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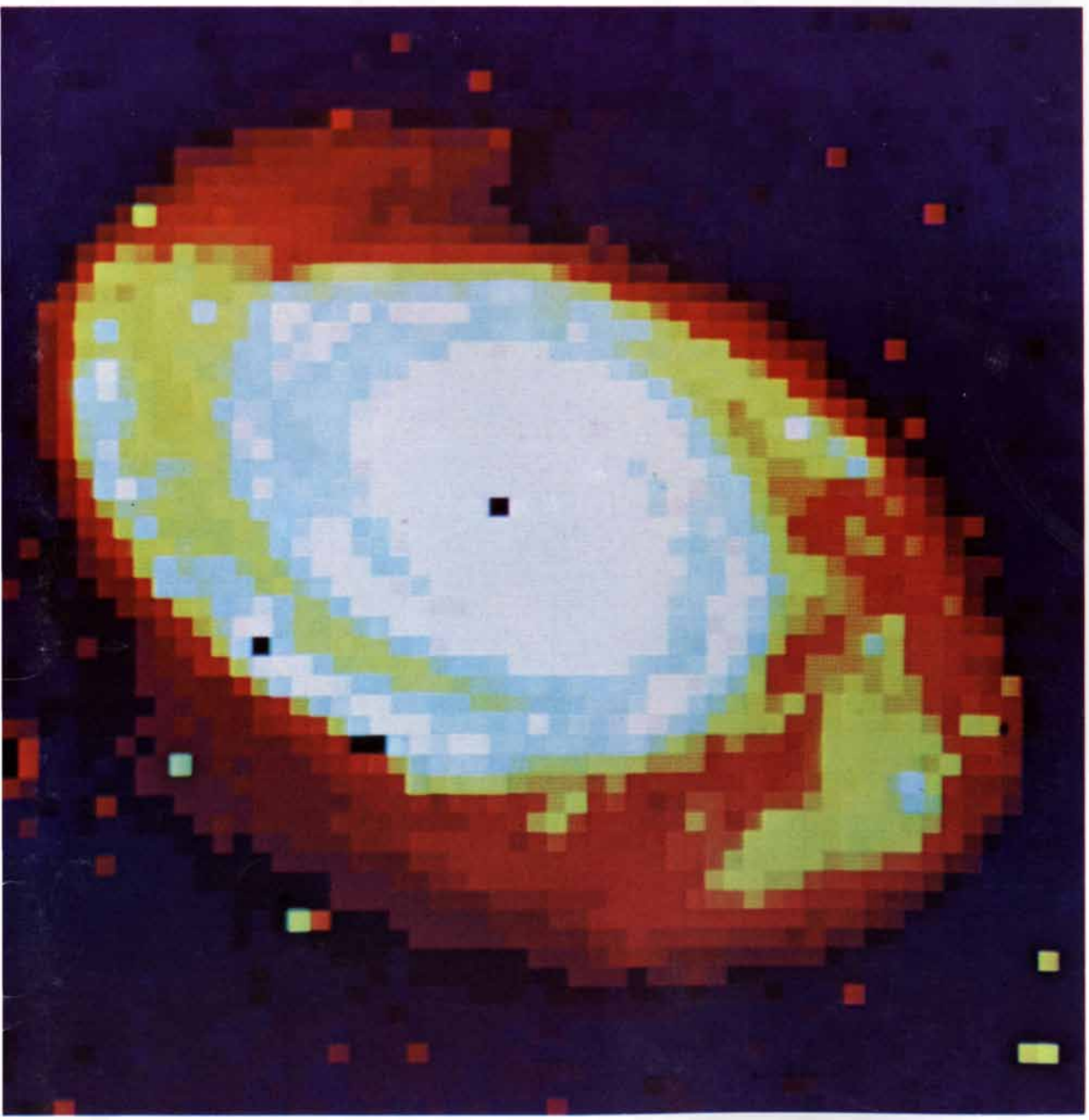

EVOLUTION OF GALAXIES

$1.50

April 1979

The Honda Prelude: a sports car for grown-ups.

Sports car. It may be the most abused term in the English language.

To some, it's a car that can accelerate away from a stoplight at blinding speed so that its neighbor is left to feel compromised and impotent.

To others, a sports car is measured differently. The roofline should not exceed waist height.

At Honda, as with all our endeavors, we see things a little more simply. As evidence, we proudly introduce the Honda Prelude.

We like to think of it as a sports car for grown-ups. People who are realistic about things like 55 mph speed limits and their personal comfort during a long trip.

This doesn't mean that a sports car for grown-ups has to be sedate. For the performance minded, the Prelude has a new advanced 4-wheel

independent suspension system. Add to that our proven front-wheel drive, rack and pinion steering, 1751cc CVCC* engine and drive train and you have one of the most nimble Hondas we've ever made.

But here's the fun part. The Prelude is delivered with our version of a "moonroof." It's really a power-operated tinted-glass sunroof.

Then we've rethought the speedometer-tachometer and put them on the same axis. So both are larger and easier to read.

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We invite you to step inside a Honda Prelude. Once you get in, you may never want to get out.

And isn't that really what a sports car should be?

HONDA

We make it simple.

Established 1845 **SCIENTIFIC AMERICAN** April 1979 Volume 240 Number 4

ARTICLES

DEPARTMENTS

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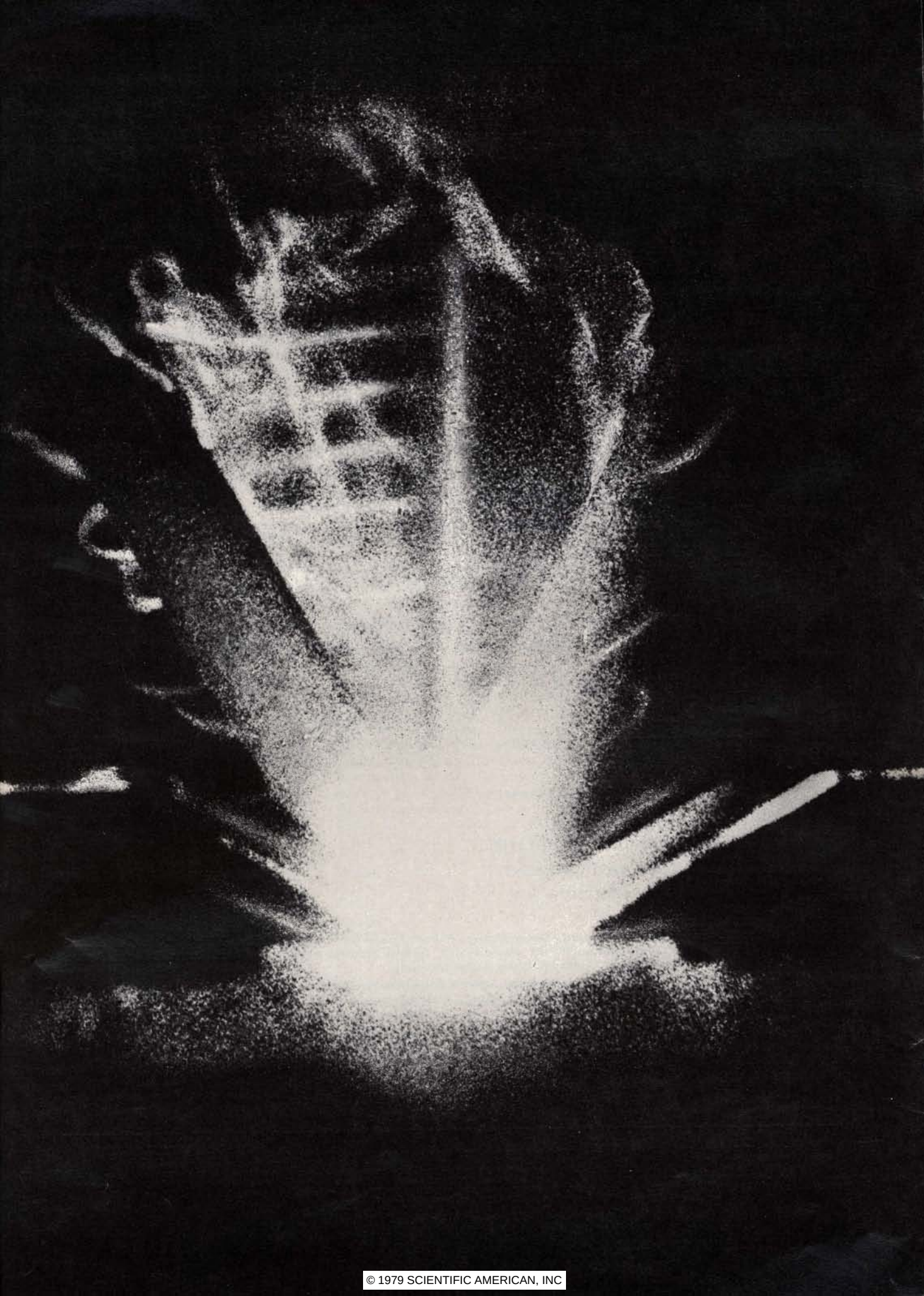

The Atomic Bond.

Using tiny explosive charges, Western Electric engineers are bonding metals with the elemental "glue" of the Universe.

Here's how it works. The atoms of all metals have a natural attraction for one another. If it weren't for the ever-present film of impurities coating the surface—the oxides, nitrides, and absorbed gasses—all metal atoms would bond to each other when brought together.

Exploding Things Together.

But the force of a high-intensity explosion on two adjacent metals will clean away the film of impurities. The explosion literally "blows" the impurities off the surfaces. So the atoms of the different metals can bond together.

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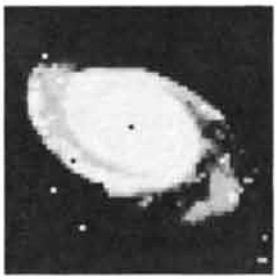
Western Electric



THE COVER

The picture on the cover depicts a typical spiral galaxy, NGC 5364, which is not unlike our own Milky Way galaxy. NGC 5364 is about 75 million light-years away in the constellation Virgo. Spiral galaxies are a type of disk galaxy in which the spiral pattern in the disk is enhanced by the presence in the spiral arms of hot young stars and associated complexes of ionized hydrogen. Disk galaxies that are born as members of rich, dense clusters of galaxies are often stripped of their disk gas and exhibit only faint spiral features (see "The Evolution of Disk Galaxies," by Stephen E. Strom and Karen M. Strom, page 72). The picture was made with the interactive picture-processing system (IPPS) developed at the Kitt Peak National Observatory. By means of this system the optical-brightness pattern of the original black-and-white photograph, made with the four-meter Mayall telescope on Kitt Peak, has been digitized and converted into an arbitrarily selected set of colors. The brightest regions in the galaxy appear here as white or pale blue; the faintest regions appear as dark red.

THE ILLUSTRATIONS

Cover courtesy of Kitt Peak National Observatory

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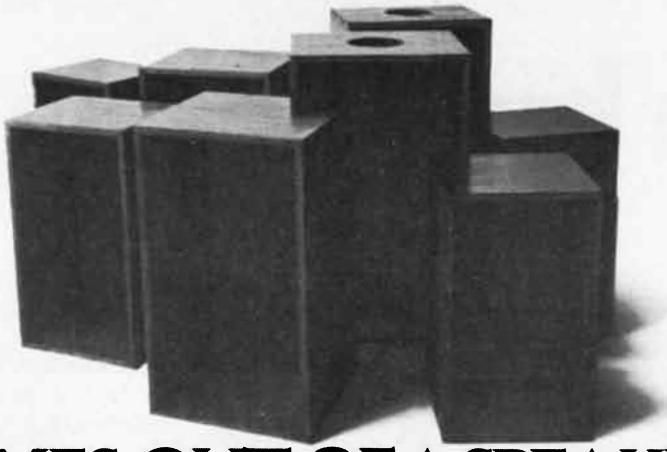

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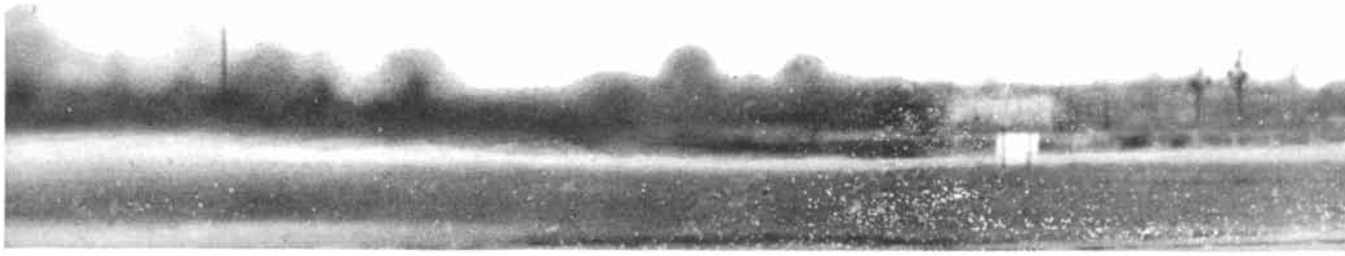
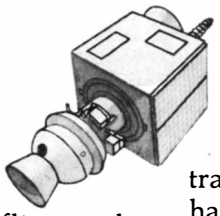


can stop in midair...



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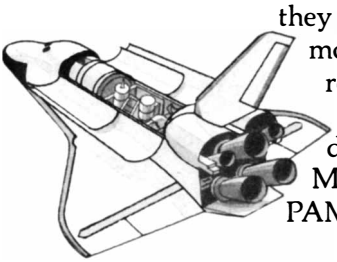

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LETTERS

Sirs:

I thank Gabriel Weinreich for his article "The Coupled Motions of Piano Strings" [SCIENTIFIC AMERICAN, January], which explains some effects I have noticed in tuning pianos but could not explain. In particular the tendency of slightly mistuned, coupled strings to reach the same frequency explains the observation that it is almost impossible to hear beats of less than one per second while bringing two strings of a trichord into tune. The beats drop out and recur abruptly even though one is certain that the tuning hammer is being pulled up at a constant rate. This, in fact, makes it impossible to tell just how "mistuned" the strings are without resorting to a fresh hammer blow to produce a fresh "prompt sound."

Perhaps Professor Weinreich would comment on two other paradoxes known to tuners. The first is the fact that a sharply struck string (particularly one rich in overtones, such as a bass string) vibrates at a higher frequency than a lightly struck one, presumably because the curvature imposed on the string by the vibrations increases the tension and hence the frequency of the fundamental and its overtones. In the case of imperfectly (unevenly) struck strings (or during una corda shifts) this dynamic "mistuning" might be expected to be even more significant than that left by the tuner. Perhaps this offers an explanation for the common practice of "sharpening up," in which the upper-octave strings are intentionally mistuned sharp by about one beat per second. These completely undamped strings contribute something called "brilliance" to the tone of the lower notes, which presumably arises from their sympathetic vibration in response to the overtones of the lower struck strings. The effect is noticeable only during the prompt-sound phase, when the large-amplitude vibrations probably shift the frequency of these overtones upward.

The other problem is particularly likely to trouble those who would attempt to synthesize piano sound or attempt a priori design changes on the instrument. Every piano teacher knows the unpleasant sound the untutored finger makes on striking ("banging") the keys roughly; hundreds of hours are spent conditioning the hands and fingers to strike the key in a manner that produces equal loudness but a much pleasanter tone. Now, the hammer action is contrived to throw the hammer against the strings, with no direct mechanical linkage possible between key and hammer for the last 1/16th inch of travel. The only apparent variable left to the pianist is the terminal velocity of the hammer, which determines the amplitude of the induced vibrations, leaving no place for all that practice to have any effect. I suspect that the answer lies in induced vibrations of the hammerhead and hammer shank, which depend on the smoothness with which energy is applied to the shank knuckle to accelerate the hammer (from a point relatively close to the fulcrum of the leverlike assembly). Presumably these vibrations could cause both horizontal and vertical "wiping" motions of the hammer on the strings, which would affect the pattern of vibration induced in the strings by the blow.

Finally, I am not as sanguine as Professor Weinreich about these physical relationships' being "completely worked out" to eliminate trial-and-error innovation. The ability of the human ear to appreciate and quantify these secondary and tertiary physical interactions is quite extraordinary. Even when the components of the sound are modeled with very high accuracy and randomness is thrown in to account for the remaining energy, the percept is "boring." As Professor Weinreich points out, the small effects are not "random." The nervous system takes great delight in discovering their underlying correlations and inferring the sources and interactions of real musical sounds. It would appear to take a signal source of almost infinite complexity to entertain an information-processing system of almost infinite complexity.

GERALD E. LOEB, M.D.

Laboratory of Neural Control
National Institute of Neurological and Communicative Disorders and Stroke
National Institutes of Health
U.S. Public Health Service
Department of Health, Education, and Welfare
Bethesda, Md.

Sirs:

Dr. Loeb touches on a number of interesting points. I agree that the tendency for trichord beats to disappear and reappear fairly suddenly is probably due to the frequency locking discussed in my article. The interesting point here is that this effect depends on the resistive, rather than springy or massy, nature of the bridge as felt at the string support point. A massy or springy support would have the opposite effect: the two normal frequencies would "repel" rather than "attract," making it impossible to eliminate the beat. The systematics of this property of the bridge (which is called its "impedance") is yet to be investigated.

The "sharpening up" of the higher octaves by a tuner is generally attributed to the fact that because of the rigidity of the string the higher overtones are not in an exact harmonic series but are sharp with respect to it. The possible importance in this connection of the additional large-amplitude sharpening has not, as far as I know, been previously noted.

In contrast, the control of piano tone by the "touch" of the player has been investigated in some detail and the conclusion is that there is no such thing. In a classic paper published in 1934 (*The Journal of the Acoustical Society of America,* Vol. 6, No. 2, pages 80–94; October, 1934) Harry C. Hart, Melville W. Fuller and Walter S. Lusby showed how the exact oscilloscopic waveforms produced by a concert pianist can be identically duplicated by dropping a dead weight onto the key. The conclusion is not, of course, that there is no such thing as pianistic skill but that this skill could not be discerned if each piece of music consisted of only a single note.

GABRIEL WEINREICH

Harrison M. Randall Laboratory of Physics
University of Michigan
Ann Arbor

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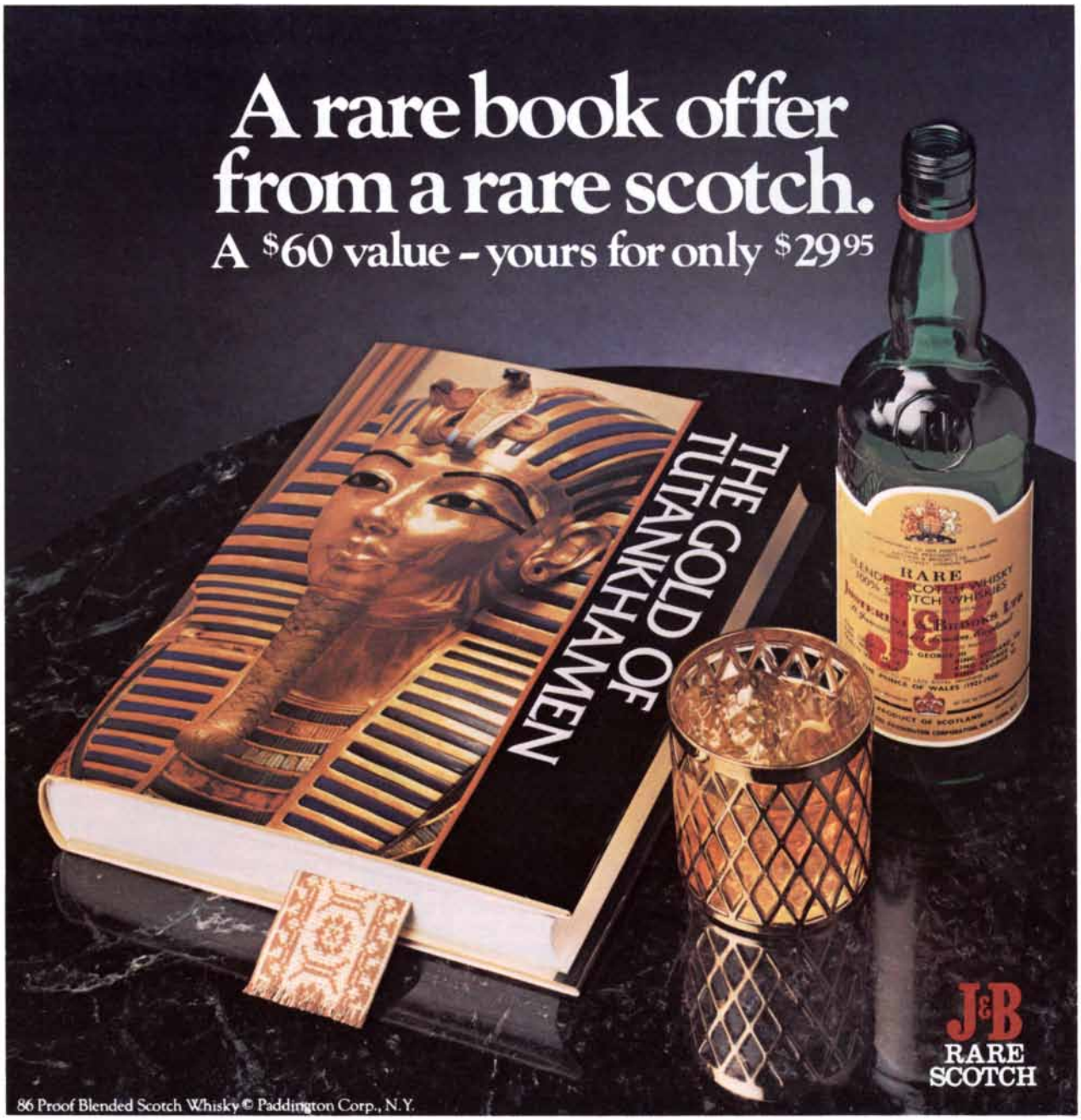

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

APRIL, 1929: "Two years ago I. G. Farbenindustrie, the great German chemical combine, undertook to erect a commercial plant for liquefying coal on a large scale. This plant, which at present produces 70,000 tons of gasoline per year, is being enlarged to a capacity of about 250,000 tons per year. Dr. Friedrich Bergius has also published some details of the yields from one metric ton of bituminous coal by his process of liquefaction. With the necessary hydrogen and ferric oxide the coal yields 525 kilograms of oil, which in turn yields 150 kilograms of motor spirit, 200 kilograms of Diesel oil and creosote oil, 60 kilograms of lubricating oil and 80 kilograms of fuel oil."

"In the revision of Rowlands' *Table of the Solar Spectrum,* which has recently been published from the Mount Wilson Observatory, no fewer than 57 of the elements have been identified by means of the spectrum lines. Such an analysis in no way exhausts the possibilities of the study of spectrum-line positions. Minute shifts of the lines are caused by motion in the line of sight, and it is an old story how these have led to the discovery of hundreds of double stars too close together to be resolved by any telescope, and also how they have led to fundamentally important determinations of the rate of motion of the sun and the stars in space. Still other small shifts and doublings of the lines reveal the existence of powerful magnetic fields in sunspots, and of a weaker one surrounding the whole of the sun's surface. And yet another shift in the spectrum of the faint companion of Sirius has provided one of the most convincing proofs of Einstein's general theory of relativity. With the wealth of attractive possibilities for investigation it is no wonder that astrophysicists have busied themselves for years with the precise measurement of the positions of the lines, both in laboratory spectra and in those of the stars."

"For several years various movements have been promoted to study the effects of drugs on the mentality. Dr. Robert E. House some years ago urged the use of scopolamine in criminology, contending that the criminal under the influence of this drug has his will inhibited so that he would invariably answer all questions truthfully and that in this way the detection of crime would be much easier. Not long ago a boy in Hawaii was abducted from school and killed. A Japanese youth who had been the chauffeur in the family was arrested but steadily maintained his innocence. He was given a drug, and while under its influence he confessed to the commission of the crime. When the drug had worn off, he repudiated his confession. Then it was found that he had in no way been connected with the crime and the real murderer was someone else. A method that tricks the suspect and catches him off his guard is contrary to justice. The case in Hawaii probably spells doom to all further efforts in promoting this method of obtaining confessions."

SCIENTIFIC AMERICAN

APRIL, 1879: "The success of the Suez Canal, and its effect on the world's commerce, bring the necessity for the Atlantic and Pacific inter-oceanic canal still more prominently forward, and it now appeals more strongly to the attention of mankind than before. Many plans have been proposed for its accomplishment, but the natural difficulties to be overcome have hitherto been considered almost insurmountable—quite sufficient to appall the stoutest heart and shake the strongest nerves. So were the difficulties considered in regard to the Suez Canal, but the time arrived when they were all overcome by engineering skill, and it would be well to inquire, speedily and sincerely, whether the time has not come to attack and subdue them in opening a ship canal through the American isthmus, as no intelligent person can fail to see that the execution of such a work would place the United States geographically in the center of the trade of the world and renew commerce on the grandest scale ever conceived by most sanguine far-seeing men."

"While we have been satisfied with the rapidly firing breech-loading rifle, carrying but one cartridge at a time, no fewer than four foreign governments, including France and Austria, have been experimenting very seriously on magazine or 'repeating' rifles. The French have adopted for their navy the Kropatschek, an Austrian invention, weighing without bayonet 10 lb. 3 oz. unloaded and 10 lb. 15 oz. loaded with eight cartridges. It, as well as the other magazine rifles experimented on, can be used as an ordinary breech-loader, and the experiments went to show that when rapidity of fire was necessary, the Kropatschek and an American repeating rifle, the Hotchkiss, could be fired as repeaters not very far from twice as quickly as when they were used as ordinary breech-loaders. It certainly seems of the highest importance that our War Office should without de-

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lay proceed to investigate the question of magazine or repeating rifles."

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THE AUTHORS

JOHN PARMENTOLA and KOSTA TSIPIS ("Particle-Beam Weapons") are physicists at the Massachusetts Institute of Technology. Parmentola is a postdoctoral fellow in nuclear physics at the Center for Theoretical Physics at M.I.T. and a member of the Panel on Public Affairs of the American Physical Society. He did his undergraduate work at the Polytechnic Institute of Brooklyn and received his Ph.D. in physics from M.I.T. in 1977. In addition to Parmentola's theoretical work on the high-energy scattering of protons by nuclei he does research on arms-control topics. Tsipis, a nuclear physicist by training, now devotes all his time to questions of defense policy and the technical aspects of arms control. A native of Greece, he came to the U.S. in 1954 to attend Rutgers University as a Fulbright Scholar. After getting his B.S. in electrical engineering and his M.S. in atomic physics he went on to obtain his Ph.D. in high-energy particle physics from Columbia University in 1966. That year he joined the M.I.T. faculty. In 1973 he became a researcher at the Stockholm International Peace Research Institute and a fellow of M.I.T.'s Center for International Studies. Last year Tsipis was appointed associate director of the Program in Science and Technology for International Security in the M.I.T. physics department.

SUE BINKLEY ("A Timekeeping Enzyme in the Pineal Gland") is associate professor of biology at Temple University. She was graduated summa cum laude from the University of Colorado at Boulder and then did graduate research at Rice University. She completed her graduate studies at the University of Texas at Austin, receiving her Ph.D. in 1971 for a dissertation on the function of the pineal gland in the daily rhythms of sparrows. After working as a postdoctoral fellow at the National Institute of Child Health and Human Development, Binkley joined the faculty at Temple, where she has continued to do research on pineal physiology.

STEPHEN E. STROM and KAREN M. STROM ("The Evolution of Disk Galaxies") are a husband-and-wife team of astronomers. Stephen Strom is staff astronomer at the Kitt Peak National Observatory and chairman of the Kitt Peak Galactic and Extragalactic Program. He studied astronomy as an undergraduate and graduate student at Harvard University, obtaining his Ph.D. in 1964. Until recently his research interests have focused on the atmosphere, composition and evolution of stars, but in the past few years he has been investigating the effect of the intergalactic environment on the structure and evolution of galaxies. Karen Strom has been collaborating scientifically with her husband since they first met in 1958. She received her bachelor's degree in astronomy at Radcliffe College in 1964. Since 1972 she has been a research associate at Kitt Peak.

GEORGES MILLOT ("Clay") is professor of geology at the Université Louis Pasteur in Strasbourg and director of the Center for Sedimentology and Surface Geochemistry of the French Centre National de la Recherche Scientifique (C.N.R.S.). He studied at the École Normale Supérieure in Paris, where he got his agrégation in natural science in 1942 and his doctorate in 1950. From 1942 to 1954 he was professor at the École Nationale Supérieure de Géologie Appliquée et de Prospections Minières and at the University of Nancy. He then went to Strasbourg, where he served as dean of the faculty of sciences. He has held a number of national scientific posts, including that of adviser for the earth sciences at the Ministry of Universities and president of the Geological Society of France. In 1977 Millot was elected to the French Academy of Sciences.

KARL ILLMENSEE and LEROY C. STEVENS ("Teratomas and Chimeras") have collaborated on basic cancer research. Illmensee is professor of biology at the University of Geneva. He received his Ph.D. from the University of Munich in 1971. After two years on the zoology faculty there he came to the U.S. to work with Beatrice Mintz at the Institute for Cancer Research in Philadelphia on mouse teratomas (tumors of the germ cells). He subsequently spent a few months at the Jackson Laboratory in Bar Harbor, Me., where he met Stevens. Stevens is senior staff scientist at the Jackson Laboratory. He obtained his bachelor's degree at Cornell University and his Ph.D. in 1952 from the University of Rochester. He then moved to the Jackson Laboratory, where in 1953 he discovered the tendency of strain-129 mice to develop testicular teratomas.

HUNG-HSIANG CHOU ("Chinese Oracle Bones") is associate professor of oriental languages at the University of California at Los Angeles. Born in 1935 in Chaochou, Kwangtung Province, China, he did his undergraduate work at the Chinese University of Hong Kong, where he studied classical Chinese literature and history. He then got his Ph.D. in archaeology, paleography and Chinese history from the Australian National University in Canberra. After teaching for two years in Hong Kong he came to the U.S. in 1969 and joined the U.C.L.A. faculty, where he has pioneered in the application of computer science to oracle-bone studies.

MICHAEL S. FELD, RONALD E. McNAIR and STEPHEN R. WILK ("The Physics of Karate") are physicists with an avocational interest in the martial arts. Feld is associate professor of physics at the Massachusetts Institute of Technology. He was educated at M.I.T., obtaining his B.S. and M.S. in 1963 and his Ph.D. in 1967. In July, 1976, he became director of the M.I.T. spectroscopy laboratory. His current research is in the field of laser physics, particularly the interaction of intense light fields with atomic and molecular systems. Feld holds a third-degree brown belt in karate. McNair is an astronaut candidate at the Lyndon B. Johnson Space Center in Houston, Tex. He did his undergraduate work in physics at North Carolina A & T State University and received his Ph.D. in physics from M.I.T. in 1976 for work on high-pressure carbon monoxide lasers. Following his graduation he became a staff physicist at the Hughes Research Laboratories in Malibu, Calif. In January, 1978, he was selected as an astronaut candidate by the National Aeronautics and Space Administration, and in July he began a two-year training and evaluation program to qualify for assignment as a mission specialist on future space-shuttle flight crews. McNair holds a second-degree black belt in karate. Wilk is a graduate student at the Institute of Optics of the University of Rochester. He was graduated from M.I.T. in 1977 and did his bachelor's thesis on the physics of karate.

LARRY KUHN and ROBERT A. MYERS ("Ink-Jet Printing") do research and development work for the International Business Machines Corporation. Kuhn is component-engineering manager of IBM's General Products Division in Tucson, Ariz. He received his B.S., M.S. and Eng.Sci.D. degrees from Columbia University, the last in 1968, and then joined the IBM Research Division in Yorktown Heights, N.Y. In 1973 Kuhn set up a program that led to the development of the ink-jet printer described in the article. Myers is manager of terminal technologies at the IBM Thomas J. Watson Research Center. He was educated at Harvard University, where he obtained his B.A. summa cum laude, his M.A. and his Ph.D. in applied physics, the last in 1964. From 1963 to 1968 he was a member of the research staff of the Watson Research Center, moving in 1968 to the staff of the Corporate Technical Committee at IBM headquarters in Armonk, N.Y., where he concentrated on communications and terminal technologies. He returned to the Research Division in 1973. Myers holds 10 U.S. patents and has another pending.

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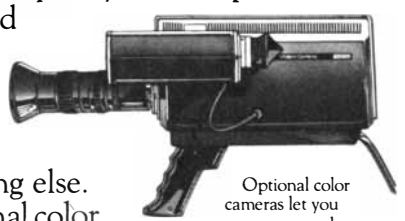

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MATHEMATICAL GAMES

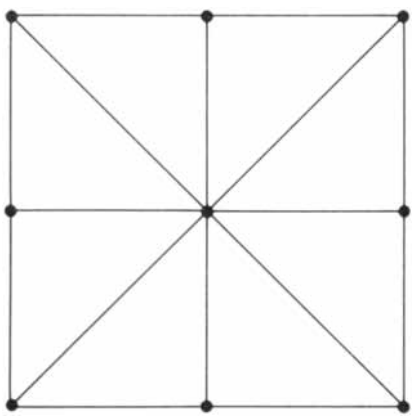
In which players of ticktacktoe are taught to hunt bigger game

by Martin Gardner

The world's simplest, oldest and most popular pencil-and-paper game is still ticktacktoe, and combinatorial mathematicians, often with the aid of computers, continue to explore unusual variations and generalizations of it. In one variant that goes back to ancient times the two players are each given three counters, and they take turns first placing them on the three-by-three board and then moving them from cell to cell until one player gets his three counters in a row. (I discussed this game in my first column on ticktacktoe, in March, 1957.) Moving-counter ticktacktoe is the basis for a number of modern commercial games, such as John Scarne's Teeko and a new game called Touché, in which concealed magnets cause counters to flip over and become opponent pieces.

Standard ticktacktoe can obviously be generalized to larger fields. For example, the old Japanese game of go-moku ("five stones") is essentially five-in-a-row ticktacktoe played on a go board. Another way to generalize the game is to play it on "boards" of three or more dimensions. These variants and others were discussed in this department for August, 1971.

In March, 1977, Frank Harary devised a delightful new way to generalize ticktacktoe. Harary is a mathematician who divides his time between the University of Michigan's mathematics department and its Institute for Social Research. He has been called Mr. Graph Theory because of his tireless, pioneering work in this rapidly growing field that is partly combinatorial and partly topological. Last year he gave a speech in the German city Xanten, thereby completing a list of about 150 cities outside the U.S. in which he has lectured that includes names beginning with the letters from *A* through *Z*. Harary is the founder and editor of *Journal of Graph Theory* and the author of *Graph Theory,* which is considered the world over to be the definitive textbook on the subject. His papers on graph theory, written alone or in collaboration with other mathematicians, number some 300. Harary ticktacktoe, as I shall call his generalization of the game, opens up numerous fascinating areas of recreational mathematics. This month, with Harary's permission, I shall summarize for the first time some of the basic results that have been obtained so far.



Ticktacktoe as a graph-coloring game

We begin by observing that standard ticktacktoe can be viewed as a two-color geometric-graph game of the type Harary calls an achievement game. Replace the nine cells of the ticktacktoe board with nine points joined by lines, as is shown in the illustration at the left. The players are each assigned a color, and they take turns coloring points on the graph. The first player to complete a straight line of three points in his color wins. This game is clearly isomorphic with standard ticktacktoe, which is well known to end in a draw if both players make the best possible moves.

Let us now ask: What is the smallest square on which the first player can force a win by coloring a straight three-point path? It is easy to show that it is a square of side 4. Harary calls this side length the board number *b* of the game. It is closely related to the Ramsey number of generalized Ramsey graph theory, a number that plays an important part in the Ramsey games discussed in this department for November, 1977. (Ramsey theory is a field in which Harary has made and continues to make notable contributions. It was in a 1972 survey paper on Ramsey theory that Harary first proposed making a general study of games played on graphs by coloring the graph lines.) Once we have determined the value of *b* we can ask a second question. In how few moves can the first player win? A little doodling shows that on a board of side 4 the first player can force a win in three moves. Harary calls this figure the move number *m* of the game.

In ticktacktoe a player wins by taking cells that form a straight, order-3 polyomino that is either edge- or corner-connected. (The corner-connected figure corresponds to taking three cells on a diagonal.) Polyominoes of orders 1 through 5 are depicted in the illustrations on pages 23 and 25. The polyomino terminology was coined by Solomon W. Golomb, who was the first to make a detailed study of these figures. Harary prefers to follow the usage of a number of early papers on the subject and call them "animals." I shall follow that practice here.

We are now prepared to explain Harary's fortuitous generalization. Choose an animal of any order and declare its formation to be the objective of a ticktacktoelike game. As in ticktacktoe we shall play not by coloring spots on a graph but by marking cells on square matrixes with noughts and crosses in the usual manner or by coloring cells red and green as one colors edges in a Ramsey graph game. Each player tries to label or color cells that will form the desired animal. The animal will be accepted in any orientation and, if it is asymmetrical, in either of its mirror-image forms.

Our first task is to determine the animal's board number, that is, the length of the side of the smallest square on which the first player can, by playing the best possible strategy, force a win. If such a number exists, the animal is called a winner, and it will be a winner on all larger square fields. If there is no board number, the animal is called a loser. If the animal chosen as the objective of a game is a loser, the second player can always force a draw, but he can never force a win. The proof of this fact is well known and applies to most ticktacktoelike games. Assume that the second player has a winning strategy. The first player can "steal" the strategy by first making an irrelevant opening move (which can never be a liability) and thereafter playing the winning strategy. This finding contradicts the assumption that the second player has a winning strategy, and so that assumption must be false. Hence the second player can never force a win. If the animal is a winner and *b* is known, we next seek *m,* the minimum number of moves in which the game can be won.

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For the 1-cell animal (the monomino), which is trivially a winner, b and m are both equal to 1. When, as in this case, m is equal to the number of cells in the animal, Harary calls the game economical, because a player can win it without having to take any cell that is not part of the animal. The game in which the objective is the only 2-cell animal (the domino) is almost as trivial. It is also economical, with b and m both equal to 2. The games played with the two 3-cell animals (the trominoes) are slightly more difficult to analyze, but the reader can easily demonstrate that both are economical: for the L-shaped 3-cell animal b and m are both equal to 3, and for the straight 3-cell animal b equals 4 and m equals 3. This last game is identical with standard ticktacktoe except that corner-connected, or diagonal, rows of three cells are not counted as wins.

It is when we turn to the 4-cell animals (the tetrominoes) that the project really becomes interesting. Harary has given each of the five order-4 animals names, as is shown in the illustration on this page. Readers may enjoy proving that the b and m numbers given in the illustration are correct. Note that Fatty (the square tetromino) has no such numbers and so is labeled a loser. It was Andreas R. Blass, one of Harary's colleagues at Michigan, who proved that the first player cannot force Fatty on a field of any size, even on the infinite lattice. Blass's result was the first surprise of the investigation into Harary ticktacktoe. From this finding it follows at once that any larger animal containing a two-by-two square also is a loser: the second player simply plays to prevent Fatty's formation. More generally, any animal that contains a loser of a lower order is itself a loser. Harary calls a loser that contains no loser of lower order a basic loser. Fatty is the smallest basic loser.

The proof that Fatty is a loser is so simple and elegant that it can be explained quickly. Imagine the infinite plane tiled with dominoes in the manner shown at the top of the illustration on page 26. If Fatty is drawn anywhere on this tiling, it must contain a domino. Hence the second player's strategy is simply to respond to each of his opponent's moves by taking the other cell of the same domino. As a result the first player will never be able to complete a domino, and so he will never be able to complete a Fatty. If an animal is a loser on the infinite board, it is a loser on all finite boards. Therefore Fatty is everywhere a loser.

Early last year Harary and his colleagues, working with only the top four domino tilings shown in the illustration on page 26, established that all but three of the 12 5-cell animals are losers. Among the nine losers only the one containing Fatty is not a basic loser. Turning to the 35 6-cell animals, all but four contain basic losers of lower order. Of the remaining four possible winners three can be proved losers with one of the five tilings shown in the illustration. The animals that can be proved basic losers with each tiling pattern are shown alongside the pattern. In every case the proof is the same: it is impossible to draw the loser on the associated tiling pattern (which is assumed to be infinite) without including a domino; therefore the second player can always prevent the first player from forming the animal by following the strategy already described for blocking Fatty. There are a total of 12 basic losers of order 6 or lower.

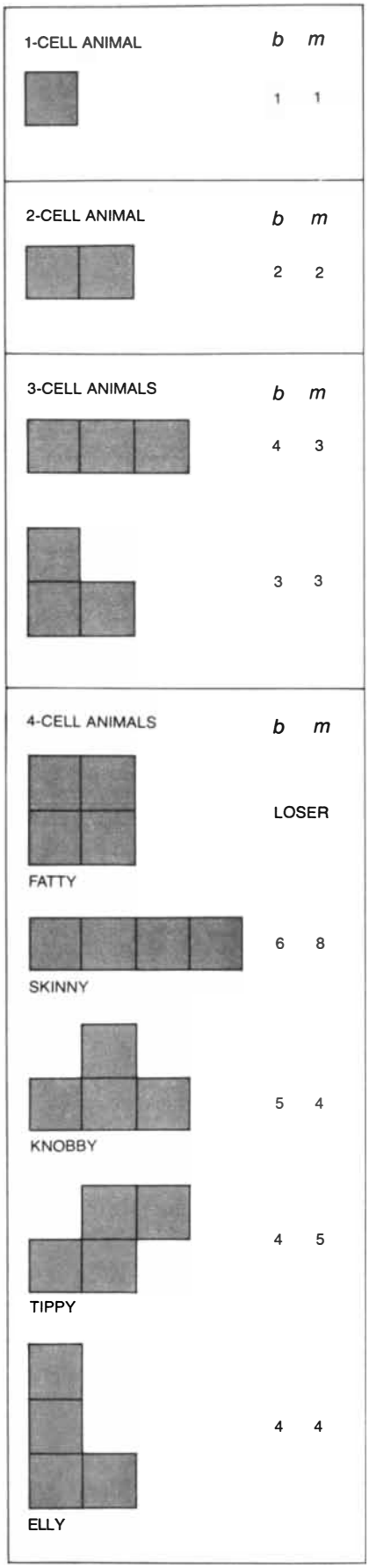
It is worth noting how the tiling proof that the straight animal of five cells is a loser (another proof that was first found by Blass) bears on the game of go-moku. If the game is limited to an objective of five adjacent cells in a horizontal or vertical line (eliminating wins by diagonal lines), the second player can always force a draw. When diagonal wins are allowed, the game is believed to be a first-player win, although as far as I know that has not yet been proved even for fields larger than the go board.

The only 6-cell animal that may be a winner is the one Harary and his colleagues call Snaky:

Although they have not yet been able to prove this animal is a winner, they believe its board number is no larger than 15 and its move number is no larger than 13. This assertion is the outstanding unsolved problem in Harary ticktacktoe theory. Perhaps a reader can prove Snaky is a loser or conversely show how the first player can force the animal on a square field and determine its board and move numbers.

All the 107 order-7 animals are known to be losers. Therefore since every higher-order animal must contain an order-7 animal, it can be said with confidence that there are no winners beyond order 6. If Snaky is a winner, as Harary and his assistant Geoffrey A. Exoo conjecture, there are exactly a dozen winners—half of them economical—and a dozen basic losers.

Any 4- or 5-cell animal can be the basis of a pleasant pencil-and-paper game. If both players know the full analysis, then depending on the animal chosen either the first player will win or the second player will force a draw. As in ticktacktoe between inexpert players, however, if this knowledge is lacking, the game can be entertaining. If the animal chosen as the objective of the game is a winner, the game is best played on a board of side b or $b - 1$. (Remember that a square of side $b - 1$ is the largest



Animals of 1 cell through 4 cells

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board on which the first player cannot force a win.)

All the variations and generalizations of Harary ticktacktoe that have been considered so far are, as Harary once put it, "Ramseyish." For example, one can play the misère, or reverse, form of any game—in Harary's terminology an avoidance game—in which a player wins by forcing his opponent to color the chosen animal. Only four animals are known to be nondraws in avoidance games. The smallest are the monomino and the domino. When the domino is the "objective," the second player can force a win on any rectangular board (including a square) for which both sides are at least 2 in length. The second player's winning strategy is to assume that the board is colored like a checkerboard and then to respond to his opponent's opening move by playing on any cell of the same color. Thereafter he continues to play anywhere he likes on cells of that color until they are all occupied. It is an interesting problem to provide a rigorous demonstration of the second player's subsequent strategy.

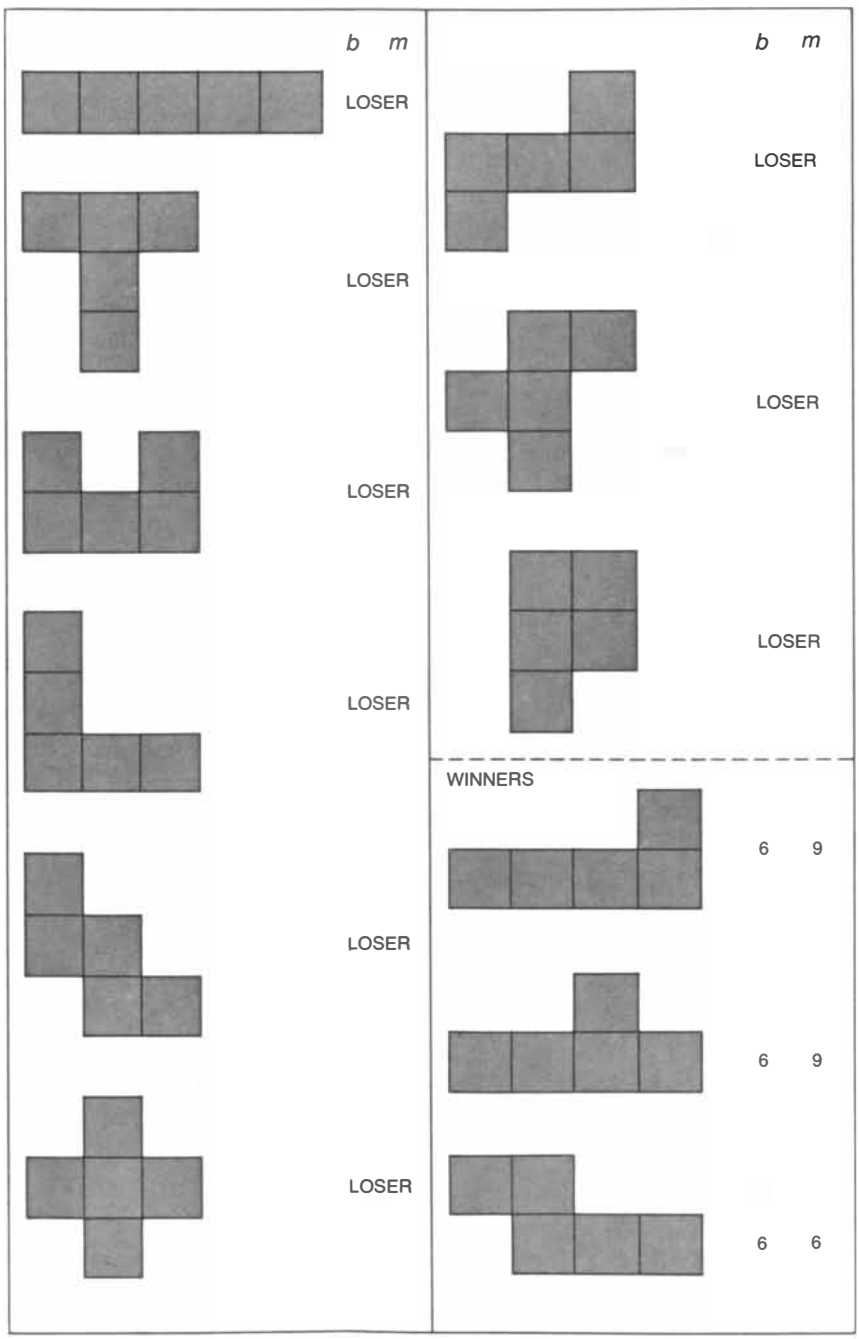
On a square board the first player can also be forced to complete the *L*-shaped 3-cell animal. Obviously the length of the square's side must be at least 3 for the game to be meaningful. If the length of the side is odd, the second player will win if he follows each of his opponent's moves by taking the cell symmetrically opposite the move with respect to the center of the board. If the first player avoids taking the center, he will be forced to take it on his last move and so will lose. If he takes it earlier in the game without losing, the second player should follow with any safe move. If the first player then takes the cell that is symmetrically opposite the second player's move with respect to the center, the second player should again make a harmless move, and so on; otherwise he should revert to his former strategy. If the length of the square's side is even, this type of symmetrical play leads to a draw, but the second player can still win by applying more complicated tactics.

On square boards the straight 3-cell animal cannot be forced on the first player. The proof of this fact is a bit difficult, even for the three-by-three square, but as a result no larger animal containing the straight 3-cell species can be forced on any square board. (The situation is analogous to that of basic losers in animal-achievement games.) Hence among the 4-cell animals only Fatty and Tippy remain as possible nondraws. Fatty can be shown to be a draw on any square board, but Tippy can be forced on the first player on all square boards of odd side. The complete analysis of all animal-avoidance games is still in the early stages and appears to present difficult problems.

Harary has proposed many other nontrivial variants of the basic animal games. For example, the objective of a game can be two or more different animals. In this case the first player can try to form one animal and the second player the other, or both players can try to form either one. In addition achievement and avoidance can be combined in the same game, and nonrectangular boards can be used. It is possible to include three or more players in any game, but this twist introduces coalition play and leads to enormous complexities. The rules can also be revised to accept corner-connected animals or animals that are both edge- and corner-connected. At the limit, of course, one could make any pattern whatsoever the objective of a ticktacktoelike game, but such broad generalizations usually lead to games that are too complicated to be interesting.

Another way of generalizing these games is to play them with polyiamonds (identical edge-joined equilateral triangles) or polyhexes (identical edge-joined regular hexagons) respectively on a regular triangular field or a regular hexagonal field. One could also investigate games played with these animals on less regular fields.

The games played with square animals can obviously be extended to

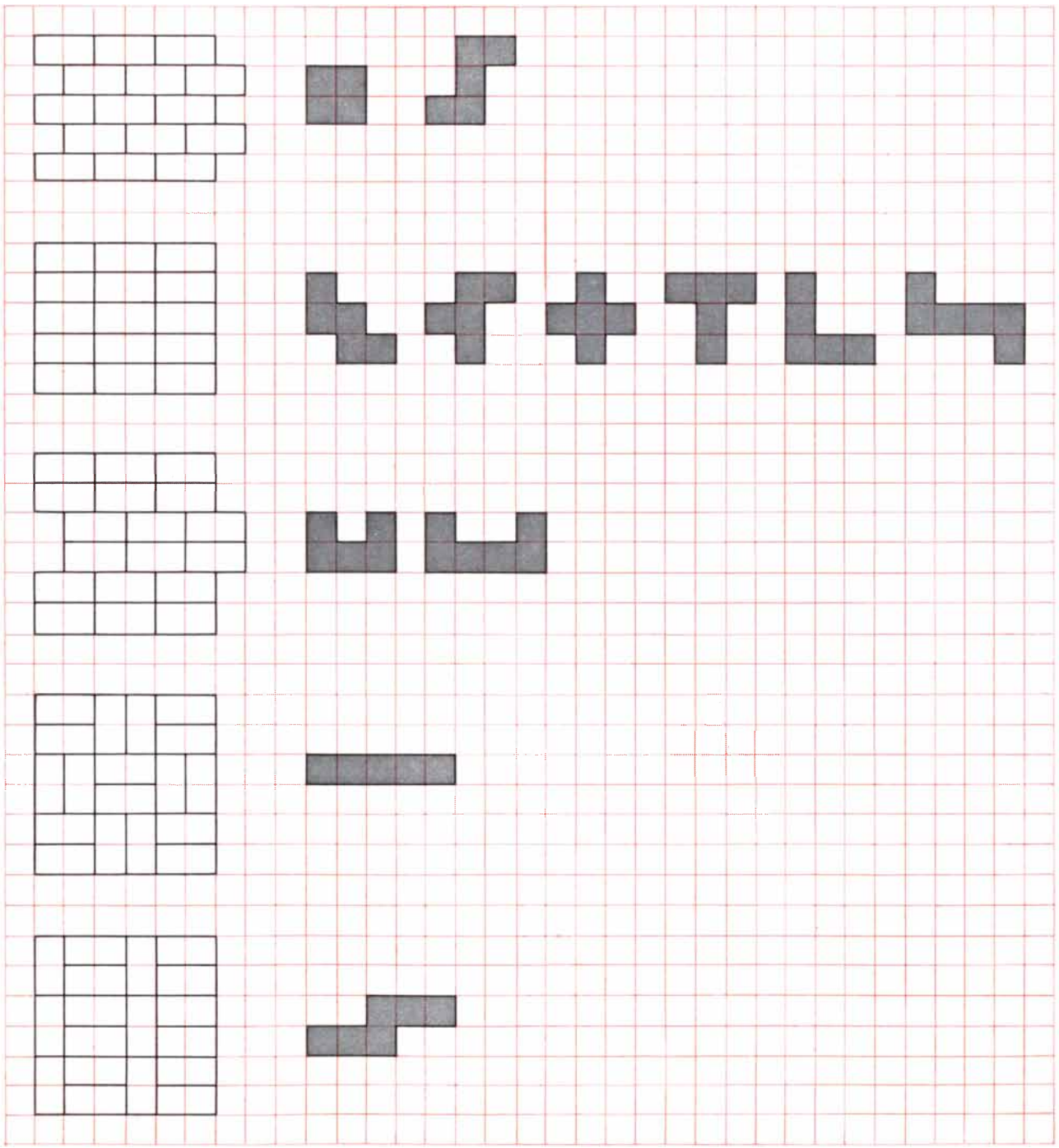


The 12 animals of 5 cells

boards of three or more dimensions. For example, the 3-space analogue of the polyomino is the polycube: n unit cubes joined along faces. Given a polycube, one could seek b and m numbers based on the smallest cubical lattice within which the first player can force a win and try to find all the polycubes that are basic losers. This generalization is almost totally unexplored.

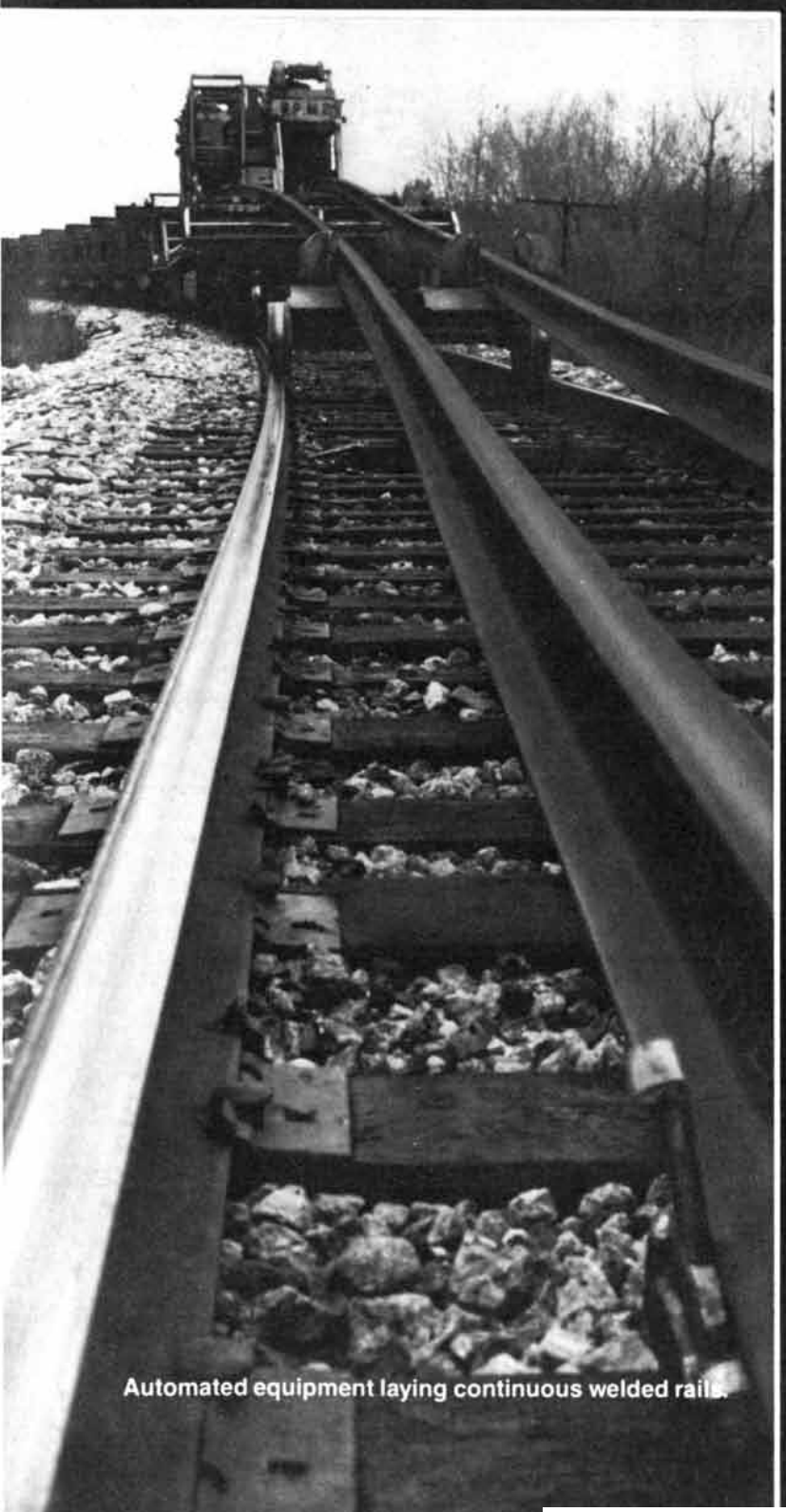
As I have mentioned, Blass, now associate professor at Michigan, is one of Harary's main collaborators. The others include Exoo, Jerald A. Kabell and Heiko Harborth, who is investigating games with the triangular and hexagonal cousins of the square animals. Harary is planning a book on achievement and avoidance games in which all these generalizations of ticktacktoe and many other closely related games will be explored, and he is also developing computer programs for playing these games both offensively and defensively.

The "impossible" hypercard discussed in this department last November suggested a number of variants. Paul T. Merva and Alexis A. Gilliland came on the funniest variant independently. They each sent in a model of the paper ring shown in the illustration on page 28. It is actually a Möbius band, and in the form depicted it seems even more mysterious than the original card. Gilliland also applied the construction to the lid of a cylindrical can and to a Klein bottle. In the case of the Möbius band as many mystery flaps as are wanted can be made in what seems to be an untwisted ring. The ring will be one- or two-sided depending on whether an odd



Tiling patterns **(left)** *for the 12 basic losers* **(right)**

Myth:
Railroads run on legends and old tracks.



Automated equipment laying continuous welded rails.

Fact:
America's freight railroads spent a record $10 billion in capital improvements and maintenance in 1978.

The only thing legendary about today's freight railroads is their record investment in track and rolling stock last year. 1979 plans call for increasing even those massive expenditures by about 20%.

In 1978, the railroads put more than 1,300 new and rebuilt locomotives into service and ordered more than 125,000 new freight cars. In addition, more than 4,700 miles of track has been replaced with new rail in each of the last two years—some 58% more than the yearly average in the previous ten years. And new crossties installed averaged more than 27 million in 1977 and 1978—36% above the 1966-1975 average.

These huge investments help increase efficiency and improve service. Just as important, they help improve safety. Even though rail traffic has increased substantially, total deaths and injuries from rail accidents continue to decline and have reached the lowest levels since record-keeping began in 1891.

Additional investments by railroads and suppliers in continuing research provide other benefits as well—development of better, stronger track and even safer cars for moving vital hazardous materials. Railroads provide 70% of the transportation for the commodities classified as hazardous, excepting only petroleum, but they are involved in less than 9% of the accidents involving hazardous materials.

For more information about America's surprising freight railroads and their multi-billion dollar investments in safe transportation, write to: Association of American Railroads, American Railroads Building, Washington, D.C. 20036.

Surprise:
America's freight railroads provide the safest, most efficient transportation on wheels.

or an even number of flaps are made. On a cardboard napkin ring (or a ring cut from a cylindrical container) it is possible to make an even number of such flaps without having to cut the ring apart and rejoin the ends.

Scores of readers wrote to insist that the answer to the social-security-number problem given in this department for last December is not unique and to offer alternate solutions. I found the situation mystifying until I realized what had happened: they had all relied on a pocket calculator with an eight-digit readout to divide an eight-digit number by 8, without checking by hand to see if there was a remainder! (Incidentally, a large number is divisible by 8 if and only if its last three digits are.) Many other readers sent correct proofs of the uniqueness of the number 3816-54729, based either on computer programs or on familiar divisibility rules plus reasoning.

Michael R. Leuze worked with a computer to examine solutions to this problem in number systems other than base 10. He found that there are no solutions in any odd base or in base 12. In base 2 there is the trivial solution 1. In base 4 there are two solutions, 123 and 321; in base 6, 14325 and 54321; in base 8, 3254167, 5234761 and 5674321. In base 14, as in base 10, there is a unique solution: 9 12 3 10 5 4 7 6 11 8 1 2 13. Leuze conjectures that there are no solutions in higher bases.

David M. Sanger generalized in a different way by asking what the numbers are whose first n digits are divisible by n, with no other requirements. His computer program found all such numbers, starting with the 45 two-digit numbers (ignoring initial zeros) and ending with the unique 25-digit number 3,608,528,850,368,400,786,036,725.

Because no 26th digit can be added to make a number divisible by 26 that number ends the sequence. There are 2,492 10-digit numbers; the smallest number is 1,020,005,640 and the largest one is 9,876,545,640. One peculiar number is 3,000,060,000. The number of numbers increases steadily from $n = 2$ through $n = 9$ and $n = 10$ (in both cases there are 2,492 numbers) and then declines steadily. For $n = 20$ through $n = 25$ the numbers of numbers are respectively 44, 18, 12, 6, 3 and 1. The last is the only number that provides a single answer for any n.

Alan Delahoy was the first of the readers too numerous to mention who sent proofs that 16 moves is minimal for the knight-switch problem. Many of these proofs begin by transforming the problem to a 12-point graph in the manner given in my book *Aha! Insight* (W. H. Freeman and Company, 1977), in the first printing of which I incorrectly gave 18 as the minimum number of moves. When the problem is in this form, it is easy to show that a solution must have an even number of moves that cannot be less than 14. (If the board has only three knights of one color, seven moves are needed to get them from one side to the other.) All that remains, then, is to show that 14 moves are too few. The insight that reduces 18 moves to 16 is the realization that backtracking one knight—returning it to a cell from which it had moved—clears the way for another knight move. All 16-move solutions have this feature.

