, 1964.

IMMUNOLOGICAL DETERMINANTS OF POLYOMA VIRUS ONCOGENESIS. Karl Habel in *The Journal of Experimental Medicine,* Vol. 115, No. 1, pages 181–193; January 1, 1962.

STUDIES ON SPECIFIC TRANSPLANTATION RESISTANCE TO POLYOMA-VIRUS-INDUCED TUMORS, I: TRANSPLANTATION RESISTANCE INDUCED BY POLYOMA VIRUS INFECTION. Hans Olof Sjögren in *Journal of the National Cancer Institute,* Vol. 32, No. 2, pages 361–393; February, 1964.

TRANSFORMATION OF CELLS IN VITRO BY DNA-CONTAINING VIRUSES. Renato Dulbecco in *The Journal of the American Medical Association,* Vol. 190, No. 8, pages 721–726; November 23, 1964.

TRANSFORMATION OF PROPERTIES OF AN ESTABLISHED CELL LINE BY SV 40 AND POLYOMA VIRUS. George J. Todaro, Howard Green and Burton D. Goldberg in *Proceedings of the National Academy of Sciences,* Vol. 51, No. 1, pages 66–73; January, 1964.

VIRUS-CELL INTERACTION WITH A TUMOR-PRODUCING VIRUS. Marguerite Vogt and Renato Dulbecco in *Proceedings of the National Academy of Sciences,* Vol. 46, No. 3, pages 365–370; March 15, 1960.

THE CHANGING HELICOPTER

AERODYNAMICS OF THE HELICOPTER. Alfred Gessow and Garry C. Myers, Jr. The Macmillan Company, 1952.

ANALYTICAL INVESTIGATION OF A HELICOPTER ROTOR DRIVEN AND CONTROLLED BY A JET FLAP. W. T. Evans and J. L. McLoud III. NASA TND-3028, 1965.

CONFERENCE ON V/STOL AND STOL AIRCRAFT. NASA SP-116, 1966.

AN EXPLORATORY INVESTIGATION OF FACTORS AFFECTING THE HANDLING QUALITIES OF A RUDIMENTARY HINGELESS ROTOR HELICOPTER. R. J. Huston, NASA TN D-3418, 1966.

THE ANTIQUITY OF HUMAN WALKING

THE APE-MEN. Robert Broom in *Scientific American;* November, 1949.

THE FOOT AND THE SHOE. J. R. Napier in *Physiotherapy,* Vol. 43, No. 3, pages 65–74; March, 1957.

A HOMINID TOE BONE FROM BED 1, OLDUVAI GORGE, TANZANIA. M. H. Day and J. R. Napier in *Nature,* Vol. 211, No. 5052, pages 929–930; August 27, 1966.

NEUTRON-ACTIVATION ANALYSIS

ACTIVATION ANALYSIS. J. M. A. Lenihan and S. J. Thomson. Academic Press, 1965.

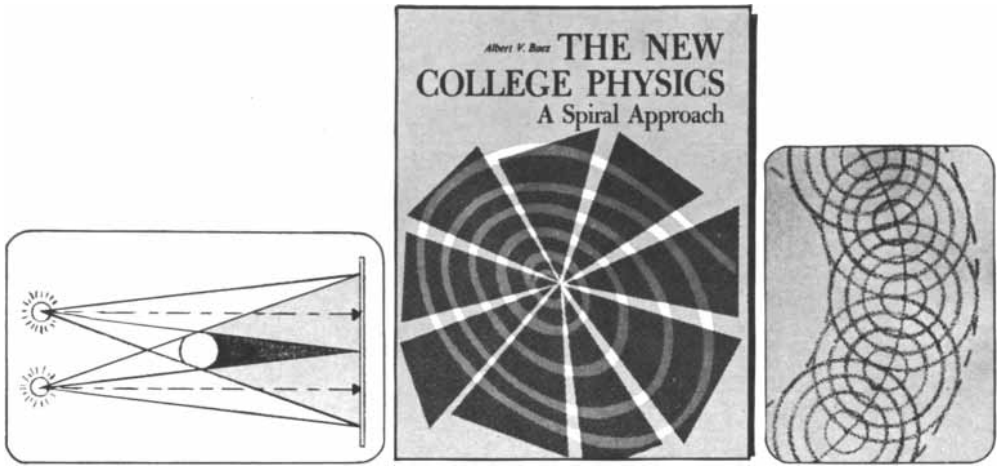
GUIDE TO ACTIVATION ANALYSIS. William S. Lyon, Jr. D. Van Nostrand Company, Inc., 1964.

NEUTRON ACTIVATION ANALYSIS AND ITS POSSIBLE APPLICATION FOR AGE DETERMINATION OF PAINTINGS. J. P. W. Houtman and J. Turkstra in *Radiochemical Methods of Analysis: Vol. I.* International Atomic Energy Agency, 1965.