Howard Rumsey, Jr., proved on a home computer that any distribution of the six knights can be reached from the starting pattern in 22 moves or fewer. Any knight pattern can be reached from any other pattern in no more than 26 moves. Rumsey found seven pairs of such patterns (not counting symmetries) for which 26 moves are required to go from one distribution of knights to the other.

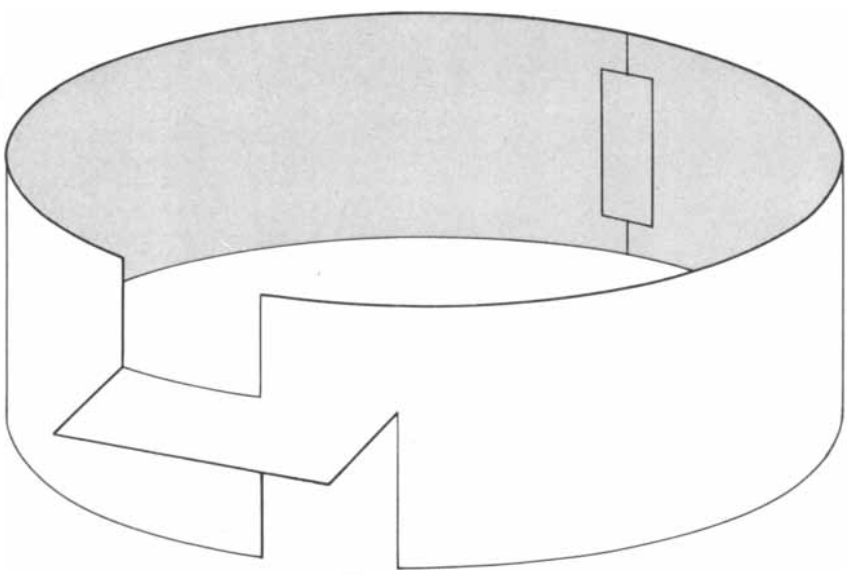
James G. Mauldon suggested replacing the middle knight on each side with a king that moves like a knight and adding the requirement that the kings change places. He found a 22-move solution to the problem. If knights are placed on the two central squares to make four knights of the same color on each side, the knights of different colors can be switched in 12 moves. Mauldon also added the proviso that these eight knights be paired with respect to the horizontal center line of the board and that all pairs be interchanged. He believes 36 moves are minimal here. He has found a 44-move solution to the problem that pairs the knights that are symmetrically opposite with respect to the center of the board.

The robot ASMOF gave "inkstand" and "crankshaft" as dictionary words containing respectively *nkst* and *nksh*. Many readers sent in other words. The commonest word for *nkst* was "prankster," but "clinkstone," "pinkster," "pinkstone," "sinkstone," "stinkstone" and archaic words found only in *The Oxford English Dictionary* were received. For *nksh* among the most common alternatives suggested were "bankshare," "monkship," "monkshood" and "tankship." Some readers composed sentences with solution words. Jim Rector closed his letter with "No thankstoyou, I thinkstoomuch."

George Starbuck found "schnappsed," another 10-letter word of one syllable, but he was topped by his friend William Harmon (both men are poets), who wrote to him: "Schnappsed can't be beat. I realized this while being broughammed to the airport." (Several dictionaries prefer the monosyllabic pronunciation of this 11-letter word.)

The robot's reasoning as to why a person cannot be exactly one-third Scottish, one-third Chinese and one-third Hungarian came in for heavy criticism. Readers were right in not taking the robot's solution seriously, since it relied on several unrealistic assumptions. In particular, ASMOF's argument assumes that all progenitors are full-blooded, which in the real world is found to be preposterous as soon as someone's ancestry is traced back a few generations.

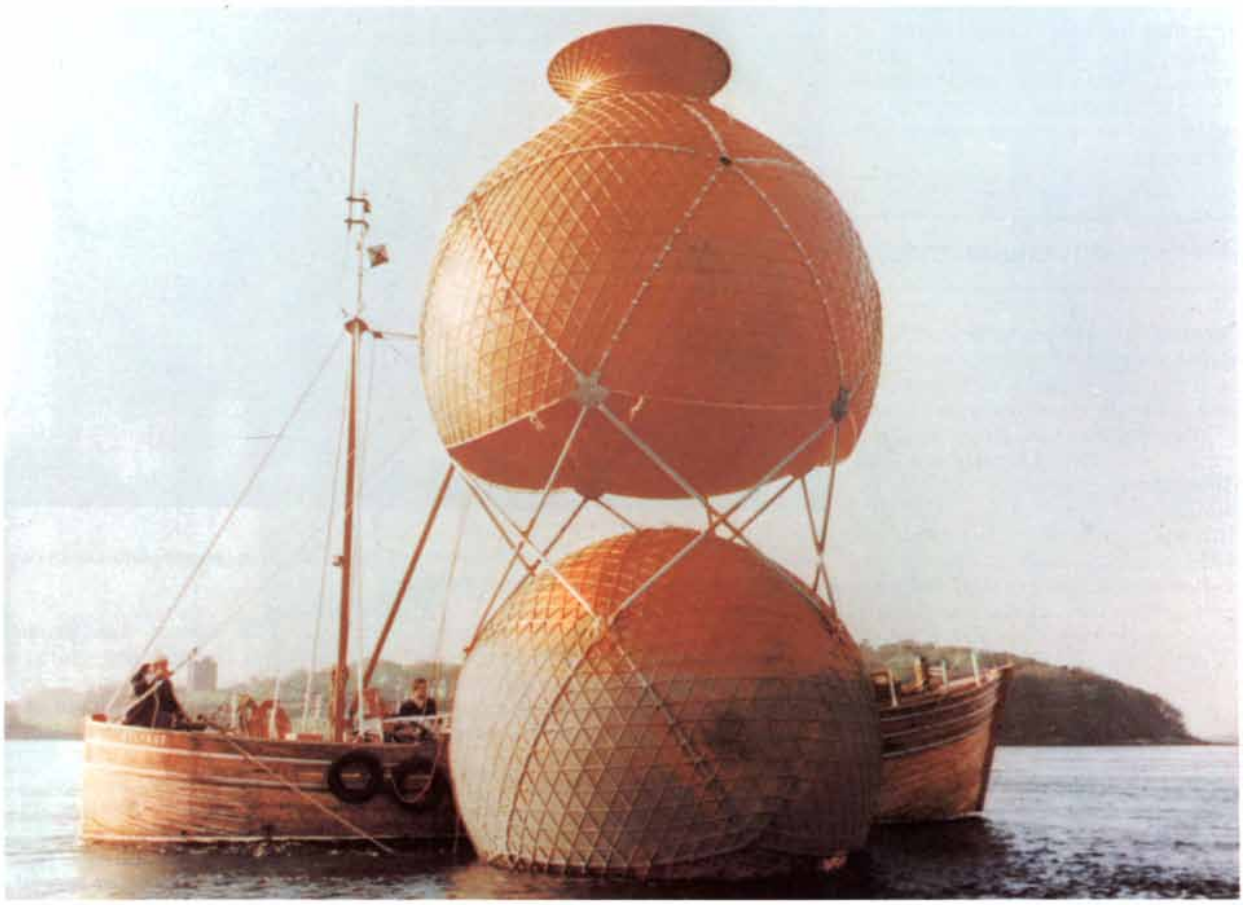
One final correction: At the end of this department for last December a prime-number proof was incorrectly attributed to Anna M. Penk. She is the mother of Michael A. Penk, a computer scientist, whose name should have appeared instead.



Mystery flap on a Möbius band

Advancing technology in Northern Ireland

This special report on developments in technology in Northern Ireland was written by Kenneth Owen, Technology Correspondent of *The Times*, London.



Wave-energy research by Queen's University, Belfast: when part-submerged, this one-tenth-scale hydropneumatic buoy harnesses wave motion to generate electricity through the piston action of water in the upper chamber.

Among the recognized centers of advanced technology, Northern Ireland is rarely mentioned. But, recognized or not, the Province has a growing capability in research, design, development and advanced-technology production. In a close-knit community where the industrial innovators include world-famous names such as Courtaulds, Du Pont, Goodyear and ICI, university research has initiated notable advances in energy, the environment and engineering. Though its technological reputation may have been modest in the past, Northern Ireland now offers an effective base from which to mount further international technology initiatives.

These were among the impressions I gained during a recent visit to the Province at the invitation of the Northern Ireland Department of Commerce. They can be illustrated by specific examples in research, development, new products and new processes.

In the realm of research into alternative energy sources, an ingenious new concept of obtaining electrical power from the motion of waves is under investigation in the Civil Engineering Department of Queen's University, Belfast, under Professor A. E. Long. Wave power, if it could be harnessed effectively, would be particularly attractive as a source of energy for the United Kingdom, and the Queen's design is one of several approaches which are being examined and tested as part of a national program.

Professor Long's team is working on a version of what is known as an oscillating water column device. It uses a moored buoy which is open at the bottom; under the action of the waves the water inside the buoy moves up and down. This forces air out and in through the open neck of the device and electrical power can be produced via generators coupled to an air turbine.

After preliminary work on a number of designs, the Queen's group is concentrating on a hydropneumatic buoy of approximately one-tenth scale. The buoy consists of two parts — an upper canopy shaped rather like a Grecian urn (but 4.5 meters in diameter), in which the hydraulic piston action takes place, and a lower 4-meter ballast sphere — connected by a tubular framework.

In the narrow neck of the urn-like canopy there is a two-blade rotor and a 45-kilowatt alternator. The rotor is a 'self-rectifying' unit (rotat-

ing in the same direction whether the airflow is entering or leaving the chamber) based on a design by Professor Alan Wells, which simplifies the pneumatic/electric conversion. This prototype wave-power device (developed in collaboration with other departments of the university and with Central Electricity Generating Board laboratories in Marchwood in England) is now being tested in Strangford Lough, Northern Ireland. According to Professor Long, it could lead to relatively inexpensive wave-power systems in the future.

Development engineering

Turning from energy research to engineering development, companies from many parts of the world have made their way in recent years to the Ashby Building, Belfast, home of the Department of Mechanical and Industrial Engineering at the Queen's University, to seek out the expertise of the academic staff in various aspects of engineering design and processes. Here the examples include the design of small engines, high-pressure engineering and explosive welding.

Professor B. Crossland, head of the department, has led research and development into the use of explosive welding (a well-established process for cladding one metal on another and for welding tubes to tube-plates) in the plugging of heat-exchanger tubes in nuclear reactors. In a single nuclear plant there may be many thousands of welded tubes, and plugging rather than replacement of faulty tubes is normally adopted.

The Belfast systems have been used for Britain's prototype fast reactor and, in association with Babcock & Wilcox, for advanced gas-cooled reactors.

Professor Crossland's other areas of research have included the properties of tungsten carbide at high pressures and temperatures, for De Beers Industrial Diamond Ltd; and problems of explosive cladding of titanium on steel for the Nobel Explosive Company.

Professor Gordon Blair of the same department has become a world authority on the design and development of small engines. His particular professional expertise is in the computer-based prediction of the detailed performance, and noise characteristics of engines, particularly two-stroke spark-ignition engines, based on their geometry and on a detailed analysis of the pulsating gas flow through the engine. His special outside interest is in motorcycles, so that theory and practice come together totally.

Professor Gordon Blair, consultant to Yamaha and other companies: engine performance can be predicted using advanced computer techniques.

Professor Blair comments, 'The computer program can now tell the engine designer not only the performance characteristics such as power output and fuel consumption of an engine fitted with intake and exhaust silencers, but will provide the design information for those silencers and their noise output'.

Professor Blair's consultancy clients on specialised aspects of two-stroke engine design include Yamaha, Mercury Marine, Harley-Davidson and McCulloch Corporation. On the experimental side, industrially sponsored work is being carried out today on reduction of fuel consumption and exhaust emission from both two- and four-stroke cycle engines.

Among companies based in Northern Ireland, Goodyear Tyre & Rubber has a consistent approach to research and development which is coupled closely to production. Applied research and development for industrial rubber products and plastics (i.e. virtually all Goodyear products except tires) is conducted at the company's international technical center located at the Goodyear plant at Craigavon, County Armagh. The center has grown gradually over the past few years; a major expansion is now under way which involves the construction of a new £3m (about $6m) purpose-built facility.

Mr Challen Taylor, director of the Craigavon center, stresses the importance of pilot production in the company's development programs. 'We go through four stages', he says. 'First, basic research. Secondly, a feasibility study involving small-scale laboratory work. Thirdly, pilot production using full-scale factory equipment operated by laboratory technicians and engineers. Fourthly, actual production in the factory'.

The center has two customers, says Mr Taylor, the factory (which means all Goodyear non-tire factories outside the United States) and the market. In other words, innovations are aimed at new in-house processes or new products for world markets. 'We're working at between 80 and 100 projects at present. Some are major modifications; some are true innovations'.

Why did Goodyear choose to locate its international technical center in Northern Ireland? Because the Craigavon plant — the largest and most up-to-date of its type — was already there. 'We have to innovate', says Challen Taylor, 'and to do this we have to be where the action is'.

A major project could take five years to complete; thus the center tries to look beyond today's needs and tomorrow's markets. 'We try to live in the day after tomorrow', Mr Taylor comments. As for recruiting the skilled staff that the center's forward-looking work demands, laboratory technicians and technical engineers tend to move from the factory — and are then encouraged to study for engineering degrees and other qualifications — while the company recruits young science and engineering graduates directly from local universities and the polytechnic and then trains them as problem-solving engineers and technologists.

New products and processes are part of the Ulster scene. Among the new products is a unique item of medical electronic equipment which literally can mean the difference between life and death for people who experience sudden heart attacks. The number of deaths from coronary attacks is enormous; most of them occur suddenly and away from hospitals; and more than 90 per cent of sudden coronary deaths result from a condition known as ventricular fibrillation — an electrical oscillation in the heart.

Against this background Professor J. F. Pantridge of the Department of Cardiology at the Royal Victoria Hospital, Belfast has been developing a range of portable defibrillators — machines which deliver an electrical charge through the patient's chest to remove the dangerous fibrillation.

Professor J. F. Pantridge, inventor of progressively smaller portable heart defibrillators: vital tools for on-the-spot resuscitation of heart-attack victims.

Defibrillation has been in use as a medical technique since 1947, but its early development was in the form of large, hospital-based, mains-powered machines. Professor Pantridge has concentrated on portable machines which can be carried in mobile emergency units, police cars, ambulances and physicians' cars; and has progressively reduced the weight of the units from 15 lb first to 7 lb and now to 4 lb. Even smaller versions are planned.

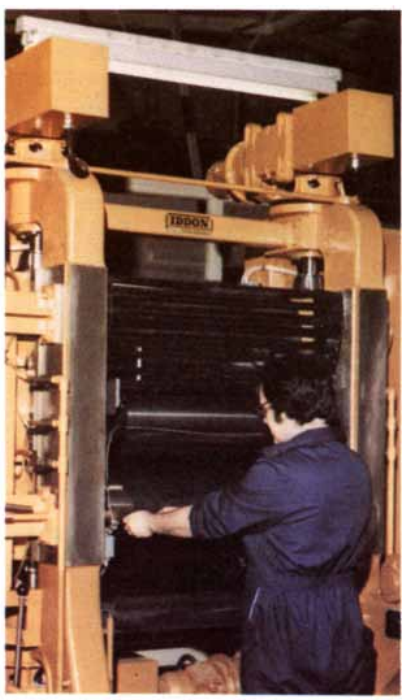
Pantridge defibrillators have been manufactured by Cardiac Recorders of London, and under a recent agreement they will be made for the American market by Coronary Care Systems (a subsidiary of Ipco Hospital Supply Corporation of White Plains, New York) in a new factory at Bangor, County Down. Coronary Care previously operated a small research and development unit in Bangor and now plans to produce a range of medical equipment there.

In the field of new processes as distinct from new products, Courtaulds' textile plant at Campsie, near Londonderry, is perhaps the most advanced of its type anywhere. It has a million square feet of floorspace under a single roof, and differs from most textile plants in that it has been designed as a complete, integrated unit. The plant is 'integrated' in the sense that it has been designed to combine the traditionally separate processes of spinning, weaving, dyeing and final making-up; it is a highly automated plant dedicated to the mass production of sheeting and 'workwear' fabrics.

Here the advanced technology lies in the control, automation and monitoring of the complete sequence of processes, and the 'fine tuning' of individual parts of the system to give the required continuous performance, 24 hours a day, seven days a week.

At present the plant takes in raw manmade fiber — polyester and Vincel (Polynosic) — at one end and dispenses lengths of finished sheeting (in a variety of designs and colors) and workwear fabric at the other. The planned making-up unit in which the sheeting will be made up and packaged as sheets, pillowcases, quilt covers and valances will be introduced later.

Calender machine used for sheeting out rubber or for applying rubber to fabric at Goodyear's international technical center, Craigavon.



Industrial relevance

These examples of research, development, new products and new processes indicate the diversity of technology in Northern Ireland to-

Woven cloth is inspected in the lower level of the weaving unit of Courtaulds' integrated textile plant at Campsie; the cloth is fed down from weaving machines on the floor above.

day — from wave energy to rubber and plastics development; from small-scale but vital medical electronics to the all-in mass production of textiles. Other examples underline the Province's strength in a number of specific areas, and demonstrate useful mechanisms for ensuring that research is industrially relevant and is followed through along the complete innovation chain from laboratory to the marketplace.

One established method of harnessing research and development to the needs of specific industries in the United Kingdom is seen in the work of the industrial research associations — specialized, cooperative laboratories whose R and D programs are primarily dedicated to serve the broad interests of their member-companies. In addition to their cooperative programs, the research associations provide ad hoc consultancy on a contract-research basis. Their funds come partly from their respective industries and partly from government research contracts where the work is judged to be of national industrial importance.

One such association is Lambeg Industrial Research Association (LIRA), located in an old country mansion at Lambeg, near Lisburn in County Antrim. Set up in 1919 to serve the linen industry, LIRA has now broadened its scope to embrace textiles generally, and has diversified into new areas such as polymers, textile applications in civil engineering, non-flammable materials and pollution control.

Ulster Polytechnic at Jordanstown, source of innovation for industry.

LIRA has also become a part of an integrated European textiles research effort — in particular, in a program in which the Lambeg laboratories have pioneered new methods of producing and processing flax fiber, based on the chemical and mechanical treatment of the fibers at certain stages of production. The resulting streamlined processing could bring flax much more into the mainstream of textile production.

In polymer films, Lambeg has established itself as a world authority on the extrusion and processing of polyolefin films for use as weaving tapes and in the production of fibers. Among the applications of these new industrial raw materials are carpet backings and, increasingly, woven polypropylene tape fabrics for civil engineering and the construction industry.

This latter field, known as geotextiles, includes the use of fabrics to help stabilize and reinforce the soil on waterlogged sites and for haul roads over soft ground; to stabilize earth embankments; and as a filtering lining for drainage systems. (New technology is often not as new as it seems: though regarded as a recent development, these geotextile techniques — though not these materials — were used by the Romans).

In the important and (for LIRA) non-traditional field of pollution control, the Lambeg establishment has developed a new range of manganese-based catalysts suitable for removing unpleasant smells and toxic substances by oxidation from the effluents of various industrial processes.

The catalysts provide an inexpensive starting material for anti-pollution oxidation. They have tackled successfully a very wide range of pollutants including odors in fish processing, animal rendering, maggot breeding and the latex backing of carpets. Other applications have included the purification of coke-oven effluent and decolorization of dyestuff liquors. One of the two industrial licensees for the patented LIRA catalysts is Carus Chemical Corporation in the United States.

Forging new links

A feature of the technology scene in Northern Ireland is the large number of interconnections between the various organisations involved. Thus LIRA has close links not only with industry but also with Queen's University (on civil-engineering

uses of textiles) and with the New University of Ulster at Coleraine (fundamental research on catalysts). Together with the Ulster Polytechnic at Jordanstown, near Belfast, the two universities in turn are closely in touch with industry's needs — which they serve in ways both traditional and non-traditional.

Queen's University at Belfast was established as a university college by Queen Victoria in 1845; the New University of Ulster at Coleraine received its first students in 1968. Eleven years later, the New University's research scientists include a group in the School of Physical Sciences who have made important advances in practical energy studies. Specifically, they have developed improved designs of heat pump which are on the brink of commercial exploitation.

Heat pumps use the principle of the refrigerator to convert heat at one temperature (for example, in the air outside a building) into heat at a higher temperature (which can be used for space heating inside the building). They can provide cooling as well as heating, and indeed current designs tend to be determined by American practice in which the requirements for air-conditioning are more important than those for heating.

According to Dr J. T. McMullan of the New University, more-efficient designs of heat pump, viable for domestic and commercial space heating, can be produced at a lower cost than current machines by concentrating solely on the heating process. On the practical side, prototype units which are being evaluated in houses in Belfast have shown a performance 20 to 25 per cent better than American models, he reports. Much of the support for the Coleraine group's work has come from the European Community's energy conservation program.

Meanwhile, back at Queen's, two special industry-oriented units are active in deliberately disseminating university expertise. One is the Low Cost Automation Centre (Director, Dr E. K. Beatty) an industrial advisory unit operated by the university with the support of the UK Department of Industry and the Northern Ireland Department of Commerce. As its name implies, the center aims to improve the level of manufacturing technology in local industry and in particular among the smaller firms. It interprets 'automation' very broadly, and operates via a general information service, a full program of training courses for managers and engineers in industry, and consultancy on specific projects. Minicomputers, data terminals, and industrial applications of microprocessors are among the course subjects; while the consultancy work often includes the design, manufacture and installation of special-purpose machinery.

Silicon wafer processing in the microelectronics laboratory at Queen's University.

Industrial consultancy in action at Northern Ireland's Low Cost Automation Centre.

The other special-purpose group at Queen's is the Wolfson Signal Processing Unit, directed by Dr Fabian Monds, one of a number of industrial units located at UK universities which are supported by the Wolfson Foundation. The unit aims to develop new products involving communications, the processing of electrical signals, microelectronic technology and medical electronics; and to provide advisory and consultancy services. The unit is attached to the university's Department of Electrical and Electronic Engineering, headed by Professor W. D. Ryan; often research in the department leads to product development in the unit.

Among microwave applications recently tackled by the Wolfson Unit is a miniaturised intruder alarm using Doppler radar, developed as a joint project with Northern Ireland Planners, a local company. The system consists of a coin-sized microwave sensor mo-

dule which can be fitted into a circular recess in a wall or door; and a compact electronics module which is compatible with commercial intruder-alarm power supplies and alarm circuits. At the heart of the sensor are microwave diodes developed in the microelectronics laboratory of the department. Production of the alarm in Northern Ireland is planned.

Another project involves telemetry applied to a paging or alarm system for elderly or infirm people living alone. Each user has a transmitter the size of a wristwatch, which generates a unique coded radio signal when activated, for example, in an emergency. The signal is received at a warden location, the source is identified, and the responsible person is alerted. This is a joint project with Lowry Electronics of Belfast.

At Ulster Polytechnic, again, among the examples of academic/industrial liaison, two novel forms have developed in recent years. One is the Polytechnic Innovation and Resource Centre (PIRC), which has two main goals: to use the expertise of the staff and facilities of the college to provide a problem-solving service on a consultancy basis, and to collaborate with outside bodies and individuals to generate ideas for new products and services which will enhance local employment opportunities.

Though relatively young — the center began operations in November 1977 — PIRC has already had an impact in improving concepts and standards of original design in Northern Ireland industry. 'We aim to do more than just consultancy', says Professor Donaldson McCloy, Head of the School of Mechanical and Industrial Engineering and chairman of the PIRC board of directors. 'We add the innovation'.

The Poly's other major industrial exercise is its participation in the 'teaching company' scheme which is being run jointly between universities or polytechnics and companies in various parts of the United Kingdom. The sponsors of the scheme, introduced over the past few years on a trial basis, are the Department of Industry, one of the main central government departments in London, and the Science Research Council, a major source of research funds for British universities.

By analogy with teaching hospitals, the idea behind the teaching company is that the resources of a university or polytechnic can be focused on particular projects or problems in the company via the appointment of a well qualified, full-time 'associate' who retains close connections with the parent academic body while doing a real, innovative job within the firm. Depending on the project, his assignment might last months or years.

The style and precise method of Britain's teaching companies varies between the participating organisations; no rigid pattern has been laid down. At Ulster Polytechnic much importance is attached to active, supportive involvement by many staff-members on the Jordanstown campus. The polytechnic's teaching company associates, whose numbers will rise from three to six this year, spend time as required with various companies in which the Northern Ireland Development Agency holds equity.

Industrial variety

For many companies in Northern Ireland, varied in type of business and in parentage, the use of advanced technology is a routine way of life. Richardsons Fertilisers of Belfast is an old-established Northern Ireland company which is now part of Imperial Chemical Industries (ICI). One of the larger users of the port of Belfast — and located at the port because of the large quantities of raw materials which it receives from abroad — the company operates what it believes to be the largest single-stream plant for compound fertilizers in western Europe.

In conjunction with a new system for using farmland more productively, Richardsons have developed a single fertilizer which is effective in achieving high output from grassland. Designed for Northern Ireland conditions, this has since been adopted more widely. Another Belfast-developed product is a 'foliar feed' fertilizer which is absorbed through the foliage of the crop and not through the roots, as is the customary practice.

On the site of a former naval airfield at Maydown, near Londonderry, the UK subsidiary of Du Pont operates four plants producing neoprene synthetic rubber, *Hylene (a chemical used in the manufacture of cushioning and insulating foams), *Orlon acrylic fiber and *Lycra elastane fiber. The neoprene plant, which was the first of the four to be built and has been in production since 1960, uses acetylene from an adjacent British Oxygen plant as its basic raw material.

The company's development group at Maydown has succeeded in doubling the output of the *Hylene plant as part of the group's continuous program of improvements. Now a major change in neoprene production at Maydown is to be introduced: the acetylene-based plant is to be replaced by a newer-technology process using butadiene as the feedstock. The new neoprene plant, which represents a $50m investment, is expected to come on stream in mid-1980.

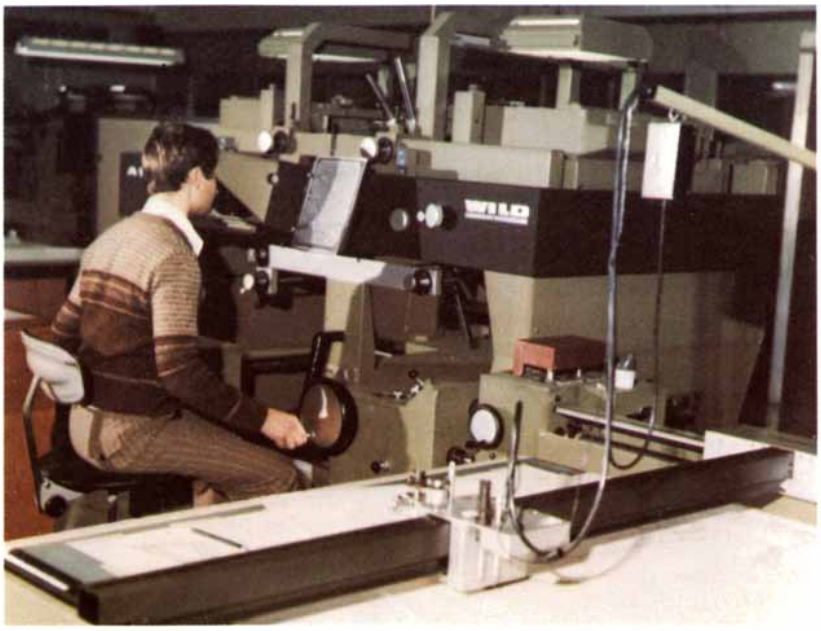
In the specialized field of aerial surveying, BKS Surveys at Coleraine have experience of aerial photography, mapping and engineering surveying based on operations in many parts of the world. In particular the company claims a world lead among commercial companies in its capacity for orthophotography – a new technology which combines the detail of aerial photography with the planimetric accuracy of a conventional line map.

Essentially an orthophoto is an aerial photograph which has been rectified and on which contour lines, spot heights, and other information are superimposed; the additional detail of the photograph compared with line maps is proving valuable in a growing range of planning, survey and land-resources work. In photogrammetry — the production of detailed line maps from overlapping aerial photographs — BKS uses advanced stereo plotters equipped with digital read-out systems.

Another specialized service is that provided by Andus Electronic of Craigavon, subsidiary of a West German company. Here the products are high-quality printed-circuit boards, the basic 'wiring' circuits on which customers mount electronic components to perform a variety of electronic functions. Andus customers include well-known companies in telecommunications, aviation electronics and computers; the Craigavon firm's output is split roughly equally between customers in the United Kingdom and the rest of Europe.

Another supplier to the electronics market is AVX Corporation of Great Neck, New York, which claims to be the world's largest manufacturer of multi-layer capacitors. Last year AVX announced its intention to set up a factory in Coleraine to supply the European market — and in particular the data-processing, telecommunications, defense, home entertainment and

*Du Pont registered trademark.



Photogrammetry at BKS Surveys, Coleraine: using stereo plotters, aerial photographs are translated into detailed maps of the areas surveyed.

other electronics-based industries — with a range of advanced products.

One of the more recently announced moves into Northern Ireland by a United States concern is also one of the most exciting. This is the plan to assemble the new De Lorean sports car for world markets in a new factory at Twinbrook, Dunmurry, on the outskirts of Belfast. Mr John De Lorean, the man behind the project, was previously with General Motors, where he played a leading part in the development and marketing of the Chevrolet Corvette. His new sports car, of advanced design and construction, is being prepared for manufacture in association with Lotus Cars of Norwich. Lotus is completing the detailed product engineering of the car, building further prototypes and carrying out pre-production testing.

Northern Ireland industry already includes a number of suppliers of automotive components – Dunlop; Michelin; Goodyear; Ford (carburetors, distributors); Arntz Belting; Tenneco Walker (exhaust systems); Bridgeport Brass; Essex International, a subsidiary of United Technologies; Sperrin Textiles and Kent Plastics. General Motors are about to manufacture seat-belts. But the De Lorean plant will be the first in the Province to assemble complete vehicles.

Advanced technology in automobiles: John De Lorean's new sports car, being developed with Lotus expertise for manufacture in Northern Ireland.

Incentives to innovation

An important addition to the existing incentives to companies in Northern Ireland to innovate in new products and processes was launched in August 1977 by the Department of Commerce. This is a scheme under which research and development grants are available for specific projects by manufacturing and processing companies. Up to £250,000 (about $500,000) per project is available, but there is no limit to the number of projects that may be proposed by each firm at any one time.

Projects must either involve the development of a new or substantially new product which will be manufactured in the Province; or contain some element of technology likely to lead to the use of new or improved processes. They must also hold the prospect of a significant improvement or expansion of the company's overall activities.

These cash grants of 40 to 50 per cent are available under the scheme towards the cost of basic research, related design work, manufacture of prototypes, final design and production drawing, equipment and buildings required, and technical consultants' fees. The rate of grant depends on the location of the company and the merits of the project.

Industry has not been slow to respond to the invitation to do more R and D on these terms. In the first year of the scheme over 150 projects from over 20 companies received Department of Commerce support. One company proposed 20 projects. Topics included traction motors, textiles in wallpapers, food processing, metal finishing, plastics extrusions, synthetic fibers, microcomputers, ambulances and buses, catalysts for effluent treatment, flax spinning, carpet manufacturing, polymers, new products based on chalk, automobile parts, the tobacco industry, plastic pipes, linen products, pulp fiber boxmaking, prestressed concrete products, forklift trucks, medical electronics, electronic telephone equipment, rough-terrain vehicles, fruit processing, milk processing and emergency systems for generating electricity.

Proposals for research and development grants under the Department of Commerce scheme are assessed by staff at the Department's Industrial Science Division (ISD) at Lisburn, a unique group of laboratories which acts as the main standards approval agency for the Province and carries out a

variety of science-based work for industry.

Subjects covered in the main industrial science branch at ISD include inorganic chemistry, metallurgy and metallurgical chemistry, chemical technology, fuel efficiency, fuel technology, building science, paint technology, organic chemistry, Alkali Inspectorate testing, instrumental methods and environmental science. There is also a water quality branch concerned with river monitoring, pollution, surveys and special investigations; and a technology promotion branch which includes a comprehensive library and information service with direct links to the computer-based information retrieval system operated by the European Space Agency.

Much of the division's work consists of technological trouble-shooting for industry – applying the analytical and testing resources of the laboratories to a wide range of investigations. ISD staff provide an industrial liaison service, visiting firms and helping to solve problems. And not only for small companies: 'It does not matter whether it's a ten-man firm or Monsanto Chemicals – out you go', says Mr John McCullins, ISD director, who likens his industrial liaison officers to 'technical commercial travellers'.

New products and processes arising from the division's research are often patented, either directly or via the National Research Development Corporation (NRDC) in London (one of the corporation's tasks is to exploit inventions arising in the UK public sector). A graffiti remover which was developed by the organic chemistry section in response to a government campaign to clean-up the much-sloganed areas of Belfast and Londonderry is now being exported to world markets under NRDC licence by Kilco Chemicals of Belfast; this product has applications for paint-removal and degreasing operations in industry. A process for obtaining protein from mussels, which originated in a degree student's project work at ISD, is likely to be exploited by a local fishery interest.

Strands of technology

These are some of the strands of advanced technology in Northern Ireland today. Others include the substantial, older-established yet still advancing technologies of Short Brothers in aircraft and missiles, and Harland & Wolff in shipbuilding.

Three main elements emerge: first, advanced industrial technology is here already, and spans a wide spectrum of industries; secondly, solid research backing from university and research association sources is readily available; thirdly, the Government includes research and development support, at all levels from the conceptual approach to day-to-day operations, as an important part of its package of incentives designed to attract established companies to come to the Province and encourage existing Ulster companies to expand into new growth areas of technology.

Many of the heads of the organizations visited for this report stress the interactions between these three elements. In technology, Northern Ireland is a close-knit community. Queen's alumni abound, but there is more to it than that. The facilities of the universities and the government laboratories *are* used by industry, because there is clear benefit. In turn, the academic and government establishments pass projects on to industry when the time is ripe for research to move on to development. There are many joint projects, and the ISD runs an 'Interlab' scheme. This lists facilities so that one group can turn to another when necessary for the use of specialized equipment.

Mr John Spence, joint managing director of Richardsons, points to the university links (for specialized analytical measurements) and the availability of good mechanical engineering resources as advantages of the Belfast location. Du Pont has found contact with government departments to be close, cooperative and flexible. Mr H. A. C. Todd, research director of LIRA, mentions the research at Queen's and at the New University that ties in with the association's programs, and joint work on polymer films with Shell NV of Delft.

In addition to the teaching company scheme there are routine interactions between industry, the academic world and government laboratories through 'sandwich' courses (which mix industry experience with university or college training); student projects at the ISD; and teaching by industrialists and government scientists at the academic institutions. 'To me the university/industry links are very important. It brings us in day-to-day contact with industry', says Professor Crossland of Queen's. 'Most of my staff are in and out of industry and that improves their lecturing capabilities'.

Northern Ireland has its own industrial scholarship scheme which attracts high-quality students who come from industry to take sandwich courses leading to bachelors' and masters' degrees (and who then return to industry). The managing director of Shorts, who is an Englishman, has praised the 'natural skill and dexterity' of the Ulsterman, which enables a company to put together a skilled workforce very quickly in the Province.

Dr Vera Furness, general manager of Courtaulds' Campsie plant, points to the help her company receives from the European Social Fund for training, in association with the training grants received from the Department of Manpower Services. And there is evidence that educational standards in Ulster schools are higher than in England or Wales, despite the 'troubles' the Province has passed through in recent years.

Five United States companies — AVX, General Motors, Coronary Care Systems, Adamas Carbide Corporation and De Lorean — chose Northern Ireland last year as the location for new plants, reflecting a growing awareness of what the Province has to offer.

Basic incentives to industrial development include grants, loans, tax allowances, the provision of factories and other benefits which add up to a financial package which is among the best in Europe; and though the research and development grant scheme was aimed primarily at established companies — encouraging them to move ahead into new activities, and at the same time upgrading job skills — it is clearly important also in attracting high-technology companies and projects from other countries.

One of the most recent government initiatives concerns the fast-growing area of microelectronics and in particular microprocessors. The goal is to ensure that industry generally adopts the microprocessor techniques that are revolutionizing so many products and processes today, and to attract more microelectronics-related companies to set up in Northern Ireland.

An interdepartmental working group on microelectronics has been set up to coordinate the interests of the relevant government departments, and to ensure that the Province's package of financial assistance, and its educational and industrial training systems are geared to the needs of this fast-moving technology. The British Government is pursuing a similar policy for the UK as a whole, including Northern Ireland. In this field, as in others, the Province aims to take advantage of the main UK schemes — but also to add a few ideas of its own.

BOOKS

Paper and communication without it, elements beyond uranium, the physical capacity of man

by Philip Morrison

PAPER BASICS: FORESTRY, MANUFACTURE, SELECTION, PURCHASING, MATHEMATICS AND METRICS, RECYCLING, by David Saltman. Van Nostrand Reinhold Company ($10.95). TOWARD PAPERLESS INFORMATION SYSTEMS, by F. W. Lancaster. Academic Press ($13.50). Every year enough newsprint is made in the U.S. to paper over the states of the Northeast. As much again is made in all the other forms of that material, which has linked author to reader for many centuries, since its invention by the Chinese during the epoch of the Roman emperors. Today most paper is made from wood fibers; the better grades also contain cotton fibers, not so much from the rags of yesteryear as from cutoffs discarded during the manufacture of new cotton goods. This magazine page is a coated stock, several layers of clay filler and white pigment having been rolled onto the moving web during its passage from a wet slurry to a shippable roll; the paper's wood content is mostly softwood fibers several millimeters long, with some dense, shorter hardwood fibers for filler, all prepared by chemically cooking out the lignin fraction of the wood. Newsprint runs three-fourths or more mechanically ground pulp; the fibers are crushed under a four-foot-wide grinding stone that turns logs into pulp under a deluge of water. The newsprint yield is high, because such pulp contains most of the wood, the lignin as well as the cellulose.

Papermaking has an air of the heroic. Trees are pretty big as raw material, so that cutting and transport has always been a heavy task. Today a tall tree can be seized by the jaws of a hydraulic diesel dinosaur on huge tires, its limbs can be sheared off, its top clipped and its trunk cut to four-foot lengths in a minute or so. Another kind of machine can instead lift and swallow an entire tree and then spew wood chips, bark and all, into a truck waiting at the output end.

The pulp is carefully bleached and prepared until finally it is delivered as a slurry (99 percent or more water) to a big moving wire mesh, the fourdrinier, that vibrates as it carries the steadily draining sheet of pulp along at speeds of up to 30 miles per hour. The dandy roll, with a texture of fine wire mesh, smooths and squeezes the web and may impress a watermark. Up and down around heated drying drums the paper flows in clouds of steam; at the dry end the sheet still contains about 5 percent water; drier paper becomes brittle. Sizings, coatings and smoothing rolls finish the paper and cutters slit the rolls to width. Sheet-cutting and packaging machines may come as a last step. Mills are mass-producers; they like to think of shipments by the carload, a nominal 20-ton minimum. A ton of paper is the yield of a couple of cords of wood, a ton and a half of coal, half a ton of bulk chemicals such as lime, clay and sulfur, and a couple of hundred tons of fresh water.

We all know some of the conventional grades: bond, offset, coated book, newsprint and tablet paper, and thicker stuffs such as bristol and tag, the file-folder material. A campaign for exceedingly lightweight opaque coated papers suited for fast color printing in large-circulation magazines has now gone about to its limit, the weight of the paper having dropped a third below the old standard in the past several years.

About half of *Paper Basics* is a primer of paper technology consisting of such background material; the rest is a knowing guide to the paper market. David Saltman is an old hand in the New York printers' world, and his concern to help the buyer of paper is manifest in detailed accounts of just how to reckon your needs (do not forget an allowance for spoilage) and how to deal with the jobbers who subdivide and pass along those mill-made carloads. Although the book is not always as complete as a reader could wish with respect to production hows and whys, it is nonetheless quick with the common sense of a complicated marketplace. The technically literate have some obligation to understand at least the simple basics of our one hard-copy medium; here is an entry. (Recycling is a real enthusiasm of this author's. Clear-cutting the forest, wherever the slope admits, appeals to him more than the preservation of wilderness, which is plainly all loss to the world of paper.)

Look away from the loggers, the smoking mills, the tense bargaining of Manhattan. In *Toward Paperless Information Systems* there sounds a voice in prophecy, that of a University of Illinois student of information systems in the large. He sets out a forecast: the end of ink on paper, apart from news and entertainment. Why produce, ship and store forever on ten thousand shelves multiplicate acres of symbols when those symbols can be summoned by microwave and cable at any place and at the very moment the reader needs them? The shelves, worldwide, turn into one prodigious central file that is quickly at the disposal of all. What our seer says is not, however, the result of plausible analysis alone, or even of forecasts by extrapolation and analogy.

"In 1972," he writes, "I discovered that the defense-intelligence community in the United States was already moving rather rapidly towards fully electronic systems" for "the dissemination, storage, and retrieval of intelligence information." He challenges our attention "in the role of provocateur," as one who has newly come to see that what the Central Intelligence Agency and its contractors have done points the way to the natural evolution of professional communications in general.

By 1981, after a decade of trial and growth, the full system called SAFE—forget the awkward rationalization of the acronym—should be working at CIA headquarters in Langley, Va. Each of the 2,000 professional production analysts who make up the learned arm of that oracular agency will have a console at hand. Doubled viewing screen and keyboard are the bare essentials; close by will be a printer, and "regionally" there will be a microfilm viewer-printer. The task of an analyst is to contribute to reports—either frequent ones, journalistic in length and timing, or more complete ones on matters of durable interest. The coverage is worldwide and includes economic, military, industrial, political and biographical topics, and more. The emphasis is policy-directed, more on current concerns and the near future than on the past, the eternal or the eventual. Into the agency pour "messages," about 6,000 or 8,000 a day. Two-thirds of them arrive by teletype (the "electricals"); the rest come on paper. They include newspaper clippings, the recordings of foreign broadcasts and the cables of diplomatic and military missions overseas.

Once SAFE comes, the analyst will begin the day with a "mail scan." Following his standing orders, or "interest profile," the screen will bring to his attention messages that have been computer-screened by key-word combinations, with these tentative computer assignments overseen by human decisions. Half of the messages are standard items that are always sent to the appropriate people, and almost 40 percent more are distributed ad hoc by the computer-human combination. The message text need be stored only once. The 28 million paper copies now sent around each year will drop greatly in number; each analyst will call up what he wants, examine either extracts of the document or the whole of it, cancel his address from the item or reroute it. He can search a mail file for recent items; that is, for a few days he can search the very text itself. Later on the message is downgraded to a text file that can be searched by various indexing schemes, but not by every word. Finally the analyst can use the microforms. These will offer not only the nonelectrical messages but also the older and more general materials. The microform store can be called up automatically by its indicators and can be displayed nearby for his use.

All of this is mail and library, so to speak, but every analyst can also build his own files. Into these he puts any item, indexed as he chooses, with standard information already included (date, source and so on). His tags will be his own, accessible to no one else and as varied as he wishes. He can mark key words with a light pen for inclusion in his index; he can add comments, which will come up with the document whenever he calls for it, both of them being displayed on the divided screen simultaneously. All searches are interactive; some files will be kept by groups or by offices rather than by individuals. Through special terminals where expert help is available the analyst can gain access to external digital files of information such as that of *The New York Times* and various medical and legal data bases. (What he will not have is access to any high-quality images. For quite some time these digital systems will not work for photography or for color.) He can compute, edit and release his work to add to the message stream directed to those he seeks to reach. With that action the system closes on itself.

Secrecy and resilience against breakdowns (by redundancy of equipment and by distribution of many functions among minicomputers throughout the network) appear to be attainable. The system promises to save money (a handy sum in paper shredders alone, one imagines) and above all to produce a "more thoroughly and swiftly informed intelligence community."

A paperless world for all scientific and technical communication is presented in scenario form in the last chapters of this book. Based on the recent literature and on the CIA experience and plans, the picture includes the economic rationale, the technical and special problems of implementation and the role of the future library, all as of the millennial year 2000. Every research

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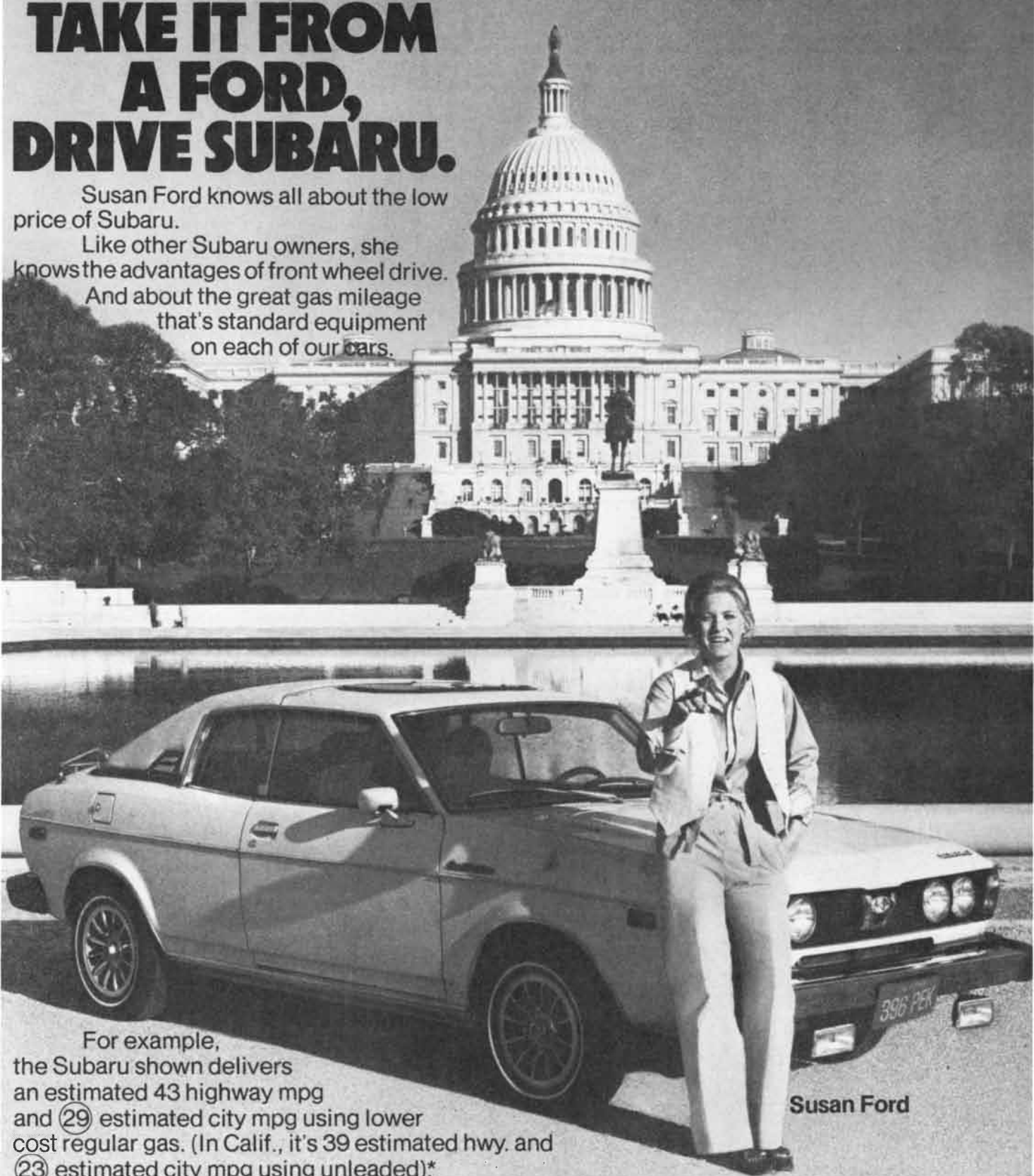

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worker her terminal, certainly (and perhaps another one at home), keyboard, screen and so on. There she can write and send letters, reports and preprints, and also receive them. "Virtual journals" will come regularly, edited, refereed, with familiar names and standards, but all by way of the screen. The researcher can skim or read carefully. A personal file will include an electronic notebook for recording research in progress as informally as the user chooses. Editing programs will facilitate the preparation of more formal reports at every level up to full publication. Drafts might be sent out for the comments of friends.

Of course, the on-line capabilities would include all kinds of reference books, bibliographies, indexes and similar tools. Just as journals will become virtual, so libraries will be without walls. Familiar colleagues—the "invisible colleges" of science—will be easy to reach by message or even in conversation. Billing for all of this would be on a pay-as-you-go basis, for items actually used or services examined. A search could widen from simple and local files to unique national sources according to need and expense. Personal files would accumulate from all of this, holding or disposing of whatever the user chose. Any portion of such informal stores could be available to particular users or to entire groups. The network foreseen is flexible, widespread and even worldwide. Its architecture might somewhat resemble the CIA example. All that CIA urgency seems less than a good model for much of science, which has a far longer attention span.

Is it feasible? The memory needed for all world journals is about 10^{13} bits of on-line storage each year, a couple of million dollars' worth a year with laser memories (it says here). An estimate (made by an English author in 1977) suggests that an investment of $2 billion would place a world electronic journal system in full operation, with a cost per year equal to the present cost of journals, mainly for the mass provision of workable terminals, of course.

Will we enter the paperless world? The roles of publishers, journals and research libraries would all change, and capital demands would be heavy. Can research workers themselves adapt? The author thinks so, the more since the CIA professionals were won over by the benefits demonstrated for their system. And it is not we old fogies who must be served but the new generation. They are used to screens.

Certainly paper will not vanish. Books are marvels of easy access, and notebooks even more so. (One would like to know the results of an inventory of the paper actually on hand at Langley in 1984.) There is opened a vision of terrible homogeneity and overload. Ad-

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vertisements, letters from dear friends with good news, first-rate papers, nonsense, long catalogues of data to be used only years after receipt—all pour in, all look just the same, with no cues to memory save the digital labels themselves. No familiar bulk or cover would mark the journal, the book or the long-expected reprint. Will textual memory work well enough? The graphic arts have practical value; visual aesthetics is not separate from thought. A notebook without graphs and sketches may suit a historian, but it would not suit a scientist. Computer output today is ugly stuff, hardly readable. Better graphics is essential, and something more than a keyboard input. Will those mass-production terminals be good enough? Visual images of quality will be seriously limited. We see how television brings us its murder and merriment, hard data and sheer fantasy, all of it in one tiny size in the same place in the same room, flat, miscolored and flickering—unreal images.

Alan Turing was surely right in principle: the digit maps all knowledge. The human brain has not evolved so, however. It enjoys many channels of input, and cross-correlation is a sovereign mental technique. Sensory dilution is a real danger; so is the extreme centralization of stores. Multiplicity has always offered protection; a single store will not save knowledge in the long pull.

Still, some of all of this will surely come to pass. The economics of symbols ensures it. Once long ago the learned must have complained: What, write down those verses? A book is far too thin a version of Homer's verse; the living bard is individual, his song a beauty. And yet for millenniums we have been able to take joy from mere ink on paper. So all things flow.

TRANSURANIUM ELEMENTS: PRODUCTS OF MODERN ALCHEMY, edited by Glenn T. Seaborg. Dowden, Hutchinson & Ross, Inc., distributed by Academic Press ($36). A couple of new elements (they are usually discovered in pairs) have been added beyond the natural end of the periodic table every four or five years for the past 40 years. The count now goes up to atomic number 106, found five years ago (and not yet named). The new alchemy makes plutonium by the ton, neptunium, americium and curium by the kilogram, berkelium in match-head bulk, californium by the gram and einsteinium (No. 99) by the milligram. All these weighable novelties are made by the absorption of neutrons one at a time at the high densities attained in nuclear reactors and nuclear explosions. The elements beyond No. 99 are not yet within reach of such step-by-step procedures; they are generally made by bombarding a heavy target nucleus with a high-energy beam of ions of a more ordinary nucleus, a few target nuclei struck by ions gaining many nucleons at one clip. For element No. 106, to take a limiting case, a quarter-milligram deposit of californium (mass 249) was bombarded by a strong beam of ions of oxygen (charge 8 and mass 18). Four neutrons were emitted in the event to yield the nucleus with 106 protons and a mass of 263 units. In all a few hundred of the new nuclei were made, all to decay within a second.

This anthology of papers on the transuranics is edited by the codiscoverer of plutonium (in secret in late 1940), who is now the distinguished leader of transuranic science. It includes about 120 papers in facsimile, with many additional references and with commentaries on each topical group of papers by the editor. The disarming beginning offers a set of half a dozen papers, by authors as redoubtable as Enrico Fermi and Irène Curie, in most of which false claims for transuranics were made. This section includes the portentous 1939 paper of Otto Hahn and Fritz Strassmann that made certain the production of barium from uranium and led to the recognition of fission.

Sections follow that include the discovery papers for all the elements from No. 93 to No. 106, in which the new element is first identified by nuclear physics or delicate radiochemical techniques. Then come the papers reporting that the new element has been isolated in weighable amounts. The techniques here are fascinating—conceptually simple but strangely ingenious and deft. There are ultramicrobalances that depend on the bending of fine quartz fibers and there are tiny platinum crucibles for heating samples in an oxygas microflame. One optical arrangement was made for measuring the absorption spectrum of einsteinium in solution, working with a couple of micrograms of the compound; the sample, a droplet about .1 millimeter in diameter, was caught in a tiny gap between the ends of two quartz-fiber light pipes carefully aligned to complete an optical path from a source to the photocell inside a spectrophotometer.

A later section gathers various studies of the chemical and metallurgical properties of the elements, examples of laboratory virtuosity in their own right. Compounds are concentrated and many of their chemical properties are studied on a single bead of a familiar ion-exchange resin, on a pinhead of activated charcoal or in a thin film of the metal evaporated into a quartz capillary for X-ray study at submicrogram quantities. The usual tricks of the tracer chemist's trade work very well. Quick experiments for a wide range of nuclear properties, or of chemical properties in solution and on crystallization (in mixed crystals), are carried out with 1,000 nuclei or fewer, the entire sample decaying away in a few minutes. These nuclei can have extreme properties. The spontaneous-fission lifetime of the isotope americium 242 is some 1,000 billion years from the ground state, but the very same nucleus has an excited state (which probably is deformed in shape, in part because of a high spin) whose life until it comes apart through fission is reduced to a hundredth of a second.

The work has proliferated from a secret specialty of the Manhattan-project radiochemists, first to a vigorous Russian group, until it now enjoys widespread international participation. There has been a long and ingenious worldwide search for natural transuranics. A Precambrian mineral, a rare-earth fluocarbonate mined for cerium in California, has yielded the all but extinct isotope of plutonium with mass 244, a nuclear species whose lifetime is less than 100 million years. The search required a couple of hundred pounds of the ore and led to the detection of about one part in 10^{18} of the isotope sought. The detection was accomplished with the mass spectrograph; such a small sample of such a long-lived species does not offer many decays for study by particle counters—one count every few years. The hunt for a superheavy nucleus near element No. 114, where there are theoretical grounds for expecting long-lived species, has been inconclusive. The stuff is surely rare even if its lifetime is geological. Glasses, minerals, hot springs, cosmic rays, meteorites and moon rocks have all been examined, but no find has been confirmed. One false alarm, etched tracks found in old lead glasses by the expert group around G. N. Flerov in Dubna, was shown by them to have been probably caused by fission of the lead induced by cosmic rays. The search will have to be pushed well below one part in 10^{13}.

This fine volume represents its intriguing field extensively. Only the puzzle of the unexplained pleochroic halos is more or less omitted (there is one allusion), although there are at least suggestions of extinct elements within those radioactive-damage spheres seen in certain old micas.

HUMAN PHYSIOLOGICAL WORK CAPACITY, by R. J. Shephard. Cambridge University Press ($39.50). Sustained physical activity requires that the fuel of the muscular engine (mainly adenosine triphosphate, or ATP) be steadily replenished at the site by the vigorous flow of red blood freshly aerated in hard-breathing lungs. Experience has provided good evidence that the normal limit to our engine's power is fixed by the rate of transport of oxygen from the air to the working muscle. Recent controversy has left that conclusion in place after five years of search-

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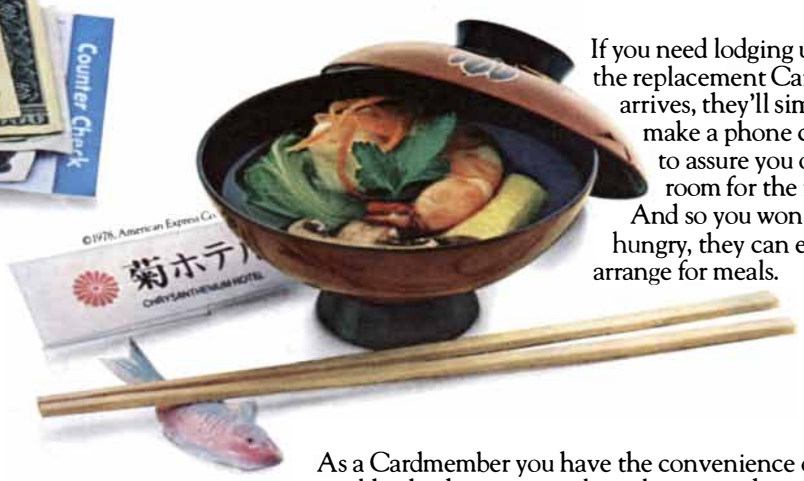

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These are just three of the exciting new components in Technics Silver Edition. Each was designed to please the eye, but, of course, their real beauty lies in what you hear.

Listening to our new DC integrated amp, the SU-8099, will tell you all you need to know about its performance. And 3-Dimensional Analysis (3 DA) will tell you about the radically new way it was designed.

3 DA is a computer measuring system designed by Hewlett-Packard and Technics. It gives audio engineers and you a far greater insight into amplifier performance than is possible with conventional separate measurements of frequency response, power, and distortion.

4000 precise measurements are plotted on a three-axis graph with power measured from 0.2 watt to rated output across a frequency band of 10 Hz to 100 kHz. Distortion is evaluated from 0.0001% with distortion components measured out to 1 *million* Hz. The result is a picture of performance you won't get with conventional specs.

Even elusive amp behavior like slewing rate and Transient Intermodulation Distortion (TIM) are easily identifiable, which helped our engineers design Silver Edition amps with appropriate slewing rate and inaudible TIM distortion.

That's one good reason the SU-8099 is hard to beat. Another is it's a true DC integrated amp. With no coupling capacitors from input to output. And the output devices are our new Super Linear Power Transistors (SLPT) with an f_T of 100 MHz which enables us to achieve a closed-loop frequency response from DC to 200 kHz −3 dB.

In the preamp section, our engineers added an extremely quiet phono equalizer complete with Technics-developed ultra-low-noise transistors. The result: an incredible phono S/N ratio of 96 dB at 5 mV. They also made it easier and less expensive to use a moving coil cartridge, because there's an MC pre-preamp built into the SU-8099.

To maintain dynamic range and avoid clipping, you need highly accurate power meters. Like our fluorescent FL power meters. They're completely electronic, highly accurate and extremely fast. So you can easily get true peak readings.

To complement our integrated amp, there's the ST-8077 tuner. A highly sensitive front end boosts sensitivity to the point where even remote FM stations can be received with a great degree of clarity and fidelity.

For inaudible distortion and excellent selectivity, the IF stage features a five-stage, differential amplifier and surface acoustic wave filtering. There's also a 19 kHz pilot-signal cancel circuit for extremely wide frequency response with excellent transient characteristics.

For accurate and easy tuning, center-of-channel indication is located on the tuning dial where it's easy to see. Two LED arrows point you in the right direction for fine tuning. And Active Servo Lock (ASL) keeps it perfectly tuned.

What you get with the RS-M44 cassette deck is just as impressive. Starting with an IC-controlled FG servo DC motor for inaudible wow and flutter and a patented HPF head for extended frequency response and head life.

For fast recognition of musical peaks, the RS-M44 features fluorescent bar-graph meters with a device attack time of five millionths of a second. Also included are separate three-position bias and EQ selectors. An oil-damped ejection door. And three memory modes: auto rewind, auto play and auto rewind/play.

The Silver Edition from Technics. Their real beauty lies in their performance.

SU-8099

Continuous Power Per channel into 8 ohms	Total Harmonic Distortion at Rated Power	Phono S/N
115 watts (20 Hz~20 kHz) 100 watts (5 Hz~100 kHz)	0.007% (20 Hz~20 kHz) 0.05% (5 Hz~100 kHz)	96 dB (5mV)

ST-8077

FM Sensitivity 50 dB (stereo)	FM Selectivity	Stereo Separation (1 kHz/ 10 kHz)	Total Harmonic Distortion (stereo)
37.2 dBf	75 dB	45/35 dB	0.1%

RS-M44

Wow and Flutter	Frequency Response	S/N
0.05% WRMS	30 Hz~17 kHz ($FeCr/CrO_2$)	67 dB Dolby* in

*Dolby is a trademark of Dolby Laboratories, Inc.

Introducing the Silver Edition. Their real beauty lies in their sound.

Technics
SILVER EDITION

ing criticism: the limit to steady work is determined by the central flows of air and blood. A measurement of maximum oxygen intake over some minutes therefore measures peak output effectively. (During brief bursts of power lasting for only a few seconds oxygen is not replenished, and for sprints of effort up to a minute or so the tolerance of oxygen deficiency is limiting.)

One cannot work for long at the maximum rate, of course. The measurement protocol is convincing on this point; the tests draw on the majority of the body muscles and exhaust the subject until such signs as nausea, severe breathlessness, ashen color and confusion are observed. Mere fatigue, pain and weakness are probably only peripheral limits. (People doing heavy work all day generally choose to operate at 40 percent of maximum power.) The devices of this stern assessment are the mechanically braked bicycle ergometer or, even better, the motor-paced uphill treadmill or the field-portable step (a couple of steps up which the subject runs repeatedly to a fast-beating signal).

This authoritative and data-rich book presents the working capacity of every condition of humanity. Here are studies of Eskimo hunters and Czech schoolchildren, of blind children in Canada and middle-aged Tunisians, of soccer players in Zaire and the Ama diving women of Japan. This bewildering variety is by no means left a jumble; on the contrary, the data are critically discussed and carefully juxtaposed to test such large questions as nature v. nurture, the heritability of individual differences and the intrinsic quality of differences among peoples, the effects of climate and day length and of occupation, nutrition and disease. The book is a report on the work of the exercise physiologists of many lands in loose cooperation under the human-adaptability section of the International Biological Programme, a decade-long project that ended in 1974. The University of Toronto author, a leader in the discipline, goes well beyond the data of that project to round out his discussion.

The reader gains some confidence from the careful account of method given by Professor Shephard. It turns out that even gas analyses carried out on the same cylinder of gas by different laboratories can differ by 30 times the error estimates of the analysts. How much slipperier are statements about populations and means when human beings must be fairly sampled in spite of differences in their perceptions of strange hospital visits, fear of self-revelation, preoccupation with or indifference to health and experience with bicycle pedals or long interrogations. Testing to exhaustion is not without some risk to the subjects, although the risk is low.

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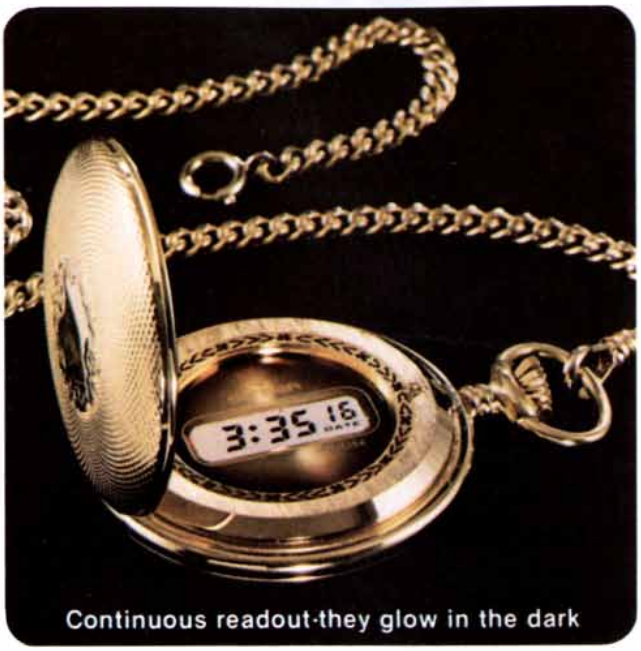

Continuous readout-they glow in the dark

Now! A new long-range guarantee on fashionable timepieces you will enjoy repair-free for years!

Sensor, the American-made watch, has developed an exciting new series of watches in both pocket and wrist style—guaranteed for 5 full years! You don't even have to replace the battery.

Of course, these superbly crafted watches will give you many, many years of accurate repair-free service. The 5 year guarantee covers **everything** except the wrist band or the chain and face protective cover of the pocket watch. Both watches feature the extended-life lithium battery which is included in the 5 year guarantee!

They glow in the dark

Both watches also feature TriLite™, a new space-age illuminating technique developed by Sensor. Two tiny glass tubes, lined with phosphor, injected with tritium, are sealed permanently by **laser beam** and mounted behind the digital display. Perpetual interaction between phosphor and tritium emits a constant glow. The soft green light becomes more pronounced as exterior light dims.

With TriLite, there's no battery drain. No button to push. TriLite is self-contained. Self-powered. And it illuminates the digital display for continuous readout, day and night, for years and years.

The 5 year **pocket watch** in 24-K 3 microns gold Swiss case is a traditionally respected design for today's popular vested suit. The large display of hours, minutes, seconds or date is at the same viewing angle as the famous "railroad watches" of yesterday. Elegant 3 microns gold Waldemar chain is also included.

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Experience either or both of the 5 Year Watches for 10 days at our expense. You have to see and try these watches to appreciate their beauty and value. That's why we encourage you to enjoy them for 10 days free trial. If you do not agree that these are the most accurate and beautiful watches you've seen, simply return for courteous refund. $110.00 each, please add $2.50 per watch for shipping and insurance. Remember, both watches are guaranteed for 5 full years...including the lithium battery!

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no harm meant that a physician with oxygen and a defibrillator went along to the tests run on the people of Igloolik on the Arctic Ocean, extending to the Eskimo volunteers the same precautions that would be taken in an urban university laboratory. An investigator who speaks Lapp or Yoruba inadequately cannot always persuade the subject, who may be a sensible person with no built-in competitive drive to better the performance of his fellows, to keep on exercising beyond the point of fatigue. Olympic athletes gathered together are hard to sample too; they rightly reject any test that might impair their performance. A random recruitment by telephone in Saskatoon turned up a volunteer sample of energetic exercisers far above the census data in vigorous activity, and a volunteer sample in Toronto "contained almost no smokers." Here we have gone far from muscle physiology indeed.

The picture of exhausted subjects all over tundra and rain forest is a little too dramatic. A less direct method was often employed. Subjects were asked to work on the load device up to some three-fourths of their peak capacity. Their pulse rate was measured, and then the data were extrapolated up to the maximum pulse-rate standard for each age; the procedure worked reasonably well, and the test was a great deal easier to carry through. It is not easy to elicit maximum performance from children. Anxiety may modify heart rate more than exercise does, both in a big city and in a little village. These human engines are under subtle controls.

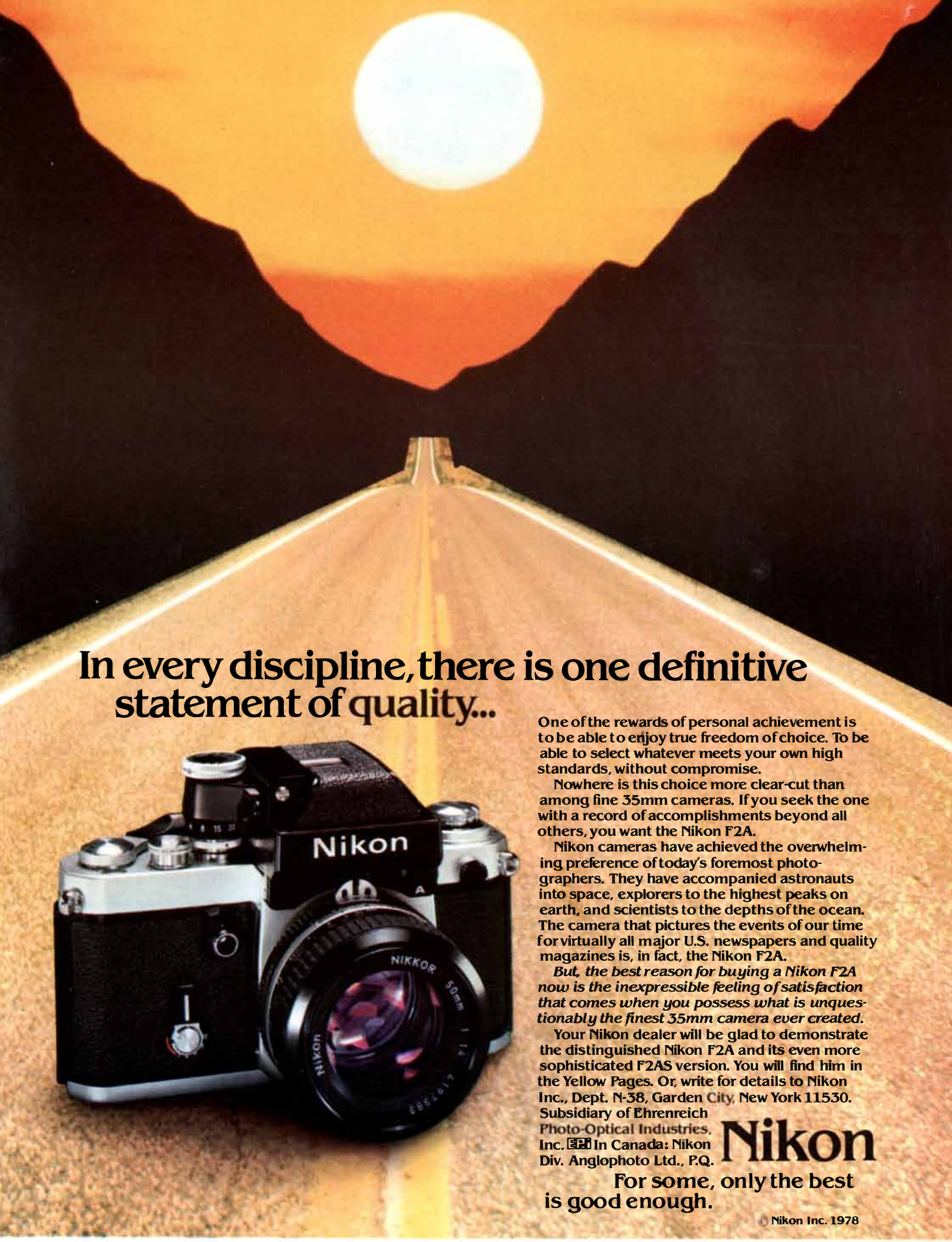
Champions are always of interest. The bulky individuals who are the skilled linemen of American football (whose weight typically runs well above 100 kilograms) show on the treadmill the highest maximum power listed in this volume: an oxygen intake above six liters per minute. But the highest values in relation to body weight are scored by cross-country skiers, one Norwegian champion in this "most vigorous of all forms of sustained muscular activity" reaching (per kilogram of body weight) an intake almost 50 percent higher than that of the big footballers. The Tarahumara Indians who dwell in the rugged mountains of western Mexico are famous for their endurance as runners. There is a well-documented case of a man who delivered the mail over a round trip of 500 miles in five days. Such mountain people show high specific rates of uptake, averaging about that of the middle range of competitive track athletes.

The sense of all these results is pretty clear. There is little evidence that the polymorphism of human beings has yet responded to strong selection for genetic differences in these deep properties. Practices and usage nonetheless do give rise to large differences, and variation within populations is strong. The Tarahumaras who no longer lived in mountain caves were just like their Mexican classmates in specific intake. The hardihood of the Eskimo in the cold and the tolerance of the Bushman for the midday desert heat owe more to know-how, culture and skills than to peculiarities of shape or size or enzymatic function. It works both ways, too. When the Arctic investigators tried running up and down the airstrip, the distance each man covered in 15 minutes was well correlated with his maximum oxygen intake. The Eskimos did not do nearly so well. It seems that they failed to pace themselves; they are not used to timed events.

Everywhere a soft life makes for soft muscles and low power. We do not yet know whether this is significant for longevity or freedom from disease. It does imply the loss of ability to survive any prolonged failures in the technological system that tempers our environment in the sheltered world: *Homo sedentarius,* a widespread variety of *H. sapiens,* may be gambling while he sits.

THE SCIENCE OF SOAP FILMS AND SOAP BUBBLES, by Cyril Isenberg. Tieto Ltd., 5 Elton Road, Clevedon, Avon, England ($20). Two common visual phenomena never fail to seize our attention every time we see them: fire and soap bubbles. The one appears all change; the other exhibits "a perfection of geometrical form and a simplicity which appeals instantly to the mathematical mind." So writes Sir George Porter in the foreword to this well-packed and nicely illustrated paperbound book by a theoretical physicist at the University of Kent at Canterbury. Professor Isenberg writes in a strong pedagogical tradition. Sir James Dewar gave a lecture titled "A Soap Bubble" at the Royal Institution of London just 100 years ago. C. V. Boys published his classic account about a decade later. A. S. C. Lawrence, who had been an assistant to Dewar, put out another fine book 50 years ago, and now, after more than a decade of lectures and demonstrations of his own in Britain and the U.S., Professor Isenberg offers us a new book in the old spirit. That spirit is represented by delight in the phenomena and an effort to render them in some degree understandable to readers of all levels of preparation.

In keeping with today's world the volume displays a sequence of striking color photographs of the chief objects of interest. The text places on its readers much heavier mathematical demands than Boys's did; the typical reader is thought of as a person who is able to read and enjoy arguments that include simple algebraic equations, derivatives and integrals. (The mathematics extends well beyond that, but the author takes some care to segregate the harder for-



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There is now a Mercedes-Benz station wagon

The new 300 TD. Before it could be a Mercedes-Benz station wagon, it had to behave like a Mercedes-Benz car.

Mercedes-Benz has engineered a station wagon that handles like – and is as solidly built as – a Mercedes-Benz car.

It does not wallow about on the road like a hippopotamus.

And it has been designed to spare its owner the aggravation of a chorus of rattles and creaks.

"First and foremost," reports *Car and Driver* magazine, "is that when you drive it empty, you very quickly forget you're driving a wagon. It handles very much like a sedan, with none of the ponderous, tail-happy lethargy we've come to expect..."

But what happens to the handling when the 300 TD is heavily loaded?

There is a sensor buried deep within every Mercedes-Benz station wagon. Should a passenger step aboard, or luggage be added, this sensor orders a special pump to send an extra supply of hydraulic fluid to the rear shock absorbers.

This raises the rear of the vehicle to its normal, most effective level.

And this, in turn, maintains the correct front-wheel geometry so that the station wagon can be steered precisely even under heavy load, instead of wallowing clumsily from side to side.

It sounds like a Mercedes-Benz car

Creaks, rattles, thrumming noises – are they the inescapable bugaboos of a station wagon?

Not so, said the Mercedes-Benz engineers.

Car and Driver agrees: "The back end doesn't sound like a crate of empty muffin tins whenever you hit a bump, which is something you can't say for your average wagon. Mercedes-Benz designers have found ways of securely buttoning down all the movable panels that usually cause station-wagon rattles..."

Good brakes are not enough

The handling ability of a car is considered of paramount importance at Mercedes-Benz. The reason is simple: if at all possible, it is always preferable to *avoid* an accident.

The new Mercedes-Benz 300 TD.
Only 2,500 will be available in the U.S. this year.

Good 4-wheel disc brakes alone are often not enough. The car must also be capable of violent evasive action without loss of control.

And so the new Mercedes-Benz 300 TD station wagon has been fitted with the sophisticated steering and suspension systems of a Mercedes-Benz car.

Steering that "talks" to you

There is zero-offset steering built into the front suspension of the 300 TD to provide more precise steering control in emergency situations.

The power steering itself has "feel." It tells your hands exactly what the front wheels are doing at every moment.

And the suspension is independent on all four wheels. Should one wheel hit a bump in the middle of a corner, that wheel alone is affected, leaving the other wheels independent to maintain their grip on the road. There is none of that alarming, sideways hop-skip-and-lurch that one expects from a less-expensive solid rear axle; the Mercedes-Benz will simply shift a few inches to one side, then smoothly resume its course.

It uses Diesel fuel. Sparingly.

The Mercedes-Benz station wagon is no gas-guzzling leviathan. For one thing, it measures a trim and nimble 15 feet 11 inches from stem to stern; it is the length of a Mercedes-Benz car. For another, it doesn't use gas at all.

The powerplant is the remarkable 5-cylinder Mercedes-Benz *Diesel.* This 3-liter engine is coupled to a 4-speed automatic transmission to achieve a balance of performance *and* economy. It delivers an esti - mated 23 mpg.

This estimate is from the U.S. Environmental Protection Agency. *Remember:* Compare this estimate to the "estimated mpg"of other station wagons. You may get different mileage, depending on how fast you drive, weather conditions, and trip length.

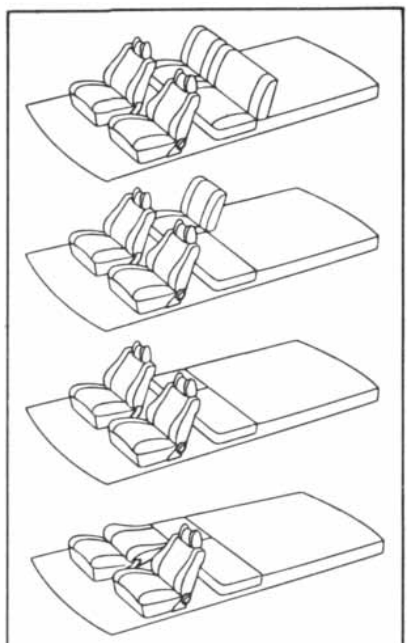
A lesson in the use of space

The interior design of the 300 TD station wagon is an object lesson in the ingenious use of space.

Raise the tailgate and look for its hinges and damper units. You'll find them tucked discreetly into the roof. It costs more to do it this way, but the Mercedes-Benz engineers wanted an absolutely smooth inner-roof surface so that bulky packages wouldn't snag on outjutting hinges.

There are seats for five adults. All of the passenger seats can be folded out of the way (*see illustration, right*) in a multitude of sizes and shapes of carrying space.

"If the object is *really* long," noted *Car and Driver,* "say a carton of record-length spaghetti or a python with rigor mortis, that's no problem either. Just unlatch and remove the right-side cushion of the second seat. Fold that side of the seatback forward. Then fully recline the passenger-side front bucket. That leaves an uninterrupted stretch from the tailgate in back to the glove-box door in front. What more could you ask?"



All of the passenger seats can be folded out of the way to provide different shapes and sizes of carrying space.

More standard equipment

In typical Mercedes-Benz fashion, the list of standard equipment is quite staggering in its length.

To name a few items: Climate control air-conditioning. Cruise control. A 4-speed automatic transmission.

Power-assisted steering and brakes. Electric window lifts.

Also, an AM/FM stereo receiver with electric antenna. A quartz-crystal chronometer. Wiper, washer, and defroster for the tailgate window. Halogen fog lamps. A pair of outside mirrors, both adjustable from inside the car.

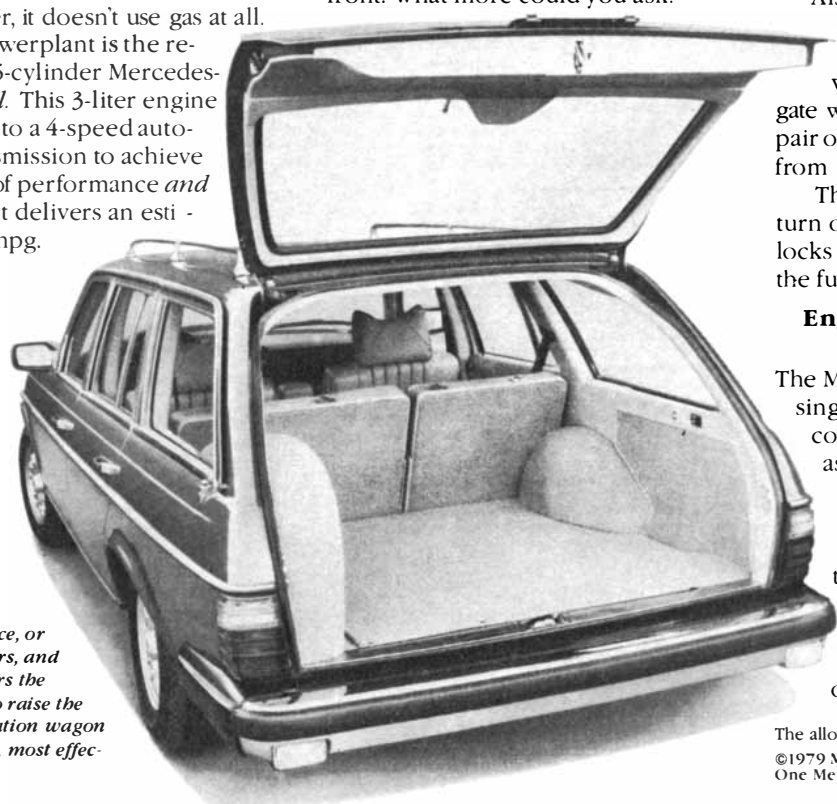
There is even central locking: a turn of the key in the driver's door locks all four doors, the tailgate, and the fuel filler port. Simultaneously.

Engineered like no other car in the world

The Mercedes-Benz aim is doggedly single-minded. It is to build safe, comfortable, practical cars with as few imperfections as possible.

This philosophy puts engineering ahead of petty economies and precludes the mass production of inexpensive cars.

A Mercedes-Benz is engineered like no other car in the world.



Load this space, or add passengers, and a sensor orders the suspension to raise the rear of the station wagon to its normal, most effective level.

The alloy wheels shown are at extra cost.

malisms.) In return the reader is led to a wonderful range of topics in mathematics and physics, all floating out of the bubble.

In the first chapter we get a summary history of the heroes of soap films, a simple molecular account of what is going on and the basic ideas of surface energy, equilibriums and optical interference. Practical recipes for good soap films are not forgotten. There is a clear and complete account of the pressure relations around a film and of the curious instability of a pair of bubbles joined by a tube. The thermodynamics of films and those remarkable multiphase phenomena that produce the play of moving color as a film drains are gone into in some detail, although this work of Karol J. Mysels is too subtle for such a brief explanation.

Then film enters as an analogue computer for seeking out minimums. First is the Steiner problem of the shortest roads linking many cities. We read in detail of the curious minimum surface that is bounded by two circular rings placed like the two tires of a single axle. For small separations the two rings are spanned by a handsome minimal film, a delicately curved hourglass form. As the separation of the rings grows the hourglass narrows at the waist. A little before the surface would touch its axis a new minimum suddenly appears: a flat disk covers both rims and nothing links the rings. There is a third solution, a short cone linking both rings to a flat disk halfway between them. The soap film finds all these minimums easily, catching effortlessly those surprising discontinuous fish that escape the net that is stretched—for continuous changes only—by the classical methods of the calculus of variations.

The crystal models based on the Bragg bubble raft and the topology of froths (studied by Cyril Stanley Smith of the Massachusetts Institute of Technology) are not forgotten; the surprising prevalence of pentagonal faces is rather slighted. Dynamics is next: water jets breaking into beads, even the vibrations of a membrane, easier for most readers to demonstrate than to follow in formulas. Here we are at upper-undergraduate level. Bessel functions are invoked, without even one plot of J_0. It is a world of physics linked by the bubble, bridging the demonstrations of Boys to the standard solution techniques for partial differential equations.

A modern compendium of the rich lore of soap film, this small book should make its way to every shelf of recreational mathematics and physics. Libraries will find the book a necessity. Its density is leavened by its photographs and relieved by an admirable categorized list of relevant books, papers, motion pictures, kits and even paintings: bubbles from Murillo to Millais!

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Who else wants to save time, trouble and aggravation? At $99, Rapidial™ is America's lowest priced, best selling automatic dialer.

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Interestingly, our survey unearthed some rather surprising and highly enterprising additional uses.

For example, most executives store *both* their most frequently called numbers, family, friends, clients or customers, service organizations and suppliers... and those important but less frequently called numbers that almost always have to be looked up.

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The Memo Caller—or daily telephone organizer—is one of the more intriguing uses we discovered. These men (or their secretaries) program each day's calls. Crossing off the ones that are completed (adding new ones as necessary). A glance assures you no one's been left out, no call back has been forgotten. And a touch of the button gets you the next man on your list.

Finally, many report leaving the bottom bank of storage cells blank. Reserving them for the flow of calls that always accompanies a special deal or negotiation.

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Particle-Beam Weapons

It is said that missiles could be shot down by accelerator. Even if such a weapon could be built, which is questionable, it would be ineffective because it would be vulnerable to countermeasures

by John Parmentola and Kosta Tsipis

Physicists familiar with the design and operation of elementary-particle accelerators have known for decades that an intense beam of charged or neutral particles can carry a potentially destructive amount of energy, capable under certain circumstances of melting a hole in a piece of metal, say, or of damaging shielded electronic circuits. Not until quite recently, however, has the notion of exploiting particle beams as the basis for a new class of weapons come to be taken seriously in some circles. The U.S. is currently financing research on a variety of schemes for particle-beam weapons, and the U.S.S.R. is probably doing much the same.

Assuming that such weapons could be developed, how would they work? What could they be used for? What are the main technical and operational obstacles that would have to be overcome for weapons of this type to be effective? In attempting to answer these questions we shall draw heavily on the results of a feasibility study conducted recently under the auspices of the Program in Science and Technology for International Security in the department of physics at the Massachusetts Institute of Technology. The study group consisted of several members of the physics faculty at M.I.T., including both of us, and some outside scientists experienced in the physics of particle beams.

Particle-beam weapons would differ fundamentally from all earlier instruments of war. Instead of transporting destructive energy to a target in the form of an explosive warhead carried inside a ponderous vehicle such as a missile or an artillery shell, a particle-beam weapon would increase the kinetic energy of a large number of individual atomic or subatomic particles and then direct them collectively against a target. Every particle that strikes the target would transfer some of its energy to the material of the target. Given a large enough number of particles hitting the target in a short enough time, the deposited energy could in theory be great enough to burn a hole in the "skin" of an offensive missile or shell, to detonate the chemical-explosive "trigger" of a nuclear warhead or to disrupt the electronics inside the target vehicle.

How does one produce an intense, high-energy beam of particles? Any singly charged particle that is subjected to a drop in electric potential, or voltage, is thereby given a push that increases its kinetic energy by an amount equal to the potential drop. Thus an electron or a proton that is subjected to a potential drop of a million volts acquires an additional kinetic energy of 1.6×10^{-13} joule, an amount equivalent to a million electron volts (MeV). Neutral particles cannot be accelerated in this way because by definition they have no electric charge. (High-energy neutral beams can be obtained, however, by first accelerating a beam of charged particles and then converting them into neutral particles.) Any electromagnetic device designed to increase the kinetic energy of a beam of charged particles by subjecting them to a sequence of such pushes is considered an accelerator. A simple linear accelerator suitable for a weapons system would consist of three basic parts: a source of particles, a device for injecting the particles into the accelerator and a series of accelerating sections.

There are several methods available for producing copious numbers of electrons and ions (electrically charged atoms). In addition there are a variety of electron and ion injectors that could in principle provide a compact, intense pulse of particles at the entrance to the accelerating section of a particle-beam weapon. Furthermore, physicists have over the years invented several different ways of accelerating charged particles traveling in a straight line. When a beam with a very high energy but a comparatively low current is required, the preferred technique is to first generate a moving electromagnetic wave, which impels a bunch of particles in front of it much as an ocean wave pushes a surfboard. That is the operating principle, for example, of many of the accelerators used today for research on elementary-particle physics, such as the two-mile one at the Stanford Linear Accelerator Center (SLAC). When a very high current and a comparatively low energy are required (as would be the case for a weapons system), the preferred approach is to expose a bunch of particles to a series of pushes supplied by an electric field that is induced by rapidly changing the magnetic field in a toroidal, or doughnut-shaped, ring of magnetic material while the particles pass through the hole in the center. An example of such an induction accelerator is the Astron machine at the Lawrence Livermore Laboratory, a device designed for fusion research. All linear accelerators in operation today fall into one or the other of these two categories.

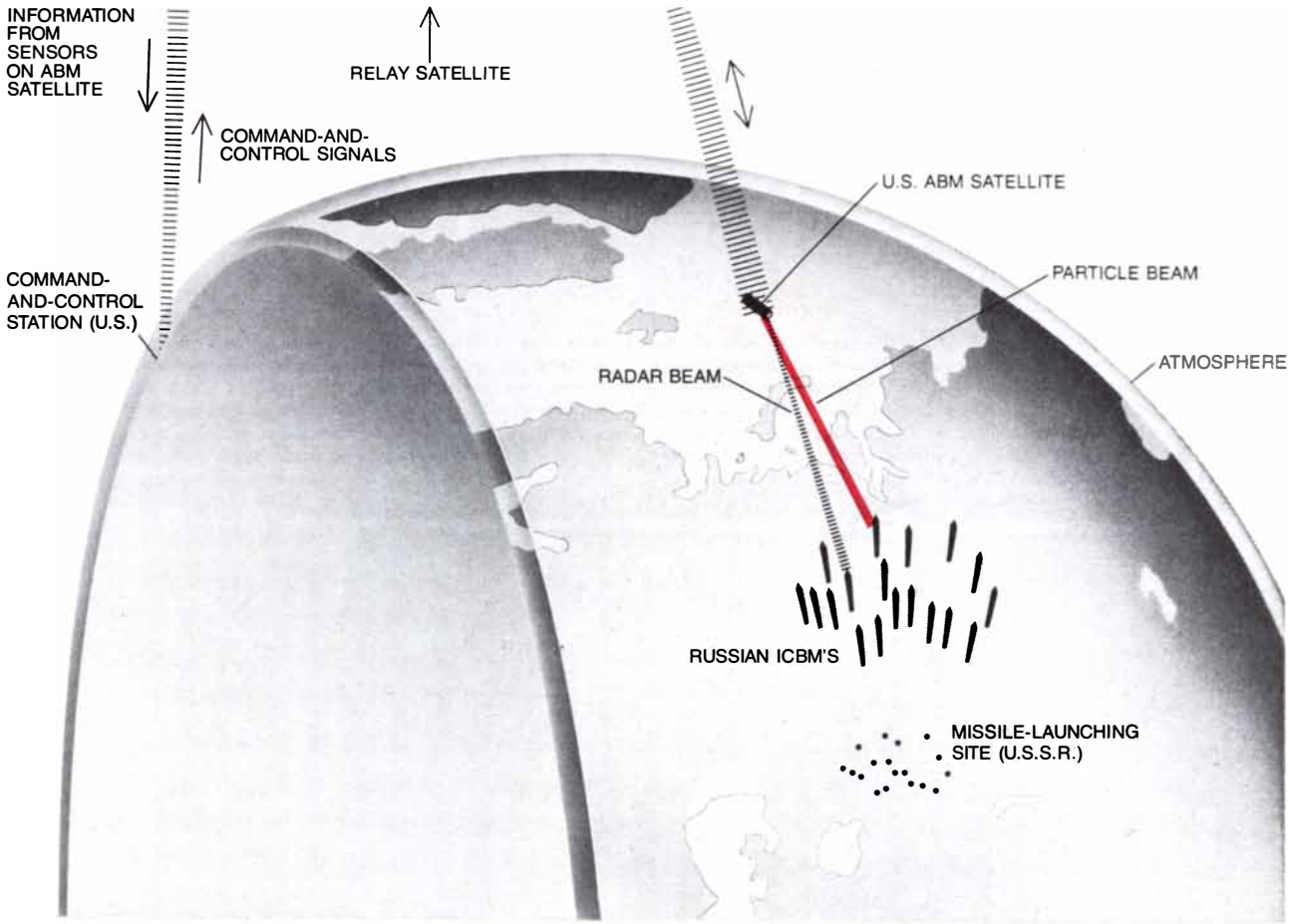
Proton energies of about 500 billion electron volts (GeV) have been achieved with the giant circular accelerator at the Fermi National Accelerator Laboratory (Fermilab), which has been in operation for several years. Machines such as the one at Fermilab usually have comparatively low fluxes of particles (on the order of 10^{14} per second) compared with what an accelerator for a particle-beam weapon would require. The power of an accelerator beam is equal to the product of the total potential drop to which the particles are subjected (while they are

inside the machine) times the current in the beam. (A current of one ampere is equal to the flow of about 6×10^{18} singly charged particles per second.) Therefore an accelerator that imparts 1 GeV of kinetic energy to each particle and has a beam current of one ampere has a power of one gigawatt (a billion watts). The total energy in a pulsed beam from such an accelerator is equal to the power in the beam multiplied by the duration of the pulse. Hence a one-gigawatt pulse that lasts a millionth of a second carries exactly 1,000 joules of energy.

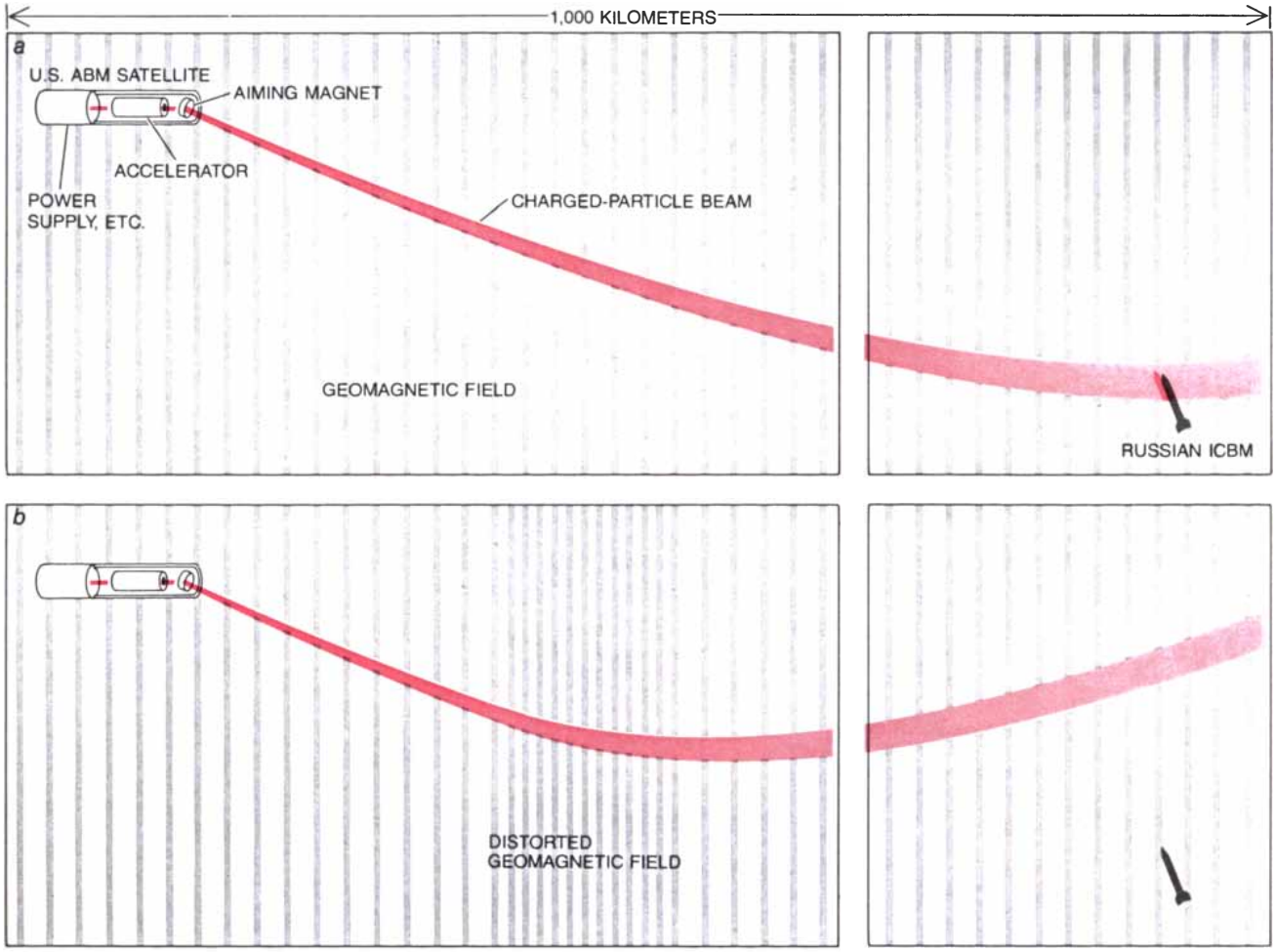
What happens when the particles in such a beam hit a target? A large fraction of them penetrate the target and travel through it. As each particle does so it loses energy principally by transferring energy to the electrons in the target in a series of elastic collisions that leave its direction of motion largely undisturbed. Eventually the energy lost in the material manifests itself as heat, raising the temperature of the target where the beam hits it. If the number of particles depositing energy in a piece of matter is sufficiently large (large enough for the rate of energy deposition to be higher than the rate at which the material can radiate or conduct heat away), the temperature could rise until the part of the target struck by the beam either melts or cracks because of thermal stresses. The amount of energy each particle deposits in the target depends on the mass and the energy of the particle, the material the target is made of and the total distance the particle travels in the target.

Obviously particle-beam weapons would have novel properties and working principles. First, they would deposit destructive energy on an area on the surface of the target rather than spreading it uniformly in a spherical volume that expands outward from the point of an explosion. It follows that a particle beam could not inflict damage on a target unless it were actually to strike it. Second, the energy that carried the particles to the target would be the same energy that caused the damage (which is not the case with conventional weapons). Third, whereas a conventional missile with destructive energy stored in its warhead travels to its target at a speed no greater than several times the speed of sound (roughly 1,500 meters per second), the destructive energy of a particle beam would travel essentially at the speed of light: 300 million meters per second.

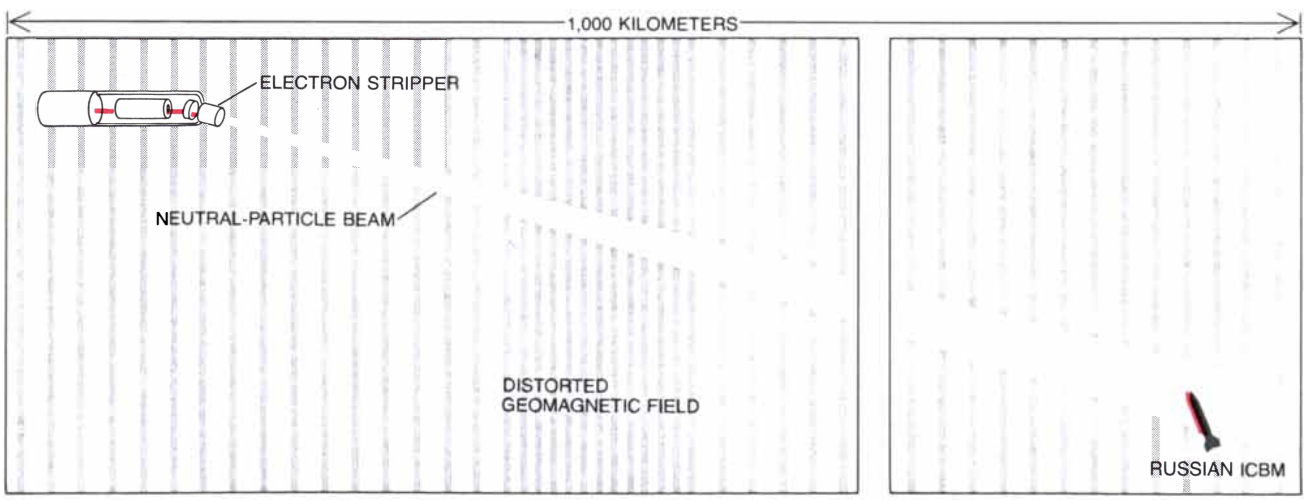
It is mainly this last property that has suggested to some that particle-beam weapons would be ideal as defensive systems against missiles. Three such applications of the particle-beam approach have been proposed: an anti-ballistic-missile (ABM) system based on a satellite orbiting the earth, intended to shoot down offensive missiles as



ONE PROPOSED USE for particle-beam weapons foresees their deployment in a new kind of anti-ballistic-missile (ABM) system based on satellites orbiting the earth and intended to shoot down an enemy's offensive missiles as they rise above the atmosphere. Assuming that the satellites were placed in orbits 1,000 kilometers high, about 150 of them would have to be carefully positioned around the earth to ensure that every possible missile-launching site accessible to the enemy would be covered at all times by at least one particle-beam weapon. In the case of a massive surprise attack against the U.S. by the U.S.S.R., depicted schematically in this illustration, the single particle-beam weapon in the right firing position at the time of the attack would presumably have to detect, identify and destroy some 1,000 ascending Russian intercontinental ballistic missiles (ICBM's) in a total elapsed time of approximately 400 seconds. Moreover, the particle beam would have to make a direct hit on each target in order to destroy it. At a range of 1,000 kilometers, for example, the satellite's radar-controlled aiming system would have to be capable of determining the position of a missile with an accuracy of one part in 100,000 every .4 second. Communications between the ABM satellite and a ground-based command-and-control station in the U.S. could be routed through a relay satellite placed in a geosynchronous, or earth-stationary, orbit at an altitude of some 40,000 kilometers.



CHARGED-PARTICLE BEAM propagating in the vacuum of outer space would be subject to a number of physical constraints, two of which are represented here. Assuming that the charged-particle beam could propagate for any appreciable distance beyond the exit port of the accelerator (a questionable assumption considering the attractive force of the opposite charges left behind), the resulting beam would tend to diverge and disperse owing to the mutually repulsive force exerted by the beam's similarly charged particles; for example, an electron beam with an energy of one billion electron volts (GeV) and an initial diameter of one centimeter would spread to a diameter of five meters at a range of 1,000 kilometers (*a*). Even if the greatly diffused beam from such a weapon could conceivably be effective in damaging an enemy ICBM, it could not be aimed reliably, since it would be deflected by random fluctuations in the earth's magnetic field (*b*). The two opposed weapons systems are drawn approximately to the same scale in these split views. Design of the ABM satellite is conceptual.



NEUTRAL-PARTICLE BEAM would propagate in space without being deflected by the earth's magnetic field. A beam of neutral hydrogen atoms, for example, could be generated by first accelerating negatively charged hydrogen ions in the satellite's accelerator and then stripping the extra electrons from the atoms by passing the beam through a rarefied gas. Assuming that the magnets for bending and focusing the original beam of charged atoms could be shielded from the geomagnetic field, a neutral-hydrogen beam of this type would spread from a diameter of one centimeter at the exit port of the accelerator to a diameter of 20 meters at a distance of 1,000 kilometers.

they rise above the atmosphere; a ship-based system designed to defend the ship against cruise missiles; a land-based ABM system deployed to defend missile silos against reentry vehicles carrying nuclear warheads.

In any of these three missions the particle-beam weapons system would have to perform the following 12 steps: Detect the target; identify it among possible decoys; point the beam at the target and if necessary follow the target with the beam; fire the beam through the intervening medium to the target; determine whether or not the target was hit; assess the damage if the target was hit; determine by how much and in what direction the beam missed the target if the target was not hit; correct the aiming of the beam by the miss distance; fire the beam once again at the target; determine the damage or miss distance depending on the results of the shot; repeat the cycle until the target is destroyed or engage a new target, and communicate the results of each beam burst to some command center.

To perform all these functions the weapons system would need in addition to the accelerator some other kinds of equipment. It would need a power supply to energize the particles in the accelerator and to run the rest of the equipment. It would need an energy-storage and staging system to feed energy to the accelerator during the short periods when the particle-beam burst was being generated, accelerated and fired. It would need a complement of sensors (some combination of radar, optical and infrared devices) capable of locating and identifying the target, of detecting whether or not the target was hit and of assessing the damage it suffered if it was hit. Finally, it would need control devices to aim the beam and to couple the sensors to the aiming mechanism so that the beam could follow the target.

Let us consider each of the three proposed missions of particle-beam weapons separately. For use against intercontinental ballistic missiles (ICBM's) during their boost phase, particle-beam weapons would have to be deployed on large satellites orbiting the earth. In order to be an effective defense system against an enemy ICBM attack on cities in the U.S. the particle-beam weapons would have to cover all possible launching sites an enemy might use, not only on his own territory but anywhere in the oceans from which his nuclear ballistic-missile submarines might launch missiles against the U.S. If the particle-beam weapon were placed in a geosynchronous orbit (that is, an orbit about 40,000 kilometers above the earth's surface that would keep it stationary above one point on the surface), it could look down on roughly a hemisphere of the earth; accordingly only two or three satellites carrying the weapons would suffice to monitor the entire surface of the earth. As it happens, it would be impractical to fire at ICBM boosters with a particle-beam weapon from a distance of 40,000 kilometers. Therefore the weapons would have to be placed in orbit much closer to the earth, perhaps no more than 1,000 kilometers above the surface. Such a deployment would have two disadvantages: each satellite could survey only a small fraction of the earth's surface, and the satellites would move with respect to a point on the surface.

As a result it would be necessary to deploy many satellites carefully spaced around the earth so that every possible missile-launching site would be covered at all times by one particle-beam weapon. Some 150 satellites with particle-beam weapons would be required for complete coverage from an altitude of 1,000 kilometers. In the case of a massive surprise attack by the U.S.S.R. against the U.S., during which the Russians would presumably launch in quick succession at least all their land-based ICBM's, this number of satellites would provide for only a single particle-beam weapon in place to confront the 1,000 or so ICBM's that would rise almost simultaneously from their silos. The rest of the satellites would be out of view of the launching sites.

Typically the boosting phase of an ICBM's trajectory lasts for about eight minutes, but since the missile would have to rise above the atmosphere before it could be attacked by the particle-beam weapon, the time available for the weapon to attack and destroy the 1,000 targets would be only about 400 seconds. Within this interval the system would have to be capable of detecting each ascending ICBM by infrared or optical sensors, identifying it (possibly among a large number of decoys) and determining its velocity and its distance from the weapon platform by radar. Unlike an ABM system designed to use missiles with nuclear warheads for intercepting an attacking ICBM, a particle-beam weapon would have to make a direct hit on the target in order to destroy it. Since an ICBM booster is about 10 meters long and the distance to it from the platform would be close to 1,000 kilometers, the radar would have to determine the position of the missile with an angular accuracy of one part in 100,000, a feat that is currently impossible. If the beam were to miss, the system would have to fire several times per second at any one of the 1,000 targets, adjusting its aim each time to compensate for the miss distance of the previous shot.

The operation of such a particle-beam weapon would be limited by two physical constraints. First, the basic laws of physics that govern the motion of collections of charged particles in space forbid the unlimited propagation of a charged-particle beam in a vacuum. For example, simple calculations indicate that most of a 1-GeV electron beam with a diameter of one centimeter and a steady current of 1,000 amperes would not propagate more than a meter or so beyond the exit port of the accelerator. Hence the very kind of charged-particle

LOCATION OF ACCELERATOR	MAXIMUM ENERGY (MEV)	MAXIMUM CURRENT (AMPERES)	DURATION OF PULSES (NANOSECONDS)	REPETITION RATE OF PULSES
STANFORD LINEAR ACCELERATOR CENTER	20,000	.00003	2,500	360 PER SECOND
SACLAY NUCLEAR RESEARCH CENTER	600	.0002	1,000	1,000 PER SECOND
MASSACHUSETTS INSTITUTE OF TECHNOLOGY	400	.0001	1,500	1,000 PER SECOND
UNIVERSITY OF GLASGOW	130	.0003	3,500	240 PER SECOND
SANDIA LABORATORIES	1.5	4,500,000	80	3 PER DAY
HARRY DIAMOND LABORATORY	15	400,000	120	1 PER DAY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY	1.6	20,000	30	5 PER HOUR
SANDIA LABORATORIES	.35	30,000	30	100 PER SECOND

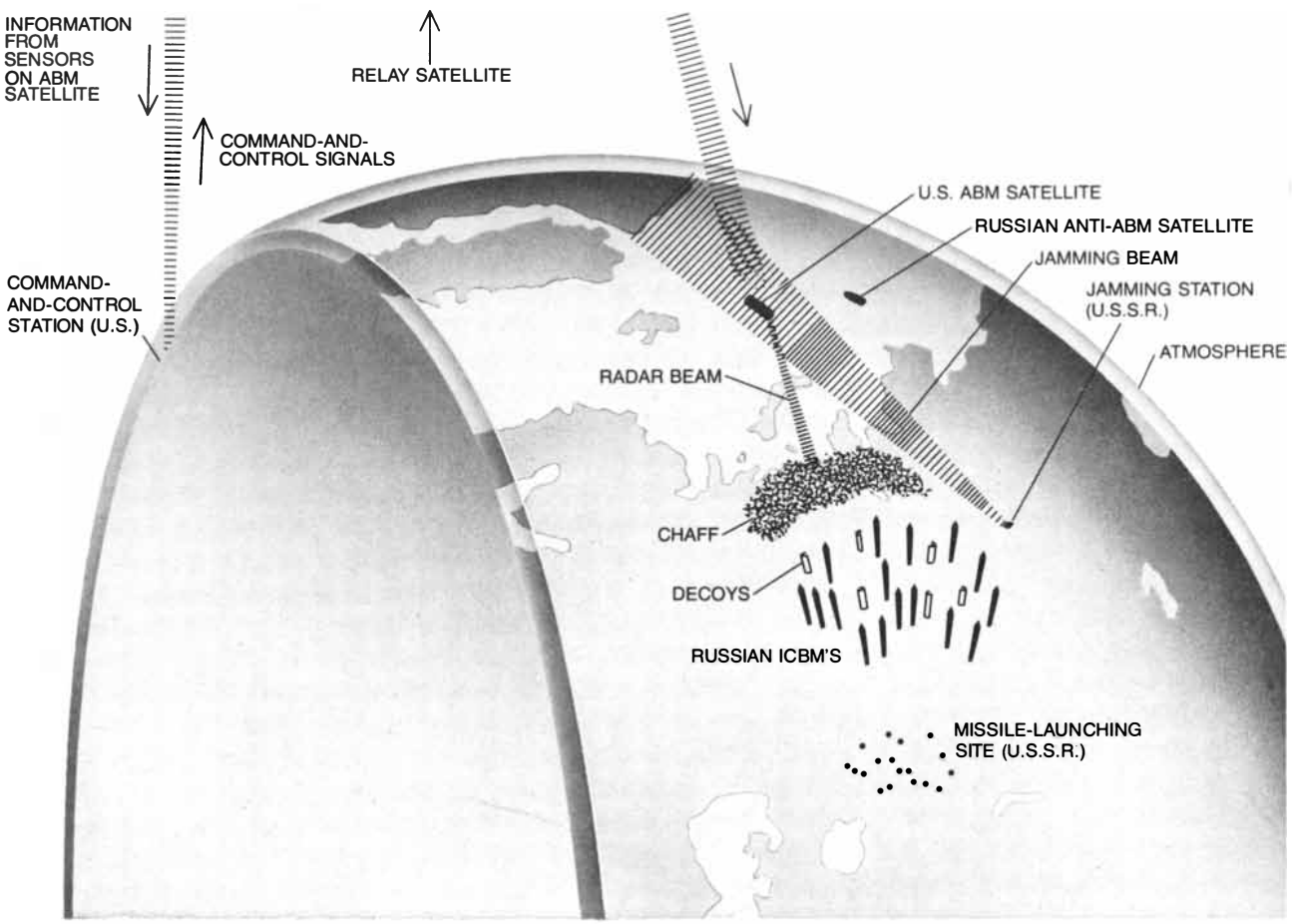
PROPERTIES OF PARTICLE-BEAM ACCELERATORS in existence today serve as a basis for grouping these experimental devices into two broad categories: high-energy, low-current machines (*top*) and low-energy, high-current machines (*bottom*). An accelerator capable of generating a beam of neutral hydrogen atoms suitable for a satellite-based ABM system would require a beam energy of 200 million electron volts (MeV), a current of between one ampere and 10 amperes, a pulse duration of .1 second and a pulse-repetition rate of several pulses per second. An electron-beam accelerator for use against cruise missiles in the atmosphere would have to be capable of generating a beam with an energy of 500 MeV, a current of 5,000 amperes, a pulse duration of 100 nanoseconds and a repetition rate of 10,000 pulses per second.

beam that would appear to be suitable as a weapon could not operate as one.

The second constraint would be as serious as the first. Each particle in a beam of similarly charged particles is subject to repulsion by all the other charged particles in the beam. In a uniform beam the net force on each particle is radially outward; as a result the beam tends to diverge and disperse soon after it leaves the exit port of the accelerator. When a beam propagates in a gas such as the earth's atmosphere, it produces by ionization enough charges of the opposite sign in its immediate vicinity to counter the outward repulsive force. In the vacuum of outer space, however, no such effect obtains, and as a result a charged-particle beam would diverge drastically because of its self-generated repulsive force. In the case of a beam of particles with a speed very near the speed of light, the beam would appear in the frame of reference of the earth as if it were taking a long time to spread out. Indeed, a 1-GeV electron beam one centimeter across as it emerges from the accelerator would spread to a diameter of five meters 1,000 kilometers away, whereas a 1-GeV proton beam would spread out to a diameter of three kilometers at the same distance. A beam that spreads out to cover a circle five meters in diameter could conceivably be used as a weapon, but there is another physical phenomenon that would prevent it from aiming reliably at a target.

The earth is surrounded by a magnetic field that is subject to significant and unpredictable fluctuations in strength as a function of both location and time. Charged particles are deflected by a magnetic field away from their original direction by an amount that is inversely proportional to the momentum of the particles and directly proportional to the strength of the magnetic field. The uncertainty in the amount of the deflection of a charged-particle beam from its original direction would be proportional to the uncertainty of the strength of the geomagnetic field at each point along the beam's path. Thus if the field could be known with an accuracy of, say, one part in 1,000, the uncertainty in the amount by which the beam could be deflected would be a thousandth of the total deflection of the beam. Since the geomagnetic field would deflect a 1-GeV electron beam by 1,000 kilometers over a range of 1,000 kilometers, the uncertainty in the position of the beam at the end of this range would be one kilometer. That would preclude aiming the beam with the accuracy required to hit a target a few meters long.

What about the possibility of using a beam of neutral particles instead? Particles without charge, such as neutrons or gamma rays, do not have any difficulty propagating in a vacuum along a straight line, but precisely because they lack an electric charge they cannot be accelerated or focused into a beam. High-energy neutrons can be produced by bombarding a target with an intense beam of protons from an accelerator. A proton that has entered a nucleus exchanges its charge with one of the neutrons in the nucleus and emerges as a neutron. The angular distribution of the emitted neutrons that come from such a reaction tends to be peaked in the forward direction. The average angle a neutron would make with the original proton beam, however, would be such that at a distance of 1,000 kilometers the neutrons would be spread over an area of several hundred square kilometers, and their density per unit area would not



COUNTERMEASURES available to a strategic military planner confronting a satellite-based particle-beam ABM system are indicated in the illustrations on these two pages. As the imaginary scene at the left shows, the particle-beam weapon could simply be destroyed by means of an explosive charge on a small satellite placed in orbit nearby. Alternatively, communications with the command-and-control station on the ground could be jammed (as could the satellite's missile-detection radar). Decoys to confuse the system's sensors or

be high enough to do any damage to a target.

A beam of gamma rays has the same shortcoming. Gamma rays can be readily generated by passing an intense electron beam through a material containing heavy nuclei, such as lead or uranium. The rays emerging downstream from the material would spread out, however, so that at a distance of 1,000 kilometers the beam would have a cross-sectional area of several square kilometers. Therefore it is impractical to produce a gamma-ray beam that could be useful as a weapon.

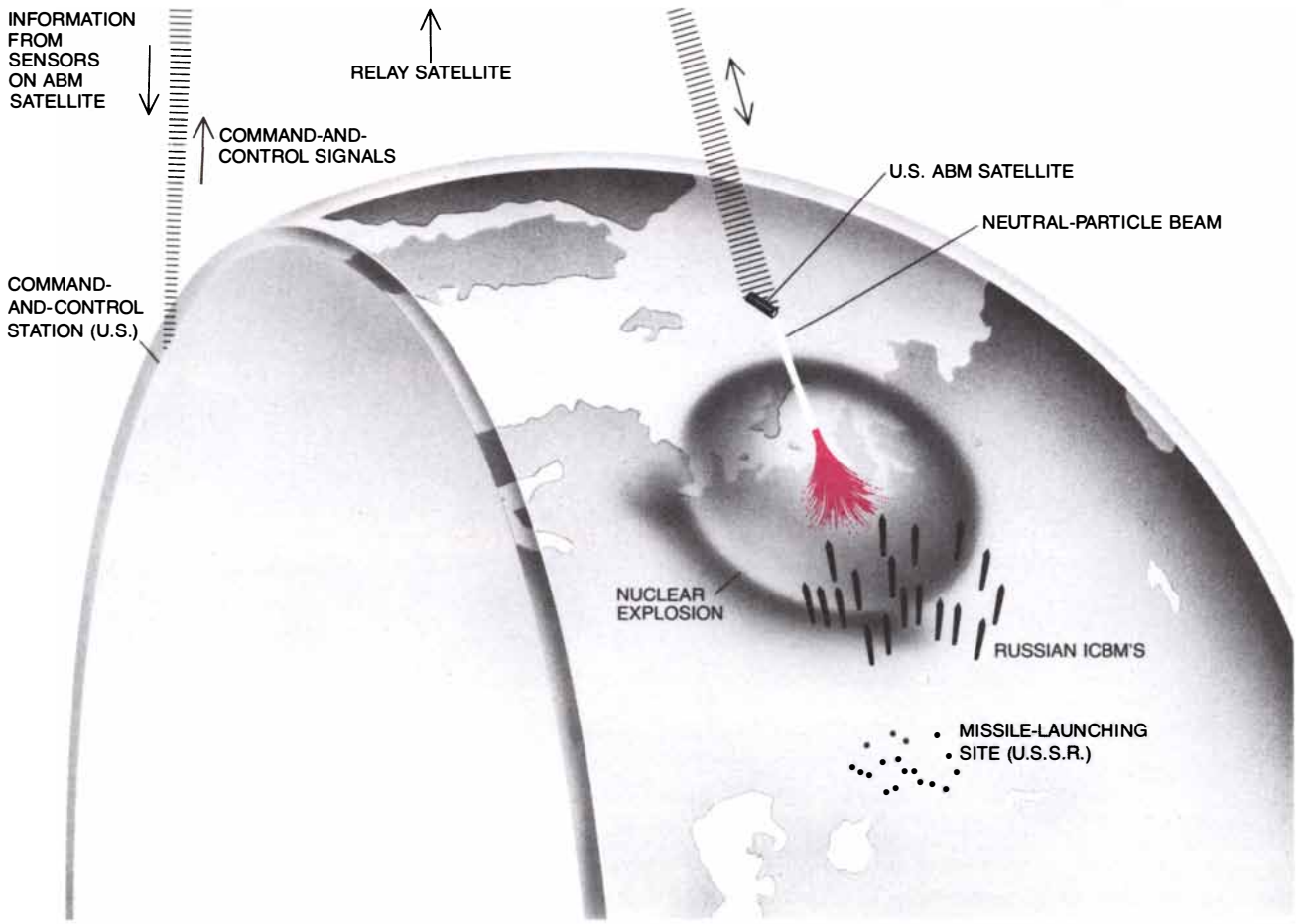
Would it be possible to accelerate charged atoms and, after forming them into a beam, neutralize them before they pass into the vacuum of space? It could indeed be done with hydrogen atoms. Ordinarily a hydrogen atom consists of a positively charged nucleus (a single proton) and an orbiting electron; hence the atom as a whole is neutral. It is possible, however, to add a second electron to the configuration and thereby make the entire atom negatively charged. Such atoms can be accelerated to high energies and focused into a beam. Immediately after the beam is generated and focused it can be neutralized by stripping the extra electrons from the atoms. It would therefore be possible (at least in principle) to generate an intense high-energy neutral-hydrogen beam suitable for use as a weapon.

The stripping of the extra electron could be achieved with reasonable efficiency, but with some spreading of the beam, by passing the charged hydrogen atoms through some rarefied gas. At a distance of 1,000 kilometers a neutral beam with a diameter of two centimeters would spread out to a diameter of about 20 meters; at a distance of 40,000 kilometers the diameter of the beam would be about 800 meters. This degree of dispersion could be maintained if the magnets for bending and focusing the beam of charged atoms could be shielded from the geomagnetic field and could maintain a predictable and stable strength with a precision of one part in a million. This task would be possible, but it cannot be considered practical.

How energetic and intense would such a beam have to be in order to damage, in a way detectable from a distance of 1,000 kilometers, an ICBM rising above the atmosphere? Detectable damage would result either from the burning of a hole through the walls of the missile's fuel container or from the detonation of the chemical-explosive triggers of its nuclear warheads. The beam would have to deposit about 2,000 joules per cubic centimeter of material to burn a hole in the walls of the missile and about 200 joules per cubic centimeter to detonate the explosive.

Consider a 200-MeV particle beam that illuminates an area totaling about a million square centimeters at the target. Not all the particles in the beam would intercept the target. The largest fraction would pass the target and be lost. Since a 200-MeV proton would deposit about 10^{-12} joule for each centimeter it traveled in a lightweight material, 2×10^{15} particles would have to hit each square centimeter of target in order to deposit a total of 2,000 joules per cubic centimeter. Since the beam would be uniform, the total number of particles in the beam would therefore be 2×10^{21} particles. It follows that the total energy in the beam would have to be on the order of 6×10^{10} joules.

The beam power required depends on



clouds of metallic "chaff" to blind them could also be deployed. The scene at the right shows a different kind of countermeasure, designed specifically to be effective against a neutral-hydrogen-beam weapon. In this approach a 100-kiloton nuclear warhead would be exploded at the upper edge of the atmosphere to lift enough air into the path of the beam to convert it into a proton beam, thereby causing it to disperse. All the countermeasures depicted would be cheap, easy to deploy and difficult or impossible for the ABM system to overcome.

how fast the necessary destructive energy must be deposited on the target. A 6×10^{10}-watt beam would deposit the necessary 6×10^{10} joules in one second of continuous deposition. A beam 10 times as powerful (6×10^{11} watts) would be needed, however, if the damage had to be completed in a tenth of a second. The increase could be achieved in practice by increasing the number of particles in the beam tenfold. If the intended destructive mechanism were the detonation of the chemical explosives in the warheads, only a tenth of this energy would be needed. Although there is no absolute lower limit on the size and spread of an intense beam at the end of an accelerator, it would be extremely difficult to produce a beam with the intensity and compactness required to shoot down a missile 1,000 kilometers away. Current technology is certainly a long way from achieving such a beam.

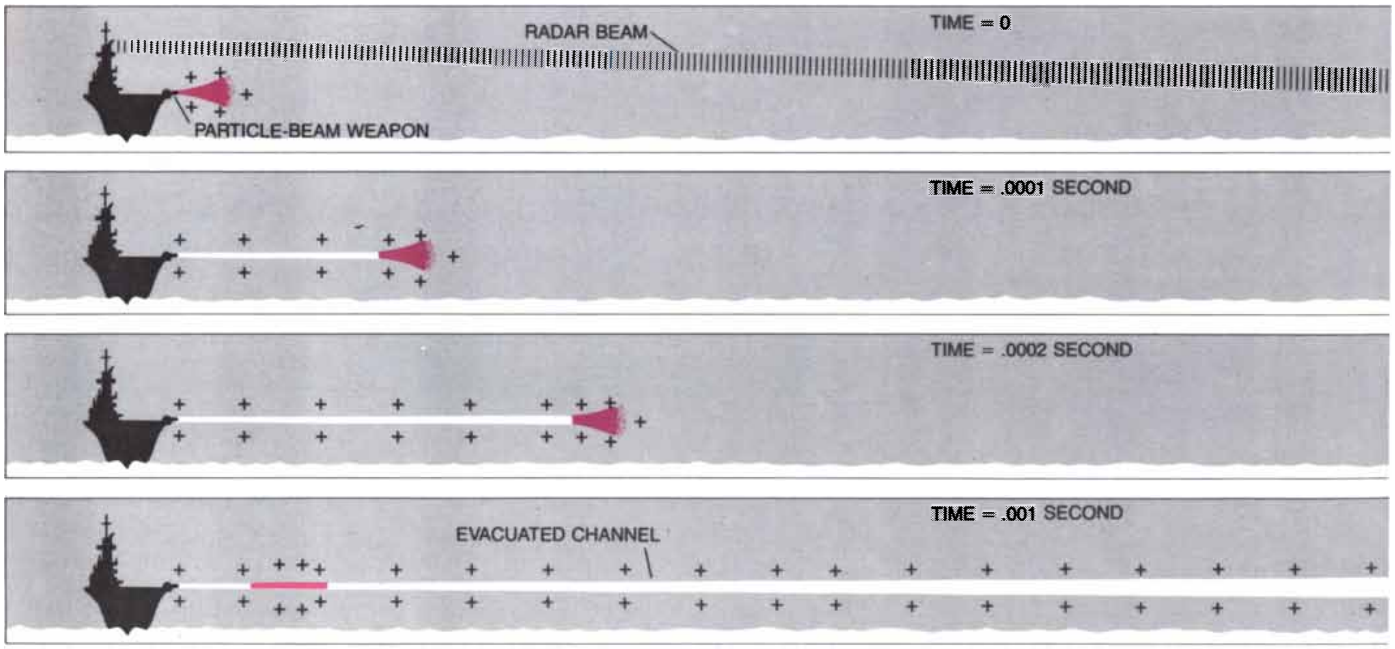
Consider now the type and size of the power supply that would be needed to operate an accelerator capable of producing a 6×10^{10}-watt beam for one second. Assuming an overall conversion efficiency from primary energy source to beam energy of 40 percent, the required energy per pulse would be 1.5×10^{11} joules. The energy stored in high explosives is about 4,000 joules per gram. Therefore 37.5 tons of high explosives would have to be set off per second in magnetic generators to provide the necessary energy for the beam. If a rocket-driven generator were used instead, it would require several dozen tons of solid fuel to produce the same amount of beam energy, since the conversion efficiency of rocket fuel to electricity is between 10 and 20 percent for energy generation in time intervals coincident with the beam pulse. As for the possibility of using nuclear explosives for powering a particle-beam weapon, problems of energy containment and radiation containment would make nuclear explosives unsuitable.