USE OF STABLE ISOTOPES AND ACTIVATION ANALYSIS FOR IN VIVO DIAGNOSTIC STUDIES. W. H. Wahl, H. W. Nass and H. H. Kramer. Radioactive Pharmaceuticals CONF-651111, U.S. Department of Commerce, 1965.

RIVERS IN THE MAKING

CHANNELED SCABLAND OF WASHINGTON: NEW DATA AND INTERPRETA-



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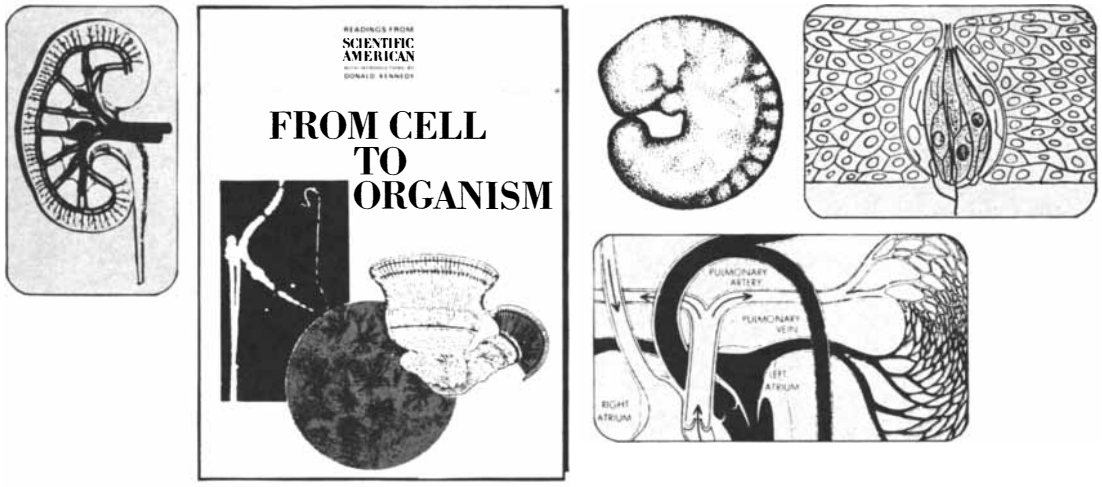

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From Cell to Organism

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W. H. Freeman and Company

660 Market Street, San Francisco, California 94104/Warner House, 48 Upper Thames Street, London, E.C. 4

TIONS. J. Harlen Bretz, H. T. U. Smith and George E. Neff in *Bulletin of the Geological Society of America*, Vol. 67, No. 8, pages 957–1049; August, 1956.

STRATIGRAPHIC-SEDIMENTARY SIGNIFICANCE OF CONTEMPORARY CLIMATE AND RELIEF IN FOUR REGIONS OF THE ANDES MOUNTAINS. H. F. Garner in *Bulletin of the Geological Society of America*, Vol. 70, No. 10, pages 1327–1368; October, 1959.

THE EVOLUTION OF BEE LANGUAGE

COMMUNICATION AMONG SOCIAL BEES. Martin Lindauer. Harvard University Press, 1961.

SOUND: AN ELEMENT COMMON TO COMMUNICATION OF STINGLESS BEES AND TO DANCES OF THE HONEY BEE. Harald Esch and Warwick E. Kerr in *Science*, Vol. 149, No. 3681, pages 320–321; July 16, 1965.

SOUND PRODUCTION DURING THE WAGGLE DANCE OF THE HONEY BEE. A. M. Wenner in *Animal Behaviour*, Vol. 10, No. 1/2, pages 79–95; 1962.

TANZSPRACHE UND ORIENTIERUNG DER BIENEN. Karl von Frisch. Springer-Verlag, 1965.

ANTIMATTER AND COSMOLOGY

ANTIMATTER AND THE DEVELOPMENT OF THE METAGALAXY. H. Alfvén in *Reviews of Modern Physics*, Vol. 37, No. 4, pages 652–665; October, 1965.

INSTEAD OF COSMOLOGY. Oscar Klein in *Nature*, Vol. 211, No. 5056, pages 1337–1341; September 24, 1967.

WORLDS-ANTIWORLDS. Hannes Alfvén. W. H. Freeman and Company, 1966.

MATHEMATICAL GAMES

ARITHMETICAL PRODIGIES. E. W. Scripture in *American Journal of Psychology*, Vol. 4, No. 1, pages 1–59; April, 1891.

AN EXCEPTIONAL TALENT FOR CALCULATIVE THINKING. Ian M. L. Hunter in *British Journal of Psychology*, Vol. 53, Part 3, pages 243–258; August, 1962.

MATHEMATICAL PRODIGIES. Frank D. Mitchell in *American Journal of Psychology*, Vol. 18, No. 1, pages 61–143; January, 1907.

THE AMATEUR SCIENTIST

MECHANISMS FOR THE GENERATION OF PLANE CURVES. I. I. Artobolevskii. The Macmillan Company, 1964.

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