It is possible that a beam 100 times weaker could damage the electronic computer inside an ICBM, and it would take only hundreds of kilograms of explosives detonated per second to provide the necessary energy. The resulting damage, however, might not cause any readily detectable incapacitation of the missile. Hence the operator of the particle-beam weapon would not know whether the ICBM was incapacitated and whether he could therefore cease firing at it and engage another target. That would be a serious operational flaw of the entire weapons system, since little time could be devoted to each ascending ICBM.

A particle-beam weapon based on neutral particles suffers from an additional serious shortcoming. It would be impossible to determine by how much and in what direction a neutral beam had missed a target. Therefore it would be necessary to fire the weapon "blindly" at the targets, relying on predetermined calibrations of the aiming magnets, a procedure that would not ensure that any of the targets would be hit.

All these difficulties point to the conclusion that even though it might be possible to construct an accelerator that would produce a beam of hydrogen atoms intense and energetic enough to cause some damage to an ICBM in its boost phase, a satellite-based neutral-particle-beam ABM system would not be practical. Even in a cooperative environment the system would have great difficulty locating and identifying the ICBM's. It would not be able to engage them all in time, it would require dozens of tons of explosives per beam pulse if it were to fire rapidly at them and cause visible damage and it would be unable to adjust the aim of the beam if there were no visible damage. Moreover, the effectiveness of the system could be easily nullified by a host of available countermeasures.

Let us consider next the first of the two proposed endoatmospheric uses of a charged-particle-beam weapon, namely the defense of ships against cruise missiles. Ordinarily a cruise missile, to avoid early detection, would fly toward a ship just a few meters above the surface of the water, where it would not be detected by the ship's radar until it was within a kilometer or so. Flying at the speed of sound, the missile would cover the last kilometer to its target in about four seconds, during which time the charged-particle-beam weapon on the ship would have to engage it and shoot it down. This means that the charged-particle beam would have to travel for

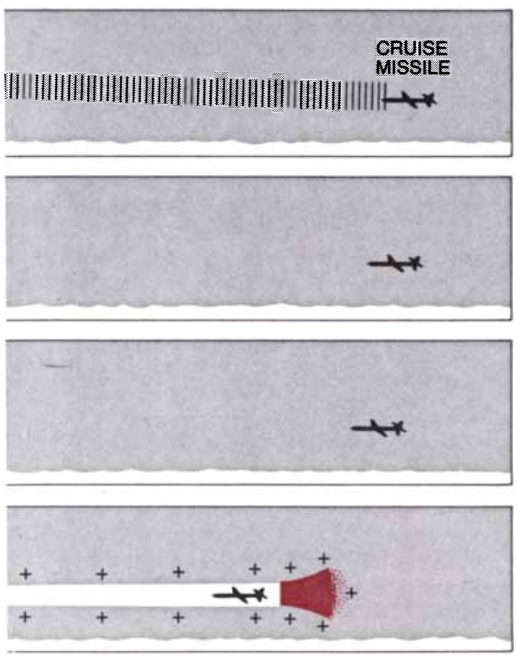


SECOND PROPOSED USE for particle-beam weapons would be as a ship-based defense against cruise missiles. An attacking cruise missile would probably fly toward a ship just a few meters above the water to avoid detection by the ship's radars until it was within a kilometer or so. The missile would cover the last kilometer to the target in about four seconds, during which time the charged-particle-beam weapon on the ship would have to engage the missile and shoot it down. A pulsed electron beam with an energy of 1 GeV, a current of 5,000 amperes and a pulse duration of a tenth of a microsecond could in principle bore an evacuated channel in the atmosphere through which subsequent pulses could travel from the accelerator to the missile with little loss of energy. Many outstanding questions about the

perhaps a kilometer through the atmosphere and retain enough energy to damage the target.

Imagine a 5,000-ampere beam of 500-MeV electrons streaming from the exit port of the accelerator toward the target a kilometer away. As the particles traveled through the atmosphere they would collide frequently with air molecules, losing some of their kinetic energy in each collision. The process would have three noteworthy effects: (1) The energy lost by the particles would heat the air in the immediate vicinity of the beam, and it would create by ionization a large number of positively charged atoms and free electrons around the beam. (2) The resulting positive charges would reduce the net electric field of the particles in the beam. (3) At the same time the self-magnetic field generated by the streaming of the beam's electrons would tend to overcome the repulsive forces among the particles that normally disperse a charged beam in a vacuum. This effect would tend to keep the electron beam confined to a stable channel.

On the other hand, as the electrons in the beam collided with air molecules they would scatter away from their original direction of motion. The scattering would be cumulative, so that a 500-MeV electron beam with a diameter of four centimeters at the exit port of the accelerator would have a diameter of about 14 meters 400 meters away from the accelerator and 132 meters a kilometer away. In addition the collisions would remove energy from the beam, so that at a distance of 400 meters from the accelerator the electrons in the beam would have only about 30 percent of their original kinetic energy, and at a distance of a kilometer they would retain only about 6 percent. Hence even though an energetic electron beam could perhaps propagate in the atmosphere to a distance of one kilometer from the accelerator, it would be so dispersed and weakened that it would not be able to inflict any damage on a missile at that distance.



propagation properties of charged-particle beams in the atmosphere would have to be answered experimentally, however, before one could conclude that such pulses would have enough energy left to destroy a cruise missile at the end of a range of one kilometer.

Indeed, it is not even certain that such a beam could propagate at all. Experiments with charged-particle beams have shown that long beams suffer from what physicists call magnetohydrodynamic instabilities: they kink and coil like a garden hose or pinch like a string of sausages. Once these instabilities set in they tend to grow until they completely disrupt the beam. The dispersal of the beam tends to be much more pronounced in a proton beam of the same energy; such a beam would spread out and become an amorphous cloud of protons a few dozen meters from the accelerator.

The preceding discussion indicates that the numerous collisions an electron or proton beam would suffer in traversing the atmosphere would reduce so severely the number of particles that could strike the target and remove so much of the energy contained in the beam that a continuous beam would not be suitable as a destructive mechanism at any useful range. Waiting to fire at the cruise missile until it is only a few hundred meters from the ship would not reduce these problems appreciably, and it would shorten the time available for firing at the missile to about a second. An alternative would be to reduce the beam's loss of particles and energy by reducing the number of collisions the particles would undergo in traveling a kilometer; in order to achieve that goal one would have to reduce the number of air molecules in the space the beam would have to traverse from the accelerator to the target. In short, one would have to bore an evacuated hole in the atmosphere through which the beam could propagate with little scattering of the particles and minimal energy losses. Such a possibility can be analyzed theoretically.

Consider a pulsed 5,000-ampere, 1-GeV electron beam with a diameter of two centimeters and a pulse duration of a tenth of a microsecond. Since the electrons would travel essentially at the speed of light, the .1-microsecond pulse would be about 30 meters long as it traveled toward the target. The total energy carried by the electrons in one pulse would then be 500,000 joules. The electrons in such a pulse would lose energy not only by colliding with the air molecules but also by radiating it away. The collisional loss of energy by such high-energy electrons in air would be approximately 2,000 electron volts per centimeter, and the rate of radiation loss in air would be about 10 times higher. Therefore as a pulsed beam of this type began to travel through the air it would deposit energy at the rate of three million watts per cubic centimeter through ionization and about 10 times as much energy through radiation emitted mostly in the forward direction. This energy would be deposited in the air molecules the beam intercepts, and eventually it would manifest itself as a pressure increase in the heated air in the immediate vicinity of the beam. The predominant effect of the rise in pressure would be to cause the air molecules to move radially away from the path of the beam pulse. The hot low-density air left behind would act as a channel through which subsequent pulses could propagate with lower energy losses and less dispersion.

Assume now that one seeks to generate a channel in which the pressure would be only a tenth of atmospheric pressure. This would mean that the air inside the channel, measuring a kilometer in length and at least a centimeter in radius, would be heated to a temperature of 3,000 degrees Celsius, a task that would call for 1.5 million joules of energy. Since each pulse would contain 500,000 joules of energy, only a few pulses would suffice to reduce the density inside the channel to a tenth of atmospheric pressure. (This calculation is an idealized one in that it assumes all the energy carried by each beam pulse would be deposited within the channel, which actually would not be the case.) The calculation indicates that one could conceivably bore such a channel to a target a kilometer away, perhaps not with just a few pulses but probably with several dozen pulses of the hypothetical beam assumed in this example. The 1-GeV electrons propagating in such an evacuated channel would lose no more than 20 percent of their original energy, and the radius of the beam would increase only by a factor of three after a kilometer of travel.

Alternatively a high-intensity laser could be used to bore an evacuated channel for the beam. Laser radiation at a typical wavelength of 10 micrometers is strongly absorbed by the atmosphere and would need a mirror about a meter in diameter to form a one-centimeter hole one kilometer away. Manufacturing such a mirror would be technically feasible.

The rudimentary analysis of the propagation of a pulsed electron beam given here indicates that the electrons might propagate stably, but the analysis is still incomplete. We have not dealt with the effects of chopping the beam into pulses and then trying to propagate toward the target several thousand pulses per second. We have ignored the fact that each

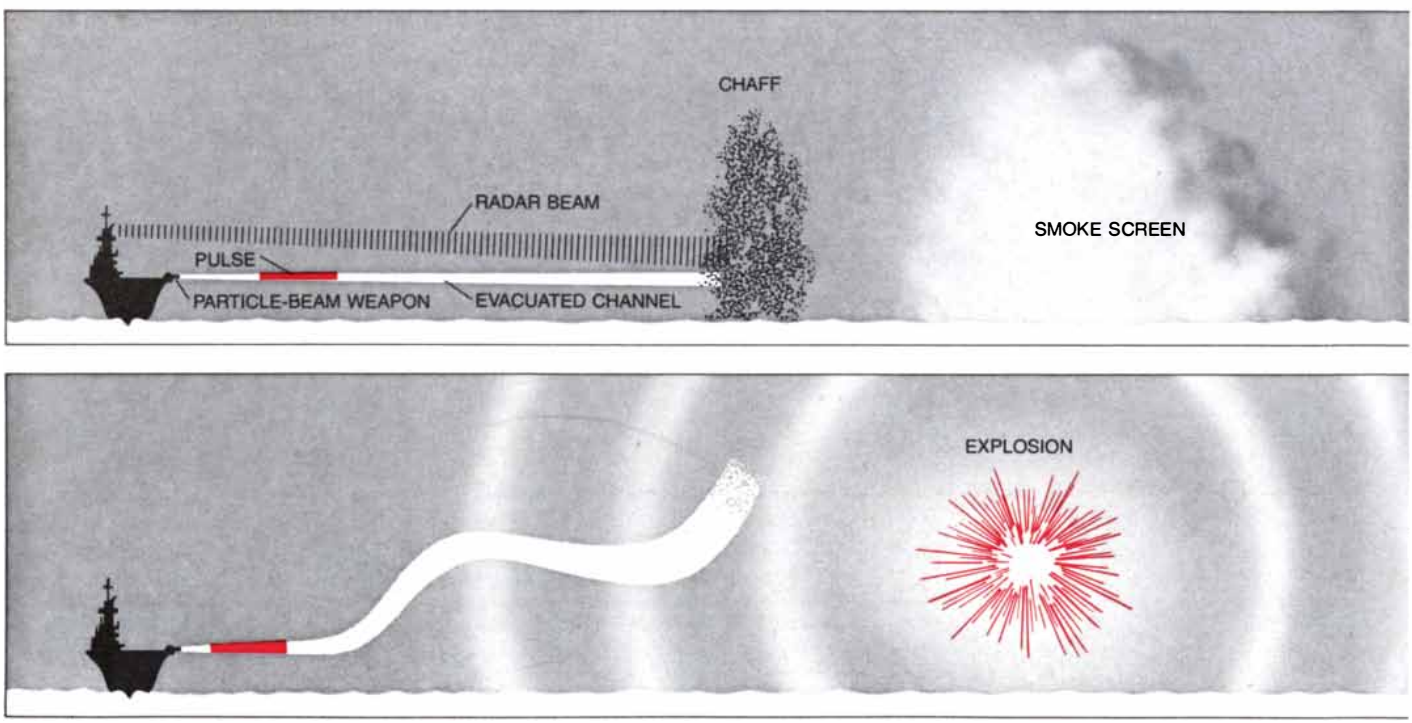
pulse would be followed by an electromagnetic wake, much like the wake generated in water by a speeding motorboat, and that the wake of one pulse would affect the behavior of the next one. We have not considered nonlinear effects that would obtain in beams with such high currents. Finally, we have not accounted for the hydrodynamic behavior of the heated channel. How long would the channel remain open? How wide should it be to accommodate a beam with a diameter of two centimeters? What effects or conditions would prove to be predictable and reproducible? All of these remain open questions to be answered experimentally.

The existing experimental evidence indicates that a low-energy electron beam (on the order of 10 MeV) does propagate well for a few meters in a channel that is between 100 and 1,000 times less dense than the atmosphere. It is not known, however, how high-energy electron pulses would behave, particularly in traveling over a distance of a kilometer. If all these open questions were to be satisfactorily resolved, it might be possible to propagate an electron beam of a few thousand amperes through the atmosphere in the form, say, of a train of .1-microsecond pulses with a repetition rate of 10,000 per second over the distance of a kilometer and still have enough energy remaining at the end of that range to destroy a cruise missile, provided of course that the beam scored a direct hit. (This last condition raises a number of operational problems for an anti-cruise-missile particle-beam system, problems we shall discuss further along in this article.)

Consider next the use of a charged-particle beam as the interceptor for an ABM system designed to protect missile silos from reentry vehicles carrying nuclear warheads. Here the charged-particle-beam weapon would be emplaced near a cluster of missile silos. The beam would have to bore a hole through the atmosphere to the target, as an anti-cruise-missile weapon would, but the performance criteria would be somewhat different. A modern reentry vehicle would approach the silo at several times the speed of sound, and therefore it would take less than a second to cover the last kilometer. In addition the particle-beam weapon would have to be able to defend its own radar, which could be physically destroyed by a one-megaton nuclear weapon exploding as far away as two kilometers or even more. Therefore if the beam is to fulfill its ABM mission, it appears essential that it be able to propagate for several kilometers in the atmosphere and destroy an incoming reentry vehicle a few kilometers away. Then if the beam were not completely charge-neutralized by the positive charges it would create as it passed through the atmosphere, it would be bent by the earth's magnetic field. The aiming uncertainty that would result from the latter effect would be several dozen meters over a range of a few kilometers. Since the target warhead would be typically about a meter long and some fraction of a meter wide, the magnitude of the aiming uncertainty for a particle-beam ABM weapon appears to be a fundamental difficulty that has no easy technological remedy. Moreover, when one considers the operational requirements of such a system, it becomes clear that a noncooperative attacker could complicate its operation further by perturbing the geomagnetic field in an arbitrary and random fashion, and by blinding the system's radar.

So far we have examined whether the laws of physics that govern the behavior of particle beams would allow the generation and propagation of a beam powerful enough to destroy a target. We have found that it appears possible in principle but extraordinarily difficult in practice to form a neutral-hydrogen beam that could propagate for 1,000 kilometers in the vacuum of space and deposit enough energy on an ICBM booster to destroy it, and that an intense, pulsed electron beam could perhaps propagate a kilometer or more within the lower atmosphere and still have enough energy at the end of that range to destroy its intended target. Is the current state of technology in the U.S. or the U.S.S.R. advanced enough to enable either side to build the accelerators necessary to generate particle beams with the properties required for a beam-weapons system?

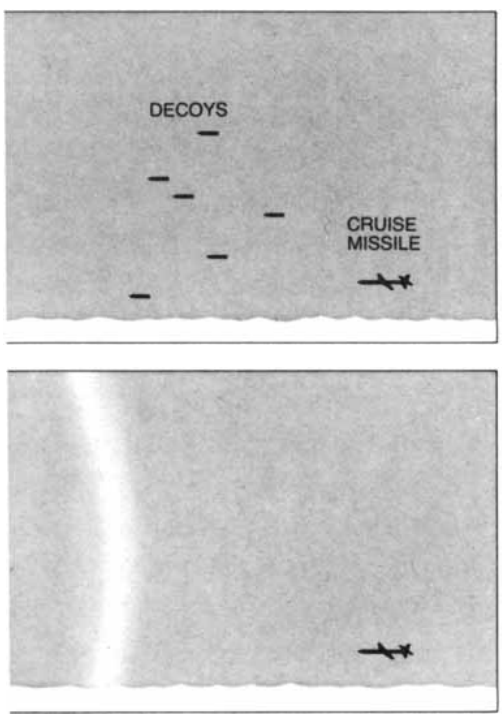
An exoatmospheric particle-beam weapon would call for a machine that could accelerate negatively charged hy-



COUNTERMEASURES that would be effective against a ship-based anti-cruise-missile electron-beam weapon are illustrated in these two views. As the scene at the top shows, a cloud of metallic chaff, a smoke rocket or a flock of decoys could be fired ahead to confuse the ship's defense systems. (The chaff might even have the further effect of disrupting the electron pulse.) Alternatively, as the

drogen ions to a few hundred MeV. Such atoms are routinely accelerated for nuclear-physics experiments in linear machines such as those at the Argonne National Laboratory and the Los Alamos Scientific Laboratory's meson-physics facility. Recent developments both in the U.S. and in the U.S.S.R. indicate that it would be technically feasible to develop the very intense sources of negative hydrogen ions needed and a suitable accelerating mechanism for generating the intense beam called for in an exoatmospheric weapon. An optimistic estimate would be that if a way could be found to generate very compact ion beams, it would be possible over the next decade to construct a negative-hydrogen-ion accelerator that could generate a beam with an initial current of 10 amperes. an initial energy of 200 MeV and a cross section of several square meters on the target 1,000 kilometers away. Such an accelerator would be about 20 meters long and could have an energy-conversion efficiency from the staging system to the beam output of about 50 percent. Its beam could damage the booster of a missile with approximately 10 seconds of continuous deposition at a distance of 1,000 kilometers and interfere with the electronics inside an ICBM in a tenth of a second at the same range.

As for endoatmospheric weapons, the technology for constructing a high-energy, high-current linear electron accelerator able to produce pulsed beams suitable for the purpose already exists. The linear induction accelerator is capable of generating short pulses with very high currents, and it has been developed both in the U.S. and in the U.S.S.R. A linear induction accelerator built at the University of California at Berkeley in 1970 is capable of producing a beam of 1,200 amperes and 4 MeV. A similar machine that could produce a 1-GeV beam would probably have to be close to 500 meters long and weigh about 250 tons. The unresolved technical questions here are whether the required repetition rate of several thousand pulses per second (which seems essential for the operation of an endoatmospheric charged-particle-beam weapon) and a suitably compact beam could be achieved. In summary, then, there seems to be no compelling reason to conclude that accelerator technology cannot, at some time in the future, make it possible to build accelerators suitable for particle-beam weapons.



scene at bottom shows, a small explosive rocket could be fired ahead to disrupt the channel in which the pulses would have to propagate.

Finally, we shall examine three further questions: What are the operational requirements each of the three missions described above would impose on a particle-beam weapon? What are the countermeasures an opponent could direct against such a system? In view of these problems, would a particle-beam weapon be practical or at least promising?

Each of the 150 or so space-based particle-beam weapons deployed some 1,000 kilometers above the earth for a boost-phase ballistic-missile defense system would have to include an accelerator, a power supply, an energy-staging system and subsystems for target detection and tracking, beam aiming and damage assessment. Each particle-beam weapon would also have to be able to detect, identify and track simultaneously at least 1,000 boosters while they were still in their boost phase, which lasts for about 400 seconds. The tracking and aiming mechanism would have to locate each booster with an accuracy of one part in 100,000.

The aiming mechanism of the neutral beam could consist of precalibrated magnetic lenses and focusing magnets, which could be mechanically steered for accurate aiming with the aid of an optical telescope. This mechanism could be supplemented with a feedback system so that as the target was being tracked the beam's sights would remain on the target. The aiming mechanism would first direct the negative-hydrogen beam at the target and then pass it through a gas "stripper" for neutralization. Since it would not be possible to ascertain by how much and in what direction the neutral beam was missing the target, it would be necessary to fire repeatedly and blindly at the target until there were observable catastrophic results. Such a procedure would be time-consuming: the total time for a single shot, approximately .4 second, would consist of the time it would take the beam to reach the target 1,000 kilometers away, the time it would take the optical signal to return to the platform indicating a kill, the time it would take the signal to reach the controlling station on the ground by way of a geosynchronous relay station and the time needed for the return command from the ground instructing the weapon to shift to another target.

An alternative to this time-consuming process would be to preprogram the weapons system to fire blindly for a fixed period at a target and then shift to another target without prior positive indication of a successful hit. This approach seems unsatisfactory on two grounds. First, the particle beam could systematically miss every target. Second, if the attacking ballistic missiles were aimed at U.S. cities, allowing even a few of them to get through would cause unthinkable damage to many urban and industrial centers. Therefore aiming blindly and shifting to a new target after a fixed number of shots would be an unacceptable procedure for protecting such areas.

In addition it is by no means certain that radars or other sensors could determine the position of the target with the required accuracy of one part in 100,000 or even of one part in 10,000. Therefore there seems to be no way to fire accurately and rapidly at an ICBM booster with a neutral-hydrogen beam from a range of 1,000 kilometers. Accordingly even if a suitable negative-hydrogen accelerator could be built, it would still be technically unfeasible to deploy a particle-beam weapon that could be operationally effective against a massive ICBM attack on the U.S.

One must also assume that a weapons system for boost-phase ballistic-missile defense would operate mostly within the line of sight of enemy territory. Consider then the countermeasures a military planner, faced with the threat of a particle-beam satellite-based ABM system, could direct against it. The most obvious method would be to destroy the particle-beam weapons. Weapons based in space in peacetime would be vulnerable to modest explosive charges on small satellites placed in orbit close to them. It is more than likely that a space-based particle-beam weapon would in the course of its operations transmit to the ground the information obtained by the detection, identification and damage-assessment sensors and that it would be controlled from the ground. The ground control would at least have to assign priorities, enable the system to fire and conduct the actual attack against the rising ICBM's. Jamming the link between the weapon and its ground control would be equivalent to neutralizing the weapon itself. Such interference is possible.

Other countermeasures an enemy might resort to would be jamming the radar the system would rely on for de-

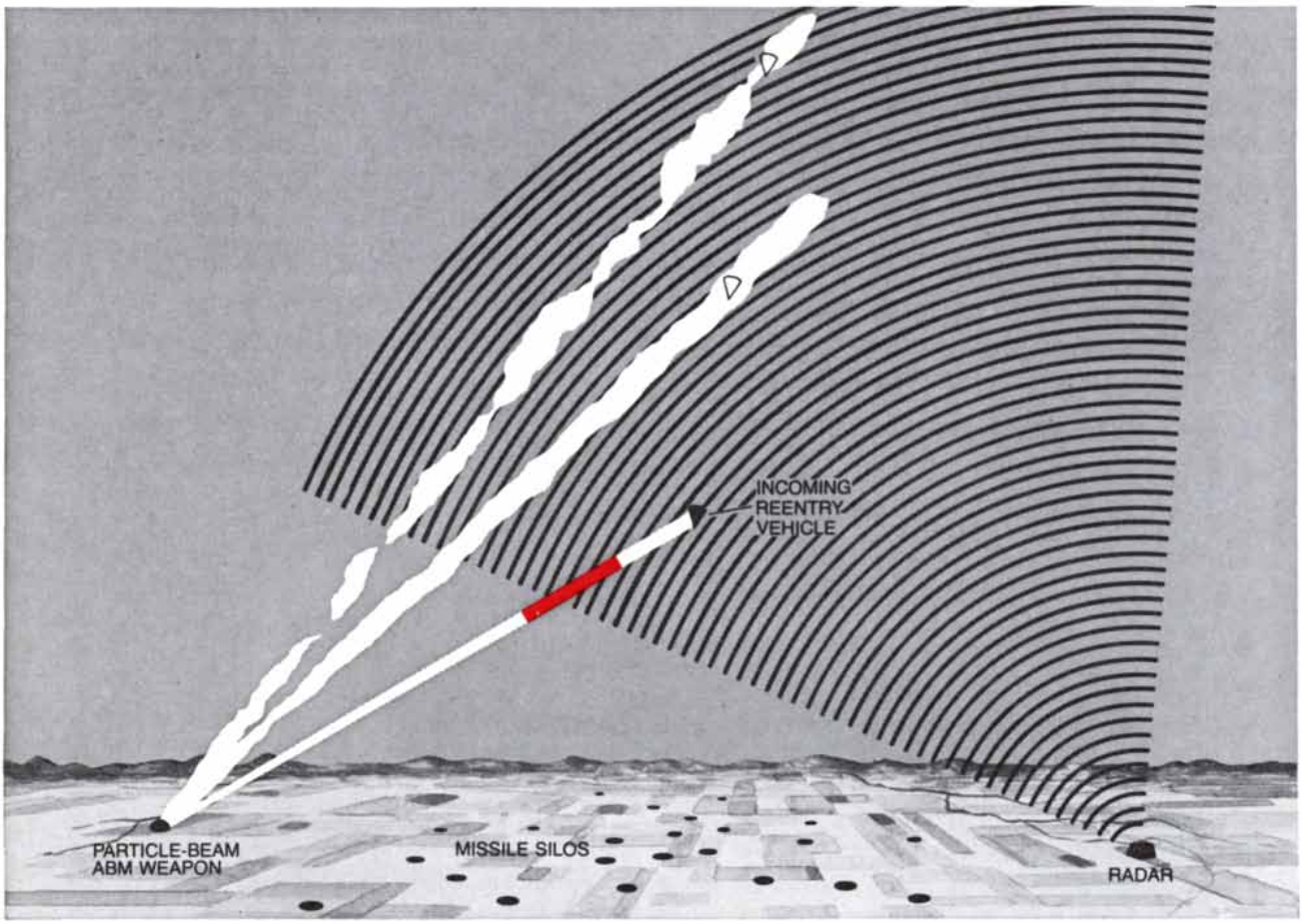
tecting its targets and also deploying decoys to confuse the system's sensors. The enemy could deploy a cloud of "chaff" (thin strips of aluminum, say) above the ICBM's so that even if the particle-beam system could detect the general location of the target by radar, it could not see through the cloud and aim the beam with the resolution needed to hit the ICBM's. Since the chaff could be carried by the missile booster, such countermeasures would be effective for sea-launched ICBM's as well as land-based ones.

Another effective countermeasure against a neutral-hydrogen-beam weapon based in space would be to interpose a thin layer of air between it and the ICBM's it is designed to attack during their boost phase. A 200-MeV neutral-hydrogen beam would become a proton beam if it were to pass through even a thin layer of air. A charged proton beam of that energy would disperse rapidly and never reach the target. We calculate that a 100-kiloton nuclear warhead exploded at the upper edge of the atmosphere could provide the energy necessary to lift enough air into the vacuum of outer space and disperse a neutral-particle beam. All these countermeasures would be fairly inexpensive, easy to deploy and impossible to overcome. Since they could predictably defeat a space-based particle-beam ABM system, it would be senseless to develop such a weapon and deploy it, even if it were technologically possible to construct the required accelerator.

Consider next the operational requirements of an endoatmospheric electron-beam weapon designed to be directed against countership cruise missiles. If the weapon did not shoot down the missile with the first burst, it would have to track the target and fire at it again. It is not clear how quickly the beam could fire repeatedly at a target that was moving laterally with respect to the ship. To fire in this manner the beam would have to abandon the evacuated channel in the atmosphere in which it had initially propagated and bore a new hole close to the preceding one. It is not known whether the atmosphere could support such a process. It is also not known how this kind of performance would depend on the motion of the target, on the size of the channel and on the state of the atmosphere in the vicinity of the ship.

It seems unlikely that the aiming of the particle beam (and its coordination with the pointing mechanisms) would be so accurate that the missile would be hit by the first shot. It would be necessary to determine by what amount and in what direction the particle beam had missed the target and to make corrections to bring it onto the target for the next shot. It is not at all clear how this might be done, and to the extent that it could be done at all by electromagnetic means the return signal could be jammed, spoofed or falsified by being reflected from other metallic objects nearby.

In addition the attacker could use several countermeasures against a ship-based charged-particle-beam weapon. For example, a subsonic cruise missile of ordinary design loses only 2 percent of its speed in the first kilometer of its unpowered glide. Under these conditions multiple decoys could be ejected from a missile, all of which would glide toward the target for the last kilometer, confusing the defense. Cruise missiles attacking a ship could fire a smoke rocket ahead of them to impair tracking by



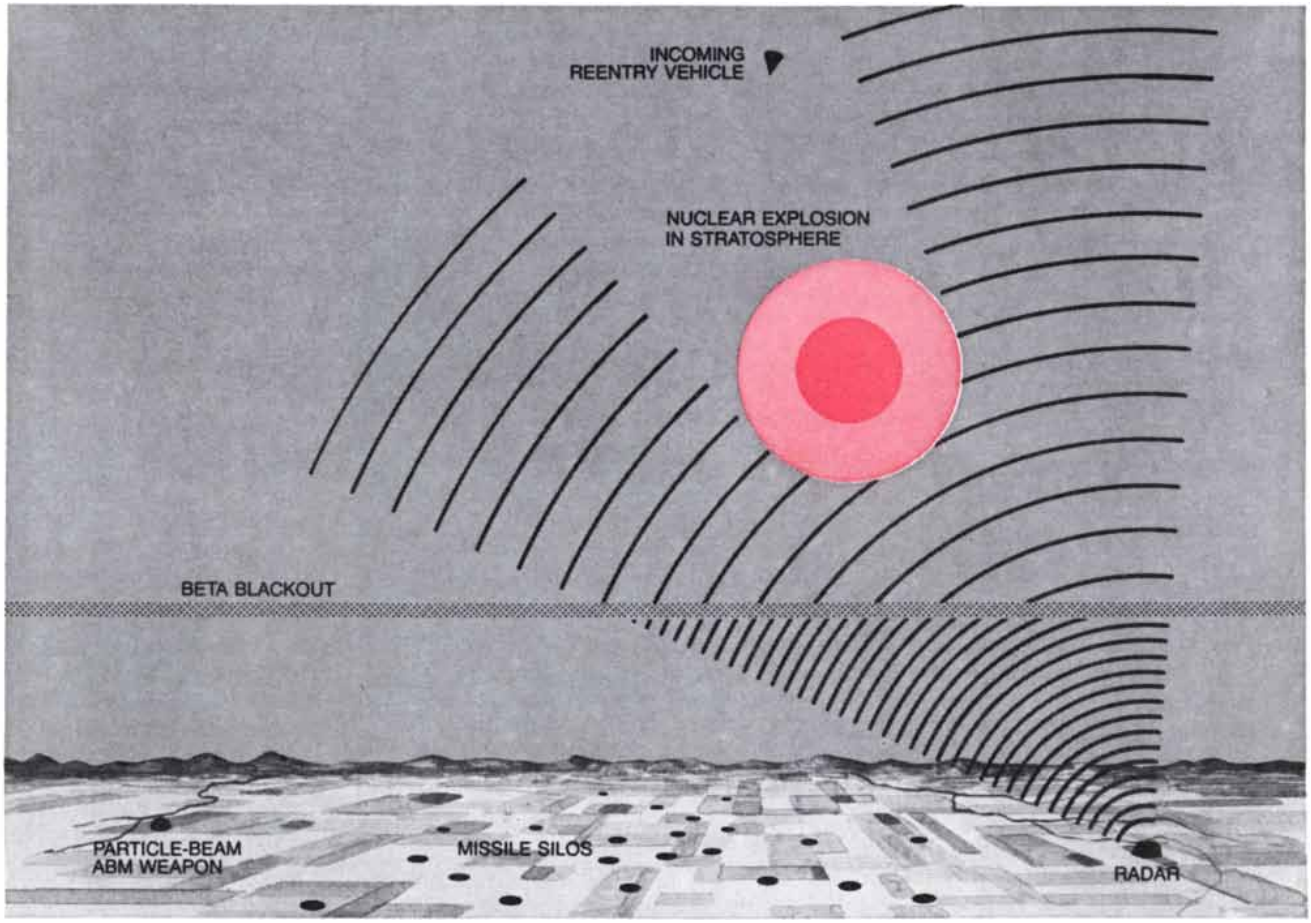
THIRD PROPOSED USE for particle-beam weapons would be as the basis for an ABM system intended to defend U.S. missile silos against Russian reentry vehicles carrying nuclear warheads. If the defense were to wait until each attacking warhead had approached to within a kilometer before attacking it, the particle-beam weapon would have to destroy the warhead in approximately .7 second, which is the time it would take for the warhead to cover the last kilometer to the target. Successive shots would have to bore new channels.

optical systems; they could also fire either chaff for countering radar or small explosive rockets for disturbing the uniformity of the air ahead of them.

Consider finally the possibility of using a land-based charged-particle-beam weapon as the kill mechanism of a hard-point ABM system. Hard targets such as missile silos are vulnerable to nuclear explosions in their immediate vicinity; therefore a reentry vehicle attacking a silo must penetrate the atmosphere and explode near the silo. In principle a particle-beam weapon defending the silo could wait until the attacking warhead had approached to within a kilometer before attacking it. A modern reentry vehicle would have a velocity of no less than five times the speed of sound, and so it would take about .7 second to cover the last kilometer to its target, during which time the particle-beam weapon would have to either destroy it or cause it to veer off course.

If the reentry vehicles were of the maneuverable type, the particle-beam weapon would have to track and fire at its target through the dust-filled atmosphere, which might have been disturbed by earlier bursts of the beam or by the explosions of incoming nuclear warheads. There is no evidence that a beam could propagate stably under such conditions. In any event the most vulnerable part of a silo-defending charged-particle-beam weapon would be the radars that would have to detect, identify and track the incoming reentry vehicles. These radars could be blinded for extended periods of time by a nuclear explosion in the stratosphere over the silos; they could also be damaged by a nuclear detonation several kilometers away. These are the same vulnerabilities that plagued earlier ABM schemes that were supposed to rely on missiles rather than particle beams. Using a particle beam would not change the vulnerability of the radars; on the contrary, it would increase the required accuracy of the radar manyfold, since a direct hit on the target would be mandatory. A determined enemy could explode a nuclear warhead high above the silos to blind the radars and disturb the geomagnetic field, then explode another warhead close enough to the radars to destroy them and lift some dust into the atmosphere and (since by now the particle-beam weapon would be blinded) proceed to attack the silos themselves unhindered by the particle-beam weapon.

One can conclude that the operational requirements for a particle-beam weapon in any of the three missions contemplated here are formidable. Aiming the beam with an accuracy of one part in 100,000, measuring by how much the beam missed the target and assessing damage to the target within the narrow time limits inherent in these missions are operations that would be essential, and yet they seem extraordinarily difficult if not altogether impossible to perform. Countermeasures that would be easy and inexpensive to deploy would be effective in confusing or completely neutralizing a particle-beam weapon. The performance characteristics of such a system would not overcome the vulnerabilities and weaknesses of earlier ABM schemes that were based on missiles as interceptors, nor would they lend themselves to the development of an effective substitute for these earlier systems. It is therefore highly questionable that such a system could function at all, let alone be operationally effective, in any of the three missions we have examined here.



COUNTERMEASURE that could be relied on to thwart a "hard point" ABM system based on the use of charged-particle beams is illustrated here. A nuclear warhead could be exploded in the stratosphere over the missile silos to blind the ABM system's radar or to disrupt the channels in which the pulsed beam of charged particles would have to propagate through the atmosphere. Alternatively, a nuclear detonation near the ground as much as several kilometers away could serve to disable the radar and disrupt the particle beam.

A Timekeeping Enzyme in the Pineal Gland

The activity of the enzyme N-acetyltransferase in the pineal gland of some animals provides a natural timing mechanism: a biological clock that may regulate both physiological and behavioral processes

by Sue Binkley

A biological system that is capable of measuring time can be called a biological clock. In order to be functional in the way a man-made clock is, however, a biological clock system must also possess a mechanism for communicating time information (as the hands of a man-made clock do) and a resetting mechanism. Moreover, environmental stimuli—even those that trigger resetting—must not affect the timekeeping mechanism. A clock system with all three mechanisms would be useful for timing the internal functions of an organism and relating those functions to the rhythms of the external world. In some vertebrate animals the pineal gland, a small organ embedded in the brain, embodies such a system. In particular, the enzyme *N*-acetyltransferase, which catalyzes the synthesis of a hormone in the pineal gland, provides a natural timekeeping mechanism that appears to enable at least some animals to maintain rhythms of activity that are precisely timed by the passage of the solar day.

The daily rhythms of activity that are timed by a 24-hour biological clock are called circadian rhythms, from the Latin *circa,* "about," and *dies,* "day." Circadian rhythms have a period that in the presence of environmental cues (such as sunrise and sunset) is exactly 24 hours but in the absence of such cues is only close to 24 hours. For many circadian rhythms the cues for resetting are provided by the daily cycle of alternating light and darkness resulting from the earth's rotation on its axis. Such rhythms persist in constant darkness and are suppressed by bright constant light. In the pineal gland rhythms of this kind have been discovered in the biosynthesis of the hormone melatonin.

Melatonin was first identified in the pineal gland of cattle in 1958 by Aaron B. Lerner and his co-workers at the Yale University School of Medicine. The hormone appears to mediate at least three functions of the pineal gland that relate to time and lighting cycles. These are the measurement of day length for controlling the size of sex glands in the hamster, the dark-time lightening of skin color in some lower vertebrates and the maintaining of the normal circadian rhythms of locomotor activity in sparrows, starlings and lizards. Melatonin is synthesized in the pineal from the compound serotonin. (Serotonin is thought to be a neurotransmitter, one of the substances that act to transmit nerve impulses across the synapses of the nervous system. It is also believed to function in the control of sleep.) The synthesis takes place in two stages: first serotonin is converted into *N*-acetylserotonin through the action of the enzyme *N*-acetyltransferase, and then *N*-acetylserotonin is converted into melatonin through the action of the enzyme hydroxyindole-*O*-methyltransferase (HIOMT). Recent investigations have revealed a marked circadian oscillation in the activity of pineal *N*-acetyltransferase. Through the activity of this enzyme (and probably through the resulting hormone output) the pineal gland appears to function as a biological clock that is controlled, or reset, by light.

The idea that the functioning of the pineal gland is somehow associated with light is not new. Structures that resemble light receptors were first noted in the pineal gland of several vertebrate species half a century ago. The gland is also associated anatomically with the "third eye" that is present in some lizards, amphibians and fishes. It was this association that prompted experiments investigating the connection between pineal function and light.

In 1960 Virginia M. Fiske and her colleagues at Wellesley College discovered that when rats that had been kept in constant light were killed and their pineal glands were removed, the glands weighed 25 percent less than those of rats that had been kept in constant darkness. Then in 1963 Wilbur B. Quay of the University of California at Berkeley found that the serotonin content of the pineal glands of rats subjected to alternating 12-hour periods of light and darkness showed a rise and fall that followed the daily cycle: high serotonin levels were found during the "day," or light time, and low serotonin levels were found during the "night," or dark time. Quay later observed that conversely the levels of pineal melatonin were low during the day and high during the night.

The rhythmically shifting balance of serotonin and melatonin in the pineal gland seemed to be explained in 1965, when Julius Axelrod, Richard J. Wurtman and Solomon H. Snyder demonstrated at the National Institute of Mental Health that in rats the melatonin-synthesizing enzyme HIOMT also responds to light and darkness: over a week's time the activity of the enzyme (measured as the amount of melatonin formed per hour per pineal gland) was increased fivefold by exposure to constant light. Furthermore, when the rats were subjected to daily cycles of light and darkness, the enzyme activity reached a maximum in the dark that was up to three times greater than its lowest value in the light. It appeared that the daily fluctuations in the amounts of serotonin and melatonin in the pineal gland were due to the daily oscillation in the activity of the HIOMT.

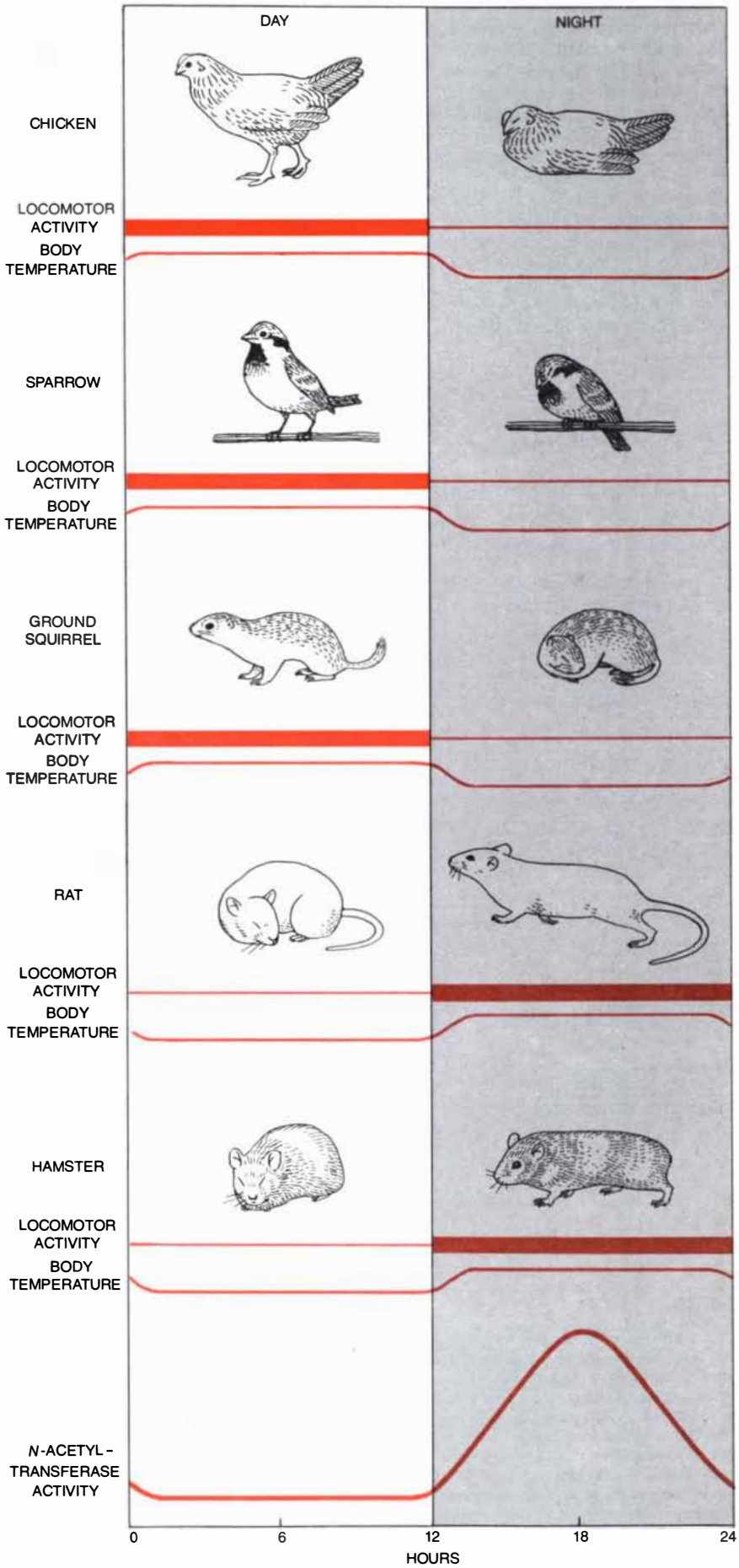
In 1970, however, David Klein and Joan L. Weller at the National Institutes of Health demonstrated that there is a far more dramatic oscillation in the activity of *N*-acetyltransferase, the other enzyme involved in melatonin synthesis. When rats were exposed to a daily cycle of light and darkness, their *N*-acetyltransferase activity reached a peak in the dark that was between 30 and 70 times its lowest value in the light. This large daily fluctuation was clearly the controlling factor in the smaller fluctuations of pineal serotonin and melatonin, that is, the *N*-acetyltransferase activity was increased in the dark so that

large amounts of melatonin were synthesized and the serotonin stores were depleted. The *N*-acetyltransferase activity fell off in the light, so that little melatonin was synthesized, and the serotonin stores were left largely intact.

Klein's findings were even more significant in view of behavioral evidence bearing on the function of the pineal gland in birds. In 1968 Suzanne Gaston and Michael Menaker of the University of Texas at Austin showed that removal of the pineal gland of the house sparrow (*Passer domesticus*) eliminates the bird's normal circadian rhythm of locomotor activity. While I was working as a graduate student with Menaker I was able to show that pinealectomy affects not only the sparrow's rhythm of locomotor activity but also its rhythm of body temperature.

More generally, it seemed extremely plausible that *N*-acetyltransferase could, either by the periodic depletion of the pineal stores of serotonin or by the periodic output of melatonin from the gland, synchronize the functioning of the cells throughout an entire organism. It had been shown that injecting sparrows with melatonin induces roosting (sleeping) and the lowering of body temperature, both of which are characteristic of nighttime physiology in these birds. Moreover, the continuous administration of melatonin to sparrows had been shown to change the normal period of those rhythms or even eliminate them entirely.

The case for the association of the pineal gland with a biological clock was somewhat weakened, however, by the fact that the biochemical and the behavioral studies had been conducted with two very different species: rats and sparrows. Therefore in 1972 I set out to sup-

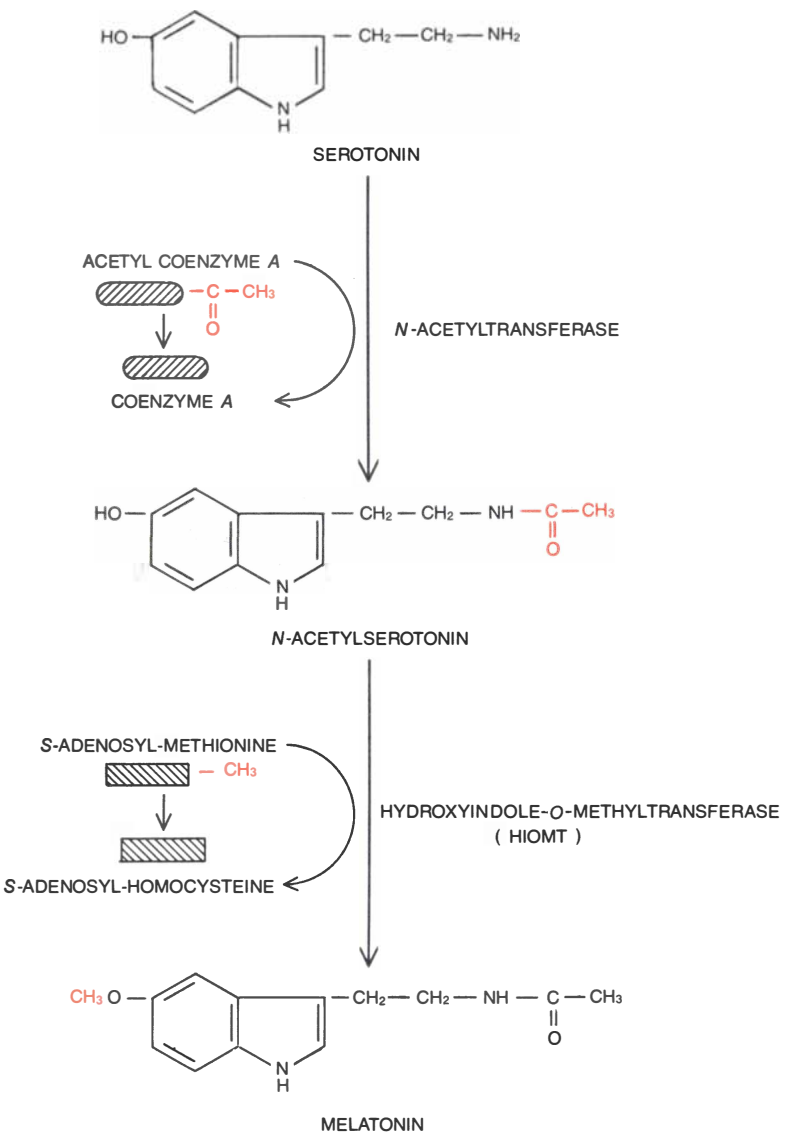


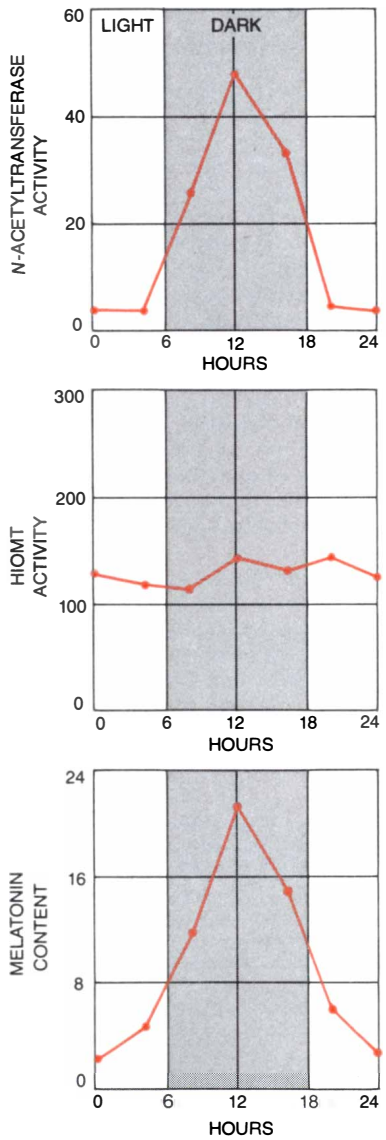
IN MANY SPECIES of vertebrates physiological processes such as fluctuation in body temperature and behavior patterns such as fluctuation in locomotor activity exhibit circadian rhythms that appear to be controlled by light. In the presence of the alternation of day and night the period of these rhythms is exactly 24 hours, but in the absence of such environmental lighting cues the period is only close to 24 hours. As is shown here, for most circadian rhythms the time (day or night) that peak activity is reached depends on whether an animal is diurnal (awake during the day) or nocturnal (awake during the night). The circadian rhythm in the activity of the enzyme *N*-acetyltransferase in the pineal gland, which has been identified in all the species shown, is an exception: its activity always peaks at night or in the darkness, regardless of whether an animal is diurnal or nocturnal. This finding suggests that the daily oscillation of *N*-acetyltransferase activity in the pineal gland is closely linked to an endogenous, or internal, timing mechanism in these animals. In this illustration patterns of locomotor activity, body temperature and *N*-acetyltransferase activity have been represented diagrammatically.

plement the behavioral evidence on the sparrow with a thorough examination of the pineal biochemical rhythms in another bird: the chicken. The early stages of this project were carried out in collaboration with Charles Ralph and Steven E. MacBride of the University of Pittsburgh and, while I was a postdoctoral fellow, with Klein at the National Institute of Child Health and Human Development. We chose to work with chickens (in most cases chicks about three weeks old) because they are obtainable in large numbers and in particular because earlier studies had indicated that their pineal gland showed high levels of enzyme activity and large quantities of melatonin. Over the past seven years we have made substantial progress in understanding the characteristics of the chicken's pineal gland rhythms and how those rhythms are regulated.

We began by exposing chicks to alternating 12-hour periods of light and darkness and measuring the pineal *N*-acetyltransferase activity at different times in the cycle. We found that there is a daily 27-fold increase in the activity of the enzyme and that the highest level of activity is attained in the dark. In addition the amount of melatonin in the pineal gland, which rises 10-fold daily, peaks at about the same time as the *N*-acetyltransferase activity. Our measurements of the HIOMT activity showed a daily increase of no more than about 1.2-fold, and so we concluded that most probably in chickens the oscillation in the amount of melatonin was indeed due to the oscillation in the activity of *N*-acetyltransferase.

Was the large-amplitude oscillation in *N*-acetyltransferase activity we had discovered in the pineal gland of the chicken a true circadian rhythm or simply a set of responses to daily changes in envi-

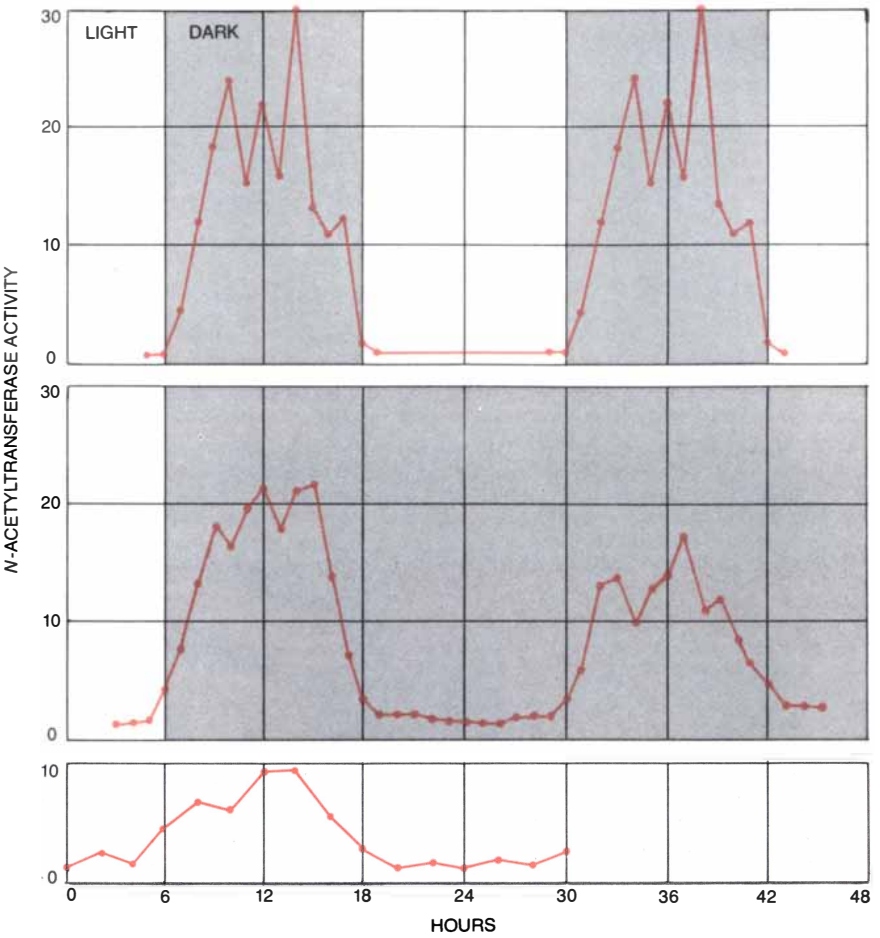




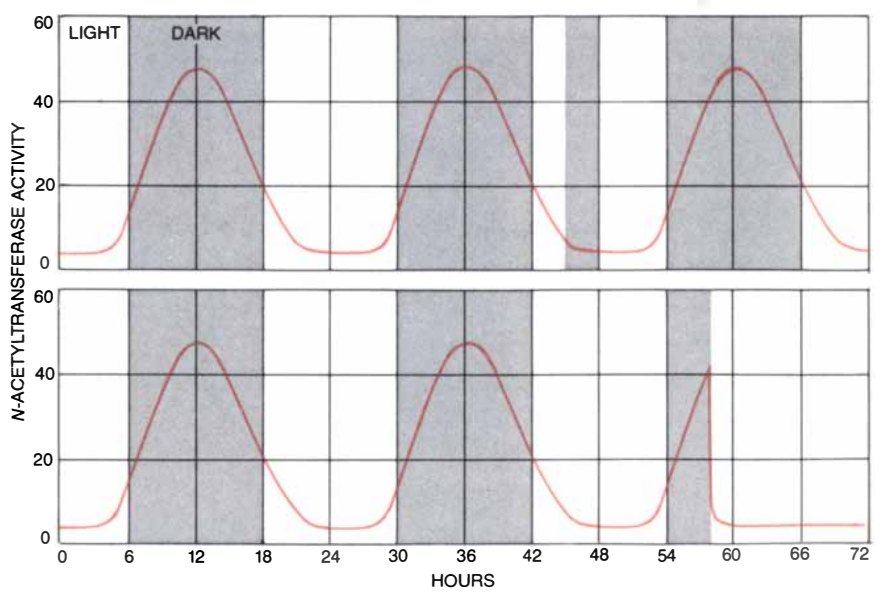
SYNTHESIS OF THE HORMONE MELATONIN, shown at the left, is the biochemical pathway in the pineal gland in which circadian rhythms of enzyme activity have been identified. In this process the substance serotonin gains an acetyl group to form *N*-acetylserotonin, and then *N*-acetylserotonin gains a methyl group to form melatonin. The first conversion is mediated by the enzyme *N*-acetyltransferase and the second by the enzyme hydroxyindole-*O*-methyltransferase, or HIOMT. To investigate the effect of light on these conversions chicks were exposed to alternating 12-hour periods of light and darkness, and measurements of the melatonin content and the enzyme activity in their pineal glands were made, as is shown at the right. This study disclosed a daily fluctuation in melatonin content that correlated closely with a daily fluctuation in *N*-acetyltransferase activity. It appears that the oscillation in the chicken's pineal *N*-acetyltransferase activity controls the output of melatonin, and there is behavioral evidence to suggest that in birds the periodic output of melatonin synchronizes locomotor activity. In the graphs in this illustration measurements from six pineal glands were averaged to obtain each datum point, and measurements of melatonin content and enzyme activity were made on each gland. Melatonin content, which was determined by a bioassay procedure that makes use of skin-lightening effect of melatonin on frog tadpoles, is given in nanograms per pineal gland. Enzyme activity, which was determined by a radiochemical assay, is given in nanomoles of melatonin formed per pineal gland per hour.

ronmental lighting? This question could be decided by placing chicks in constant darkness and measuring their enzyme activity at different points in the light cycle to which they had been synchronized. In this way it would be possible to determine whether rhythms established in that cycle still persisted. The problem with the plan was that in the absence of environmental cues small variations in the period lengths of animals' individual internal clocks may quickly cause the animals to drift out of phase with one another and with the cycle of light and darkness to which they have been synchronized. At Temple University my student Ellen B. Geller and I solved the problem by taking chicks that had been synchronized to a daily light-dark cycle, placing them in environments of constant darkness and making hourly measurements of enzyme activity. The experiments lasted for no more than two or three days, so that there was no time for the chicks to drift far out of phase with the cycle to which they had been synchronized. The results of the experiments clearly demonstrated that the rhythms of pineal *N*-acetyltransferase activity in the chicken are circadian: they persist in constant darkness, maintaining a period length of close to 24 hours, and they are reduced in amplitude by bright constant light.

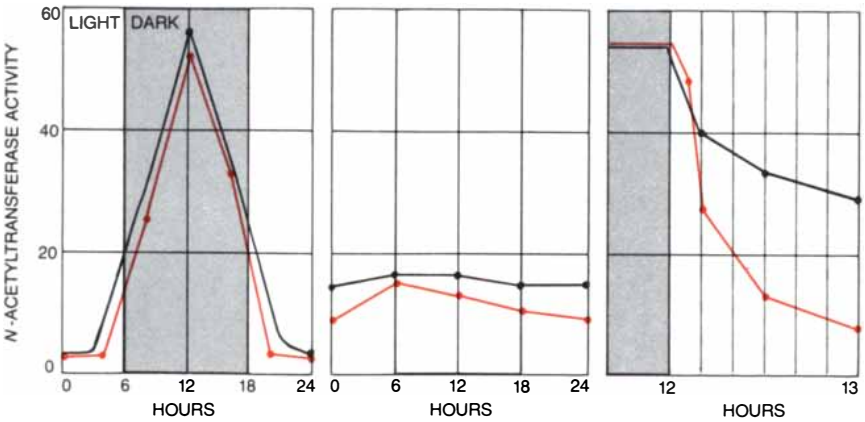
The persistence of the *N*-acetyltransferase rhythm in constant darkness suggested to us that although light generally suppresses enzyme activity in the chicken, darkness can only initiate it at certain times determined by the bird's endogenous (internal) clock. To test this conjecture we kept chicks in a daily cycle of light and darkness for several months and then exposed them to unexpected changes in lighting. We found that when chicks were plunged suddenly into darkness during a light period, 10 hours before the regular "lights out" time, there was no increase in pineal *N*-acetyltransferase activity. On the other hand, when chicks were exposed suddenly to light at any time during a dark period, their enzyme activity dropped rapidly. Hence there appears to be a period during the chicken's light (or active) time when the pineal gland is refractory to light in the sense that darkness cannot initiate enzyme activity. (This finding is satisfying because it points to a way that chickens or other animals might detect changes in the day length: the process known as photoperiodism. When a chicken is exposed to the natural cycle of day and night, the period during which it is sensitive to light, or during which darkness can initiate enzyme activity and light can inhibit it, corresponds roughly to nighttime. If this sensitivity is determined internally by an endogenous clock, then it may serve as a standard by which the chicken measures the changing length of successive nights. In this way an animal might mark the



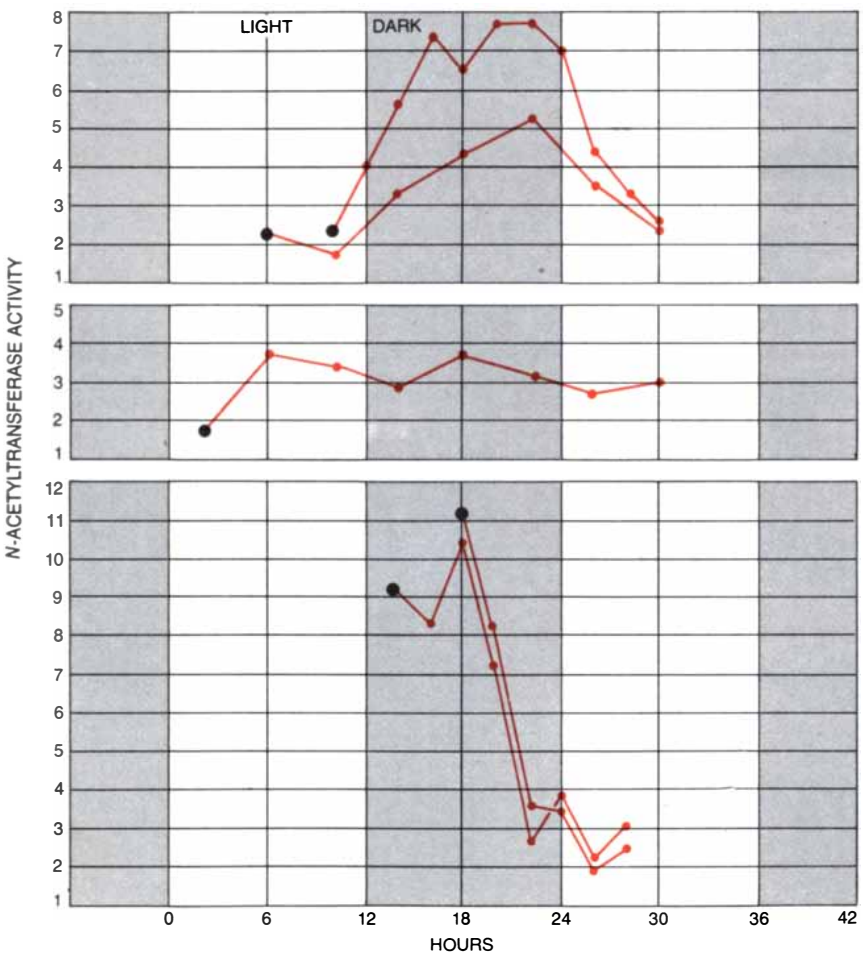
RHYTHM IN PINEAL *N*-ACETYLTRANSFERASE ACTIVITY that is observed in chicks exposed to alternating 12-hour periods of light and darkness (*top*) persists in chicks exposed to constant darkness (*middle*) and is suppressed in chicks exposed to constant light (*bottom*). These findings are consistent with behavioral evidence concerning circadian rhythms in animals: constant light, depending on intensity, can alter period of rhythms or even suppress them entirely.



CONTROL OF ENZYME ACTIVITY BY LIGHT is tested by exposing chicks synchronized to a daily cycle of light and darkness to unexpected changes in lighting. As is shown here diagrammatically, when chicks were exposed to darkness early in a light period (*top*), there was no increase in pineal *N*-acetyltransferase activity. Whenever light was introduced in the course of a dark period (*bottom*), however, there was a rapid decrease in enzyme activity. These findings show that although light can always suppress *N*-acetyltransferase activity in the pineal gland of chicken, darkness can only initiate it at certain times determined by endogenous clock.



ENZYME ACTIVITY IN BLIND CHICKS (*black curves*) **is almost indistinguishable from the enzyme activity in normal ones** (*color curves*) **when the birds are exposed either to alternating periods of light and darkness** (*left*) **or to constant light** (*middle*). **When light is introduced at the midpoint of a dark period in a light-dark cycle** (*right*), **however, *N*-acetyltransferase activity drops less rapidly in blind chicks, implying that although eyes are not principal photoreceptors for regulation of enzyme activity, some light perception for response takes place there.**



TIME OF DAY that a chicken is killed (*black dots*) **determines the *N*-acetyltransferase activity of its pineal gland when it is cultured in constant darkness. When chicks were killed late in a light period of a daily light-dark cycle** (*top*), **the enzyme activity of their pineal glands in culture rose and fell over a 24-hour period; the beginning of the rise and the end of the fall corresponded roughly to "dusk" and "dawn" in the cycle. When chicks were killed during a dark period** (*bottom*), **the activity of their pineal glands in culture began at a characteristically high dark-time value and dropped by about "dawn" to a low light-time value. These findings suggest that the pineal gland has a "memory" of previous lighting conditions as well as an intrinsic timekeeping ability. The discovery of a rise and fall in enzyme activity of pineal glands in culture demonstrates that organ has intrinsic mechanism for initiating enzyme activity. When chicks were killed early in light period, cultures showed no rise and fall in enzyme activity** (*middle*).

passing of the seasons and thus regulate its activities in an annual cycle as well as a daily one.)

We turned next to the issue of how the regulation of the chicken's circadian rhythm of pineal *N*-acetyltransferase activity is effected. Over the past 20 years much progress has been made in determining how the pineal gland operates in the rat. Our own continuing studies show, however, that there are differences between the clock mechanisms of the rat and those of the chicken.

Consider first the question of how chickens perceive light. Klein found that in the rat light perception for the regulation of pineal chemical rhythms was accomplished by the eyes, but there are a number of experiments showing that the changes light induces in the circadian rhythms of birds are not necessarily mediated by the eyes. Moreover, in 1968 Jean K. Lauber of the University of Alberta discovered that in blind chickens as well as normal ones pineal HIOMT activity is suppressed by constant light. By the same token we have found that in a daily cycle of light and darkness or in constant light blind chickens exhibit the same patterns of *N*-acetyltransferase activity as normal ones. On the other hand, when we measured the effect on chicks of sudden exposure to light during the dark period of a daily light-dark cycle, we found that in blind birds the pineal *N*-acetyltransferase activity drops less rapidly. We conclude that both the eyes and nonvisual photoreceptors are involved in mediating the response of *N*-acetyltransferase activity to light. We have found that the *N*-acetyltransferase activity in chick pineal glands maintained outside the body in organ culture responds to changes in lighting conditions, which indicates that the pineal gland itself is capable of responding to light. (This nonvisual light response may be effected by photoreceptorlike structures found in the pineal gland of birds.)

Once light is perceived, how does it come to regulate enzyme activity in the chicken's pineal gland? Experiments by Wurtman and by Klein, Weller and Robert Y. Moore have established that in the rat light information is conveyed from photoreceptors in the eye to the pineal gland along a nerve pathway that includes the superior cervical ganglion. Lauber has demonstrated, however, that the removal of the chicken's superior cervical ganglion has no effect on the response of HIOMT activity to constant light, and we got similar results with *N*-acetyltransferase activity in daily light-dark cycles. Therefore it appears that the neural mechanism of enzyme regulation, as well as the site of photoreception, differs in rats and chickens. These findings led me to suspect that the chemical processes might also be different.

In the rat the pineal gland is linked to the superior cervical ganglion by nerve fibers that release the neurotransmitter norepinephrine. Norepinephrine (and a variety of similar substances called adrenergic) act to stimulate the production of adenosine 3′5′ monophosphate, or cyclic AMP, which in turn acts as a "second messenger" to initiate *N*-acetyltransferase activity in the rat's pineal gland. In my laboratory we injected chicks in either the light or the dark period of a daily cycle with a variety of adrenergic compounds to see whether the compounds would have the same effect they have in rats. We also measured the *N*-acetyltransferase activity in organ cultures of chick pineal glands that had been treated with the same compounds. The results of these experiments show that a number of compounds (including norepinephrine and another adrenergic compound, isoproterenol) that stimulate the activity of the enzyme in rats have the opposite effect in chickens: they inhibit activity. Hence in chickens norepinephrine may act not to initiate *N*-acetyltransferase activity but to inhibit it—to shut off the pineal gland.

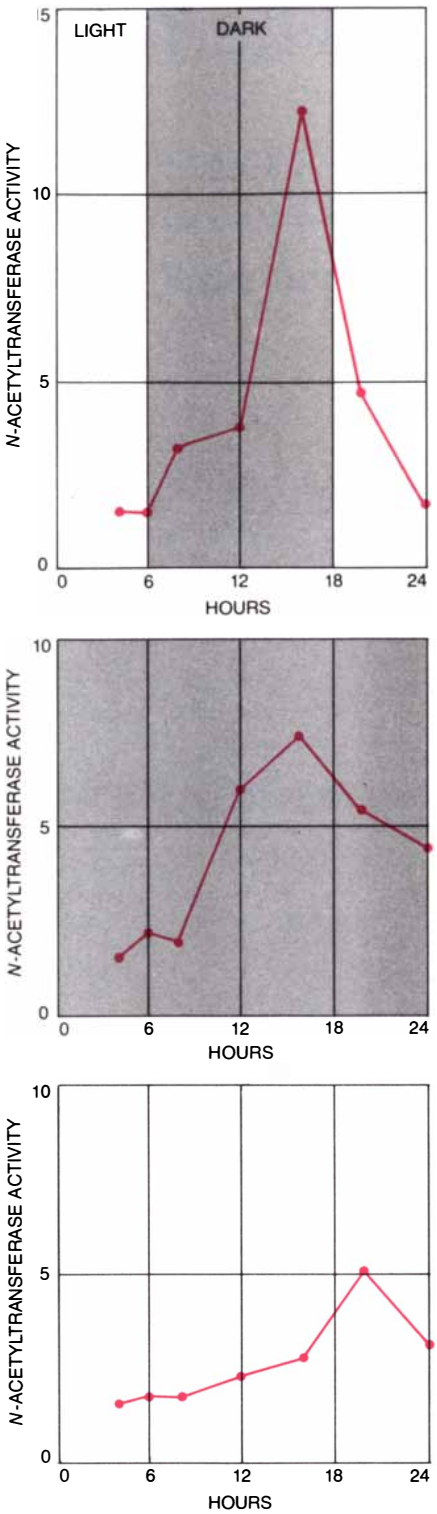
What, then, turns on *N*-acetyltransferase activity in the pineal gland of the chicken? In testing the effects of a variety of compounds on the *N*-acetyltransferase activity of chick pineal glands in culture we have so far not found any compound that is even close to bringing about the 27-fold increase seen in living chicks exposed to a daily cycle of light and darkness. This result suggested to us that the initiation of pineal enzyme activity in chickens might not require neural input, that the mechanism for initiation might in fact be intrinsic to the pineal gland. None of the experiments we did to test this hypothesis yielded convincing results, however, until we made an important discovery: the enzyme activity of a pineal gland in culture depends on the time of day the chick from which the gland was taken was killed.

We discovered that when a chick synchronized to a daily light-dark cycle is killed late in a light period and its pineal gland is cultured in constant darkness, the *N*-acetyltransferase activity in the culture rises and then falls [*see bottom illustration on opposite page*]. We conclude that the pineal gland is indeed capable of intrinsically initiating the activity. Moreover, the beginning of the rise and the end of the fall in the *N*-acetyltransferase activity are roughly correlated with the times of "dusk" and "dawn" in the previously established light-dark cycle, implying that the pineal gland also has an intrinsic timekeeping ability. When a chick is killed at any point in a dark period, its pineal gland culture exhibits a high initial level of enzyme activity that drops by about "dawn" to a low light-period level. Thus the pineal gland seems also to have a "memory" of the lighting conditions to which the chick was exposed.

We are currently of the opinion that the pineal clock's resetting mechanism involves both light perception and this memory of time. More precisely, it appears that the biological clock can be reset only in that period when the system is not refractory to light (when *N*-acetyltransferase activity can be inhibited), and that the refractory period can be imposed by the memory of a previous light-dark cycle. No rise and fall in enzyme activity is seen in cultures of pineal glands obtained from chicks killed early in a light period, and so we suspect that in the early "morning" some factor is missing from the pineal gland that allows *N*-acetyltransferase activity to be turned on (or perhaps that some factor is present that prevents the initiation of activity). This unknown factor could be synthesized within the gland or it could originate elsewhere, say in the blood or at nerve endings.

The pineal gland appears to be closely associated with a biological clock in many species of vertebrate animals. Since some animals that lack the organ display circadian rhythms of activity, however, it is evident that the pineal gland is not the only biological clock but rather is one of many. In fact, the persistent oscillation I have described in the activity of *N*-acetyltransferase in the pineal gland of the adult rat appears to originate elsewhere: in the suprachiasmatic nucleus of the hypothalamus. This finding is not as disturbing as it first appears to be. At present I view the vertebrate mechanism for generating circadian rhythms as a hierarchy of structures capable of oscillation. I believe these structures are organized so that one of them acts as a pacemaker, keeping all the others synchronized. Future studies should disclose exactly how the structures are ranked and how they interact. I suspect that these interactions differ from species to species, depending on the various ways the species have adapted to their environment.

In summary, the pineal gland has been shown to be more than a biological structure capable of keeping time. Through the output of melatonin this biological clock can communicate time information, and although the timekeeping mechanism is readily reset by light cues (either directly or through neural signals), there is no evidence to suggest that environmental stimuli cause it to run faster or slower. All the functions of the pineal gland that have been studied so far appear to be in some way involved with time and cycles of light and darkness. A complete understanding of how the pineal gland and its hormones might act as a light-controlled biological clock to perform these functions does not seem to be far off.



EVIDENCE FOR LIGHT PERCEPTION in the pineal gland itself is obtained by culturing glands under various lighting conditions. For the experiments shown here the pineal glands were all taken from chicks killed late in the light period of a daily light-dark cycle, so that a rise and fall in enzyme activity over a 24-hour period could be expected. As the graphs demonstrate, in pineal glands cultured in the same daily cycle (*top*) the enzyme activity rose higher and fell more sharply than it did in glands cultured in constant darkness (*middle*). Exposure to constant light (*bottom*) reduced and delayed peak in enzyme activity.

The Evolution of Disk Galaxies

A spiral galaxy can evolve into a smooth disk without spiral arms. Whether or not it does so depends on its environment: the galaxy most likely to evolve into a smooth disk belongs to a rich cluster

by Stephen E. Strom and Karen M. Strom

Ever since galaxies were first recognized as being "island universes" outside our own Milky Way galaxy they have been utilized as probes of the large-scale structure and evolutionary history of the universe. Their usefulness for this purpose depends critically on knowledge of when the galaxies were formed and how their bulk properties (size, luminosity and color) and detailed structure have changed with time. The development of plausible models of galaxy formation and evolution has therefore presented astronomers with a stimulating challenge. Developing such models is particularly difficult because most galaxies were evidently born some 15 billion years ago and evolved most rapidly at a time well before the present epoch. Hence there are no "snapshots" of nearby galaxies in a variety of evolutionary stages.

How then can one develop the observational basis for shaping and testing models of galaxy formation and evolution? First, one can test the models against the observable characteristics of the nearby, highly evolved galaxies that are most amenable to detailed study. Second, one can look back in time by observing galaxies located at distances of several billion light-years and comparing their properties with those characteristic of nearby systems. Third, one can search for nearby galaxies that are young or that appear to have evolved slower than the typical systems.

Recent studies of disk galaxies illustrate the usefulness of all these approaches. A disk galaxy has two morphologically distinct parts: a central bulge consisting of a spheroidal aggregation of stars and a surrounding disk consisting of stars fanning outward in a thin layer. The relative sizes of the bulge and the disk vary from a nearly pure bulge in some galaxies to a nearly pure disk in others. The bulge region of most disk galaxies seems to be totally lacking in young stars. The disk region, however, varies considerably in star-forming activity. In disk galaxies of the spiral type newly formed stars and their associated complexes of ionized hydrogen gas define the spiral arms that show up spectacularly in photographs. In disk galaxies of the SO type, on the other hand, the disks are smooth and devoid of young stellar complexes. Furthermore, the disks of SO galaxies show no evidence of the gas required to fuel star formation in the future.

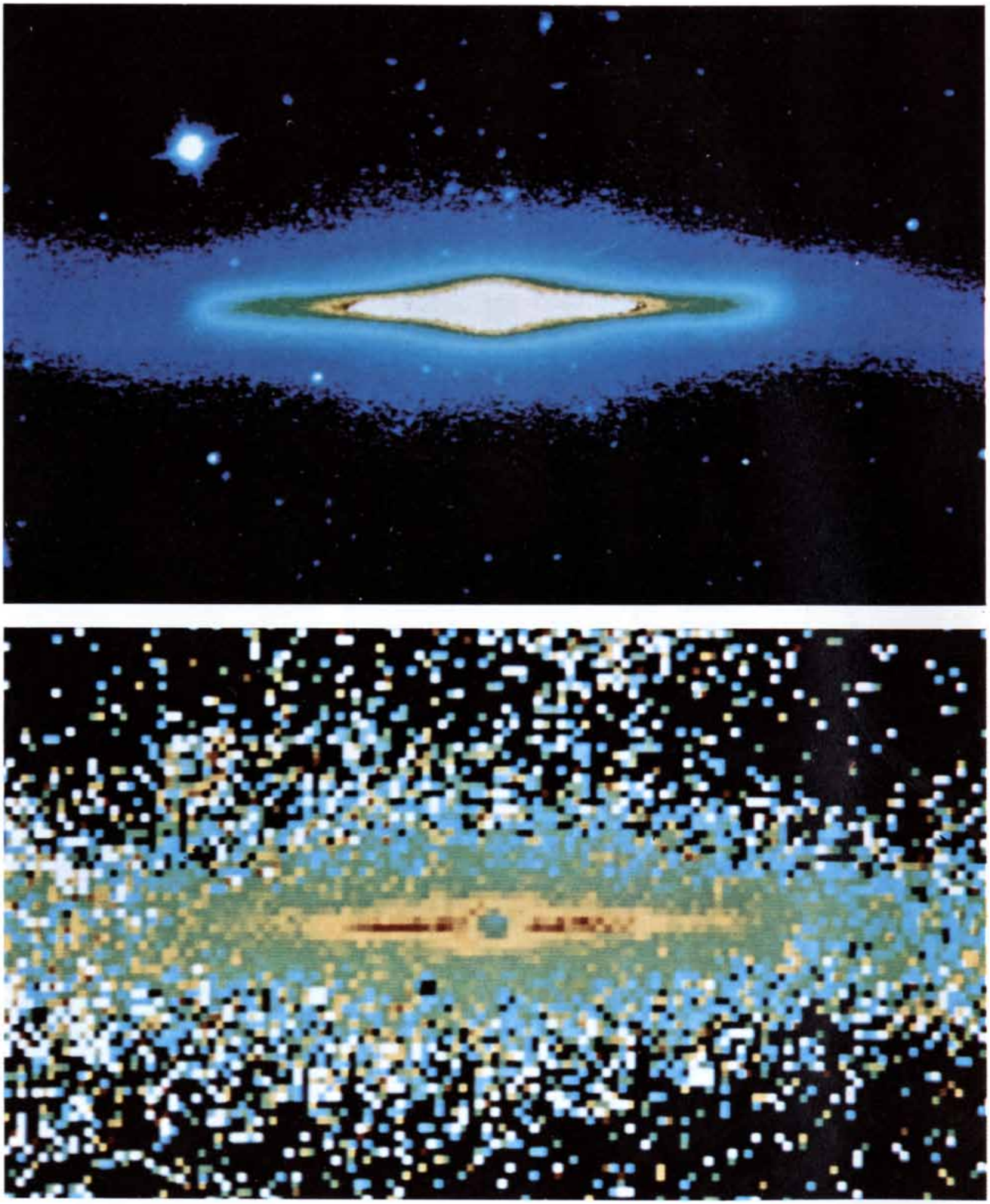
Spiral galaxies seem to inhabit environments that are significantly different from those of SO galaxies. Whereas spirals are the dominant type of system in regions where galaxies are sparse and widely spaced, they are rare in the central regions of the densely populated great clusters of galaxies, which may consist of from a few hundred to more than 1,000 individual galactic systems in a volume of space ranging from a million to 10 million light-years across. SO galaxies, in contrast, are by far the commonest type of disk system in the great clusters and are less abundant than spirals in regions of lower galactic density.

Current studies of galactic evolution are aimed at isolating the genetic and environmental factors that control the appearance of galaxies as a function of time. What accounts for the relative prominence of the bulge and disk components? Why do stars continue to form in spiral galaxies but not in SO galaxies? What accounts for the difference in the frequency distribution of spirals and SO's in regions with different densities of galaxies? We shall present evidence suggesting that the answers to these questions can be found primarily in the environmental conditions that prevail during the evolution of a galaxy.

Disk galaxies probably begin their life early in the history of the expanding universe as roughly spherical, rotating protogalactic clouds consisting chiefly of clumpy hydrogen and helium gas. When the self-gravity of the cloud overcomes the competing effect of the expansion of the universe, the cloud begins to collapse. The collapse proceeds most rapidly in the central region of the cloud and slower in the outer regions. When the central region reaches a certain density, stars begin to form, consuming much of the available gas. The result is a spheroidal system between 10,000 and 100,000 light-years in diameter containing between 10^{10} and 10^{12} stars, a system that is outwardly similar to the galaxies designated elliptical.

The low-density gas remaining in the slowly collapsing outer regions of the cloud is so diffuse that in those regions rapid star formation is precluded. Much of the gas therefore remains in unprocessed clumps. When the gas clumps collide, they heat up; their kinetic energy is thereby converted into radiation that escapes from the galaxy. The clumps collide primarily along the axis of rotation of the protogalactic cloud. Eventually the energy in the clump motions parallel to the rotation axis is dissipated in collisions, with the result that the gas finally settles into a rotating disk. When the density of the gas reaches a critical value, stars begin to form. The relative sizes of the disk and the bulge depend on the efficiency of star formation early in the collapse of the protogalactic cloud. If a large fraction of the cloud is initially made into stars, the amount of gas remaining to form a disk will be small. The system will therefore have a large bulge and a small disk.

Instabilities in the newly formed stellar disk lead to the generation of a spiral-wave pattern in the disk stars. A time-sequence recording of the density distribution of stars on the surface of the disk would show density-wave crests appearing to move through the disk at an angular speed called the pattern speed and designated Ω_p (capital omega with a subscript p, for pattern). The disk gas at a given distance, r, from the center of the galaxy moves in orbit around the center at an angular speed, $\Omega(r)$, that typically exceeds Ω_p. Frank H.-S. Shu and William W. Roberts, Jr., of the University of Virginia and their collaborators showed that as the gas flows through the density-wave crests a shock wave is generated if both the quantity $\Omega(r) - \Omega_p$ and the wave amplitude are sufficiently

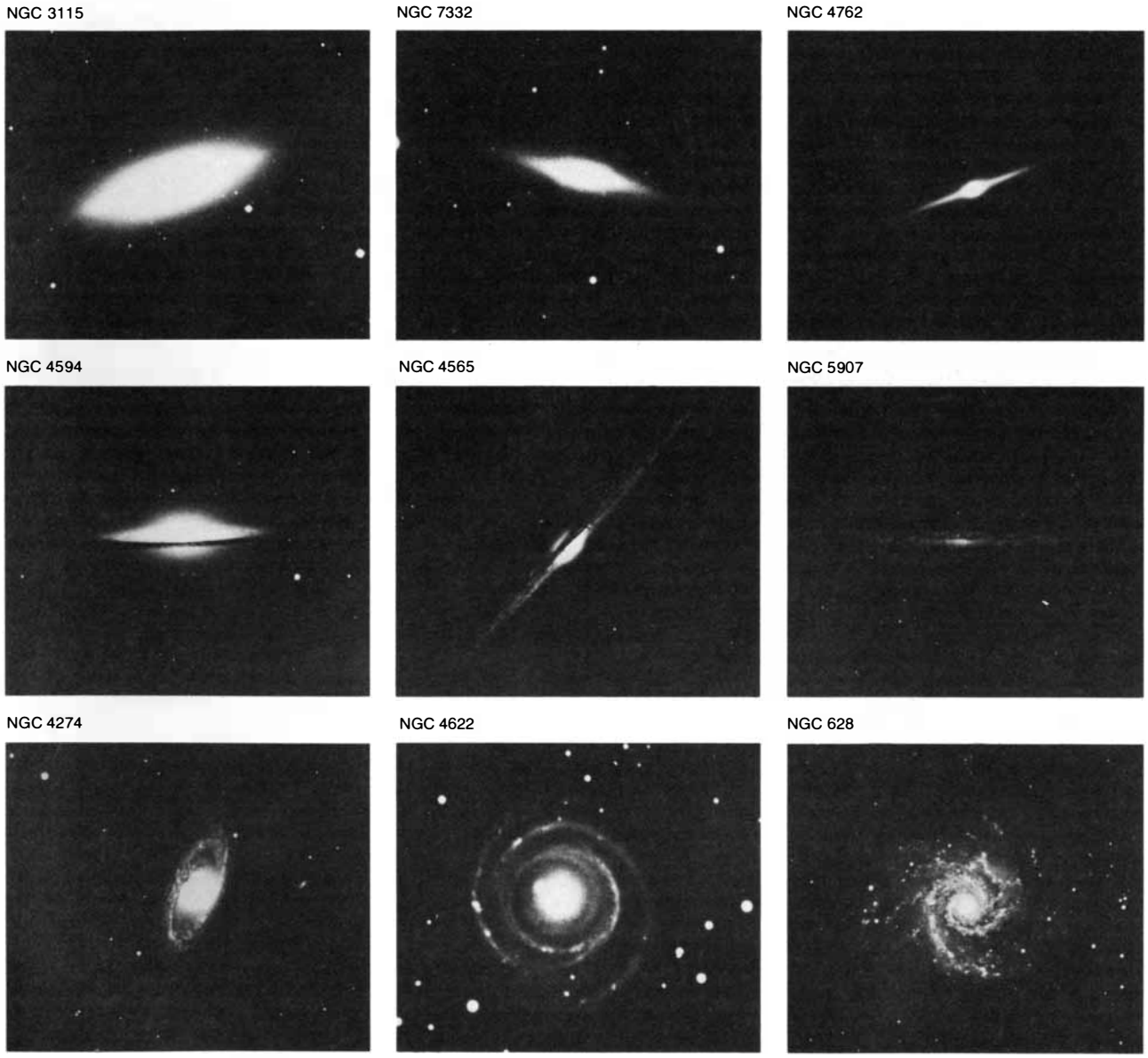


SPIRAL GALAXY NGC 4762, the flattest edge-on galaxy known, is depicted here in two color-coded images created by the authors with the aid of the interactive picture-processing system (IPPS) recently developed at the Kitt Peak National Observatory. For comparison a conventional photograph of NGC 4762, which is 60 million light-years away, appears at the top right in the set of nine galaxies illustrated on the next page. Under computer control, the IPPS presents a digitized picture on a display screen. By typing in simple instructions the astronomer can quickly see the effect of altering brightness levels or choosing color-coding schemes to emphasize features of interest. In the top picture the original photograph of NGC 4762 has been manipulated so that the bluest areas correspond to the faintest regions of the galaxy. The bottom picture is synthesized from two photographs of the same galaxy, one made in the ultraviolet, the other in the red. Galactic regions with the highest ultraviolet-to-red ratios are coded in blue. They can be seen to correspond with the faint (blue-coded) areas in the top picture. The authors believe the blue regions are dominated by old stars that contain only small amounts of elements heavier than helium. In contrast, the stars in the red-coded regions are believed to be rich in heavier elements.

large. The conditions in the compressed region behind the shock wave are believed to be conducive to forcing the collapse and fragmentation of the gas, thereby producing clusters of stars. The luminous, hot but short-lived stars in the newborn clusters define the bright arms that are the most prominent features in photographs of spiral galaxies.

The rate at which star-forming events are induced by the shock waves depends on the frequency with which the gas encounters the crests of the density waves. The frequency is approximately equal to 1 divided by $\Omega - \Omega_p$ and usually is highest toward the inner region of the galaxy and decreases outward. Hence the rate of star formation and the resulting depletion of gas are highest in the inner regions. As the galaxy evolves, gas is exhausted by the formation of stars, first in the central regions and then over an increasingly large fraction of the disk. The most rapid exhaustion of gas is expected in systems with a prominent bulge, a high rate of rotation of the bulge with respect to the disk and a large value of $\Omega - \Omega_p$.

Fuel for the formation of more stars can be provided only by the slow ejection of gas by dying stars in the disk, the infall of gas left over from the formation of the galaxy or the accretion of gas from outside the galaxy. Sandra M. Faber of the University of California at Santa Cruz and John S. Gallagher of the University of Illinois have suggested, however, that such sources of replenishment may be nullified by the effects of a wind of high-velocity gas emanating from the spheroidal bulge region. The energy of the wind would derive from two sources: from the heat generated by supernova explosions and that generated by collisions between the shells of gas ejected by dying stars. If the heating is strong enough to overcome radiative cooling (the energy escaping as photons,



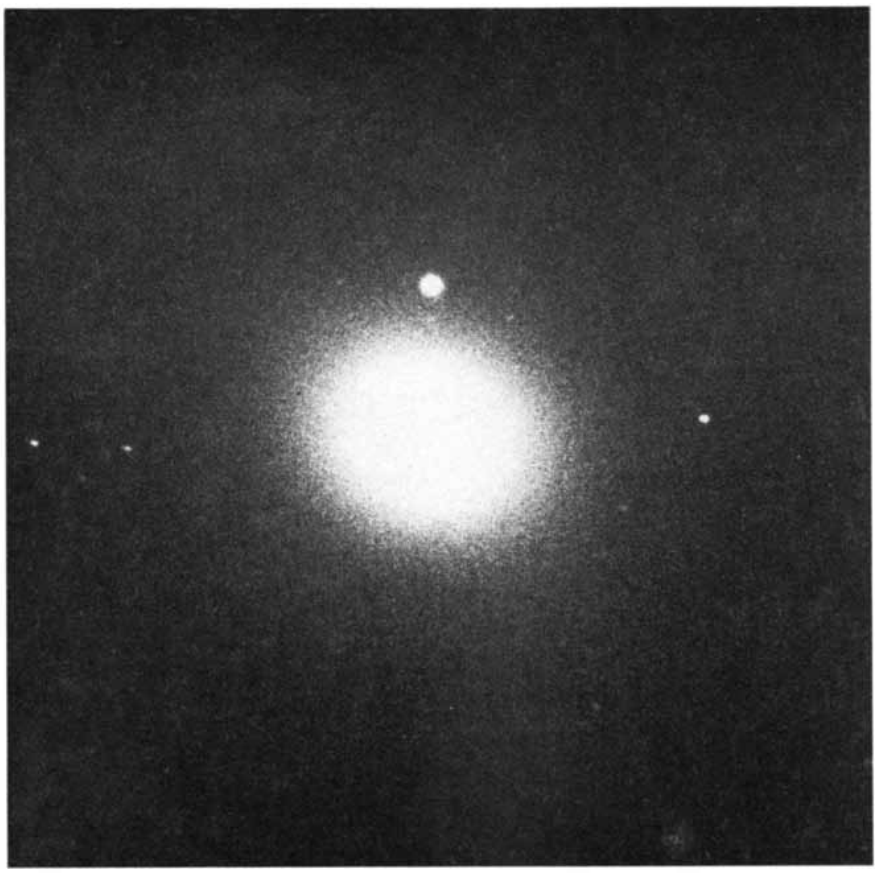
DISK GALAXIES can be divided into two broad categories: spiral systems and SO systems. Both kinds of galaxy have a central bulge and a surrounding disk. The disks of spiral galaxies have visually prominent arms because they are studded with complexes of bright, newly formed stars. The disks of SO galaxies, in contrast, are smooth, show no spiral structure and are devoid of young stars. The three photographs in the top row depict SO systems viewed nearly edge on, arranged in order of the decreasing prominence of their bulge with respect to their disk. No evidence of recent star formation is visible. The photographs in the middle row show three galaxies of the spiral type, also seen edge on and in order of decreasing bulge-to-disk ratio. The galaxies in the bottom row illustrate the probable face-on appearance of spiral galaxies in the middle row. The bright knots in the spiral arms of the galaxies represent newly formed stellar complexes.

or quanta of electromagnetic radiation), the equilibrium temperature of the gas in the bulge will be so high that the gas will no longer be gravitationally bound to the bulge. In general massive bulges will produce the strongest winds. If the pressure of the outflowing wind is high enough, it will deplete the surrounding disk of its gas.

When all the gas has been removed by the formation of stars or the action of galactic winds, the bright spiral arms defined by newly formed stars disappear. The density-wave pattern in the older disk stars, however, remains. The subsequent fate of the density wave in a system free of gas is not well understood. Our best guess is that the wave will at first increase in amplitude and then will damp out within a few galactic rotations, say within half a billion to a billion years. If our assumption is correct, gas-free disk systems will then resemble SO galaxies. The time needed for a spiral galaxy to be transformed into an SO galaxy depends on the amount of gas left after the initial formation of disk stars, the rate of star formation and the rate at which gas is added to or removed from the disk.

Although this picture seems quite plausible, so far there is no convincing observational evidence to support the hypothesis that spiral galaxies evolve naturally into SO systems when all sources of gas have been removed by star formation or galactic winds. The search for such evidence currently centers on attempts to compare the frequency of SO galaxies in a sample of disk systems where the gas-depletion rate should be high with the frequency of such galaxies in a second sample where the gas-depletion rate should be low. If SO galaxies evolve from spirals, one would expect to find the highest frequency of SO galaxies in systems characterized by high gas-depletion rates. If star formation is the dominant mechanism of gas removal in spirals, $\Omega - \Omega_p$ will measure the star-formation frequency and implicitly the gas-depletion rate. Hence SO's should be the dominant type among disk systems that have a large value of $\Omega - \Omega_p$, namely those with a prominent bulge. Spirals should be observed most frequently among galaxies with a lower bulge-to-disk ratio and a smaller value of $\Omega - \Omega_p$.

If galactic winds rather than star formation dominate the depletion of gas at late stages of the evolution of a disk, one would expect the systems with the strongest winds to evolve most rapidly from spiral to SO. Since galaxies with a large bulge-to-disk ratio should have the strongest winds, one would again expect the highest frequency of SO galaxies among disk systems with large bulges. Several investigators are attempting to measure the relative abundance of SO galaxies in samples of disk galaxies differing in their bulge-to-disk ratio, but so far no definitive results have been presented.

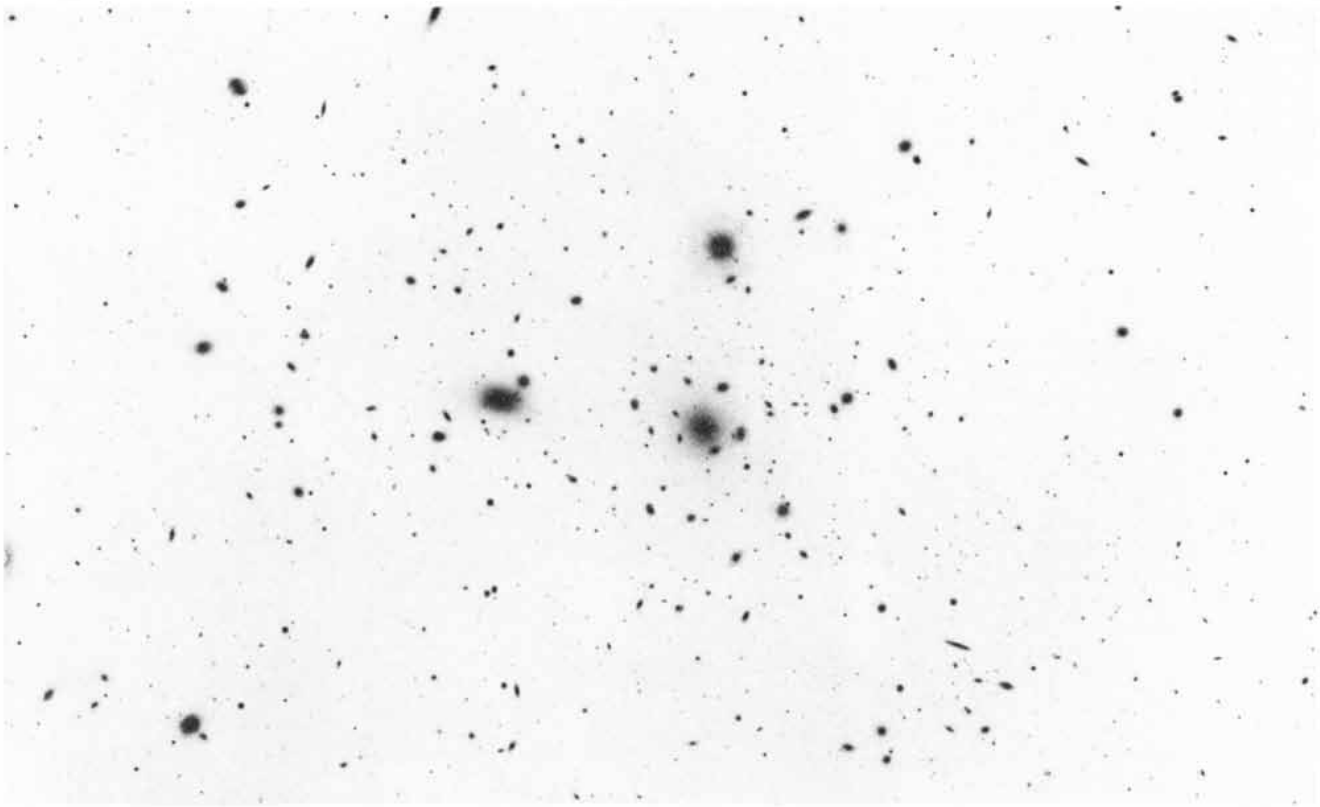


GIANT ELLIPTICAL GALAXY NGC 4472, representative of systems that have no disk, is presumed to be spheroidal in shape. Like SO galaxies, it is entirely lacking in young stars. Such giant galaxies have a mass about 10^{12} times the mass of the sun, which makes them five or 10 times as massive as our own large spiral galaxy. NGC 4472 is 60 million light-years away.

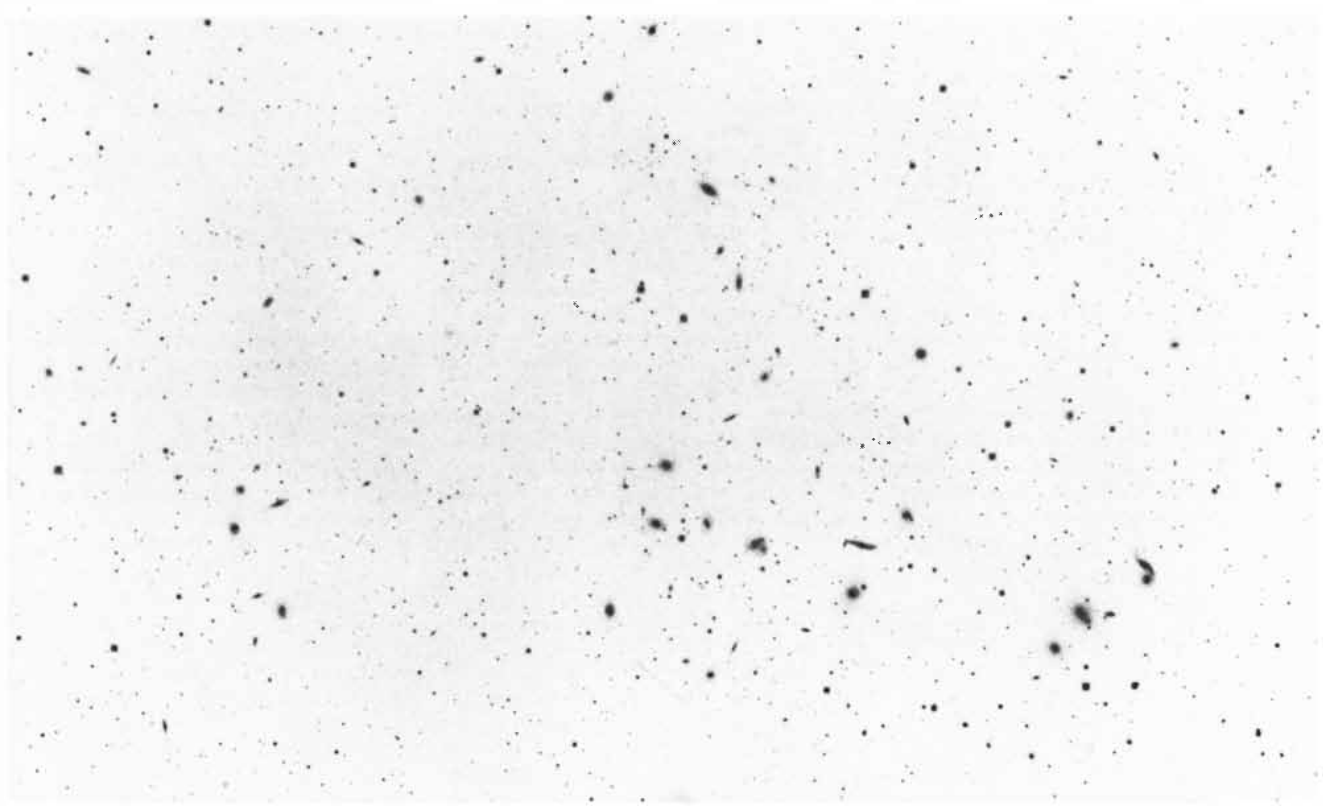
If the removal of gas from a spiral galaxy results in an evolutionary transition to an SO galaxy, what accounts for the greater frequency of such transitions in rich clusters of galaxies? Recent X-ray observations of galaxy clusters may have provided the essential clue to the solution of the mystery. X-ray surveys of the sky in the range of photon energies between 1,000 and 10,000 electron volts by the *Uhuru* satellite reveal a number of luminous X-ray sources associated with rich clusters of galaxies. The X-ray flux appears to be highest in clusters that have the highest total mass, the highest density of galaxies and the highest concentration of galaxies toward the center of the cluster. The X rays are thought to represent the radiation emitted by energetic electrons that are accelerated in a field of positive ions. The emission arises within an intracluster medium that varies in density from about one electron to 10 electrons per 100,000 cubic centimeters elevated to a temperature of about 10^8 degrees Kelvin. The density of the gas is highest in the center of the cluster and decreases smoothly toward the outer regions of the cluster.

J. Richard Gott III of Princeton University and James E. Gunn of the California Institute of Technology suggest that spiral galaxies moving through the intracluster medium will be subject to a "ram" pressure high enough to remove the disk gas. The ram pressure depends on the density of the gas within the intracluster medium and the velocity of the galaxy with respect to the medium; the pressure is highest for dense mediums and high velocities. From density estimates based on X-ray observations of the rich cluster of galaxies in the constellation Coma Berenices and from velocity measurements of individual cluster galaxies Gott and Gunn conclude that spiral galaxies passing through the center of the cluster could not retain their disk gas. In clusters of lower total mass and lower galaxy density, and in the outer regions of rich clusters, both the density of the intracluster medium and the expected galaxy velocities with respect to the medium are too low to strip away the disk gas. In such regions spirals are therefore free to complete their normal evolutionary development.

The various models of galaxy evolution that attempt to explain the diver-



CLUSTER OF GALAXIES IN COMA BERENICES, about 420 million light-years away, is a rich, centrally concentrated cluster with several thousand members, only a fraction of which are included in this negative print of a photograph made with four-meter reflector at Kitt Peak. Central region of the cluster is dominated by SO and elliptical galaxies. As in other rich clusters, spiral galaxies are rare.



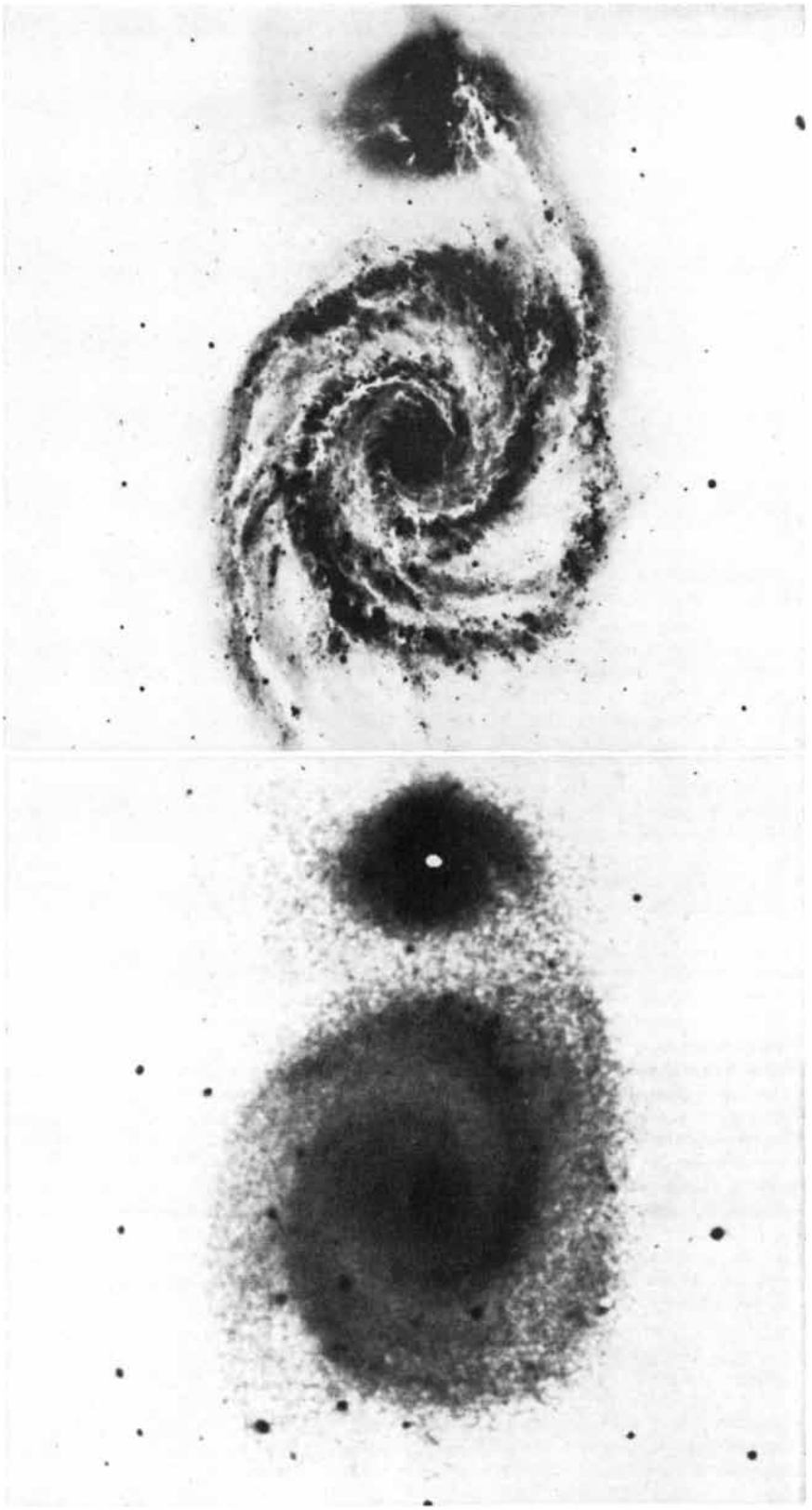
CLUSTER OF GALAXIES IN HERCULES is an open, irregular system 740 million light-years distant. Its several thousand members are packed much less densely than those in the Coma cluster. Unlike the Coma cluster, it includes a high proportion of spiral galaxies. Whereas hot intragalactic gas in the Coma cluster is a strong source of X rays, the Hercules cluster shows little evidence of gas between galaxies and is not an X-ray emitter. The photograph of the cluster was also made with the four-meter reflector at Kitt Peak.

gent pathways that yield either elliptical or spiral galaxies can be tested in three general ways. The first way is to study samples of galaxies in nearby clusters. The second is to compare the characteristics of nearby galaxies with those of the most distant (hence the youngest that can be observed). The third is to search for nearby galaxies that give signs of being younger than typical nearby systems. The three approaches are given in the order of their difficulty, and we shall now discuss them in the same order.

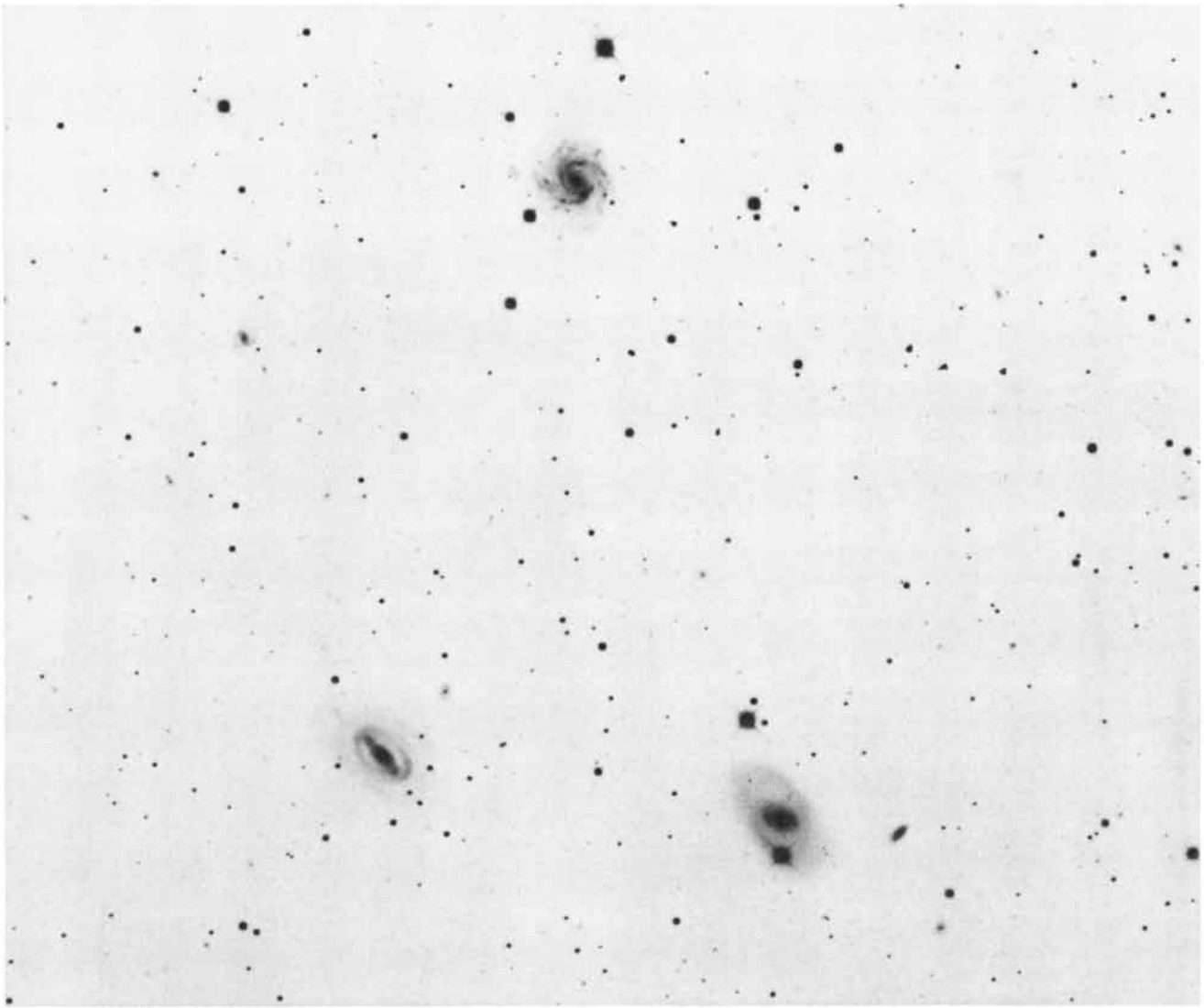
Studies of the detailed distribution of spiral and SO galaxies in nearby clusters of galaxies offer considerable support for the Gott-Gunn explanation of how spirals in rich clusters can be stripped of their disk gas. Jorge Melnick and Wallace L. W. Sargent of Cal Tech and Neta A. Bahcall of Princeton have computed the frequency of occurrence of SO galaxies in a number of galaxy clusters known to be X-ray sources. Their data show that the frequency is highest in clusters that have the largest spread in galaxy velocities and the highest X-ray luminosities. In such an environment the stripping of spirals is expected to be the most efficient. Melnick and Sargent also found that the frequency of SO galaxies decreases in the outer regions of all the clusters in their sample, a result that is consistent with the lower probability of stripping in the cluster regions characterized by a lower density of gas.

At the Kitt Peak National Observatory, working in collaboration with Susan Wilkerson and Eric Jensen, we have recently found examples of galaxies that may have been stripped of their disk gas within the past few billion years. Examination of photographs of X-ray-emitting clusters of galaxies reveals a number of disk galaxies where no newly formed stellar complexes are visible but where the spiral-wave pattern in the old disk stars is still evident. Several examples of such "smooth arm" spirals can be seen in the clusters Abell 262 and Abell 1367 [*see illustrations on next two pages*]. The amplitude of the spiral wave (as measured by the contrast in surface brightness between the arm regions and the regions between them) seems to be correlated with the measured color of the disk: the highest wave amplitudes are associated with the bluest disks, and the systems with the lowest wave amplitudes have the reddest disks. Blue colors are characteristic of stellar aggregates in which stars have formed fairly recently; red colors suggest that no stars have formed for several billion years.

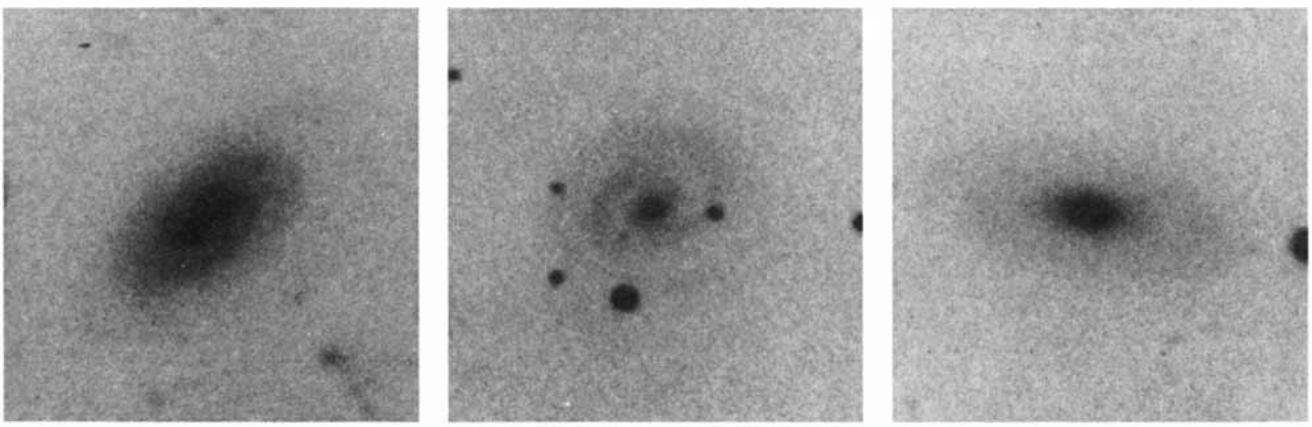
We believe spirals with smooth arms and a low wave amplitude are galaxies that were stripped of their disk gas and stopped forming stars several billion years ago; they are nearing the end



MESSIER 51 consists of a magnificent spiral galaxy, NGC 5194, and a small, irregular companion, NGC 5195, about 10 million light-years away. When the galaxies are photographed in blue light (*top*), the spiral arms of the large system are clearly delineated by newly formed complexes of hot, young stars and their associated regions of ionized hydrogen. When the galaxies are photographed in the near infrared (*bottom*), the images are dominated by the population of stars that are older, cooler and redder. The infrared picture reveals the rather smooth wave crests that map the current location of the wave pattern in the disk of the large spiral system. The blue-light picture was made with the four-meter reflector at Kitt Peak. The infrared one was made by Eric Jensen with an image intensifier on the 90-centimeter telescope at Kitt Peak.



TWO "SMOOTH ARM" SPIRAL GALAXIES, UGC 01350 and UGC 01344, can be seen at the bottom of this negative print of the cluster of galaxies Abell 262. Their appearance is distinctly different from that of the spiral galaxy UGC 01347 (*top center*), in which knots of newly formed stars and ionized gas are clearly visible. It is believed the smooth-arm systems are spiral galaxies whose disk gas has been stripped away from them within the past billion years or so either by an intragalactic "wind" or as a result of the motion of the galaxy through the intergalactic medium. Abell 262, which is about 300 million light-years away, is a cluster that emits X rays.



THREE SMOOTH-ARM SPIRALS may represent "snapshots" of spiral galaxies caught in the process of becoming SO galaxies as their disk gas is stripped away. The galaxy NGC 3860 (*left*), in the galactic cluster Abell 1367, has smooth but clearly visible arms with high-amplitude waves. In NGC 1268 (*middle*), a member of the rich Perseus cluster, wave crests in the spiral arms are much less visible. In IC 2951 (*right*), and also in Abell 1367, the arms have almost disappeared. Analysis of disk colors suggests that NGC 3860 was stripped of gas between 10^8 and 10^9 years ago, whereas IC 2951 was stripped more than 2×10^9 years ago. Photographs were made at Kitt Peak.

of their transformation from the spiral configuration into the SO one. In such galaxies the stellar population of the disk is dominated by longer-lived, redder stars. Spirals with a high wave amplitude and smooth arms may be galaxies that were stripped of their disk gas only a few hundred million years ago. As a result their disk color still reflects the contribution of young, blue stars that were formed just before the gas was stripped away.

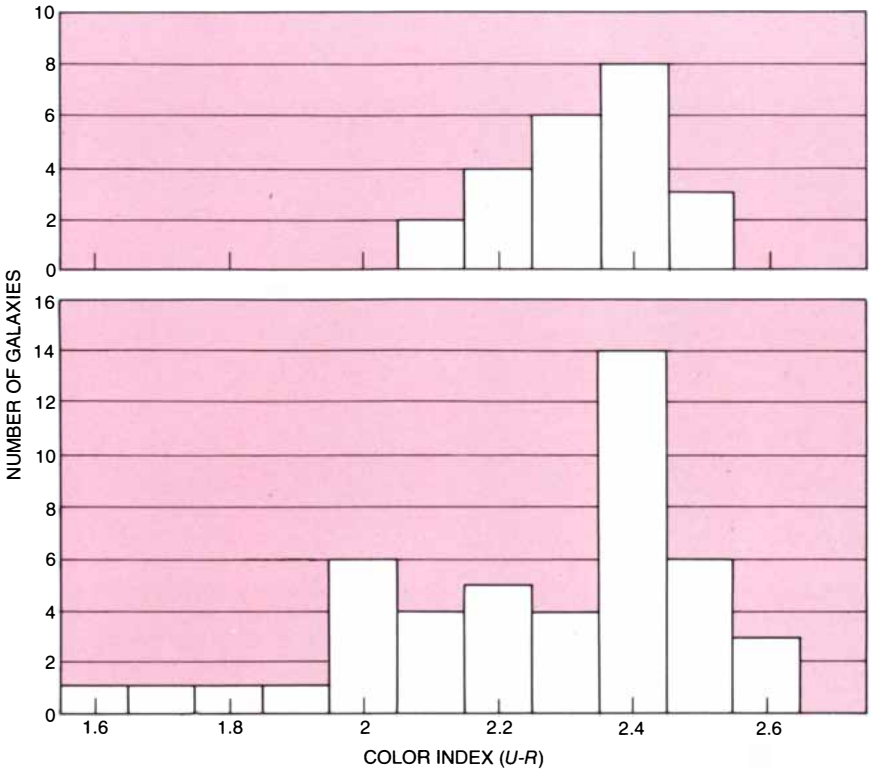
The smooth-arm spiral galaxy NGC 3860, located in the X-ray cluster Abell 1367, appears to be surrounded by "shreds" that may consist of ionized gas recently removed from the system. Since no other galaxy in the cluster is surrounded by shreds of similar appearance, the genetic association between the shreds and NGC 3860 seems highly plausible. More definitive proof that the shreds have been stripped from NGC 3860 waits, however, for spectroscopic study. If the line-of-sight velocities of both the shreds and the galaxy are close to the mean velocity of other galaxies in the cluster, one can be almost certain that the shreds are a part of the galaxy cluster Abell 1367. Furthermore, if the abundances of the chemical elements in the shreds (as determined by spectrographic analysis) are similar to the abundances characteristic of the disk gas in normal spiral galaxies, one can conclude that the shreds were torn from the disk of NGC 3860. If the measured velocities and the inferred chemical composition of the shreds indicate they originated in NGC 3860, the stripping hypothesis will have passed its most direct test.

The observed colors of SO systems in the Coma Berenices cluster of galaxies also lend support to the Gott-Gunn picture. When we analyzed the frequency distribution of disk colors for edge-on SO galaxies in the Coma cluster, we found that the outer region of the cluster appears to contain significantly more blue SO's than the central region. The red disk colors characteristic of the central region of the Coma cluster suggest that spiral galaxies were transformed into SO's more than several billion years ago. The presence of blue SO's in the outer region of the cluster can be explained by two plausible hypotheses. The first hypothesis supposes the blue SO's were stripped of their disk gas only recently after an excursion through the central regions of the cluster, where the intracluster gas density is high enough to accomplish the stripping. The second hypothesis assumes that the blue SO galaxies evolved from spiral galaxies in which the gas was not stripped away but was exhausted in the formation of many generations of stars. If the last stars formed within a billion years of the current epoch, the blue relics of these events could account for the observed colors.

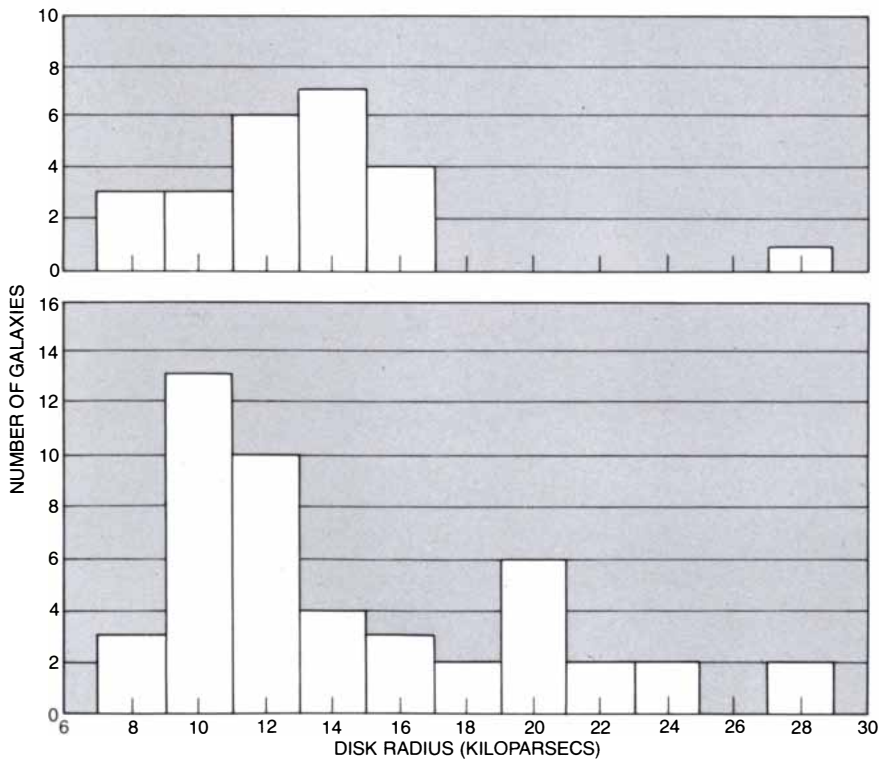
The sizes of the disk galaxies in the Coma cluster also seem to show the effect of environment on the evolution of such galaxies. A plot of the frequency distribution of the measured sizes of edge-on SO galaxies in the central and outer regions of the Coma cluster shows that many more large disk systems are present in the outer regions. This result could be explained if star formation were truncated by the removal of disk gas at a fairly early stage in the evolutionary history of the disk systems in the central region. Since the conversion of gas into stars proceeds slowest in the outer region of a galaxy, one can speculate that relatively few stars were formed before the gas was stripped away. SO's in the outer regions of the cluster, and thus less affected by stripping, may have completed a larger fraction of their natural evolutionary history and may therefore have formed a larger number of stars in their outer disk. This interpretation may, however, be complicated somewhat by the possible importance of tidal interactions of galaxies in the dense central region of the Coma cluster. Nevertheless, studies of disk galaxies in nearby clusters tend to support the view that the galaxies' evolutionary history is significantly affected by environmental factors.

The second general approach to testing models of galaxy evolution involves the study of the most remote galaxies. Galaxies with a brightness between 10^{11} and 10^{12} times that of the sun can be observed to vast distances. The time it takes light to travel from the most distant systems observed to date approaches 10 billion years. Observations of remote galaxies located at a variety of distances, or "look back" times, offer the possibility of measuring evolutionary changes directly. Unfortunately galaxies more distant than four billion light-years have an angular size of only a few seconds of arc, which is only slightly larger than the average image distortions introduced by the passage of galactic light through the earth's turbulent atmosphere. As a result even the

FIELD NEAR THE SMOOTH-ARM SPIRAL GALAXY NGC 3860 in the cluster Abell 1367 appears in a color composite photograph prepared with the aid of the Kitt Peak interactive picture-processing system. The colors were obtained by weighting the values in three black-and-white photographs made with the four-meter telescope in the ultraviolet, blue-green and red regions of the spectrum. The yellow-red colors of the spiral are typical of older stars in disk systems. The blue, irregularly shaped shreds may be ionized gas recently stripped from NGC 3860 as it sped through the intracluster gas at some 1,500 kilometers per second.



DIFFERENCES IN DISK COLORS are observed when edge-on SO galaxies within 2.1 million light-years of the core of the Coma cluster (*top*) are compared with edge-on SO galaxies more remote from the core (*bottom*). For this comparison the index of disk color (*U–R*) measures the ratio, on a logarithmic scale, of luminosities in the red and near ultraviolet. Large values of *U–R* mean the disk is dominantly "red" and so contains few newly formed blue stars.



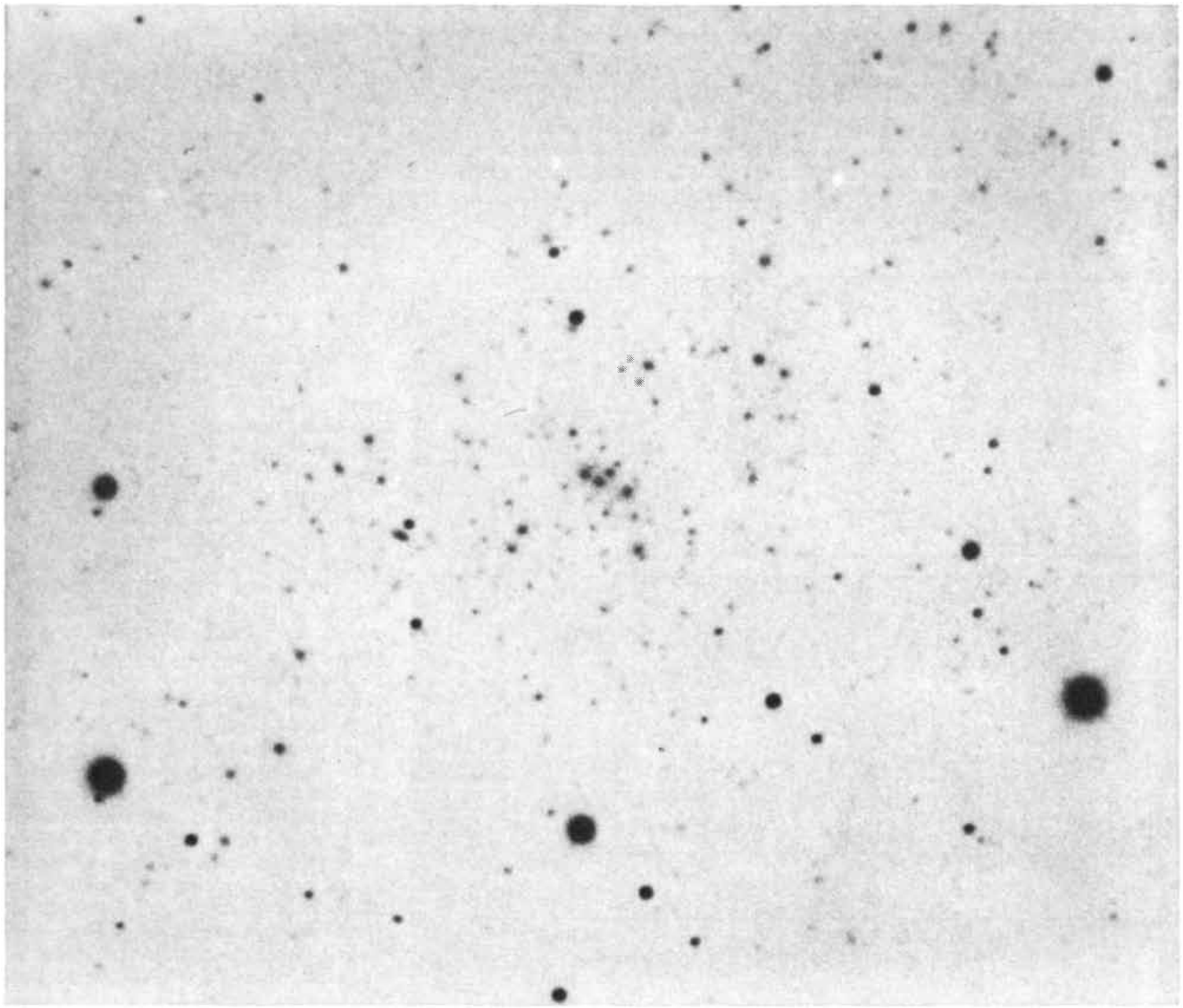
DIFFERENCES IN DISK SIZES are also apparent when edge-on SO galaxies within 2.1 million light-years of the core of the Coma cluster (*top*) are compared with similar but more distant galaxies (*bottom*). It is evident that there are more disks of large size in the outer region of the Coma cluster than there are in the inner region. One kiloparsec is equal to 3,260 light-years.

largest ground-based telescopes are unable to reveal the structural detail needed to classify galaxies as spirals, SO's or ellipticals.

In late 1983 or early 1984 the National Aeronautics and Space Administration will place a 2.4-meter telescope in orbit by means of the space shuttle. The direct-imaging television camera in the orbiting observatory will be able to resolve features separated by only about .05 second of arc, making it possible to classify galaxies and conduct crude structural studies at look-back times of more than five billion years. Until then considerable progress can be made by comparing luminosities and colors measured for distant galaxies with those observed for nearby systems. If reasonably large samples of galaxies are observed, it should be possible to estimate the evolutionary effects.

The feasibility of making such empirical studies of galaxy evolution has recently been demonstrated by Harvey Butcher of Kitt Peak and Augustus Oemler, Jr., of Yale University. With the aid of a sensitive television-camera detector system developed at Kitt Peak by C. Roger Lynds, Butcher and Oemler have recorded the luminosities and colors of a large sample of galaxies in two remote clusters, one seven billion light-years away and the other 8.8 billion. The nearer cluster, known as Cl 0024 + 1654, is receding at .39 times the velocity of light. The farther one, a cluster surrounding the radio galaxy 3C 295, is receding at .46 times the velocity of light.

These two distant clusters appear to be as rich in galaxies and as centrally concentrated as the Coma cluster is. If they were as highly evolved some eight billion years ago as the relatively nearby Coma cluster (whose light has taken less than half a billion years to reach us), the two distant clusters should resemble the Coma cluster, being poor in spiral galaxies and rich in elliptical and SO systems. Since few, if any, stars have formed recently in the elliptical and SO systems of the Coma cluster, the colors of these galaxies are predominantly red. Butcher and Oemler observed that in contrast the brightest galaxies in the distant clusters include many blue-colored systems, presumably spiral galaxies that are producing young, blue stars. Assuming a correspondence between galaxy color and galaxy type identical with that observed for nearby galaxies, Butcher and Oemler deduced that more than half the galaxies in the distant clusters are spirals and that the rest are ellipticals or SO's. In the Coma cluster fewer than 10 percent of all the galaxies are spirals. Hence although the overall character of the distant clusters resembles that of the nearby, spiral-poor clusters such as the Coma cluster, the distri-



ONE OF MOST DISTANT CLUSTERS, Cl 0024 + 1654, is receding from the earth at .39 times the velocity of light, which implies that it is nearly seven billion light-years away. The study of such clusters can potentially reveal whether galaxies, seen as they appeared long ago, are less highly evolved than the older galaxies that populate much nearer clusters. The cluster Cl 0024 + 1654 is so far away that its galaxies are barely distinguishable from the images of stars within our galaxy. The cluster consists of several hundred galaxies, most of which are visible in the plate from which this print was made. Photograph was made by C. Roger Lynds with the four-meter Kitt Peak reflector.

bution of galaxy types in them appears to be quite different.

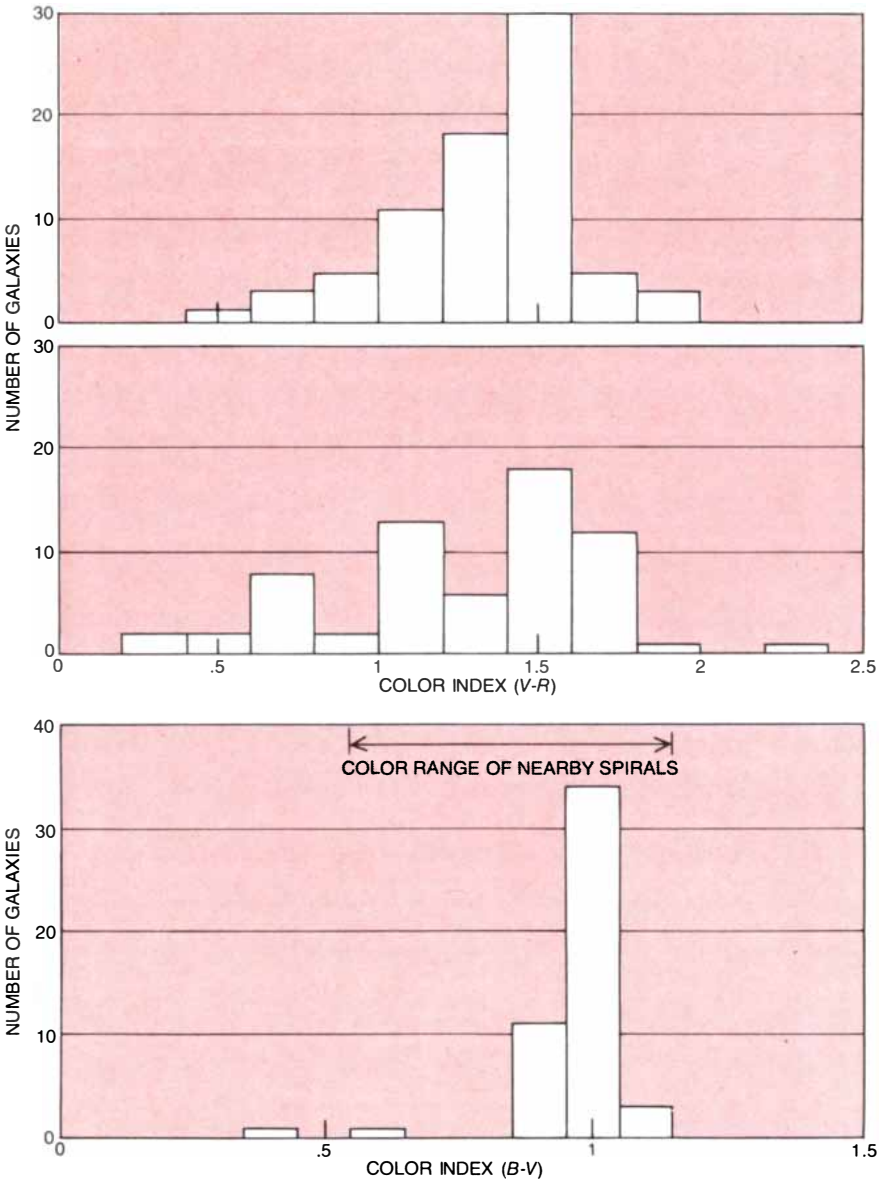
If the blue galaxies in the two distant, and therefore young, clusters are indeed spirals, it is tempting to suggest that disk galaxies in similar environments have undergone significant evolutionary changes over the past eight billion years. It is possible that in younger clusters of galaxies only a small fraction of spirals have been stripped of their disk gas and transformed into SO's, whereas in Coma-like clusters nearly all the spirals have been stripped. With results available for only two distant clusters it is perhaps premature to embrace this explanation for the differences in the observed color distributions. Nevertheless, the application of sensitive panoramic detectors to the investigation of distant clusters promises to provide additions and challenges to the subject of galaxy evolution.

The third approach to testing hypotheses of galaxy evolution is to search for relatively nearby spiral galaxies whose development appears to be "retarded." Working in collaboration with William Romanishin, we studied a class of spiral galaxies whose surface brightness, or luminosity per unit of area, is so low that they are clearly discernible only on long-exposure plates made with the 1.2-meter Schmidt telescope on Palomar Mountain and with the four-meter Mayall reflector at Kitt Peak. Although such low-surface-brightness (LSB) systems are no more than 60 million light-years away, they are barely visible above the background sky light. Otherwise they are similar in size and appearance to normal bright spirals. The chief difference is that the disks of LSB galaxies are considerably bluer than the disks of normal spiral galaxies.

The combination of low surface brightness and blue color suggests that compared with the disks of normal spirals the LSB disks are currently populated by relatively few stars. Hence the major contribution to the light of the LSB disks must be made by relatively blue stars younger than three to four billion years. In contrast, the red disk colors of galaxies similar to our own suggest that an overwhelming majority of the disk stars in them were probably formed more than 10 billion years ago. If star formation in LSB galaxies has been rela-

tively inefficient (or possibly absent) until the comparatively recent past, LSB systems may not have consumed a large fraction of the gas initially present in their disks.

Tentative confirmation of this speculation was provided recently by observations of several galaxies of the LSB type at the radio wavelength of 21 centimeters emitted by un-ionized interstellar hydrogen. Working with the 1,000-foot parabolic antenna at Arecibo in Puerto Rico, Nathan Krumm, E. E. Salpeter, Romanishin and we found that some LSB spirals evidently contain more than twice the amount of hydrogen found in normal spirals of a similar type. If LSB galaxies are in fact disk systems that are relatively less evolved than normal spirals, detailed study of this unusual class of nearby spirals may provide a glimpse into the past history of our own galaxy.

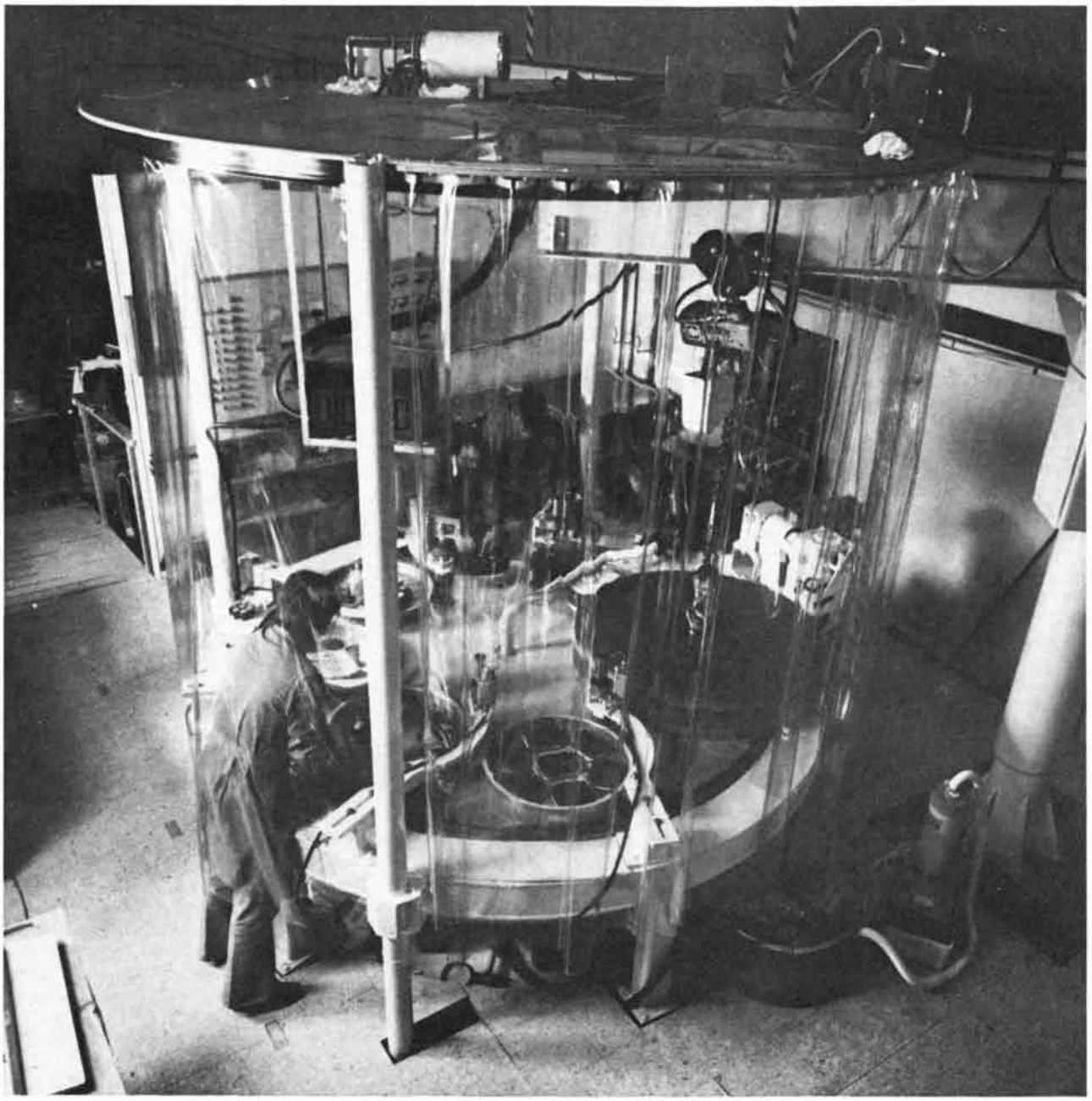


MAJOR DIFFERENCES IN GALAXY COLORS are revealed when the distribution of the colors in the nearby Coma cluster (*bottom*) is compared with the distribution of colors in two very distant clusters, Cl 0024 + 1654 (*top*) and 3C 295 (*middle*). Cluster 3C 295, receding at .46 times the speed of light, is seen as it looked about 8.8 billion years ago. The colors in the Coma cluster are expressed in terms of the index *B–V*, which measures the ratio of observed "visual" light (wavelength .55 micrometer) to blue light (wavelength .42 micrometer) on a logarithmic scale. The colors in the two distant galaxies are given in terms of the *V–R* system, in which the red measurement is at a wavelength of .65 micrometer. As plotted, the *V–R* index is almost equivalent to the *B–V* index in the rest frame of the receding clusters. The distribution of the colors of galaxies in the distant clusters is distinctly broader than it is in the Coma cluster and in fact is much closer to the range of colors characteristic of nearby spiral galaxies. Thus although the distant clusters are equivalent in richness and concentration of galaxies to the Coma cluster, they appear to contain many more spiral galaxies. This suggests that if the Coma cluster could have been observed as it was seven or eight billion years ago, fewer of its spiral galaxies would yet have been converted into SO and elliptical galaxies by the stripping away of their gas.

The study of galaxies is entering a new phase. In the past much of what is known about galactic structure was derived from the qualitative examination of photographs made with large telescopes. Pioneering efforts to classify galaxies, based on their general appearance, provided the basis for much of the current physical understanding of galactic structure. With the advent of sensitive panoramic detectors and advanced computing methods for the analysis of digitized photographs one can now quantify the color of galaxies and the distribution of surface brightness. For example, many of the new results reported here were obtained with the new interactive picture-processing system (IPPS) developed at Kitt Peak. The system enables one to display digitized pictures of galaxies, to enhance them by emphasizing given brightness levels and to select particular regions for which, say, a brightness or a color measurement is desired. The rapid, real-time interaction with pictorial data increases the efficiency of data analysis, making it possible to study hundreds of galaxies in a variety of settings.

We expect that such quantitative studies will make it possible to address a variety of fundamental questions empirically for the first time. Are galaxies of a given type basically similar in structure or do similar-looking galaxies in rich clusters exhibit measurable differences from their counterparts that are not bound within clusters? If such differences exist, what accounts for them? Can environmental effects such as the stripping of disk gas account for all structural differences, or is it possible that galaxies found in the dense central regions of rich clusters were formed in a way fundamentally different from the way galaxies located outside clusters or in irregular clusters were formed? Is the star-forming history and dynamical evolution of cluster galaxies different from that of noncluster galaxies?

In addition to their implications for understanding the life histories of galaxies, answers to such questions will directly affect the confidence astronomers can place in efforts to use galaxies as standards of brightness and distance in probing the large-scale structure of the universe. One may also learn from such studies the sizes and masses of the first condensations to emerge in the early evolution of the universe. Were these condensations on the scale of stars, star clusters, galaxies or galaxy clusters? Our brief review summarizes only a few of the first results in the renewed quest of understanding how galaxies form and evolve. We hope it conveys some of the excitement of that quest.



Here is the latest of what we use to polish a large optical surface flat to less than 1/20 of a wavelength and smooth to 10 angstrom units, which is only ten times the diameter of a hydrogen atom. We don't need such equipment to make the products for which we are most widely known. However, we do make some very special products for some very special customers like, for example, space telescope people and the folks who are trying to see if arrays of huge lasers can ignite a speck of deuterium to give back significantly more energy than the titanic bolts they hurl at it.

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SCIENCE AND THE CITIZEN

Psi-Fi

Research on psychic phenomena, or "psi," is thriving. The Parapsychological Association has some 300 members, who study such phenomena as extrasensory perception (which can be subdivided into mental telepathy, clairvoyance and precognition) and psychokinesis (the moving of objects or the disturbing of physical processes by mental action alone). In 1969 the association was admitted to the American Association for the Advancement of Science as an affiliate. Courses in parapsychology are given for credit at colleges and universities, doctorates are awarded, and research is funded by wealthy individuals, by institutions and by the U.S. Government. Up-to-date techniques and apparatus are invoked: elaborate statistical procedures, random-number generators, computers, subatomic-particle counters and interferometers. Increasingly physicists, engineers and others not trained in psychological experimentation have entered the field along with their equipment. Some parapsychologists consider the physicists naive interlopers; others are impressed by their results.

What should the attitude of science and scientists be toward parapsychology? Does freedom of inquiry demand the right to pursue notions that run counter to the basic findings of modern science and that have persistently failed to produce enough confirming evidence to elicit broad acceptance? Most scientists, even the most skeptical, would argue that investigations that do no harm should not be proscribed, that freedom to publish should not be abrogated. Whether parapsychology is science and should be called science is another question, and this question has now been raised by John Archibald Wheeler, formerly of Princeton University and now of the University of Texas at Austin, a well-known theoretical physicist and a former president of the American Physical Society.

In a letter to William D. Carey, executive officer of the American Association for the Advancement of Science, Wheeler asked that a five-person "Committee for the Review of Parapsychology in the A.A.A.S." be set up to advise on whether the Parapsychological Association should remain an affiliate of the country's leading organization of all the sciences. He would also have the committee report on whether parapsychology "by now has produced *any* 'battle-tested result,'" on how much the affiliation with the A.A.A.S. has helped parapsychology's fund-raising efforts and on what effect parapsychology's affiliation has had "on the public image of the A.A.A.S." Carey distributed copies of Wheeler's letter to members of the executive committee of the association's policy-making council.

Wheeler's challenge was prompted by his participation in a session on "science and consciousness" at the A.A.A.S. meeting in Houston in January. He found that he and Eugene P. Wigner of Princeton, "two people from the world of physics, were being put together on a panel with several parapsychologists." He dealt with that by adding to his prepared talk on the relation between quantum mechanics and consciousness two appendixes. In one of them he expressed his displeasure at learning that "so-called extrasensory perception would be taken up in one of the papers" delivered at the session. He asked: "How can pseudoscience fail to profit in prestige and acceptability by being on the same platform as science? And how can science fail to lose?" He also suggested that parapsychology be voted out of the A.A.A.S. In the other appendix he examined parapsychology's right to be called a science. "Every science that is a science has hundreds of hard results," he said, "but search fails to turn up a single one in 'parapsychology.'"

The tendency of what may appear to be hard results in parapsychology to eventually be upset has been illustrated by several publications within the past year. Russell Targ and Harold E. Puthoff, physicists at the Stanford Research Institute, had reported (in *Nature* and in *Proceedings of the IEEE*) experiments in which a subject attended by one experimenter was shown to display extrasensory "remote viewing" ability by dictating a description of a remote site being visited by a team of other experimenters. Transcripts of nine descriptions and lists of the nine sites in the sequence in which they had been visited were given to judges, who sought to match transcripts to sites by themselves going to the sites. The judges' matching of transcripts and sites indicated that the subject had a remarkable ability to divine where the experimenters were at a given time and to describe the site.

In a letter to *Nature* last summer David Marks and Richard Kammann of the University of Otago in New Zealand reported that their examination of five unpublished transcripts given to a judge revealed cues in each of them revealing the transcript's position in the sequence. For example, the experimenter remarks to the subject that the current trial represents the "second place of the day" or says "Nothing like having three successes behind you." On the basis of such cues Marks was able to match each of the five transcripts with the proper site—without visiting the sites! When the cues were edited out, on the other hand, two research psychologists were unable to match transcripts and sites at a level significantly better than chance.

John G. Taylor of King's College in London is a physicist whose book *Superminds* in 1975 accepted and celebrated the metal-bending powers of the Israeli psychic Uri Geller and some juvenile amateur spoon-benders. Now he has in effect taken it all back. In a letter to *Nature* last November, Taylor and a colleague, E. Balanovski, reported on intensive tests of subjects alleged to have powers of psychokinesis (including metal-bending), psychic healing, dowsing and telepathy. They found either no psychic effects at all or some dubious effects, which they concluded were not paranormal.

Their argument in these cases is based on their conviction that electromagnetism is "the only known force that could conceivably be involved." Careful measurements over a broad spectrum detected no unusual electromagnetic radiations from the psychics and no human sensitivity to low-level signals. Taylor and Balanovski observed metal-bending only under relatively uncontrolled conditions. Having determined the energy required to bend metal, they concluded that "there is no known mechanism in the body to achieve a peak power output" sufficient to do the trick, and "it is difficult to suppose that this would be possible without severe tissue damage." The Taylor retraction will not convince the many parapsychologists and paraphysicists who discount the role of electromagnetic fields and postulate instead "quantum effects" or some force as yet unknown.

Some recently reported psi effects, to be sure, have not yet been successfully controverted. In every generation a few results are reported by respected investigators that seem impossible to explain away. As Hudson Hoagland of the Worcester Foundation for Experimental Biology pointed out some years ago in an editorial in *Science,* however: "Unexplained cases are simply unexplained. They can never constitute evidence for any hypothesis." And from time to time even the apparently valid results are shown to be invalid. A case in point is a well-known card-guessing experiment reported in the 1940's by the respected English parapsychologist S. G. Soal. There were allegations at the time that Soal had been seen to alter some digits in score sheets to achieve impressive results, but the reports were discounted. Last May, Betty Markwick, a statistician who is generally sympathetic to parapsychology, reported in *Proceedings of the Society for Psychical Research* proof that Soal had altered the score

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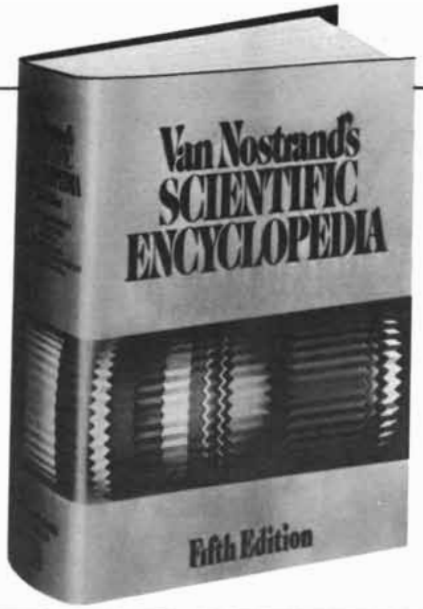

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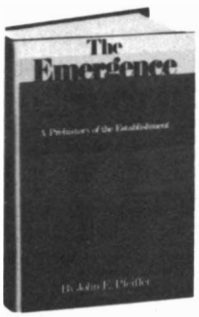

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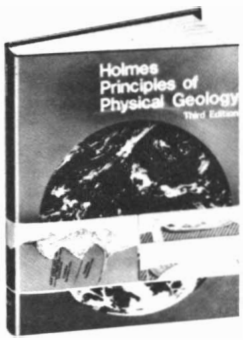

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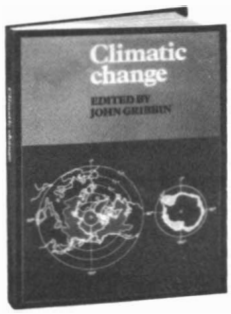

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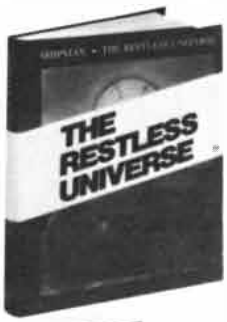

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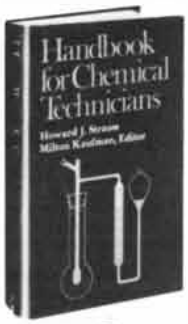

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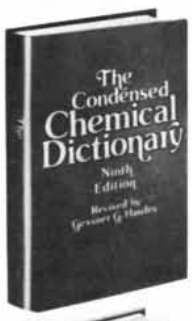

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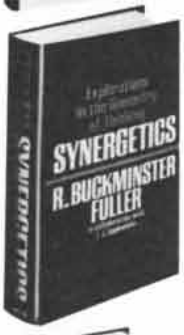

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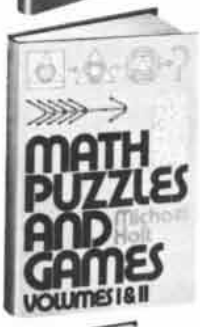

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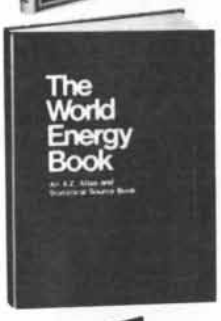

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Bell-shaped Uranium

Expert opinions on the probable role of nuclear power in the future energy budget of the U.S. vary widely, depending on a complex set of social, economic, technological and geological assumptions, not the least of which is the estimated size of the uranium resource as a function of diminishing ore grade. According to one interpretation, most metals of low abundance in the earth's crust, such as uranium, are characterized by a bimodal pattern of geological distribution: there are high-grade ores on the one hand and low-grade deposits (ordinary rocks) on the other, with a distinct gap between the two diagrammatic peaks of crustal abundance. This hypothetical model of the geochemistry of the trace elements, when it is applied to uranium, leads to certain conclusions about the long-term availability of uranium fuel for nuclear reactors. It implies that once the comparatively scarce high-grade deposits of uranium ore are depleted mining operations will have to switch abruptly to the more abundant low-grade deposits, a transition that would entail a sharp increase in fuel costs and hence a drastic revision in the competitive economics of conventional, or nonbreeder, nuclear power.

It is therefore significant that the results of a major new study of both the global distribution of uranium in various types of rock and the distribution of different grades of uranium ore mined in the U.S. appear to contradict the bimodal-distribution hypothesis. The study, conducted over the past six years by two research geologists, Kenneth S. Deffeyes of Princeton University and Ian D. MacGregor of the University of California at Davis, suggests instead that the distribution of uranium can be more accurately described by a single log-normal, or bell-shaped, curve representing, in their words, "either ... a single unimodal distribution or ... a composite of a large number of multimodal distributions." The ascending slope of that curve, the two investigators find, indicates "approximately a 300-fold increase in the amount of uranium contained for each 10-fold decrease in ore grade."

In a book-length report prepared for the Department of Energy, Deffeyes and MacGregor present their results and draw a number of conclusions. From their examination of the available data they conclude that in the range of uranium deposits being mined now (and to be mined through the rest of the century) the amount of recoverable uranium will continue to increase roughly 300-fold for each 10-fold decrease in the grade of the minable ore. This conclusion, they point out, "is robust, in that we have derived it from the global geochemical distribution of uranium, and we have also derived it from the U.S. uranium-mining history and from a wide variety of subsets of the U.S. uranium-mining history." Moreover, they add, their extrapolations based on the effort expended for uranium exploration "do not disagree" with the foregoing conclusion.

The acceptance of such a conclusion has several far-reaching consequences, which Deffeyes and MacGregor summarize as follows: "Nuclear generation of electric power with conventional, nonbreeder reactors need not be greatly dislocated by the cost of uranium exploration, mining and extraction through the rest of this century.... The U.S. probably will not be forced to import uranium in this century, although overseas producers such as Australia could sell uranium in the U.S. market if they were to set up attractive prices.... Neither the reprocessing of spent fuel elements nor the breeder reactor, as it is now proposed, are dictated in this century as a response to the geologic scarcity of uranium.... Long-range uranium-exploration efforts and metallurgical research on the extraction of lower-grade deposits should focus on the 300- to 800-parts-per-million range. Deposits in the 100-parts-per-million range will not be exploited until sometime well into the next century."

According to Deffeyes and MacGregor, "we see nothing in the data that would lead one to suspect a gap" between high-grade and low-grade uranium deposits as postulated in the bimodal-distribution model. In their view the absence of any evidence for such a gap leads in turn to additional consequences: "Ore deposits of the general style that are currently minable will continue to be discovered in lower-grade versions for a few years before the geologic type slowly shifts to larger deposits of types that never produce high-grade concentrations.... The coproduction of uranium with other materials will become increasingly common.... The coproduction of uranium and phosphorite and the coproduction of uranium and energy from lignites [low-grade coals] are likely to become the next large sources, particularly since uranium is concentrated in the ash. Exploration for additional coproduct pairs may be rewarding.... Deposits such as the Chattanooga shale, of low uranium concentration and without known by-products, will be economically difficult to extract in this century."

The conclusions of the Deffeyes-MacGregor report, which differ substantially from several uranium-resource estimates made in recent years by both Government and non-Government analysts, are offered tentatively. "The data available do not bear unique-

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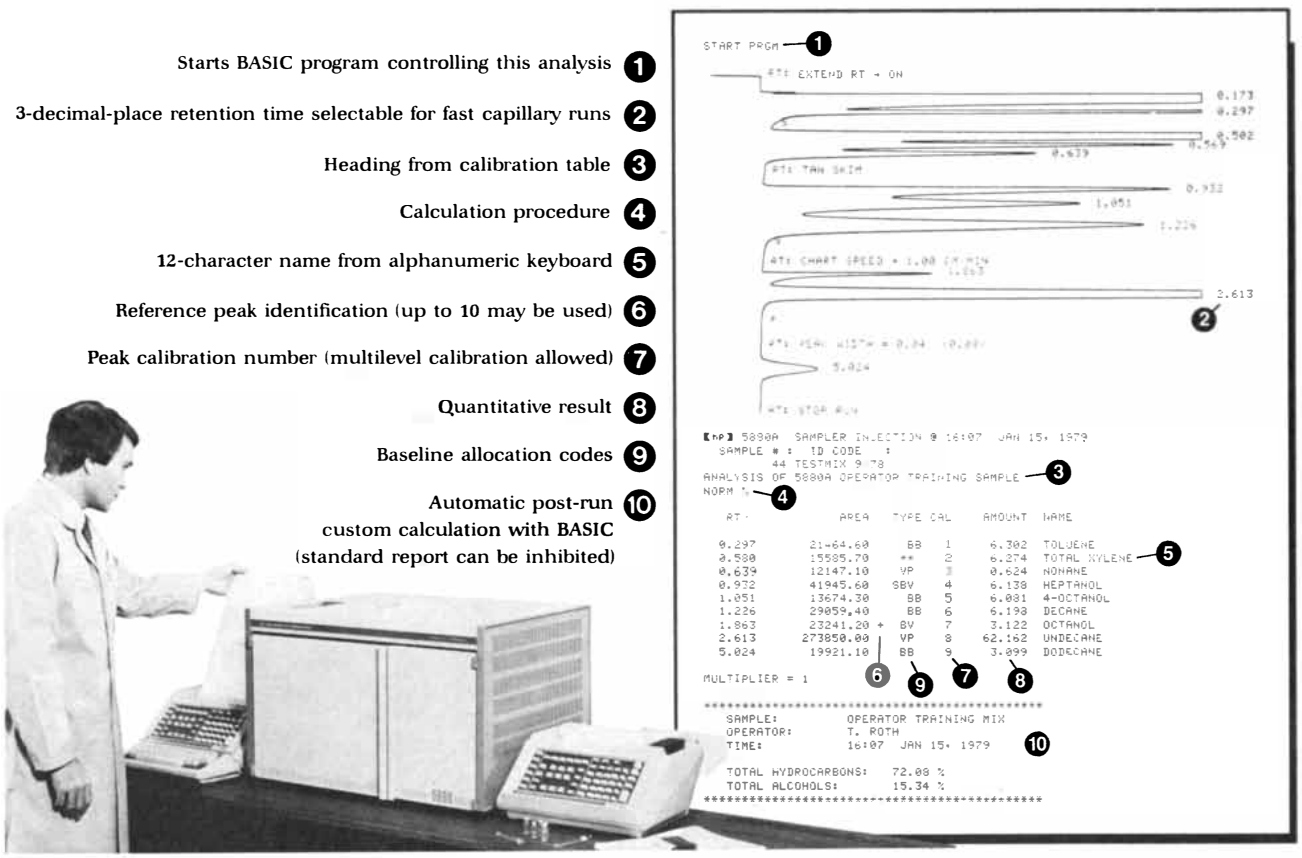

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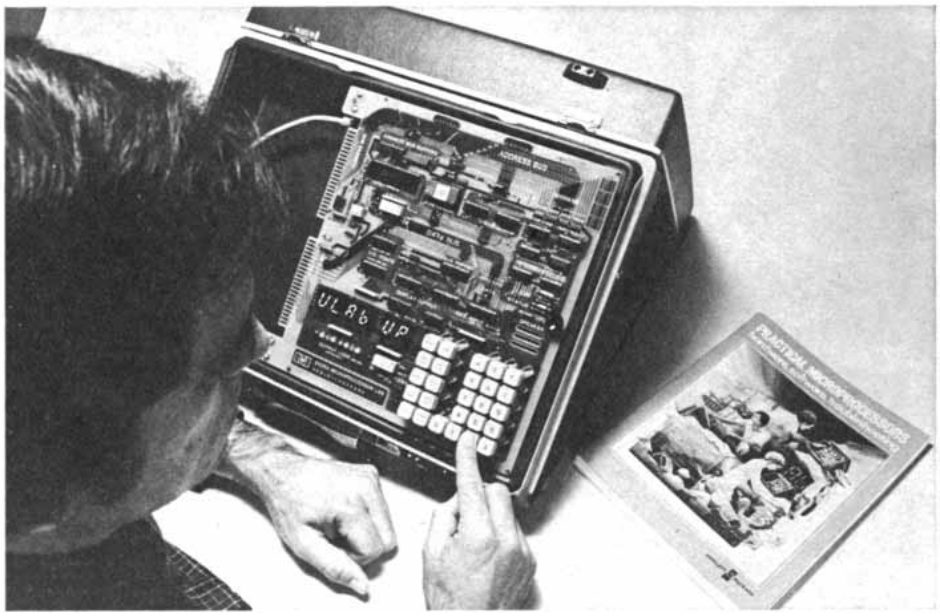

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ly on the problem and it is not possible to get a rigorous evaluation within well-defined statistical limits." Nevertheless, Deffeyes and MacGregor write, "it is possible to ... extract a qualitative or semiquantitative assessment [of the geological distribution of uranium], particularly with reference to the distinction between a simple bimodal versus a multimodal or log-normal type of distribution."

Interfering with Cancer

Interferon is the generic name for a class of small proteins, secreted by virus-infected animal cells, that act on nearby uninfected cells to render them resistant to a broad spectrum of viruses. Although interferon is not specific to any particular virus, it exerts its protective effect only on cells of the same species of animal that manufactured it. In the 22 years since interferon was discovered by Alick Isaacs and Jean Lindemann at the National Institute for Medical Research in England evidence has accumulated that it plays other important roles in the body's complex defensive reactions against both viruses and neoplastic, or cancer, cells. Interferon has been shown to retard the rapid division of tumor cells, to enhance the expression on tumor cells of cell-surface antigens (foreign proteins that induce the immune response) and to either activate or inhibit B lymphocytes and natural killer cells, two classes of white blood cells participating in immunological reactions.

Since all these effects are potentially useful in the treatment of cancer, there has been much interest in the possibility of using interferon for that purpose. Until recently the scarcity, impurity and enormous cost of human interferon has severely limited the scope of clinical trials in human cancer patients, but advances in the production and purification of human interferon have now made larger clinical studies feasible. The American Cancer Society is about to embark on a major investigation of the antitumor effects of interferon on as many as 120 patients, and other clinical research projects are getting under way in Europe and Japan.

The rationale for clinical trials of interferon is the same as that for any new experimental cancer therapy: its proved effect on certain animal tumors (usually transplantable mouse tumors) and its freedom from unacceptable toxicity in animals and man. Interferon has fulfilled these two requirements as well as or better than other accepted forms of experimental cancer therapy. In several animal species it has been shown to inhibit the multiplication and spread of cancer-causing viruses and the virus-induced transformation of normal cells into cancer cells. Although there is still no unequivocal proof that any human tumors are caused by viruses (with the exception of benign warts), much circumstantial evidence favors such an association, and human interferon preparations have been shown to inhibit a virally induced tumor in two species of primate. The antitumor effect of interferon may also be the result of its inhibitory action on rapidly dividing cells, which appears to be independent of its antiviral effect. For example, mouse interferon can completely inhibit the growth of small numbers of highly malignant tumor cells in living mice. Interferon is apparently without toxicity for normal cells and is not antigenic or allergenic in the same species from which it was obtained. Moreover, since cells do not become tolerant to the effects of interferon, it can be expected to be essentially safe and effective during repeated and prolonged administration.

The first systematic attempts to study the antitumor effects of interferon in man were made by Hans Strander and his colleagues at the Karolinska Hospital in Stockholm. In 1974 they tested interferon therapy on 21 patients with osteogenic sarcoma, a rare but highly malignant bone cancer, usually of people between the ages of 10 and 25. This cancer was chosen for study because of its poor prognosis (only 20 percent of those who suffer from it survive beyond two years) and its quantifiable end points: the time of appearance of metastases in the lungs and death in a predictable percentage of patients. After an operation to remove the primary tumor interferon was administered to the patients by injection three times a week for 18 months. Although the number of patients in the study was too small to provide statistically convincing results, it was the impression of the treating physicians that the interferon-treated group showed roughly a doubling of cases with long-term, metastasis-free survival when compared with both past and present control patients.

The results of more recent clinical experiments have also been encouraging. Interferon-induced regression of tumors has been demonstrated in patients with multiple myeloma and breast cancer in studies performed by Jordan U. Gutterman and his colleagues at the M. D. Anderson Hospital in Houston. In addition Thomas C. Merigan and his colleagues at the Stanford University School of Medicine reported in December in *The New England Journal of Medicine* that prolonged administration of interferon to three patients suffering from a slow-growing lymphoma (a tumor of the B lymphocytes) caused the tumors to shrink markedly. Interferon had no beneficial effect, however, on three other patients with diffuse, rapidly spreading lymphoma at a later stage. Merigan is not sure why there was such a difference in responsiveness to the therapy in the two sets of patients, but he points out

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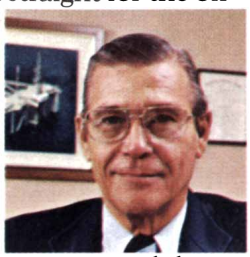

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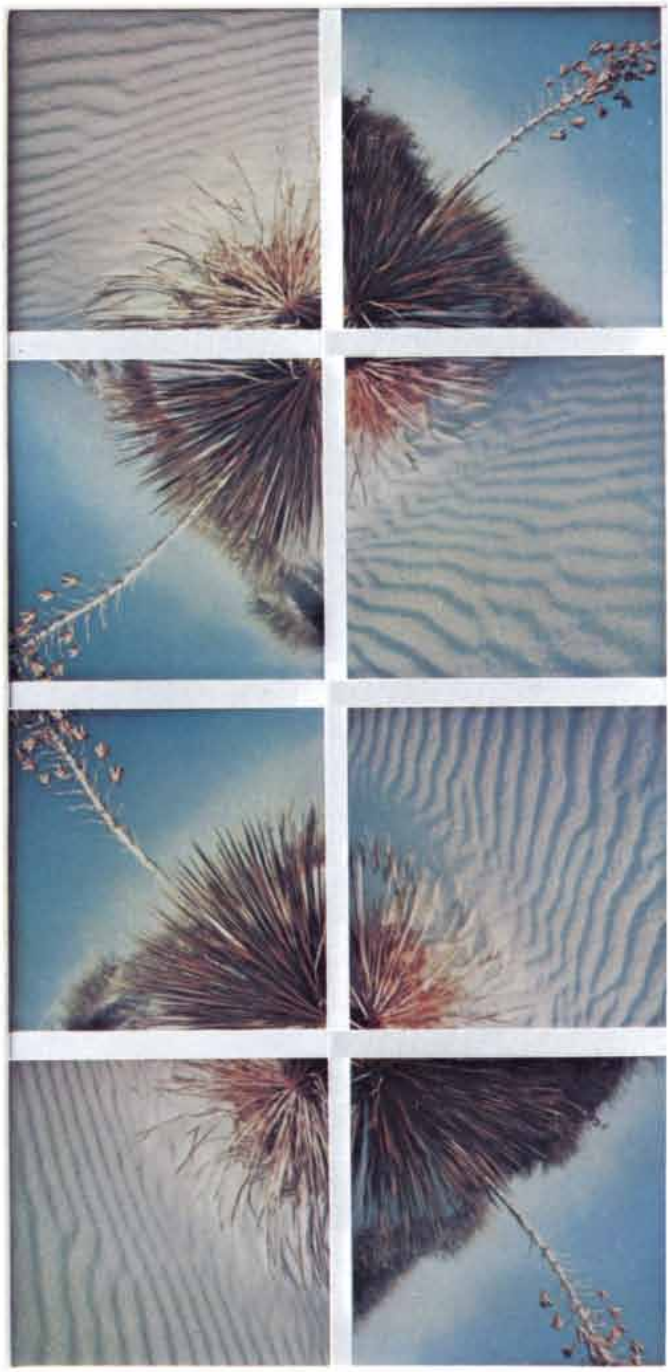
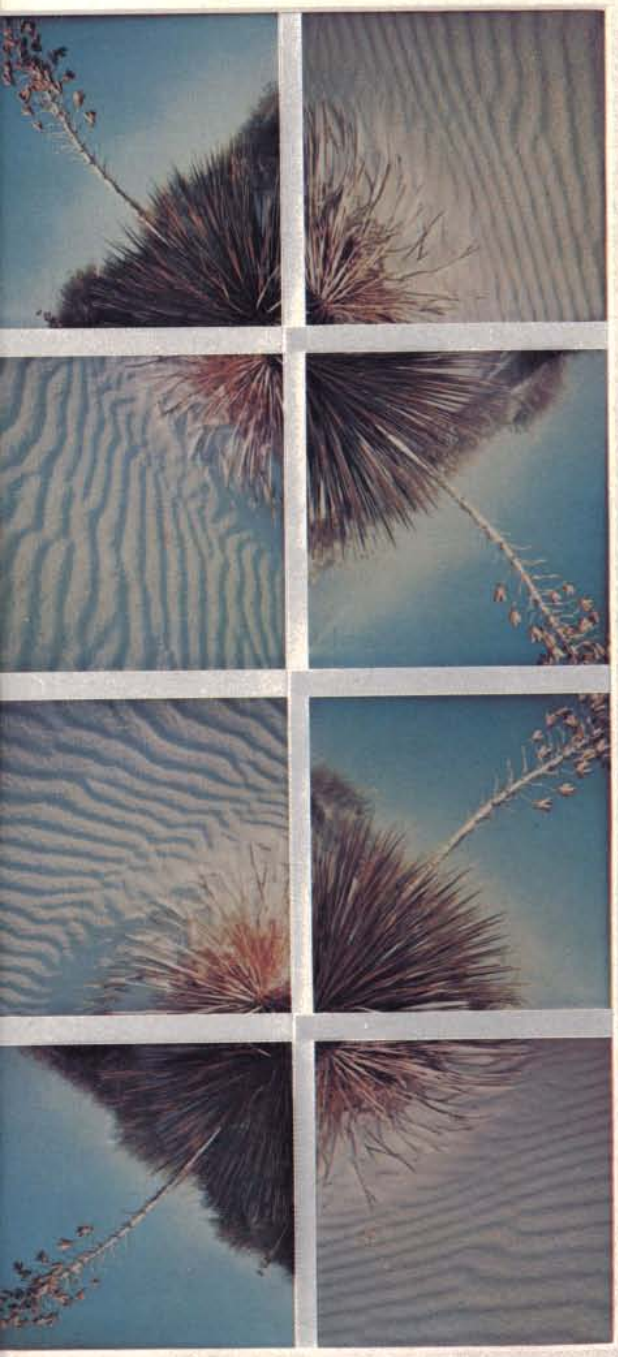


At Sunset, 4:30 and 6:30 p.m., White Sands, New



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that the patients who did not respond to interferon had undergone other therapies, such as radiation and conventional chemotherapy, which tend to suppress the functioning of the body's immune system. It is therefore conceivable that the interferon was failing to potentiate an immune response to the cancer in those patients.

Although these preliminary clinical studies tend to demonstrate the effectiveness of interferon in treating certain human tumors, many more patients will have to be evaluated before a clear verdict can be reached. Caution is particularly in order because clinical studies involving small numbers of patients are often misleading. In the past positive impressions of the efficacy of an anticancer drug have resulted from an inaccurate assessment of the variability of certain cancers.

The most important aspect of the interferon work, according to Merigan, is that it represents a new approach to cancer chemotherapy. Whereas conventional anticancer drugs work by being more toxic to cancer cells than they are to normal cells (and hence often have severe side effects), interferon may work by inhibiting the division of tumor cells or by enhancing the immune response of the host. Since interferon is a natural substance manufactured by the body's own cells, it may prove to be effective longer than other anticancer drugs before serious toxic side effects appear. According to Mathilde Krim, head of the Interferon Laboratory at the Memorial Sloan-Kettering Institute for Cancer Research in New York: "Even in the event that interferons should have only weak effects on tumor growth, their complete lack of toxicity would assure them a high therapeutic index and make them an attractive form of cancer therapy, particularly in combination with other modalities of treatment."

The clinical findings to date have been sufficiently promising to inspire a massive international research effort. The American Cancer Society has committed $2 million to buy human interferon for clinical studies on a range of malignant tumors (including multiple myeloma, breast cancer, melanoma and lymphoma) and expects that the investment will attract an additional $4 million in research funds from hospitals, universities and the private sector. The British Medical Research Council is organizing clinical studies on the effects of interferon on acute myeloid leukemia, skin cancer, myeloma, lung cancer, stomach cancer and lymphoma. Clinical work on hepatoma (liver cancer), osteogenic sarcoma and other tumors is beginning in France, Japan and West Germany. If these trials are carefully done, they should provide statistically valid information on the usefulness of interferon for treating a broad range of cancers.

Before clinical experiments can begin on a large scale, however, enough human interferon must be made to meet the growing demand. Since interferon is secreted by cells in minute amounts and tends to stick to contaminating proteins in cell extracts, early efforts to purify it from cultured human cells were unproductive and frustrating. A critical advance came in the late 1960's when Kari Cantell, a virologist at the State Serum Institute in Helsinki, developed a method for the large-scale production and purification of human interferon from white blood cells. Cantell and his colleagues obtained large amounts of these cells from the 600 to 800 units of blood drawn each day by the Finnish Red Cross Blood Transfusion Service. Although Cantell's laboratory is providing nearly all the material for current clinical studies of human interferon, other research groups around the world are currently seeking to develop alternative sources.

One approach has been to induce the manufacture of interferon in human fibroblasts (precursor connective-tissue cells) or epithelial cells grown in large numbers in tissue culture. Unfortunately the interferon secreted by these cells is chemically distinct from that secreted by lymphocytes and appears to have a somewhat inferior biological activity. Even worse, it tends to stick to proteins at the site of injection and so does not enter the circulating blood in large amounts.

A more promising source is human lymphoblastoid cells (immature cells of the lymphatic system), which can be cultured in continuous cell lines for long periods and make an interferon similar to that of lymphocytes. To induce these cells to secrete interferon, however, they must be treated with the Epstein-Barr virus, which has been associated with a human tumor (Burkitt's lymphoma). The induced interferon must therefore be highly purified so that patients are not exposed to potentially dangerous material from the Epstein-Barr virus. The Burroughs Wellcome group in London has apparently solved this problem and is currently purifying human interferon from lymphoblastoid cells on a large scale. These workers have devised a 1,000-liter fermenter production facility with an on-line purification system that removes virtually all viral nucleic acids and contaminating protein from the final interferon product. Because of the high degree of purity obtained, human interferon derived from lymphoblastoid cell lines will be subjected to clinical trials in England this year.

An entirely different approach would be to synthesize interferon chemically, a possibility that is being investigated by Christian B. Anfinsen and his colleagues at the National Institute of Arthritis, Metabolism, and Digestive Diseases. The task would be formidable but not impossible; interferon is a relatively

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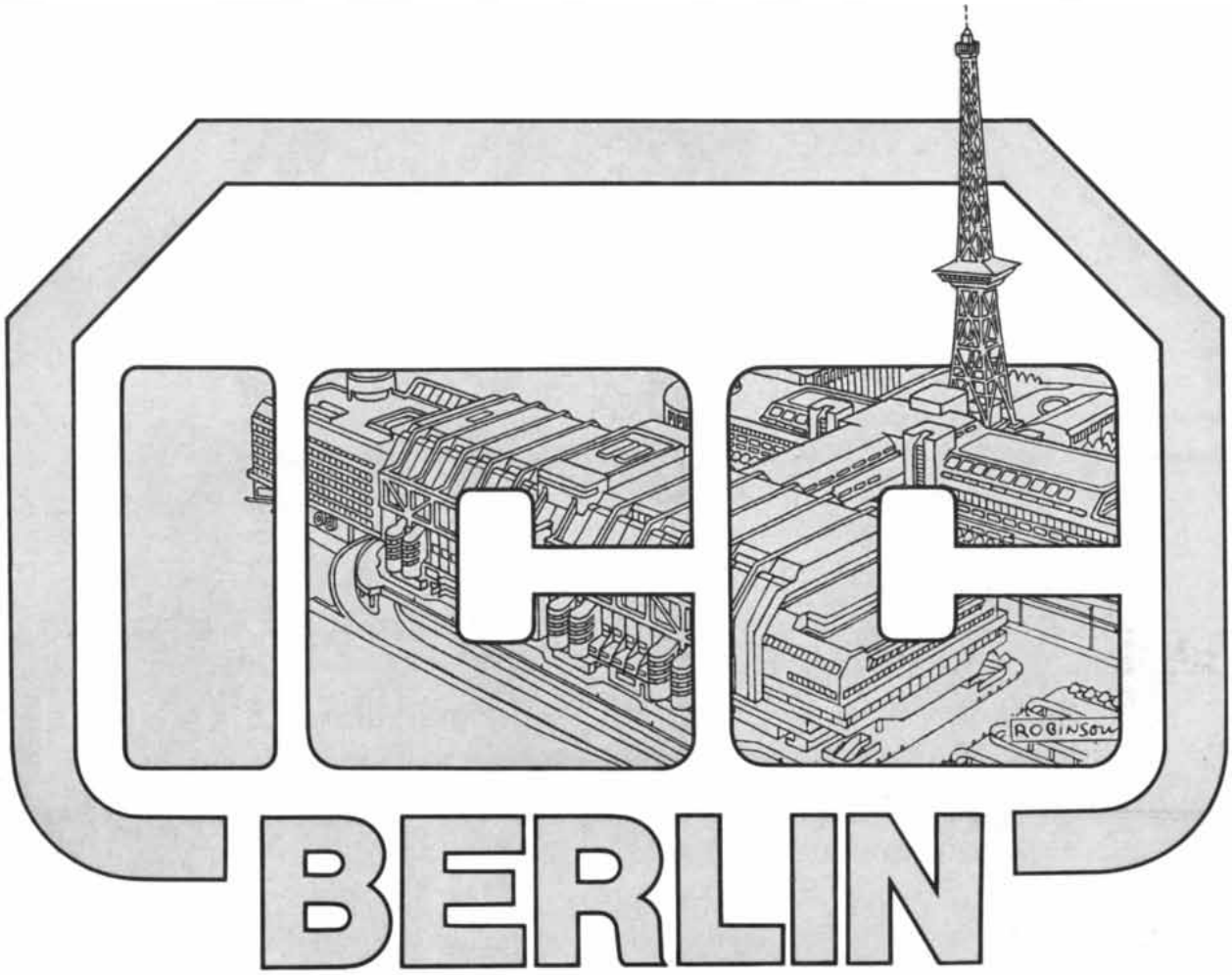

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small protein with a molecular weight of between 20,000 and 30,000 daltons. The first challenge is to determine the sequence of amino acid units of human lymphocyte interferon.

Other laboratories, among them Charles Weissmann's group at the University of Zurich and Sidney Udenfriend's group at the Roche Institute of Molecular Biology in Nutley, N.J., are attempting to apply recombinant-DNA techniques to the interferon supply problem. One approach would be to introduce the human genetic material incorporating the interferon gene into a bacterium such as *Escherichia coli* and then select out the bacterial clone that contains the interferon gene and induce the bacterium to secrete the protein. The problem with this "shotgun" approach would be to find out which bacterial clone harbored only the interferon gene. Once the amino acid sequence of human interferon is known, however, it might be possible to synthesize the DNA that codes for this sequence. The synthetic DNA could then be spliced into a ring of extrachromosomal DNA carried by *E. coli* and the bacterium induced to manufacture and secrete human interferon. Although formidable technical hurdles remain to be overcome before such a production method becomes practicable, a number of research groups are currently attempting to produce human insulin and other useful proteins in bacteria, and the recombinant-DNA technology being perfected in these related investigations should be applicable to the manufacture of interferon.

Small Talk

A new wave of microprocessors is now arriving; it is at least the fourth wave since the central processing unit of a computer was first built into a single "chip" of silicon some eight years ago. The new processors are made up of smaller circuit elements packed more densely on larger chips, and so by the crudest measure—total number of circuit elements—they are more powerful than their predecessors. It would have been a surprise if they were not. What is more interesting is how these added capabilities are being exploited. A major share of the machines' resources have been dedicated to improving their literacy in higher-level computer languages, which constitute the almost universal medium of communication for large computers.

In principle even the most rudimentary computer, such as the simple tape-marking mechanism imagined 40 years ago by A. M. Turing, can execute the most complicated procedures. Writing the necessary programs, however, can be so difficult with such a machine as to be impractical. A hierarchy of languages has been devised as an aid to program writing. The computer itself

recognizes only the patterns of bits, or binary digits, called machine language. Simple languages called assemblers replace the binary notation with symbols that are more concise and more easily remembered. In higher-level languages entire routines consisting of tens or even hundreds of machine instructions are represented by a single statement. What is more, the language relieves the programmer of such chores as keeping track of where information is stored in the computer's memory.

A higher-level language is itself a program or a set of programs, which must be adapted to operate on a particular machine. The characteristics of the machine determine the ease with which the language can be constructed and how well it will perform. Among the characteristics considered to be most important for a higher-level-language computer are regularity in the organization of the processor and in its set of instructions and the ability to generate position-independent programs. (A program is position-independent if it can be placed anywhere in the computer's memory without change.) The design of the most recent microprocessors clearly reflects these objectives.

The microprocessors of the preceding generation are almost all eight-bit machines: they can handle data only in segments of eight bits, or one byte. The total volume of information they can address conveniently is some 65,000 bytes. When a program makes reference to some location in this memory-address space, it must sometimes specify directly the actual, or absolute, address. One other distinguishing feature of these machines has to do with their architecture, or basic organization: almost all arithmetic and logical operations are required to take place in a single register, called the accumulator.

Three recently announced microprocessors serve to represent the new generation. They are the Intel 8086, made by the Intel Corporation, the Z8000, made by Zilog Inc., and the MC68000, made by Motorola Semiconductor Products, Inc. The Intel processor is on the market now; the other two should be available later this year. Although the three processors differ in many details, they can be considered as a group for comparison with the older technology.

Where the older machines invariably operate on one byte at a time, the new ones handle data in a variety of forms. Single bytes are still accommodated, but a 16-bit "word" is the standard width of most data paths in the processor, and a 32-bit word can be addressed in a single operation. Individual bits can also be manipulated, and calculations can be carried out with binary representations of decimal numbers.

The volume of accessible memory is also greatly enlarged in the new processors. The address space extends to

roughly a million bytes (one megabyte) in the Intel 8086, to one megabyte or eight megabytes in the Z8000 and to 16 megabytes in the MC68000.

The architecture of the new processing units has been made more regular and at the same time more versatile. Instead of a single accumulator the machines have several equivalent registers. The Z8000, for example, has 16 general-purpose registers, each register 16 bits wide. Each can serve as an accumulator for arithmetic and logical operations, but it also can hold a constant or can point to an address in memory. An instruction that can be executed in one register can generally be executed in any of them.

The methods provided for specifying addresses are explicitly devised for position-independent programs. Absolute addresses must be avoided in such programs because they bind the program to a fixed position in the computer memory. One alternative is relative addressing, in which memory cells are counted off from the present position of the program in the address space. In another method, called indirect addressing, the address given in a program specifies not the actual location of the desired data but a register or a memory cell where the address will be found. The instruction sets of the new processors make it convenient to calculate addresses in either of these modes or in various combinations of them. Multiple registers and indirect addressing also provide efficient means for passing constants or results from one program to another when both programs are position-independent.

Certain other features of the new processors are reminiscent of techniques employed in the largest computers. For example, in order to speed operations all three devices fetch instructions from memory before they are needed. While one instruction is being decoded the next few instructions are placed in a queue, where they will be ready for immediate execution. The Z8000 and MC68000 also have two operating modes, which Motorola designates "supervisor" and "user." A similar partitioning is essential in large computer systems to prevent multiple programs from interfering with one another.

Precisely because a computer is a machine of limitless versatility, it is difficult to find a quantitative measure of performance. A figure of merit recently suggested in the magazine *Electronics* is derived by multiplying the number of instructions by the number of data types and the number of addressing modes and dividing the product by the average time required for the processor to execute an instruction. This standard was employed to compare the Z8000 with the first eight-bit microprocessor, the Intel 8008, introduced in 1972. The performance of the Z8000 is better by a factor of more than 100.

Physician, did you miss any of these significant developments in medical science?

• The lidocaine level in the blood may fall below the therapeutic range when the drug is given as a single bolus followed by a continuous infusion. To avoid a "therapeutic hiatus," a second bolus should be given 20 to 30 minutes after the first bolus...

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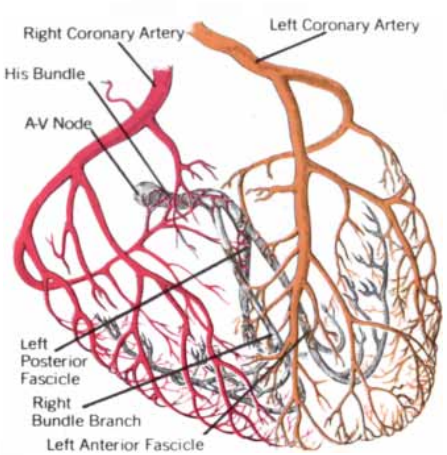

Branches of the right and left coronary arteries supply blood to the AV node and intraventricular conduction system.

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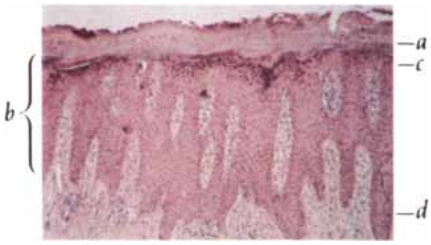
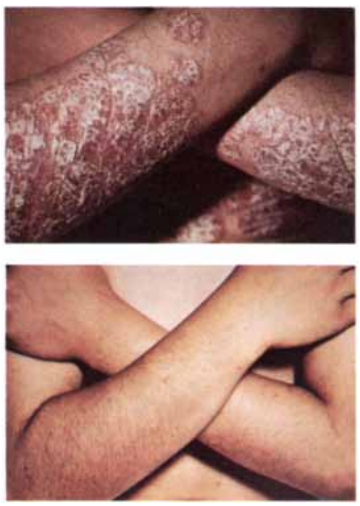


Histopathologic changes in psoriasis.



Extensive psoriasis (top) cleared completely (bottom) after four weeks of treatment with anthralin.

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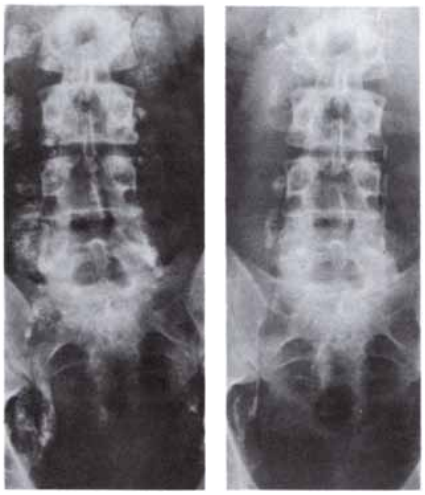
E. William Hancock, M.D., F.A.C.P., Professor of Medicine, Stanford University School of Medicine

Roman W. DeSanctis, M.D., Professor of Medicine, Harvard Medical School, and Physician and Director, Coronary Care Unit, Massachusetts General Hospital

Adolph M. Hutter, Jr., M.D., F.A.C.P., Associate Professor of Medicine, Harvard Medical School, and Assistant Physician and Associate Director, Coronary Care Unit, Massachusetts General Hospital

Eve Elizabeth Slater, M.D., Instructor in



Extensive retroperitoneal Hodgkin's disease before and after MOPP chemotherapy.

Medicine, Harvard Medical School, and Chief, Hypertension Unit, Massachusetts General Hospital

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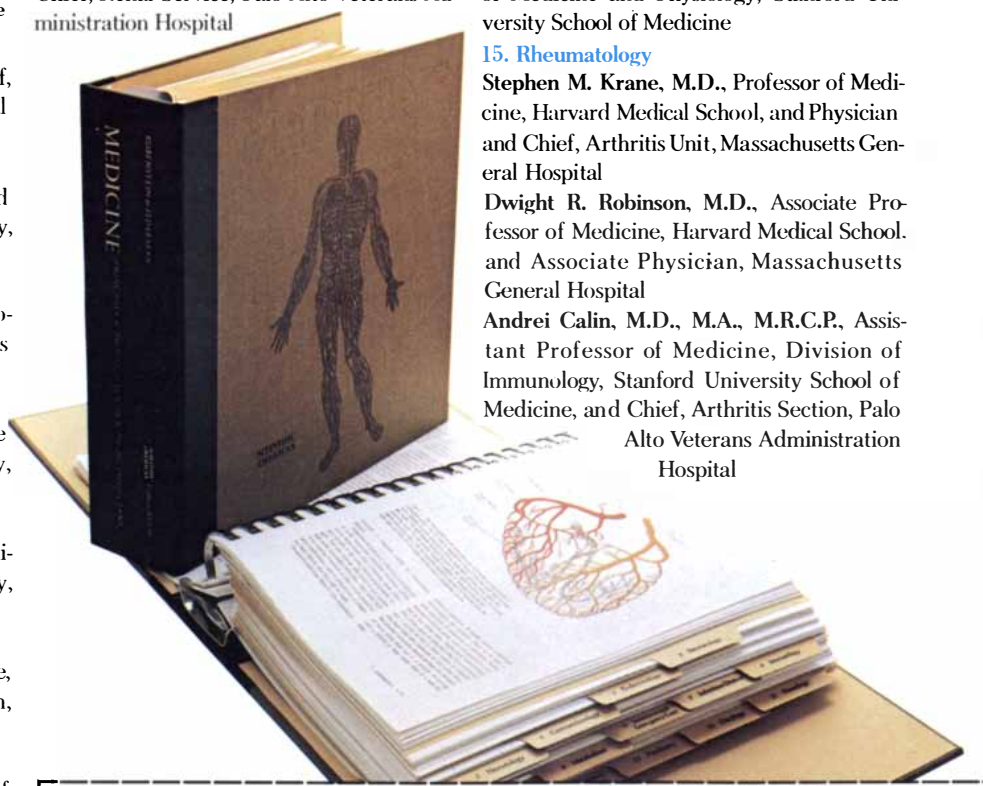

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It has myriad uses principally because it consists of fine particles, which result from the nature of clay minerals. These minerals are created and destroyed and created again in a long geological cycle

by Georges Millot

The crust of the earth is rock, but much of it is covered by the small particles that result from the breakdown of rock. These particles, which together with organic matter make up soil, are broadly classified by particle size as sand, silt or clay. All are abundant and widely distributed; any given sample of soil is likely to contain a mixture of sand, silt and clay. The finest particles are those of clay, and the size of the clay particles is established by the properties of clay minerals. These properties therefore underlie the unique role played by clay both in geological processes and in human affairs.

To the earth scientist clays are not only particles and aggregates of particles but also rocks consisting of clay minerals. Clay minerals are silicate crystals that are so fine-grained they are best described as microcrystals. They nonetheless have the perfect or nearly perfect structure of other crystals.

In most rocks one can plainly see the constituent mineral crystals. A piece of granite, for example, reveals to the eye crystals of quartz, feldspar and mica. The crystals of clay minerals, however, are so minute (many of them less than two micrometers across) that they cannot be resolved with the unaided eye or even with a hand lens. Not until the techniques of X-ray diffraction, differential thermal analysis and electron microscopy became available did it become possible to extract, identify and study the clay minerals.

As a result of the application of these techniques it is now possible and useful to technically distinguish clay minerals from clays. The former are the characteristic minerals of clays, the latter the rocks in which the clay minerals are mixed in various proportions (and perhaps mixed also with sand, calcium carbonate and iron oxides) to yield the great diversity of clays in nature. Thus the term clay is applied in four different senses, referring to particle size, to minerals, to rocks and, in the commonest usage of all, to a plastic material.

The Clay Minerals

In a clay mineral the elements oxygen, silicon, aluminum, iron, magnesium and potassium (in an ionic state, that is, having at least one more or one less electron than the un-ionized atom and therefore having an electric charge) are spheres arranged in a regular three-dimensional pattern. The spheres are the building blocks of the clay minerals, and the arrangement of the building blocks determines the type of mineral. Each type of "building" constitutes a clay-mineral group, of which seven are generally recognized. One should bear in mind that in every basic group a typical element can to some extent be replaced by another element. For example, aluminum might replace silicon, or magnesium might replace aluminum. This kind of replacement gives rise to the clay-mineral species, of which about 50 are recognized. Six of the seven clay-mineral groups are composed of layered silicates (more precisely phyllosilicates, from the Greek *phyllon,* leaf); in the seventh group the minerals take the form of laths.

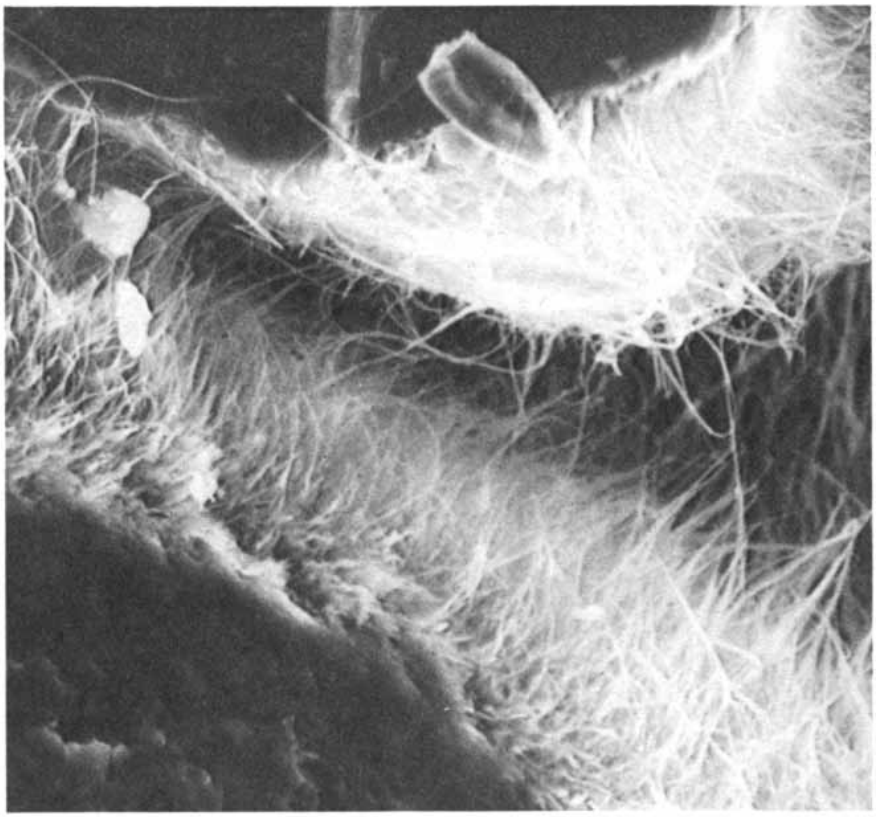
The kaolin group, which yields the white clays that are useful in (among many other things) making chinaware and giving whiteness and body to paper, is named for a hill in China where white clay was extracted for centuries. The principal species in the group is kaolinite, which is one of the layered silicates. Electron micrographs of kaolinite often show well-formed hexagonal flakes, each flake made up of layers. X-ray diffraction reveals that the spacing between consecutive layers is seven angstrom units (an angstrom being a ten-millionth of a millimeter). The chemical formula of kaolinite is $2SiO_2$,-Al_2O_3,$2H_2O$. Kaolinite is thus exclusively silicoaluminous.

In the kaolin group about 10 species can be distinguished. The most familiar species after kaolinite is halloysite. Its layers are separated from one another by sheets of bound water, and the flakes are so thin that they frequently roll up and look like tubes. The other species are distinguished by the partial replacement of aluminum by iron, magnesium, nickel or manganese.

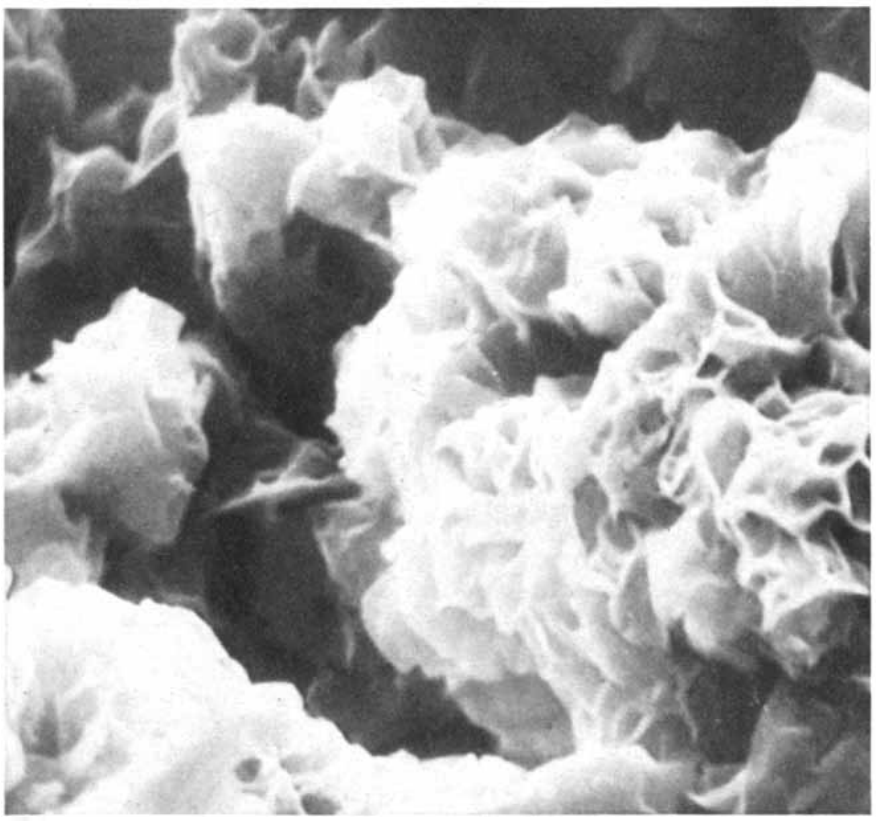
The illite group is named for the state of Illinois. Among clay minerals in their natural state the illite minerals are the commonest. They have the structure of microscopic micas composed of flakes that show irregular outlines under the electron microscope. The spacing between consecutive layers is 10 angstroms. The layers are bound to each other by potassium atoms. The chemical formula of illite is close to that of white mica, but with more water and less potassium. The best-known allied species is glauconite, in which aluminum is replaced by iron. This green mineral is typically found in clays of marine origin.

The third group was until recently called montmorillonite after the town of Montmorillon in France, but it is now also known as smectite, a word descriptive of a layered structure. Its microcrystals are extremely fine-grained, thin-layered and lacking in regular outlines. The layers are not tightly bound one to another and so water, numerous elements and organic matter can enter the spaces between layers. The distance between layers can therefore vary from 10 to 17.5 angstroms. This characteristic gives the smectites properties of absorption and adsorption that are much esteemed for industrial purposes. The most familiar smectite species is montmorillonite. Allied species are beidellite, in which silicon is partially replaced by aluminum, nontronite (aluminum partially replaced by iron), saponite and

CLAY MINERAL appears in the scanning electron micrograph on the opposite page. The mineral is dickite, a variety of kaolin, which exhibits well-formed hexagonal "books," or flakes, each one made up of leaflike layers. The specimen is shown at an enlargement of 15,000 diameters. The micrograph was made by W. D. Keller of the University of Missouri at Columbia.



ILLITE LATHS, enlarged 1,500 diameters in this scanning electron micrograph, were formed in the pores of a sandstone in Mississippi. Illite is one of the commonest clay minerals, although it is likelier to appear as flakes than as the whiskerlike laths shown here. This micrograph and photographs on the opposite page were furnished by Necip Güven of Texas Tech University.



SMECTITE GROUP of clay minerals, formerly called the montmorillonite group, has extremely fine-grained, irregular and thin-layered crystals. In this scanning electron micrograph provided by Wayne F. Hower of Halliburton Services the enlargement is 15,000 diameters.

stevensite (aluminum partially replaced by magnesium).

Next is the chlorite group, which gets its name from the Greek *chloros,* a pale or light yellow green. The group includes a large variety of species, each one created by the replacement of one element by another in the crystal structure. The layers are closely bound by ions of hydrated magnesium, aluminum or iron; the distance between consecutive layers is 14 angstroms.

The term vermiculite, which is the name of the fifth group, originates in the tendency of these clay minerals when they are heated to take on the appearance of small worms. (*Vermiculus* is the Latin for little worm.) In clay vermiculites the distance between consecutive layers is 14 angstroms, but water between layers can be removed by heating, so that the distance collapses to 10 angstroms.

The mixed-layer clay mineral group consists of a considerable variety of forms that are intermediates of the five groups I have described so far. With X-ray diffraction one can determine whether the spacing between layers in a given specimen alternates regularly or is irregular, in rather unstable states of equilibrium, which are stages in the evolution from one mineral to another.

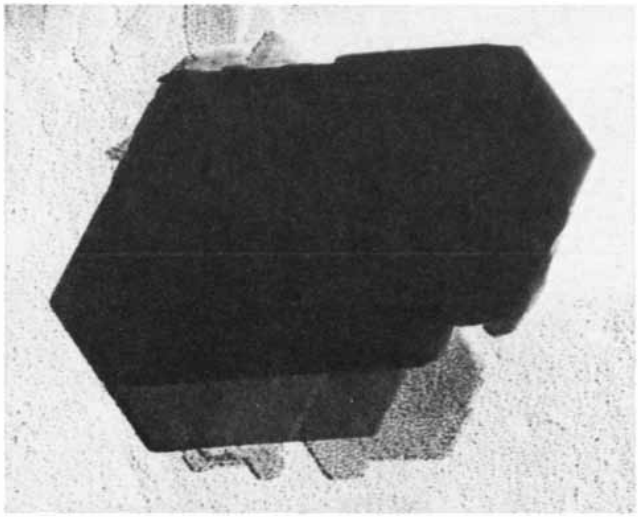
The lath-form group has a double name: the sepiolite and attapulgite group. Sepiolite is an ancient name of Greek origin and in some places is a synonym for meerschaum; clays of this group are employed to make meerschaum pipes. The name attapulgite comes from Attapulgus in the state of Georgia, where clays of this type are found. The clay minerals of the group contain relatively large amounts of magnesium.

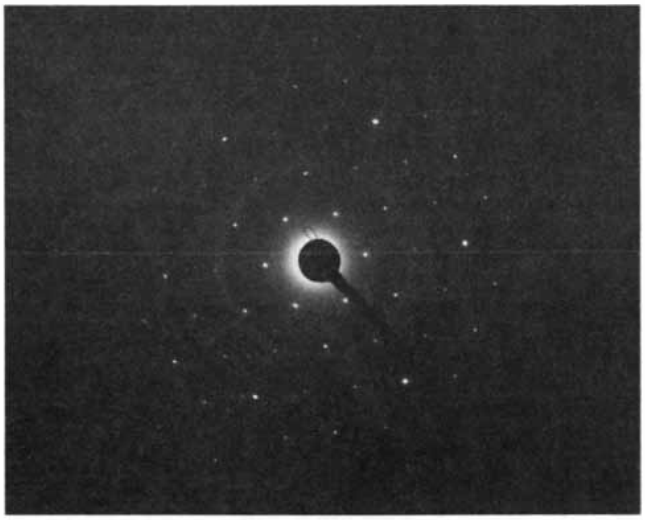
The Geological Cycle

The seven groups include about 15 minerals that are quite common. Clay minerals do not occur in the rocks of the deep part of the earth's crust, but they are abundant at the surface. The answer to this contrast lies in the cycling of matter through a series of geological processes.

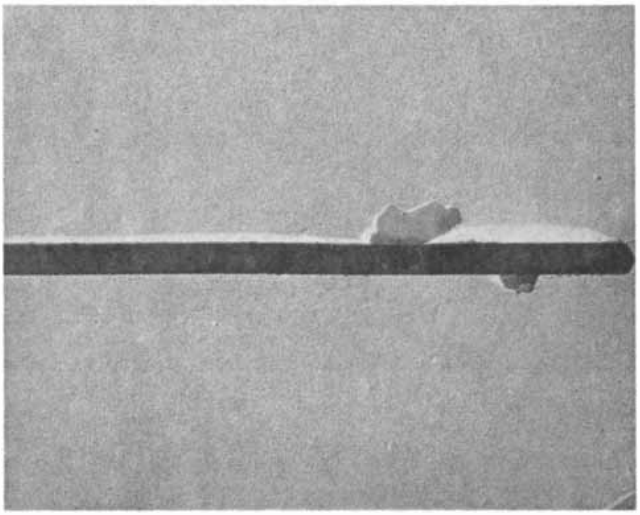
The cycle proceeds in five stages. Rocks deep in the crust are brought to the surface by volcanic action and the folding and faulting processes that build mountain chains. At the surface the rocks undergo weathering and erosion. The products are transported (mainly by water) over long distances and eventually are deposited in sedimentary basins. The sediments are slowly buried and transformed into rocks in the process termed diagenesis. These sedimentary rocks undergo metamorphism and granitization, which transform them ultimately into gneiss and granite.

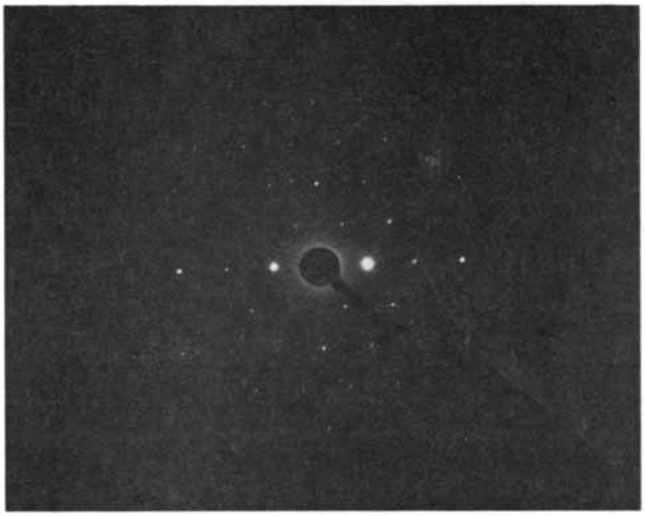
Clay minerals appear only in the three middle stages. Indeed, the principal gen-



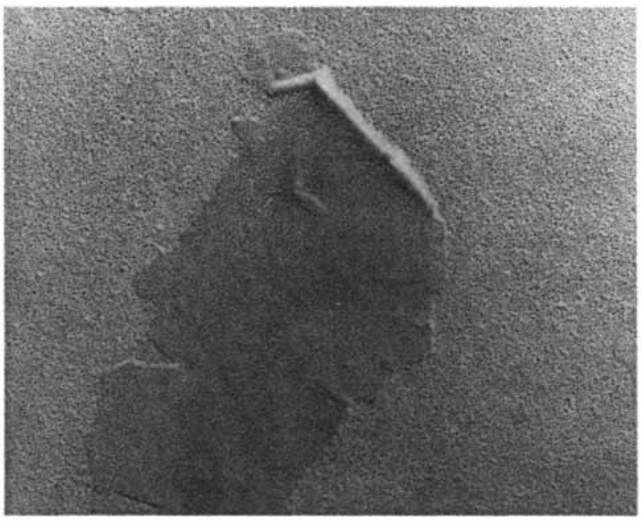


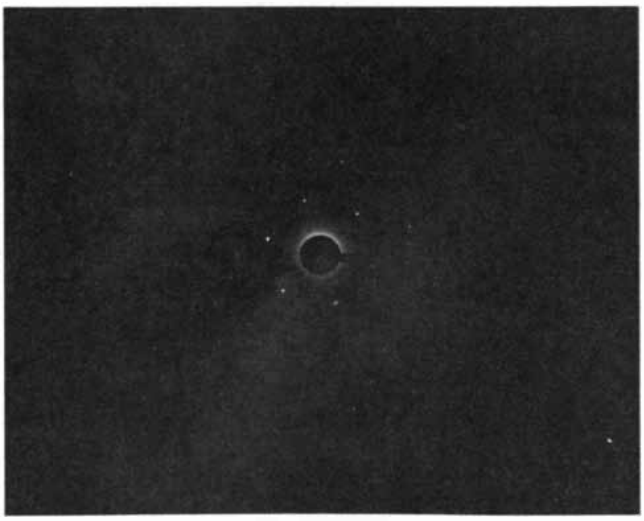
KAOLINITE CRYSTAL is enlarged 64,000 diameters in a transmission electron micrograph (*left*); its selected-area electron-diffraction pattern is at the right. Bright spots in the diffraction pattern resulted when the atoms of the crystal scattered the electrons in a beam; they show the regular arrangement of the atoms in the crystal structure. Beam stop, a part of the apparatus, made the spot at the center.





ILLITE LATH is shown in a transmission electron micrograph, enlarged 15,000 diameters, and in a selected-area electron-diffraction pattern. Hexagonal symmetry of the bright spots in the pattern reflects hexagonal arrangement of the atoms in the crystal structure.





FLAKE OF MONTMORILLONITE, a member of the smectite group, appears at an enlargement of 60,000 diameters in the transmission electron micrograph at the left; its crystal structure is indicated in the photograph of its selected-area electron-diffraction pattern.

esis of clay minerals is in the weathering processes that give rise to soil, that is, in the second of the five stages. In the sedimentation stage the clay minerals may be mildly transformed in various ways, and there may be some genesis. In the stage of burying and diagenesis the clay minerals progressively recrystallize and so disappear as such. For example, illite takes on potassium and turns back into mica.

Weathering includes two principal processes: fragmentation and hydrolysis. Fragmentation is the disintegration of primary rocks and minerals through such mechanisms as alternate wetting and drying, freezing and thawing and salt crystallization. Hydrolysis entails a slow reaction of primary minerals with water to form new minerals. It is hastened and also to a large extent controlled by organic matter originating in vegetation. As one might suppose, the activity of hydrolysis increases as rainfall and temperature increase.

The weathering of rocks varies considerably according to the climate of the area. In cold, mountainous regions hydrolysis is minimal. Water tends not to circulate because of freezing, and vegetation is either sparse or absent. Fragmentation is the dominant process, with the result that the only clay minerals formed are composed of disintegrated and slightly decomposed primary micas and chlorites.

Hydrolysis also operates minimally in deserts. The temperature is high but water is scarce. As a result the amount of chemical weathering is minor.

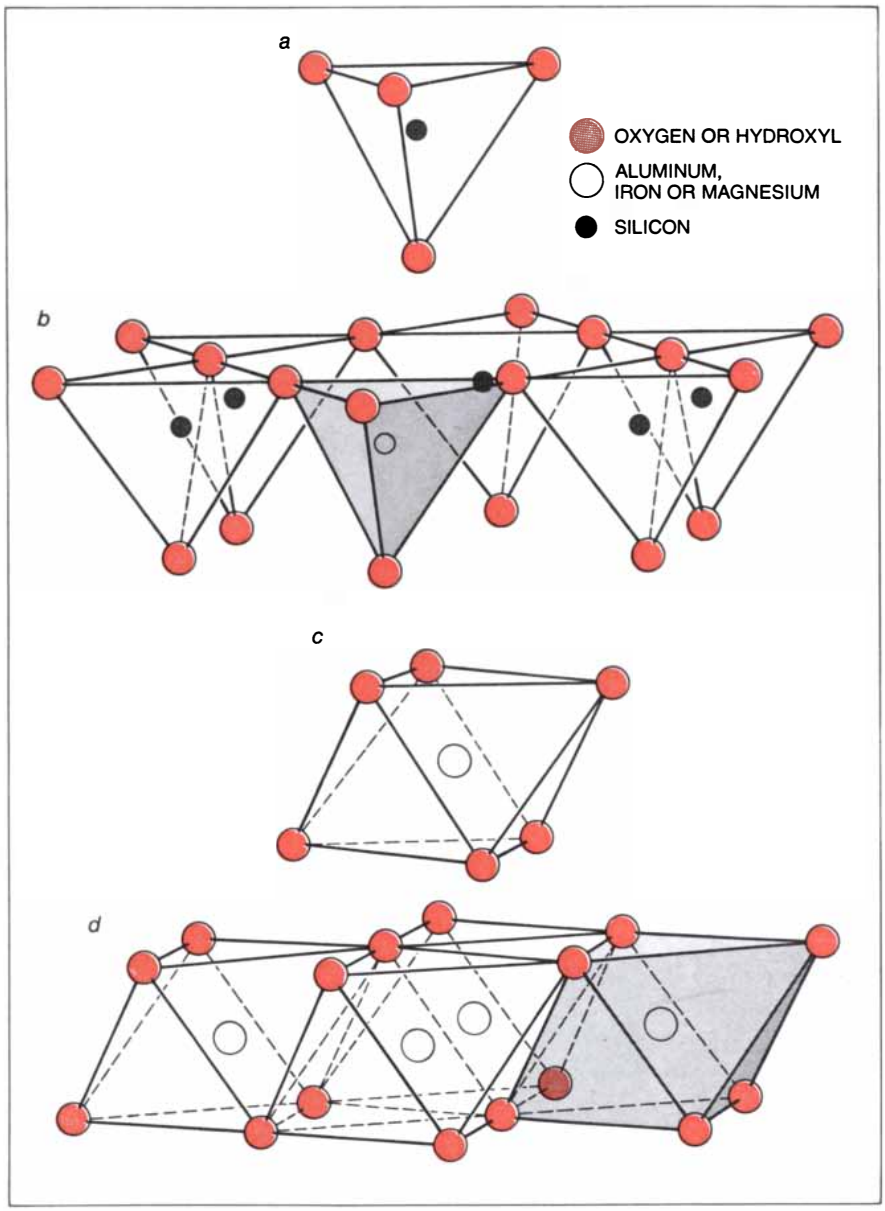
In temperate regions both fragmentation and hydrolysis are at work. The chief weathered minerals are primary micas and chlorites, which give rise to such clay minerals as illites and chlorites. With continued weathering the most soluble ions are removed, and the original minerals give way to increasingly degraded structures such as vermiculites and mixed layers.

Hydrolysis is at its peak in tropical regions with alternating wet and dry seasons. Elements are released from minerals and then combine again, giving rise principally to two clay minerals: montmorillonite and kaolinite. Montmorillonite develops particularly well in the weathered products of rocks such as basalt and in places that have long dry seasons or poor drainage, so that the weathered products become richer in silica, alkali and alkaline-earth metals. Kaolinite is formed best in the weathered products of rocks such as granite and in places that have high rainfall and good drainage, which tend to remove silica and alkali, leaving weathered minerals that are relatively rich in aluminum.

In equatorial and humid tropical places the annual rainfall exceeds two meters and can amount to as much as 10 meters. Hydrolysis is predominant because of the high rainfall and temperature and the heavy leaching. If the area is well drained, silica and soluble cations (positively charged ions) are removed from the rock, leaving the weathered products relatively enriched in alumina and thereby favoring the formation of kaolinite. If the drainage is still better or the process goes on longer, even more silica is removed and alumina remains, resulting in the aluminous mineral gibbsite.

To put it another way, the genesis of clay minerals can be viewed as a gigantic process of subtraction. Rain leaches and dissolves rocks and carries away the elements in the order of their solubility: sodium, potassium, calcium, magnesium, iron, silicon and aluminum. The remaining elements combine into clay minerals. A moderate leaching yields the mixed layers and the vermiculite of the Atlantic countries. A stronger leaching, which still leaves in place some of the silicon, iron and magnesium, gives rise to the smectites of Mediterranean and semihumid tropical countries. A very strong leaching leads to kaolinite and ultimately to gibbsite.

The earth's surface is hence a huge factory that manufactures clay minerals. The minerals differ, however, according to the climatic zones. Kaolin



ATOMIC STRUCTURE of most clay minerals consists of tetrahedrons of silica and octahedrons of alumina. A silica tetrahedron (*a*) has one silicon atom equidistant from four oxygens or hydroxyls (OH). The tetrahedrons are arranged in a sheetlike hexagonal network (*b*) by the sharing of oxygen atoms at the basal corners of the tetrahedrons. (This hexagonal arrangement is reflected in the symmetry of the bright spots in the electron-diffraction patterns.) In the octahedral unit (*c*) an atom of aluminum, iron or magnesium is equidistant from six oxygens or hydroxyls. The units form sheetlike layers (*d*) by the sharing of oxygens between adjacent octahedrons. The two-dimensional repetition of the tetrahedral and octahedral units and the stacking of these sheets in several combinations give rise to the flakelike form of most clay minerals.

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TECHNICAL DATA

Type TTL metering 110 SLR camera, bayonet mount (80-degree setting angle).
Film Cartridge 110 film format; ASA set automatically for film in use.
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Viewfinder Eye-level pentaprism finder with instant-return mirror; green or yellow LEDs indicates correct handheld exposure, or need for flash/tripod.
Exposure Metering Center-weighted, TTL metering at full aperture via SPD cell; EV Range: 3-17 (24mm F 2.8 lens; ASA 100).
Shutter/Automatic Diaphragm Programmed electronic shutter with programmed body diaphragm; Range: F 2.8 to f/13.5.
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minerals tend to appear in a belt along the Equator, smectites in Mediterranean and tropical zones with contrasting seasons, mixed-layer clay minerals and vermiculites in temperate zones and illites and chlorites in cold regions. The zones have sinuous boundaries according to the effects of oceans, regional climate, topographical relief and the composition of the parent rocks, but the concept of clay-mineral zones based on climate is valid nonetheless.

Effects of Sedimentation

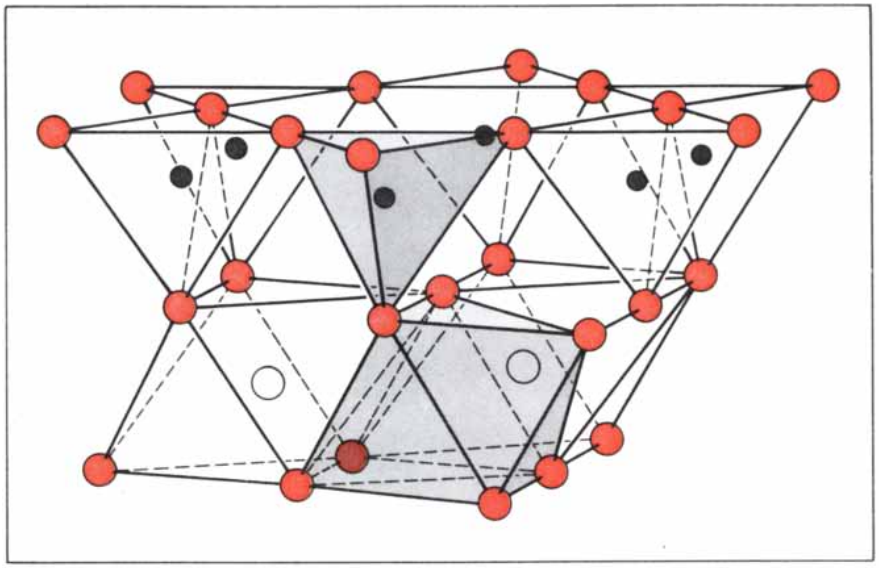
Erosion attacks soils and the products of weathering. Every year streams and rivers carry billions of tons of material, including clay minerals, from the continents. The materials settle in sedimentary basins, mainly in the oceans but also to a considerable extent in lakes.

All the measurements of what happens to clay minerals in the process of transport and sedimentation indicate that they are carried to the sedimentary basins without being changed and that they settle there in the same state. This process might be called inheritance, since the characteristics of the deposited clay minerals are inherited from the nearby continent.

Oceanic sediments demonstrate this inheritance. The clay minerals provide an image of the weathering that produced them: chlorites and illites in the colder oceans; mixed-layer clay minerals, vermiculites and degraded chlorites and illites in the oceans near Temperate Zone continents; kaolinites near tropical zones and the Equator. The zones of smectite are less distinct except where volcanic eruptions provide ash, which is commonly transformed to smectite in marine environments. Clay mineralogy applied to ancient sedimentary rocks provides a means of reconstituting their origin and sometimes of ascertaining the type of climate that prevailed at the time they were formed.

Although sedimentary clay minerals are dominated by inherited characteristics, other processes can affect them. Conditions in the sedimentary environment can transform clay minerals as follows. On the nearby continent clay minerals were degraded by the subtraction of ionic potassium, magnesium, iron and silicon. These ions were leached out and carried in solution to the sedimentary basins. When degraded clay minerals enter a region where ions are strongly concentrated, they tend to reacquire ions of the kind they lost through leaching. The process is sometimes called fixation. Hence the original minerals tend to be reconstituted. Sometimes the process is followed by crystal growth.

This kind of reconstitution can be seen as a counterpart of degradation. It is a process of addition, whereas degradation is a process of subtraction. The first evidence of reconstitution was obtained from certain estuaries and salt marshes, but the most notable examples are found in European and African rocks of the Triassic period, which were formed some 200 million years ago. Degraded clay minerals were rebuilt into splendid magnesium chlorites through the fixation of magnesium. Similarly, in Cretaceous rocks, formed perhaps 100 million years ago, degraded clay minerals or iron smectites became glauconites (members of the chlorite group) through the fixation of potassium.



LAYER OF KAOLINITE is made up of a tetrahedral sheet and an octahedral one. They are combined in a unit in which the tips of the silica tetrahedrons and one of the two sheets of the octahedral grouping form a common plane by means of shared oxygens. Spacing between the top of one layer of tetrahedrons and octahedrons and top of the next is seven angstrom units.

In the process of reconstitution major elements and also minor ones are fixed in degraded clay minerals. For example, boron is fixed and incorporated in the crystal lattice, particularly when the environment is rich in salts. The analysis of these clay minerals therefore provides an indicator of the salinity of the environment in which they originated.

A third (but rare) mechanism that generates clay minerals in sediments is neoformation. It entails the synthesis of new clay minerals in sedimentary basins from ions of silicon, aluminum, iron, magnesium and potassium in natural solutions. The process goes on in sedimentary basins where ions are concentrated by evaporation. A good example is the alkaline chemical sedimentation that deposits limestones, cherts, phosphates and magnesium-based clay minerals, including attapulgites, sepiolites and stevensites. Here sedimentation is adding new clay minerals to the inherited ones.

Diagenesis and Metamorphism

After sediments settle to the bottom of the sedimentary basin they are buried, accumulating progressively but slowly to thicknesses of as much as 4,000 meters. As this accumulation continues, the temperature and the pressure increase, water is expelled from sediments and sedimentary muds become sedimentary rocks: calcareous muds become limestones, sands become sandstones, and so on. This is the phenomenon called diagenesis.

By diagenesis clayey muds become mudstones and then shales. With further heating and compaction the process becomes metamorphism, in which shales become slates, phyllites and finally schists. In the course of the initial diagenesis during burial the clay minerals are affected in various ways. Many of them, such as kaolinite, vermiculite, montmorillonite and the mixed-layer species, begin to disappear. In contrast the relative amounts of illite and chlorite progressively increase. As metamorphism continues to alter clays beyond diagenesis, the resulting schists are composed of sericite and chlorite. The minerals have almost reached the mica stage.

Continued metamorphism transforms schists into micaschists and gneiss. The clay minerals recrystallize into micas and feldspars and other primary minerals. At the end of the cycle no original clay minerals remain, although the precursors of clay minerals are in the rocks and will participate in a new cycle if the rocks are thrust up to the surface and exposed to weathering.

In terms of what happens to the clay minerals the geological cycle is a geochemical one. Clay minerals are the silicates typical of the surface of the earth's crust, whereas the rocks of the depths (granitic and gneissic) and some rocks formed at the surface (basaltic) have no clay minerals. Weathering at the surface induces degradation and hydrolysis of rocks, creating the clay minerals. This

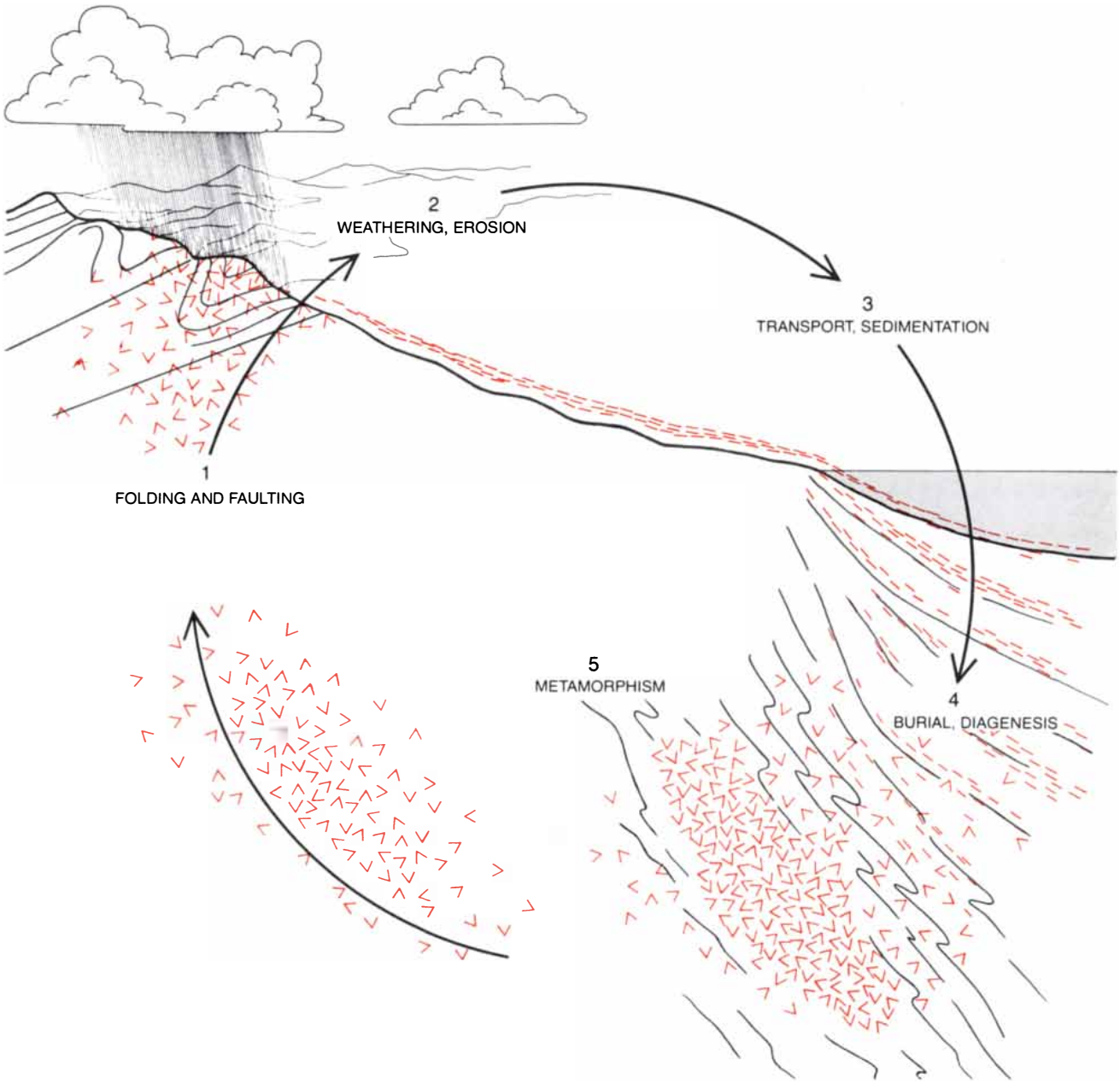
is the zone of the clay minerals' birth. Sedimentation receives the clay minerals largely by inheritance and shapes them to a small degree by reconstitution or forms new ones. This is the zone of the initiation of the clay minerals' evolution. Diagenesis acts on the clay minerals of sediments during their burial. Because of increasing temperature at depth the clay minerals recrystallize into other silicates and disappear. This is the zone of the clay minerals' continued evolution and ultimate death.

In short, the system is cyclical. When primary silicates are brought to the surface, they are hydrolyzed to yield clay minerals. When the clay minerals are carried to sedimentary basins and buried at great depths, they (the silicates of the surface) recrystallize and regenerate the primary silicates.

No material extracted from the earth is put to a wider variety of uses than clay, and no material except flint has been used longer. For 10,000 years people have found applications for clay, and new uses appear every year. Indeed, clay can be described as one of the world's principal ores.

The most numerous applications are in ceramics. The value of clay in this respect arises from its plasticity and the fact that it becomes hard when it is fired. Hence it can be shaped easily, and then after firing the shape is permanent and the object has become both mechanically and thermally resistant.

At first ceramic objects were made of illite-rich earths, because the tempera-



GEOLOGICAL CYCLE in which clay minerals are formed and then obliterated is portrayed. It begins (*1*) when rocks from the deep part of the earth's crust are thrust up to the surface by tectonic processes such as folding and faulting. At the surface the rocks are broken down mechanically and chemically by weathering (*2*), and many minerals are changed (by the removal of ions in the order of their solubility) into the typical clay minerals, which are represented by flat colored shapes. The products of weathering are eroded and then transported, mainly by water, to sedimentary basins (*3*). There they are gradually buried. The increasing pressure and temperature at depth slowly turn the sediments into rocks. The clay minerals are modified in the process termed diagenesis (*4*). The transformed minerals are represented by *V* symbols. Diagenesis grades into the more intense process called metamorphism (*5*), in which the sedimentary rocks are changed into schists and gneisses. Final stage is granitization, in which the rock and its minerals completely melt and from which the primary minerals crystallize. Clay minerals are gone, having been transformed back into primary minerals that are ready to participate in a new cycle.

tures required for firing were low. In time (sooner in the Orient than elsewhere) people learned how to find more refractory earths to build furnaces, so that the firing temperatures could be increased. The result was stoneware, which is made by firing clay at a temperature high enough to make the object partly melt and so become impermeable. Wall tiles, ceramic pipes and stone pots are among the objects made in this way. When one works with kaolinite at even higher temperatures, one obtains domestic and sanitary faiences. When the kaolinite is quite pure and melting is complete, a translucent glass is obtained; this is porcelain. The domestic types (chinaware, Dresden china, Bohemian china and Sevres porcelain) are well known, but one should bear in mind the huge production of industrial porcelain for electric insulators.

Building and Engineering

Since antiquity clays have been employed in building. Clay mixed with sand or straw is the plasterlike material termed daub. Even today a third of mankind live in houses made of clay. I need hardly dwell on the widespread use of brick. Tiles too are made of common clay, but they are fired at higher temperatures so that they become impermeable. After bricks and tiles come cements. A mixture of limestone and clay (about 25 percent) is fired at a temperature of 1,400 degrees Celsius. The silica and alumina of clay generate calcium silicates and aluminates, which on being mixed with water yield the small, entangled and resistant crystallites characteristic of hardened cement.

Ceramics are also important in the refractory industries, that is, in high-temperature furnaces. The walls of a furnace must be protected against the heat by a refractory coating, which is normally made of a mixture of clay and sand. The greater the amount of pure kaolinite in the mixture is, the higher the temperature can be (as high as 1,800 degrees C.). Such coatings are crucial in brick kilns, glass furnaces, bread furnaces and numerous kinds of metallurgical furnaces.

The fact that clay can be made into impermeable pastes has also been exploited since antiquity. Cisterns and feeder lines from catch basins were coated with clay so that they would carry water to gardens and fields without leakage. These properties are still exploited in water pipes and canals. Porous soil can be made impermeable by the injection of mixtures of water and clay. Injection of clayey mud is a common adjunct of drilling for oil. Pumped constantly into a drill pipe, the mud cools the drill bit and then rises along the pipe, carrying away the drill cuttings.

Another engineering application relies on vermiculite. When vermiculite is heated, water in its crystal structure is driven out. It is then that the mineral twists like a worm, expands and becomes light and porous. A 30-story building made of concrete containing vermiculite weighs 5,000 tons, whereas without vermiculite it would weigh 19,000 tons. Vermiculite also serves as a thermal or sound insulator in the walls of buildings and ships.

Clay minerals, particularly montmorillonite, can fix numerous extraneous molecules on the surface of their flakes by adsorption. This property has been known since ancient times, when the finest-grained clays (fuller's earths) were employed to clean clothes and to scour wools. Today in rural Morocco people clean clothes with "ghasul," which is named for a clay pit containing natural stevensite. During World War II soaps in Europe were made with a high percentage of montmorillonite.

These adsorbing properties find many applications in industry. Among them are the decolorizing of mineral oils, the filtration of beer, wine and syrup, the clarification of water and the scouring of wool. Clays that have been calcined (heated to drive off volatile matter or to effect other changes) or treated with acid become quite active and are put to work as catalysts in many industrial operations. The huge surface area of their flakes speeds up such industrial chemical reactions as cracking, oxidation and synthesis.

The adsorptive capabilities of clay also play a profoundly important role in agriculture. Clay minerals readily adsorb many free mineral ions in the soil. Moreover, the ions are loosely bound and therefore are easily exchanged with, say, hydrogen from the roots of plants. Hence the clay minerals act to provide a source for the nutrient minerals required by the plants.

The ability of clays in the smectite group to form stable colloidal suspensions is very useful in the preparation of polishes, cosmetics, pesticides and many other substances. Kaolin, or white clay, serves widely as a filler and coating for paper. (A ton of the paper on which this magazine is printed contains 432 pounds of kaolin. Without it the paper would be much less opaque and would absorb so much ink that the illustrations could not be reproduced.)

Recent research has shown that a number of organic polymers can be bonded to the surface of clay minerals. The possibility thus arises of an entire industry making synthetic compounds of clay and organic materials. Several products of this kind have demonstrated greater thermal and mechanical resistance than products made of standard clay.

A number of investigators think the adsorptive properties of certain clays may have played a crucial role in the

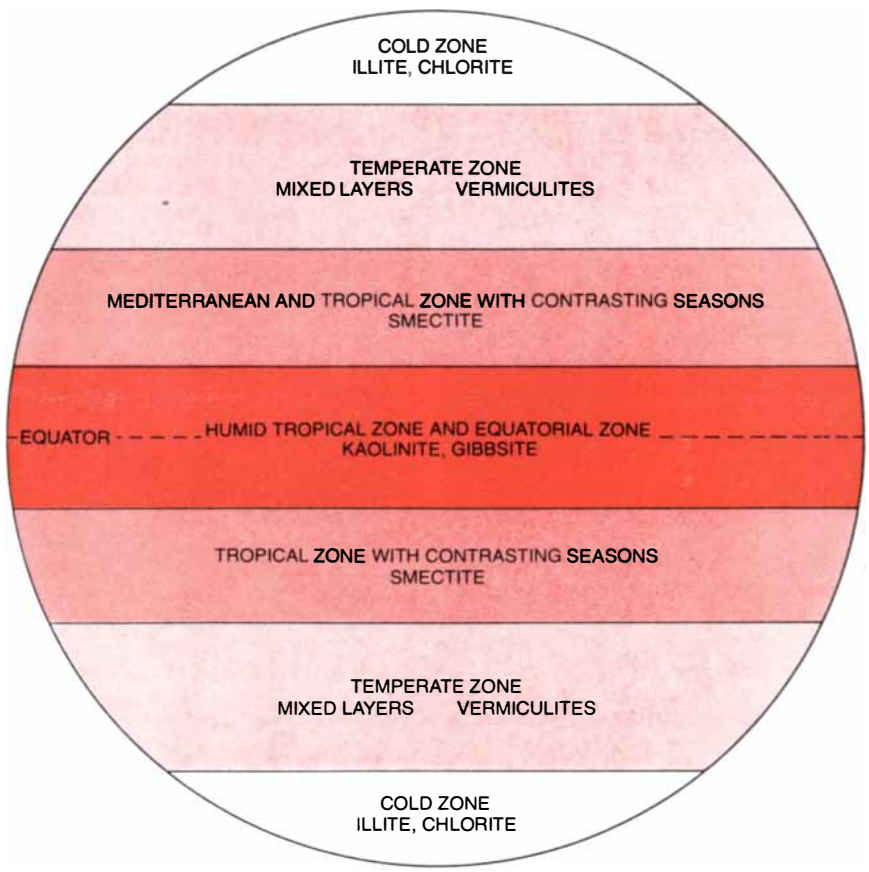
origin of life. The hypothesis arises in the effort to simulate the conditions on the primitive earth under which amino acids may have formed proteins.

Clay and Life

On this hypothesis single amino acids formed into the longer chains called peptides on the surface of clay particles. The clay is thought to have acted as a template and catalyst for the formation of long peptide chains, or proteins. The hypothesis was tested experimentally by Noam Lahav of the Hebrew University of Jerusalem, David H. White of the University of Santa Clara and Sherwood Chang of the Ames Research Center of the National Aeronautics and Space Administration.

They added a small amount of the amino acid glycine in solution to various clay minerals. They then exposed the clay sequentially to dehydration at 60 degrees C., heating at 94 degrees and rehydration with water. They also exposed similar combinations of clay and glycine to temperatures of 94 and 25 degrees without changing the conditions of wetness or dryness. The main findings were that more peptides were produced at various temperatures when clay was present than when it was absent and that the production of peptides was higher when both temperature and moisture fluctuated than when only the temperature was changed.

On the basis of these findings the three investigators proposed that the fluctuation of temperature and moisture brings about a distribution and redistribution of amino acids on the surface of clay particles that favors the amino acids' linkage into peptide chains. When water touches the surface of the clay, the active sites on the surface that catalyze the formation of peptides from amino acids are cleaned. When higher temperatures evaporate the water, new catalytic sites become available for other amino acids, which join an existing chain or form new chains. Because more than one kind of amino acid must have been present in the waters and on the surface of the primitive earth, the same cycle of fluctuating temperature and moisture could have led to the formation of increasingly complex peptides and ultimately to the precursors of the large protein molecules that are synonymous with life.



CLIMATIC EFFECTS give rise to different types of clay minerals. For example, in equatorial and humid tropical places the chemical leaching is heavy and the elements that remain are reorganized in the form of kaolinite, which is an aluminosilicate rich in aluminum compared with other clay minerals, or of gibbsite, which is an aluminum hydroxide. The zonation is not distinct. Any clay mineral can occur in the soils and sediments of any climatic zone, but the tendency of clay minerals to form in different parts of the earth's surface is as indicated here.

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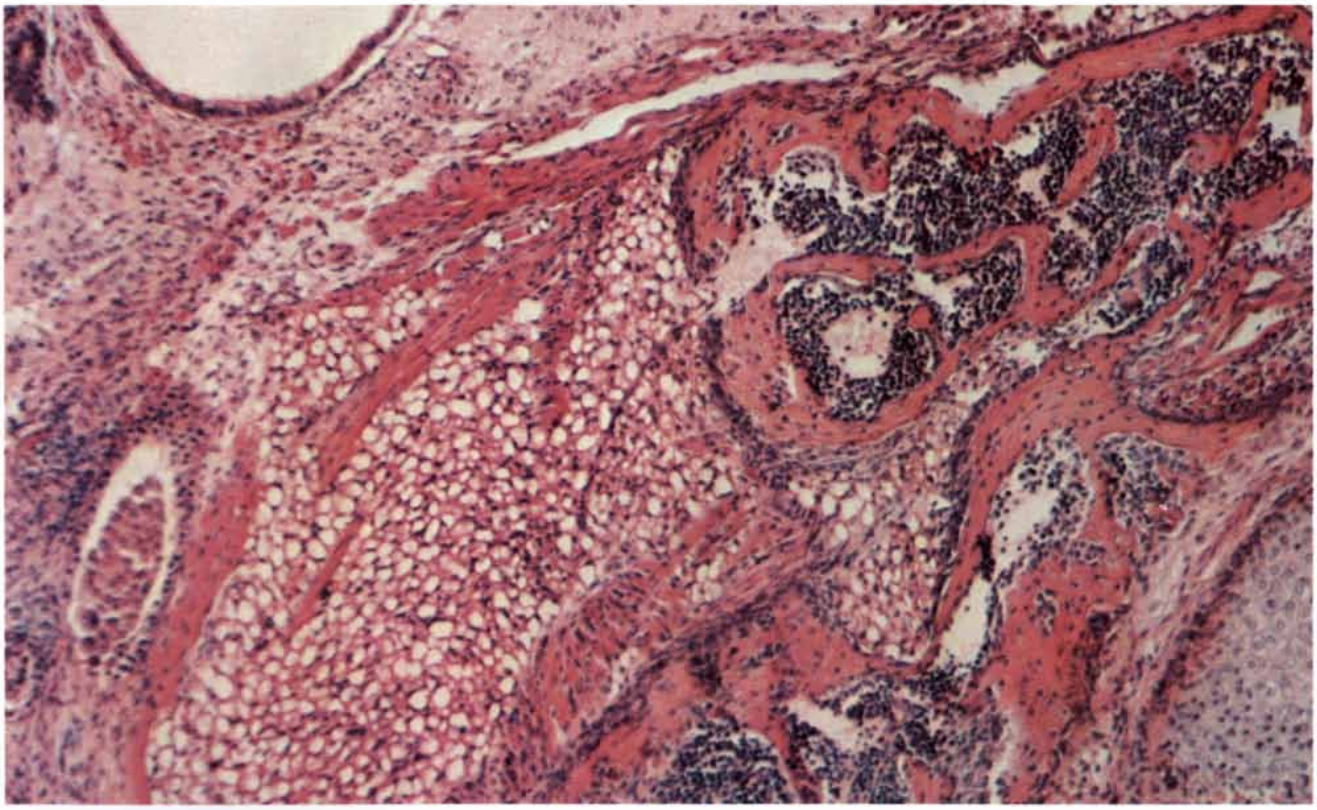
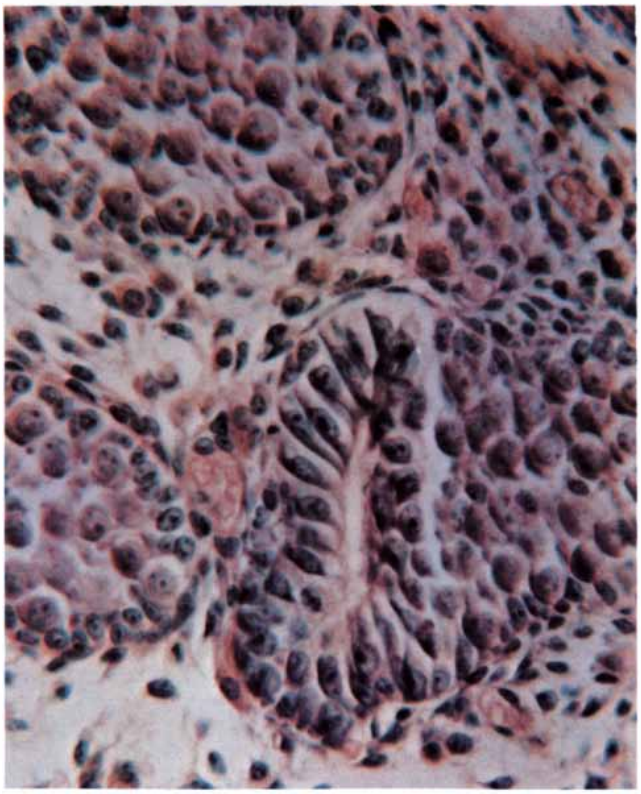


TESTICULAR TERATOMA from an adult male mouse of strain 129 displays well-differentiated but chaotically arranged tissues of many kinds (*diagram on opposite page*). All the tissues result from differentiation of embryonal carcinoma cells, the tumor's stem cells.



SPONTANEOUS TERATOMA develops within a seminiferous tubule of a testis of a male mouse fetus. An early teratoma (*oval structure*) composed of embryonal carcinoma cells is seen here among the normal germ cells (its cells of origin) in a tubule of a 16-day fetus.

EXPERIMENTAL TERATOMA (*oval structure*) can be readily induced by grafting genital ridges (the embryonic precursors of the gonads, containing the germ cells) taken from a 12-day male mouse fetus to the testis of an adult male mouse of the same genetic strain.

Teratomas and Chimeras

Teratomas are tumors composed of a jumble of differentiated cells and tissues. Their malignant stem cells can differentiate normally in the mouse embryo and give rise to chimeras, or genetic mosaics

by Karl Illmensee and Leroy C. Stevens

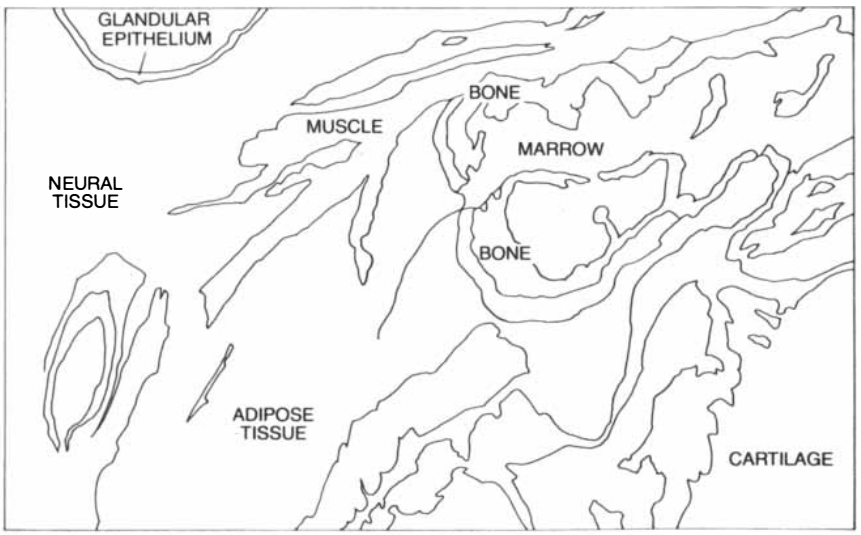
A teratoma is a tumor composed not only of neoplastic cells (like other tumors) but also of many kinds of differentiated cells and tissues at various stages of maturation. A typical teratoma may include, for example, nerve cells, muscle cells, blood cells, skin cells, glandular cells and cells of other specialized types; the cells may be aggregated into actual muscle fibers, glandular or brain tissues, cartilage or bone; embedded in the mass may be hairs and teeth. Teratomas deserve their name, which is derived from the Greek combining form for "monster." Yet the very properties that make teratomas seem monstrous also make them fascinating biologically, and the availability of experimentally induced mouse teratomas has provided a valuable investigative tool for pathology, immunology, genetics and developmental biology.

The stem cells from which teratomas proliferate resemble undifferentiated embryonic cells in their structure and biochemistry and in the protein antigens displayed on their surface. The stem cells are potentially malignant, however, and are called embryonal carcinoma cells; they are responsible for the uncontrolled growth of teratomas. When an embryonal carcinoma cell divides, it may give rise to two new embryonal cells, to one such cell and a normal differentiated cell or to two differentiated cells of almost any type. As long as the tumors contain embryonal carcinoma cells they continue to grow; such tumors are malignant and are referred to as teratocarcinomas. When all the embryonal cells differentiate into various kinds of normal tissue, the tumors stop growing; they are benign and are usually referred to simply as teratomas.

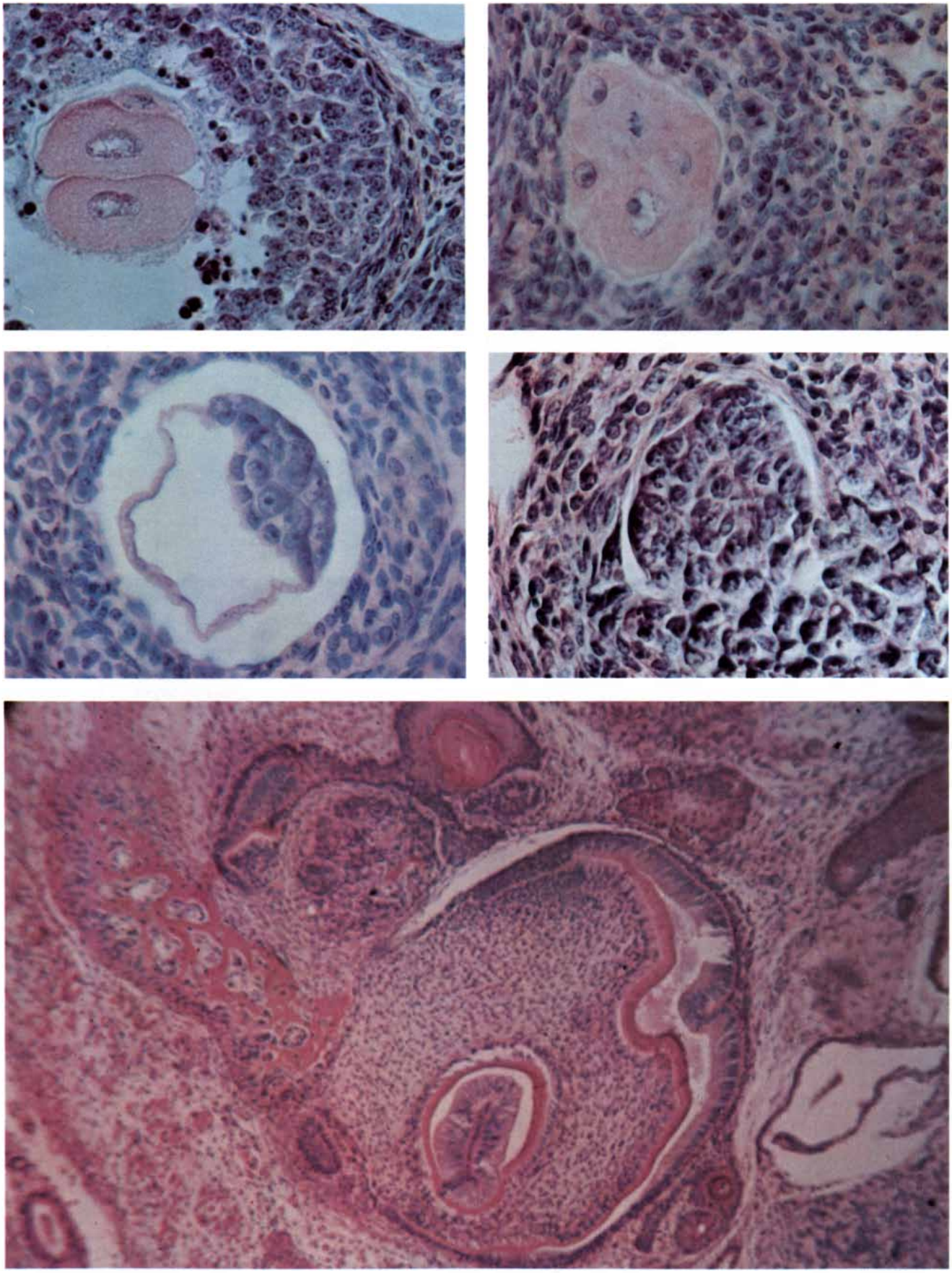
Teratomas were reported in the ovary or the testis of human beings in the 19th century, but until recently their origin remained a mystery; their heterogeneous composition led to the incorrect assumption that they resulted somehow from the inclusion in a fetus of portions of another fetus that had been aborted. Our investigations have established that teratomas originate from germ cells: from eggs in the female and from precursors of sperm cells in the male. In a manner of speaking, a teratoma serves as a model of a mammalian embryo. In our investigations we exploit this similarity to study a central question in development: How does a single cell, the fertilized egg, differentiate to form all the different cell types and tissues of the organism?

Since the embryonal carcinoma cell is malignant and nonetheless gives rise to normal tissues, we have also learned something from teratomas about the nature of neoplastic transformation. Some of the most interesting findings have come from experiments in which we and our colleagues produced mouse chimeras, or genetic mosaics, some of whose normal tissues were derived from an embryonal carcinoma cell, demonstrating that these malignant tumor cells can lose their neoplastic properties under the appropriate environmental conditions.

The induction of teratomas in rats and chickens was reported as early as 1907 by the pathologist Max Askanazy of the University of Geneva, but the experimental manipulation of teratomas in mice dates back only to 1953, when one of us (Stevens) first noted a testicular teratoma in a mouse of strain 129, one of many inbred mouse lines maintained at the Jackson Laboratory in Bar Harbor, Me. Examination of large numbers of male mice of the strain revealed that about 1 percent of them developed teratomas spontaneously. The tumors were recognizable as early as a week after birth, when they were notable in that they still contained undifferentiated proliferating cells as well as the differentiated cells of a typical mature teratoma. Clearly mice of strain 129 were some-



VARIETY OF TISSUES in a testicular teratoma is indicated by this diagram of photomicrograph at top of opposite page. The tumor contains tissues that normally are derived from all three embryonic germ layers: cartilage, bone with marrow, adipose tissue and muscle fibers, all from mesoderm; neural tissue from ectoderm, and glandular epithelium from endoderm.



OVARIAN TERATOMA arises from parthenogenesis in a female mouse of strain LT. Without fertilization an egg in the ovary cleaves spontaneously (*top left*) and progresses to form a morula (*top right*) and a blastocyst (*middle left*). Then it becomes disorganized (*middle right*) and eventually develops into a teratoma (*bottom*) containing several well-differentiated tissues (*diagram at top of opposite page*).

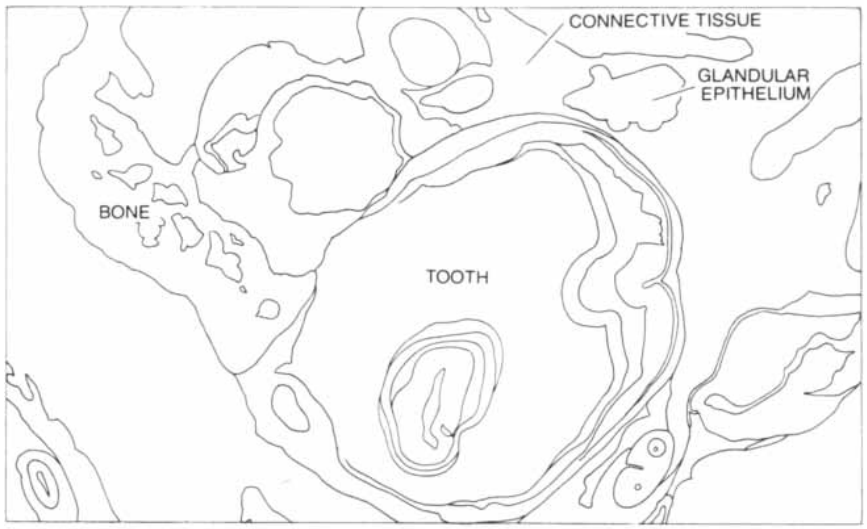
how predisposed to teratoma formation. By selective breeding it was possible to develop a subline of the strain in which some 30 percent of the males eventually developed teratomas. That made it feasible to investigate a number of questions, notably: When do teratomas first appear, and from what kind of cell do they originate? What genetic and environmental factors influence their formation?

Teratomas could be identified in fetuses of the strain-129 subline as early as the 15th day of gestation. The tumors were composed of clusters of undifferentiated cells resembling those of a normal five-day mouse embryo. All the teratomas in 15-day fetuses were found among the primordial germ cells in the seminiferous tubules of the testis. These tubules are formed of Sertoli cells and contain only primordial germ cells. Because the tumors were situated within the tubules and because their cells had the structure and even the ultrastructure of germ cells it seemed most likely that the cell of origin of a teratoma was a primordial germ cell.

The resemblance to an early embryo persisted for a time as the tumor developed. In newborn mice the teratomas contained differentiated cells that corresponded to the three primary germ layers in normal development: ectoderm, endoderm and mesoderm. There were two kinds of epithelium. One resembled the ectoderm of early embryos and developed, in later teratomas, into skin or nerve tissue; the other resembled the embryonic pharynx and developed into respiratory or alimentary tissue. Between the epithelial tissues there were mesodermal cells that developed into cartilage, muscle or bone.

The relative sizes of teratomas in newborn mice and at fetal stages going back to the 15th day of gestation suggested that the tumors originate at the 12th day. The next step in the attempt to understand the initiation of teratomas was therefore to dissect the genital ridges (the fetal structures from which the testes or ovaries develop) from 12-day fetuses of strain 129 and several other inbred strains and graft them to the kidney, liver and testis of adults. The object was to see if the genital ridges, which contain the germ-cell precursors, would form testes with teratomas and if the particular site of the graft would influence the differentiation of tissues within those teratomas.

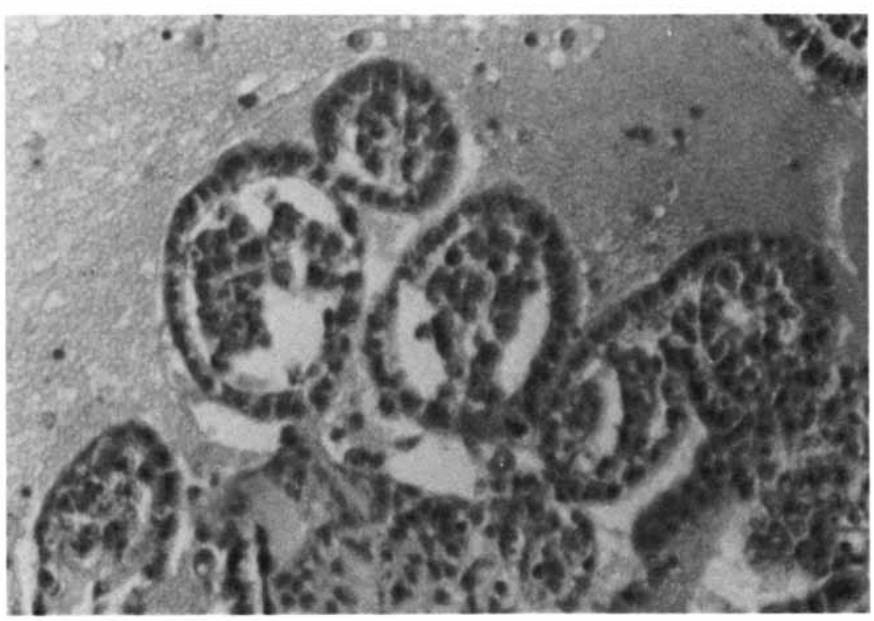
When male genital ridges were grafted to the kidney or the liver, they developed into testes in which teratomas were formed at about the usual rate for strain 129. When the genital ridges were grafted to the testes, on the other hand, about 70 percent of them formed teratomas. When genital ridges from 13-day fetuses and older ones were similarly grafted, the incidence of experimentally induced teratomas fell off sharply with increasing fetal age. In other words, after the 13th day of gestation the germ cells undergo a stage of maturation that prevents the formation of teratomas.



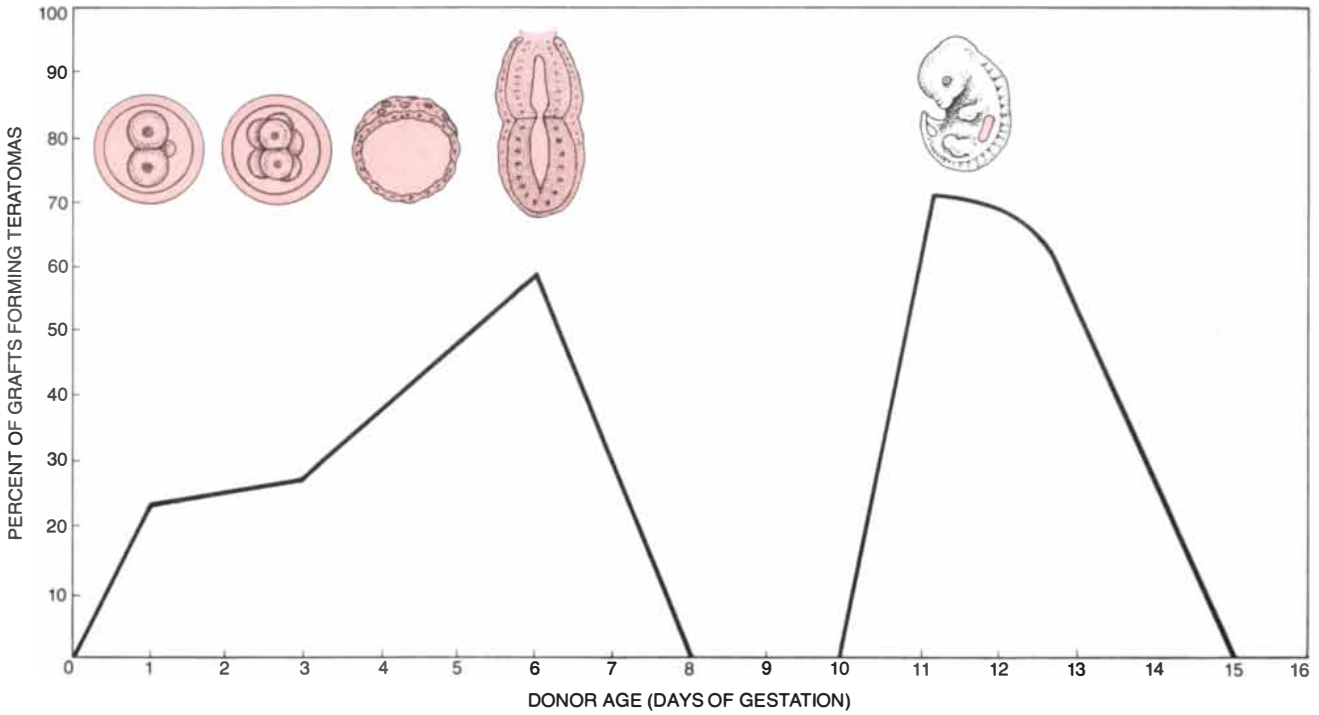
VARIETY OF TISSUES in an ovarian teratoma is indicated by this diagram of the color photomicrograph at the bottom of the opposite page. The tumor contains a tooth, bone, connective tissue and glandular epithelium, all derived from malignant embryonal carcinoma cells.

The ability to induce teratomas experimentally at a rate that was much higher than the spontaneous incidence opened the way to the intensive investigation of these tumors, and it specifically made possible a new approach to establishing the cell of origin. Mice that are homozygous for a mutation called *Steel* (that is, mice in which two homologous chromosomes both carry the mutated gene) lack germ cells and are sterile. The mutation was introduced into the teratoma subline of strain 129, and 12-day genital ridges of *Steel*-bearing fetuses and their littermates were grafted to the testes of adult mice. Some of the fetuses were homozygous for *Steel* and some had only one *Steel* gene. (Mice homozygous for *Steel* have white coats and their littermates have black coats, so that we could identify the homozygous fetuses by also grafting fetal skin tissue to the testes and later noting the color of the grafted patch.)

Of the genital ridges from the normal littermates, 75 percent developed into testes with teratomas, about the usual incidence for experimental teratomas. In sharp contrast, all the grafted genital



EMBRYOID BODIES originate from embryonal carcinoma cells injected into the peritoneum (abdominal cavity) of adult mice. These bodies are composed of a group of embryonal carcinoma cells surrounded by primitive endoderm and to some extent resemble early embryos.



EXPERIMENTAL TERATOMAS are induced by grafting an early embryo (*left*) or the genital ridge (*color*) of a fetus (*right*) to an extrauterine site in an adult mouse. As curves indicate, a six-day embryo or an 11-to-13-day genital ridge is most likely to produce a teratoma.

ridges from the littermates that were homozygous for *Steel* developed into testes without teratomas. The normal genital ridges contained primordial germ cells; the genital ridges of the homozygous littermates did not. The experiment therefore proved what the earlier observations had suggested: Testicular teratomas originate from primordial germ cells that—for reasons still unknown—are transformed into neoplastic cells.

The similarity of teratomas and early embryos suggested another experiment, in which we grafted early embryos to the testis or kidney of adult hosts. When an embryo up to what is called the egg-cylinder stage (the sixth day of gestation) is grafted to one of these extrauterine sites, it continues to develop, but in a disorganized way, the embryonic cells proliferating and differentiating into most kinds of mature tissues. After a month about half of the successful grafts resemble teratomas composed of various well-differentiated adult tissues. The other half form typical teratocarcinomas that contain not only differentiated cells but also undifferentiated embryonal cells similar to the stem cells of spontaneous teratocarcinomas.

The embryo-derived teratomas resemble those of the ovary and testis in every characteristic that can be observed, even though they originate not from germ cells but from the ectodermal cells of embryos. (When embryonic cells other than ectodermal ones are grafted to extrauterine sites, they do not form teratomas.) Apparently the embryonic ectodermal cells up to the sixth day of gestation are able to give rise to many kinds of cells and tissues, including the normal derivatives of endoderm and mesoderm as well as of ectoderm, and possibly (although it has not yet been demonstrated) to germ-cell precursors in addition.

The main source of teratoma material has been the transplantable teratocarcinoma. A teratoma is grafted under the skin of another mouse that is histocompatible with the original host. If the teratoma is malignant, it grows; after three weeks some of the tumor material is transplanted to another histocompatible mouse. (If it were not transplanted, it would continue to grow and eventually would kill its host.) The process is repeated every three weeks. Some transplantable teratocarcinomas have been maintained in this way for many years. The malignant stem cells of some of them remain pluripotent (able to differentiate into a variety of cell types); in other cases the stem cells' developmental potential becomes limited after several transplant generations, so that the cells differentiate into just a few kinds of tissue or even only one kind—for example nerve tissue, or skeletal muscle, or endoderm.

When cells from some transplantable tumors are injected into the peritoneal cavity of a mouse, they stimulate the cells lining the peritoneum to produce an accumulation of fluid, or ascites. Tumor cells suspended in the fluid continue to proliferate as ascites teratocarcinomas, which tend to form small structures very similar to normal five- or six-day mouse embryos: an inner group of cells resembling primitive ectoderm, surrounded by a single layer of cells analogous to the primary endoderm of early embryos. Such structures were first observed in 1940, in human testicular teratomas, by the French pathologist Alfred Peyron. He called them "embryoid bodies," and indeed he was so struck by their similarity to normal embryos that he reported (in spite of their location) that he had discovered a remarkable collection of early human embryos.

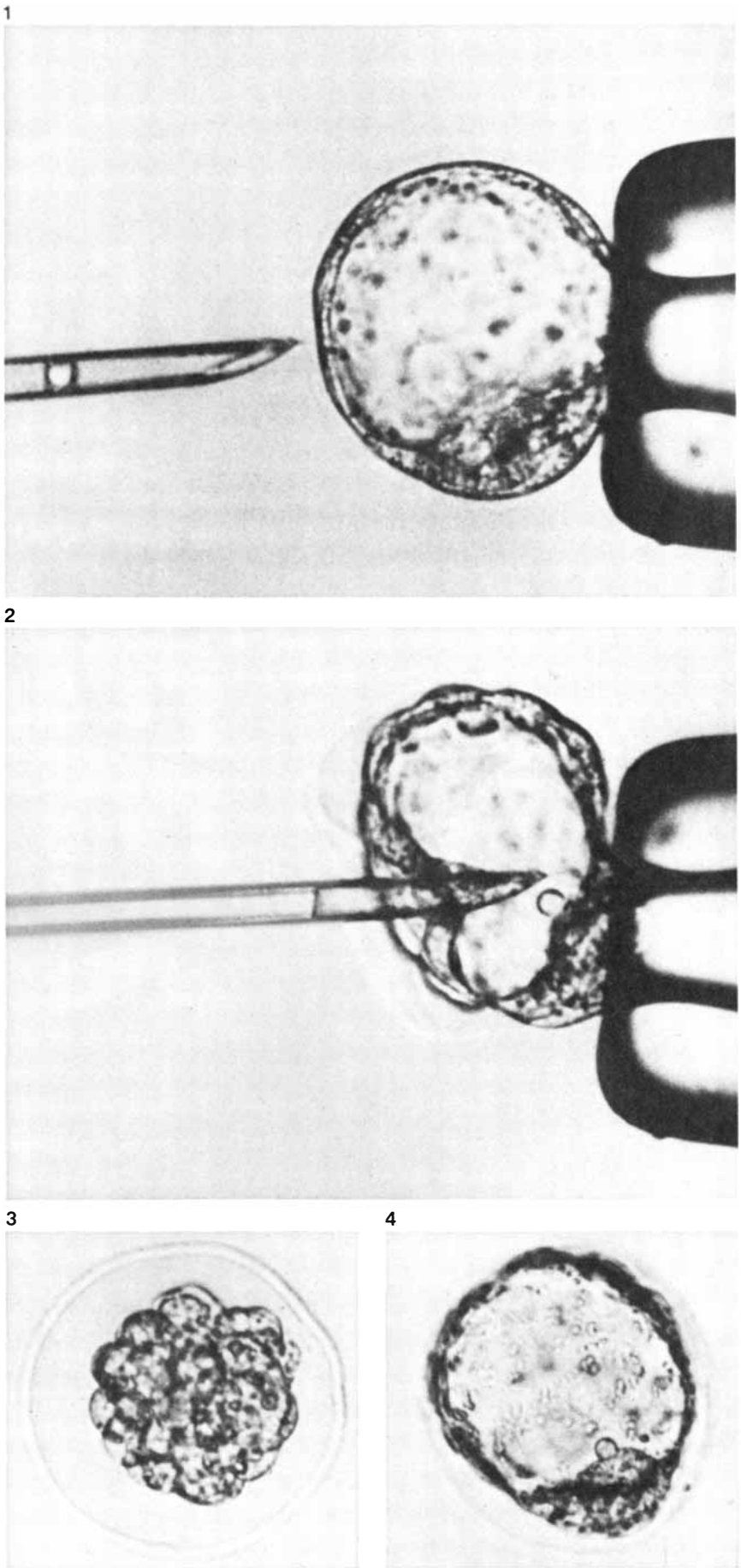
In the intraperitoneal fluid the mouse embryoid bodies grow and then divide to form two new bodies, and they can be retransplanted and maintained by this regime for many years. If an embryoid body is grafted to any of several sites in an adult mouse, it grows to form a solid tumor composed of several types of differentiated tissue as well as undifferentiated embryonal carcinoma cells. This means that the stem cells in embryoid bodies are capable of retaining their pluripotency for many years even though they do not express it. Since they are readily identified and manipulated, they have become a primary tool in the study of differentiation.

In 1964 Lewis J. Kleinsmith and G. Barry Pierce demonstrated at the University of Michigan that even a single teratocarcinoma cell can remain plu-

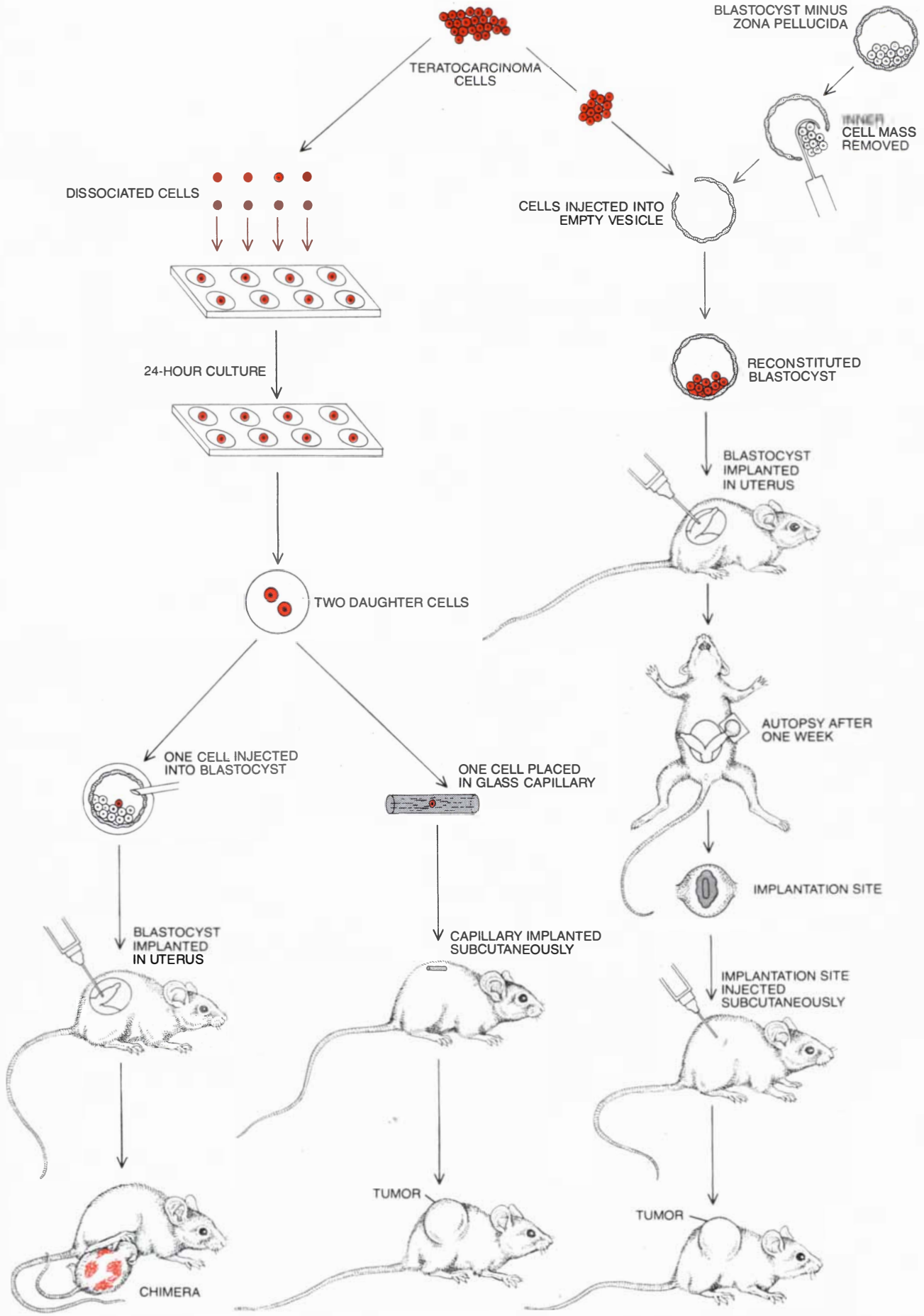
ripotent. They placed a single embryonal carcinoma cell in a small glass capillary and implanted the capillary under the skin of an adult mouse. The implanted cell divided, and the clone of daughter cells proliferated and differentiated into various cell types, eventually giving rise to a multidifferentiated tumor. Several observations made it impossible, however, to conclude from this kind of experiment that embryonal carcinoma cells are in fact totipotent, that is, really equivalent to normal early embryonic cells in their developmental capability. For one thing, some daughter cells continued to be malignant, suggesting that perhaps their neoplastic transformation was genetically prescribed. For another, some of the differentiated tissues remained abnormal and immature. The absence of certain tissues, including kidney, thymus, lung and liver, in all the many solid tumors that were examined suggested the stem cells might be comparable to late-embryonic cells whose developmental capacity has become limited.

In spite of the many morphological, biochemical and immunological similarities between teratocarcinoma cells and normal embryonic cells there was, after all, one big difference: the teratocarcinoma cells were malignant, and some of their descendants appeared to remain malignant through many generations. To demonstrate teratocarcinoma-cell totipotency clearly one would have to show that the malignant properties of the cells did not necessarily persist but were reversible under appropriate environmental conditions. Such conditions might be obtained by placing the malignant teratoma stem cells in close association with normal cells of the early embryo.

In 1974 Ralph L. Brinster of the University of Pennsylvania School of Veterinary Medicine reported such experiments. He injected teratocarcinoma cells into blastocysts, which are very early (four-and-a-half-day) embryos, placing the injected cells near the blastocyst's inner cell mass, some cells of which give rise to the later embryo. Then he transferred the blastocysts to the uterus of "foster mothers," females that had been made "pseudopregnant"



TERATOCARCINOMA CELL is injected microsurgically into a mouse blastocyst, which is a $4\frac{1}{2}$-day embryo. The blastocyst, about .075 millimeter in diameter, is fixed to the end of a blunt pipette; a single tumor cell is seen in the injection pipette (*1*). The cell is injected and attaches to the inner cell mass, the cells that will give rise to the developing embryo (*2*). The blastocyst collapses after the manipulation (*3*) but expands again after a few hours in culture (*4*); the tumor cell remains attached to the inner cell mass, with which it will become integrated during further development.



(by being mated to vasectomized and therefore sterile males) so that the foreign embryos would become implanted and develop to term. Of the mice that were born, one had brownish patches on its otherwise white coat. The white coat was derived from the strain that had supplied the blastocysts and therefore most of the embryonic material; the brownish patches were the "agouti" color (from hairs with black and yellow bands) of the animals from which the injected teratocarcinoma cells had come. The mouse was apparently a chimera (a word derived from the name of a beast in Greek mythology that had the head of a lion, the body of a goat and the tail of a serpent).

Brinster's report of coat chimerism was an encouraging indication that embryonal carcinoma cells could lose their malignancy and differentiate normally. Unfortunately the blastocysts he implanted had originated from a randomly bred strain of albino mice whose genetic heterogeneity made it impossible to identify any participation of the tumor cells in other tissues. In 1974, together with Beatrice Mintz of the Institute for Cancer Research in Philadelphia, we injected embryonal carcinoma cells from a strain-129 ascites teratocarcinoma into blastocysts of other inbred strains carrying a number of genetic markers so that cells derived from the blastocysts could later be distinguished from those derived from the tumor.

The embryoid bodies from which the injected embryonal carcinoma cells were taken had a long history. At the Jackson Laboratory in 1967 a six-day male embryo of strain 129 had been grafted to the testis of an adult host, inducing the formation of an experimental teratocarcinoma that was propagated as a transplantable tumor for a few generations and then converted into an ascites teratocarcinoma. The latter was maintained for eight years in the peritoneal fluid of mice and served as the source of the embryoid bodies from which we got the embryonal carcinoma cells for injection.

A series of experiments produced about 40 healthy chimeric mice, some of which reached an age of more than a year (about half the normal mouse life span) before they were autopsied for further analysis. In these chimeras there was no sign of teratomas. (Occasionally teratomas did develop in nonchimeric progeny, that is, in mice that otherwise showed no teratocarcinoma-cell contribution in their tissues.) In the healthy chimeras we were able to identify, in addition to the coat-color patches, a large number of gene products specific to the teratoma subline of strain 129 (which is to say to the embryonal carcinoma cells) rather than to the blastocyst strain. These products included hemoglobin in red blood cells, immunoglobulins in plasma cells, liver proteins in liver cells, black melanin in certain epidermal cells, yellow melanin in hair-follicle cells and an electrophoretic variant of the enzyme glucose phosphate isomerase in virtually every organ. All three embryonic germ layers—endoderm, ectoderm and mesoderm—were represented in the tissues displaying such markers, as were tissues not ordinarily observed in teratocarcinomas, including liver, kidney and lung. In two instances cells derived from the embryonal carcinoma cells even formed spermatozoa that fertilized eggs and gave rise to healthy offspring whose tissues expressed all the strain-129 (or embryonal carcinoma cell) markers.

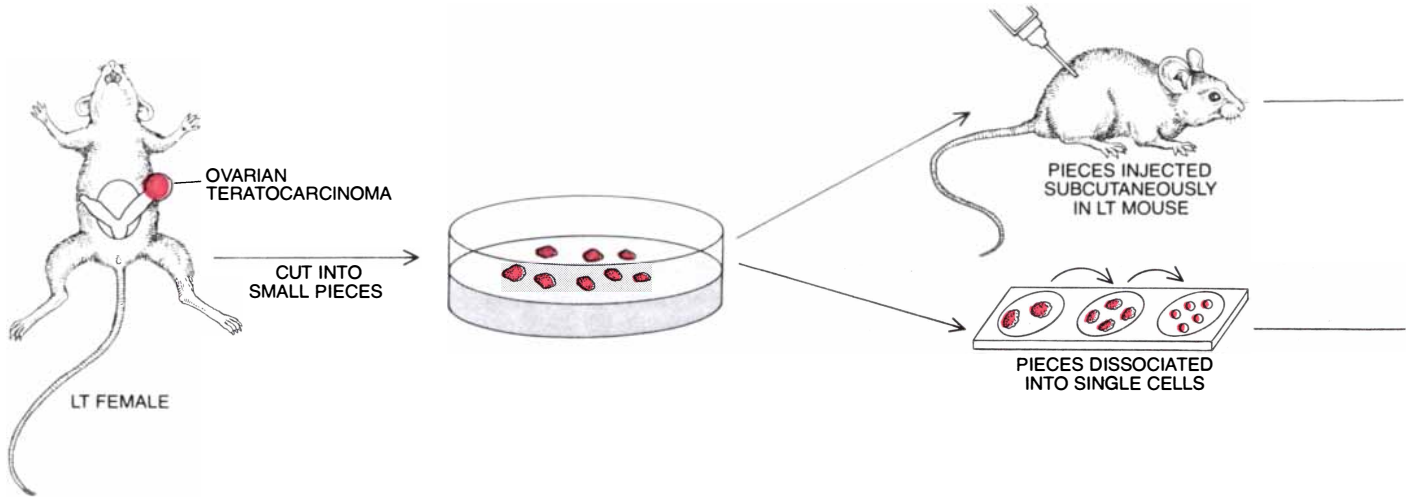
Seeking to demonstrate normal differentiation by a single embryonal carcinoma cell, we went on to inject single cells into blastocysts. The results were intriguing: the single tumor cell contributed clonally to all major tissues of a chimeric mouse, which grew normally to adulthood. Totipotency equivalent to that of early embryonic cells was thereby established unequivocally for individual embryonal carcinoma cells. After almost eight years—some 200 transplantation generations—as components of a highly malignant tumor, these teratoma stem cells were able to express their full genetic repertory in an orderly sequence of differentiation into somatic and germ-line tissues. The reversal of malignancy was apparently a stable process, because when pieces of the tumor-derived mosaic tissues were grafted under the skin of histocompatible mice,

BLASTOCYST-INJECTION EXPERIMENT demonstrated the ability of a single teratocarcinoma cell to differentiate normally. Teratocarcinoma cells are dissociated with a protein-digesting enzyme and are cultured singly. Some tumor cells divide to form two daughter cells, one of which is injected into a blastocyst of a different mouse strain. The blastocyst is placed in the uterus of a pseudopregnant "foster mother," where it gives rise to a healthy chimeric mouse (*left*) that has tumor-cell-derived tissues in the coat (*color*) and in internal organs. The other daughter cell, in a glass capillary, is implanted under the skin of an adult mouse and develops into a teratocarcinoma (*middle*), showing that a single tumor cell can either differentiate normally or remain malignant depending on the environment. In order to demonstrate that the presence of embryonic cells is required for the reversion of malignancy, teratocarcinoma cells are injected into a blastocyst from which the inner cell mass has been removed (*right*); the reconstituted blastocyst is placed in the uterus of a foster mother, where it implants. The implantation site is removed and transplanted under the skin of a mouse; it forms a teratocarcinoma.

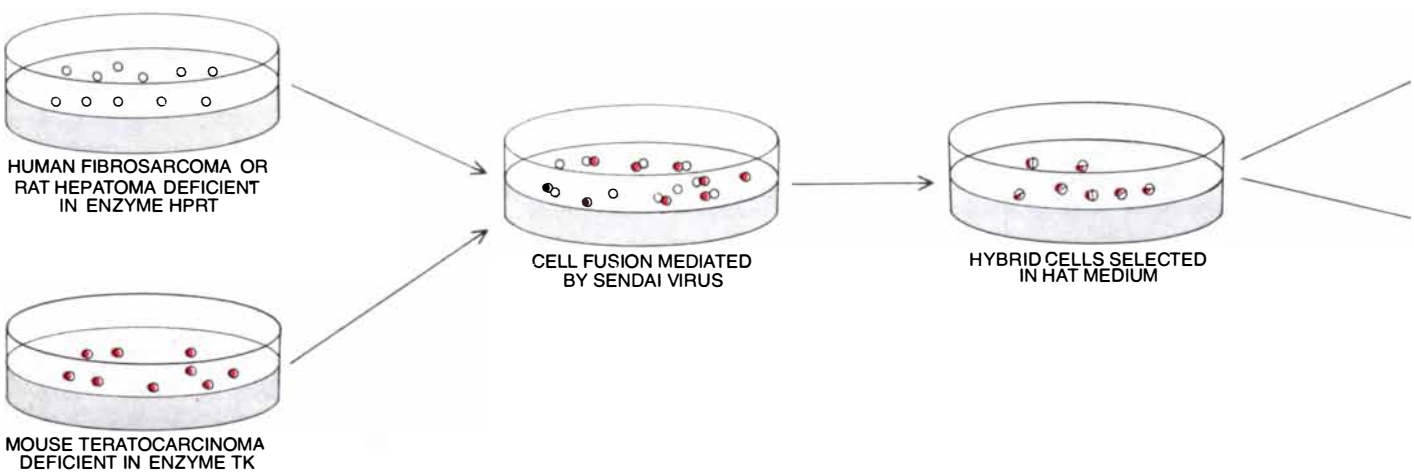
they never formed tumors. Yet when the original embryonal carcinoma cells were implanted subcutaneously, they formed large teratocarcinomas.

One could still argue that the embryonal carcinoma cell population was heterogeneous with respect to malignant properties, so that one cell might be able to differentiate normally and another cell might be destined to form a tumor. The alternative explanation of the experimental results was that a single embryonal carcinoma cell can either differentiate normally or give rise to a tumor, depending on the microenvironment into which it happens to be injected. In order to distinguish between these two possibilities we varied the experiment once again. Single embryonal carcinoma cells were cultured in an appropriate medium, and some divided to form two daughter cells. One daughter cell was injected into a blastocyst and developed in a foster mother; the other daughter cell was implanted under the skin of an adult mouse. In some cases the cell injected into a blastocyst participated in normal tissue differentiation whereas its subcutaneously implanted sister cell gave rise to a teratocarcinoma. Apparently the embryonic environment made the difference.

Additional evidence to support this conclusion was obtained by injecting embryonal carcinoma cells into blastocysts but depriving them of the environ-



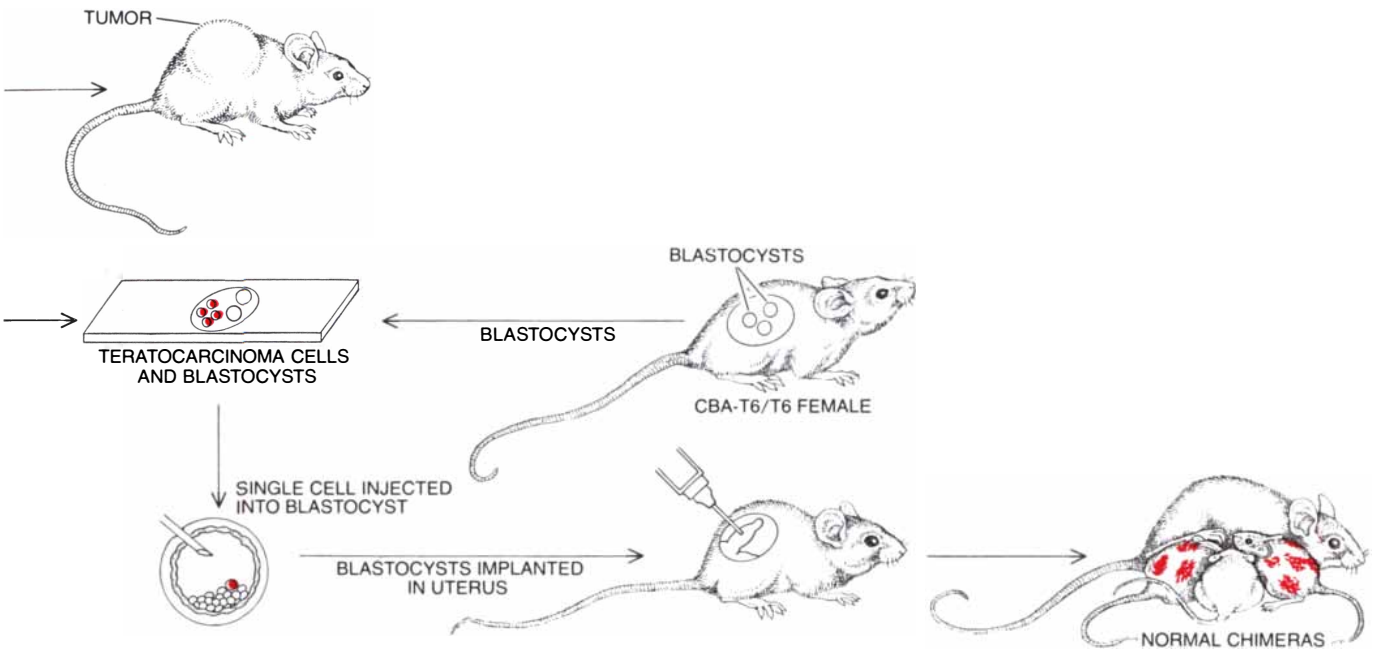
OVARIAN TERATOCARCINOMA is removed from a female of strain LT and cut into small pieces. Some pieces are implanted under the skin of another LT mouse, where they form a malignant tumor. Other pieces are dissociated to obtain single cells, which are injected



BIOASSAY SYSTEM was developed by combining cell-hybridization techniques with the blastocyst-injection procedure. Cells from a mouse teratocarcinoma deficient in one enzyme (TK) are cultured in the presence of inactivated Sendai virus with human or rat tumor cells deficient in a different enzyme (HPRT). Some of the cells fuse, forming hybrid cells that are maintained in a special culture medium

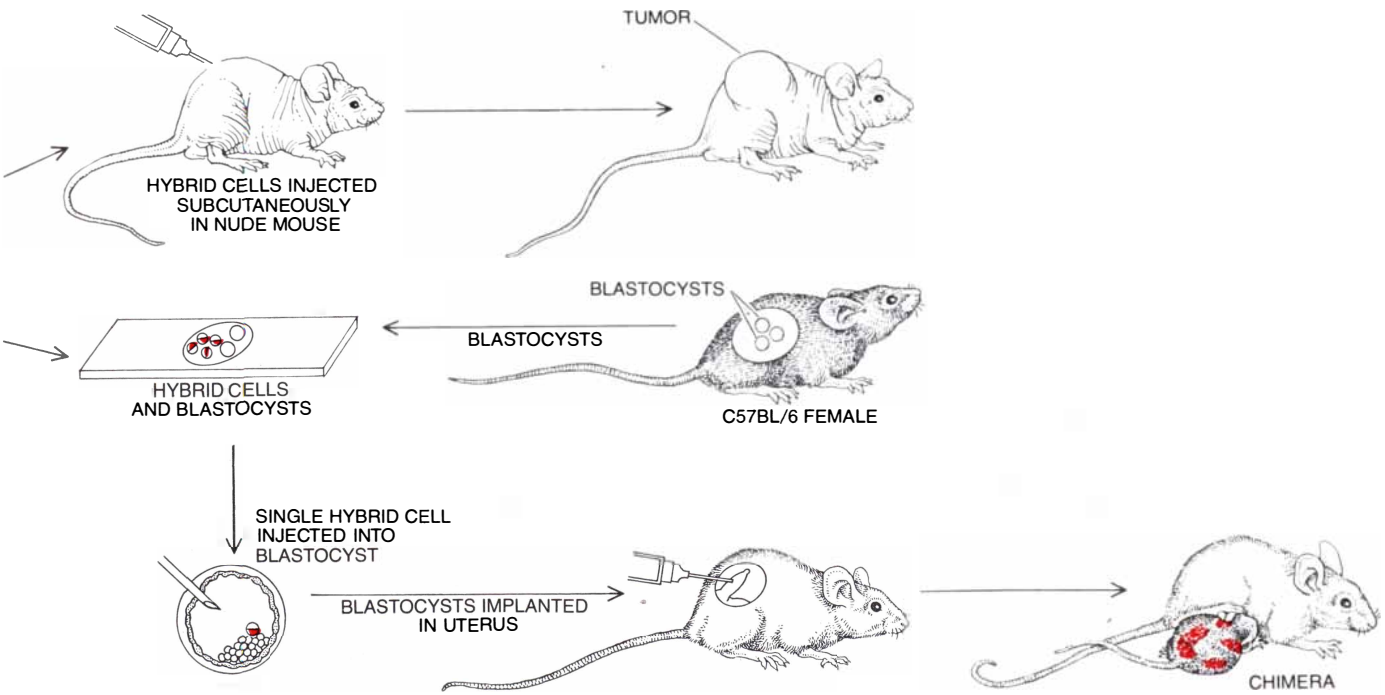
mental influence of normal embryonic cells. The entire inner cell mass (which gives rise to the later embryo) of blastocysts was removed, and in its place some 20 embryonal carcinoma cells were injected into the empty trophoblasts, or casings. When it was placed in the uterus of a foster mother, a reconstituted blastocyst containing only tumor cells was able to implant but did not develop into an embryo. When the implantation site (the uterine wall and the blastocyst) was excised and placed under the skin of a histocompatible host, it gave rise to a teratocarcinoma. Enzyme analysis of the tumor established that it originated solely from the embryonal carcinoma cells, not from the trophoblast or the uterine tissue. Apparently, then, the malignant stem cells retain their neoplastic properties if they are left to themselves; they revert to normality only when they are closely associated with normal embryonic cells. At present we do not know what signals cause a once-malignant cell to take part in normal development.

In an inbred mouse strain designated LT about half of the females develop ovarian teratomas. These bizarre tumors arise from eggs that for some unknown reason are activated parthenogenetically in the ovary and, without fertilization, cleave and develop into early embryos, then become disorganized and form teratomas rather than



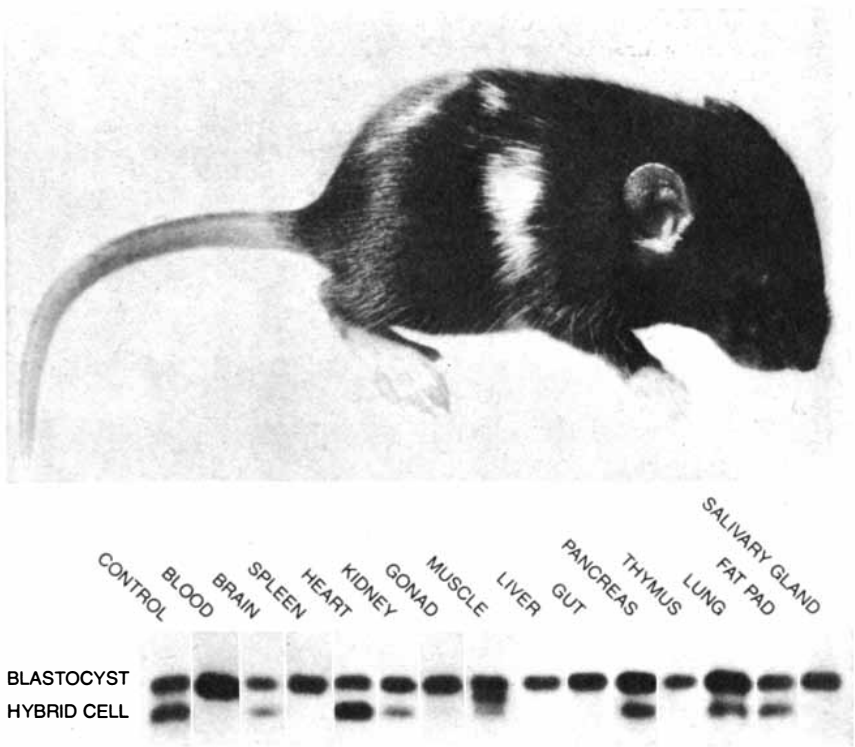
into blastocysts taken from females of a different strain; the blastocysts are implanted in the uterus of a pseudopregnant foster mother.

Her progeny include normal chimeric mice that have tumor-cell contributions in the coat, in internal organs and even in the germ line.



(HAT) in which only the hybrid cells can survive. Injected into immune-deficient "nude" mice, the hybrid cells form malignant tumors. In contrast, when the malignant hybrid cells are injected into

blastocysts derived from a strain of black mice and the blastocysts are implanted in a foster mother, the cells differentiate normally, contributing to the coat and various organs of the chimeric progeny.



HYBRID-CELL CHIMERA shows a black coat (from the blastocyst strain) with white patches derived from the injected mouse-human hybrid cell. The blastocyst-strain variant and the hybrid-cell variant of the enzyme glucose phosphate isomerase in the chimera are separated by starch-gel electrophoresis. The two variants migrate different distances in an electric field, as is shown by the control bands (*left*). The slower-moving hybrid-cell variant (*lower bands*) is present in seven tissues. In skeletal muscle the two variants form a heterodimer, a combined enzyme molecule whose presence attests to the functioning of hybrid-cell enzyme in chimera.

fetuses. Occasionally an ovarian tumor can be converted into a transplantable teratocarcinoma by subcutaneous injection into adult mice of the same genetic line, and these tumors are amenable to experimental analysis. Did the neoplastic growth of ovarian tumors result from stable genetic changes or were these malignant cells, like those of embryo-derived teratocarcinomas, capable of reverting to normal differentiation?

We injected single ovarian teratocarcinoma cells into genetically marked blastocysts of a different mouse strain and placed the injected blastocysts in the uterus of foster mothers. The transplantations gave rise to several normal chimeric mice with tumor-derived contributions in the coat and in all major organs. One female chimera turned out to have in her ovaries functional eggs that had originated from the injected teratocarcinoma cells. When those eggs were fertilized, they gave rise to healthy offspring—to normal mice whose "genetic mother" was a tumor. The results demonstrated that female teratocarcinoma cells, like their male counterparts, lose their malignant properties in an embryonic environment and differentiate normally into adult tissues, and that in rare instances the tumor-cell genes can even be transmitted to succeeding generations. The neoplastic transformation that produces ovarian teratocarcinomas is therefore unlikely to be the result of a deficiency or an alteration in the egg's genetic composition.

In support of this idea we found that eggs from the pigmented LT strain that had begun to divide parthenogenetically and had reached the eight-cell stage could be removed from the oviduct and aggregated with normal eight-cell embryos from an inbred albino strain. When such aggregates were placed in foster mothers, several normal chimeric (pigmented and albino) mice developed. When one female chimera was mated to an albino male, she gave birth to both albino and pigmented offspring. The pigmented progeny could only have been derived from eggs descended from the parthenogenetic eight-cell embryo. We conclude that the developmental aberrations that produce both ovarian and testicular teratocarcinomas are causally related to changes in gene function rather than in gene structure.

We should mention that evidence from a somewhat different kind of experiment has tended to contradict our finding of complete reversion. Teratocarcinoma cell lines have been maintained in laboratory cultures rather than in the live animal, and have been shown to be capable of differentiating into many types of tissues. In Richard L.

Gardner's laboratory at the University of Oxford, Virginia E. Papaioannou and her colleagues injected such cultured teratocarcinoma cells into blastocysts (between 20 and 40 cells per blastocyst), implanted the blastocysts in foster mothers and obtained several chimeric mice. Most of these chimeras developed tumors a few months after birth. We believe the tumors may have resulted from the fact that the large numbers of cells injected were not able to become fully integrated during early development. Moreover, in the course of being cultured in a laboratory medium the tumor cells could have accumulated chromosomal and other abnormalities that were not necessarily implicit in the genetic or developmental makeup of the original embryonal carcinoma cells.

The overwhelming preponderance of evidence from cancer research through the years has seemed to justify an assumption that malignant transformation is a permanent change of state: "Once a cancer cell, always a cancer cell." Recent evidence from tumor research in both plants and animals suggests that the dogma may not always be applicable, at least for certain tumors. It is conceivable that transformation to the malignant state results not always from stable mutations in gene structure but sometimes from reversible, nonmutational changes in gene expression, which give rise to abnormalities in the course of differentiation and hence to neoplastic growth.

We hope to exploit the teratocarcinoma system to trace the origin and causes of malignant transformation and to investigate the mechanisms underlying the cellular interactions that sometimes bring about a reversion from the malignant state. Teratomas may not be unique in their ability to revert to normality. Our technique for introducing a teratocarcinoma cell into a mouse embryo and assaying its full potentialities in the living animal may be applicable to other neoplastic cells. If it is, we may be able to determine whether more specialized tumor cells have undergone stable genetic changes or are still flexible with respect to developmental potential and can, at least to some extent, become integrated into normal tissues.

The combination of our blastocyst-injection procedure with the technique of cell hybridization has recently opened up a new line of research on differentiation. The hybridization technique is valuable for identifying particular enzymes and other gene products and relating them to genes on particular chromosomes; the injection of tumor cells into blastocysts makes it possible to introduce hybrid cells into live animals and thereby attain a bioassay of the activity of those genes.

We have undertaken such combined

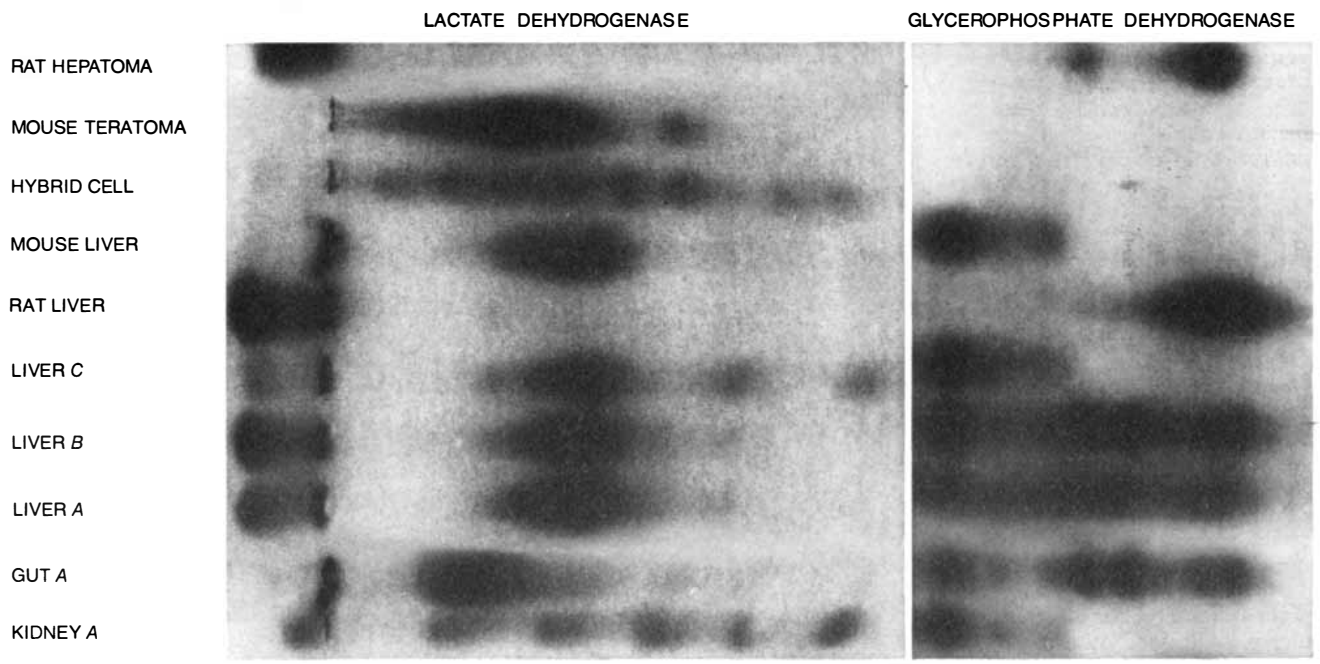
experiments in collaboration with Carlo M. Croce of the Wistar Institute of Anatomy and Biology in Philadelphia. In his laboratory, techniques for establishing varied cultured-cell lines derived from mouse teratocarcinomas were adapted to obtain teratocarcinoma cells that were deficient in a particular enzyme, thymidine kinase (TK). They were fused with cells from either human or rat tumor cells that were deficient in a different enzyme, hypoxanthine phosphoribosyl transferase (HPRT). Only the interspecific hybrid cells were able to grow in a special medium in which both parental cell types died [see "The Genetics of Human Cancer," by Carlo M. Croce and Hilary Koprowski; SCIENTIFIC AMERICAN, February, 1978].

In the selective medium the hybrid cells lost most of their human or rat chromosomes, but they retained the foreign chromosome with the genetic locus for TK, which was necessary for survival. The genes for TK and for the enzyme galactokinase are linked (both on a single chromosome) in man, in the rat and in the mouse. The human and the rat form of galactokinase can easily be distinguished from the mouse form by electrophoresis, which provides a biochemical marker for detecting the presence of the foreign gene product and thereby demonstrating the normal expression of the foreign genes in the hybrid cells. The retention of several rat chromosomes in the mouse-rat hybrid cells enabled us to search for a number of rat-specific enzyme forms, making possible a more extensive analysis of gene expression. Both kinds of interspecific cells retained their malignant properties, forming large tumors when they were implanted under the skin of "nude" mice (which have impaired immunity and would therefore accept the foreign-tissue graft).

We decided to explore the full potential of these hybrid tumor cells in an environment promoting normal differentiation. Together with Peter C. Hoppe of the Jackson Laboratory and our colleagues at the University of Geneva we transplanted single hybrid cells into genetically marked blastocysts, developed the blastocysts in foster mothers and obtained several healthy chimeric mice in which the hybrid tumor cells could be shown to have contributed to the coat and to various internal organs. Apart from one liver tumor none of the tumor-derived tissues showed any structural abnormalities. Apparently the malignant hybrid cells had differentiated normally and were integrated into the new generation of mice during development.

Foreign gene products were also detectable in the chimeric mice. The human form of galactokinase was found in the heart of one chimera and in the kidneys of another. The rat forms of nine different enzymes were recovered from several organs of three adult chimeras. The fact that some rat-gene products discovered in the animals had not been detectable in the hybrid cells in the culture medium and that the chimeras also produced heteropolymers (hybrid molecules composed of both the rat and the mouse forms of certain enzymes) demonstrated that the foreign genes were being functionally expressed in the adult animals. The synthesis of enzyme variants that are found only in adults further indicated that rat-gene expression continued to be modulated as the chimeric mice developed. We are now extending the analysis to other genes in an effort to learn at what developmental stage they are expressed and how they influence differentiation and disease, and ultimately to understand the mechanisms that control gene expression.

The 25 years of research with experimentally induced mouse teratomas have yielded a number of insights into the origin, genetics and developmental properties of these unusual tumors. The striking observation that the malignant stem cells of teratocarcinomas contribute to normal tissue differentiation in chimeric mice has drawn attention to the fact that the neoplastic state can sometimes be reversed. Now that we can hybridize embryonal carcinoma cells and thereby make them carriers of foreign genetic material for integration into an excellent bioassay system—the tissues of a developing animal—the way should be open for new advances in the study of mammalian differentiation and of the process of neoplastic transformation and its reversion.



RAT ENZYMES are detected in extracts from the organs of three chimeric mice (*A, B, C*) derived from blastocysts injected with mouse-rat hybrid cells. The first five electrophoresis bands from the top show the migration patterns of two enzymes, lactate dehydrogenase (LDH) and glycerophosphate dehydrogenase (GPD), in the rat hepatoma and mouse teratocarcinoma cells, in the hybrid cells and in normal mouse and rat liver. The next five bands document the presence of rat enzyme variants in the liver of all three chimeras and in the gut and kidneys of chimera *A*. Rat-gene function during mouse development is attested to by several results: there is GPD activity in the chimeras that was not present in the mouse teratoma or the hybrid cells; there are rat-mouse heteropolymers (for example GPD in the liver of *A* and *B* and the gut of *A*); there is an adult form of rat LDH (in liver of *A, B* and *C* and kidneys of *A*) that was not detectable in hybrid cells.

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Chinese Oracle Bones

In the Shang dynasty of 3,000 years ago aristocrats liked to seek the advice of their ancestors. The questions, engraved on bone or on turtle shell, are clues to the origins of Chinese civilization

by Hung-hsiang Chou

Of the world's great ancient civilizations the only one that survives in recognizable form is the civilization of China. Two elements have contributed to this longevity: a system of writing that can be traced back for more than 6,000 years and a pattern of religious beliefs emphasizing ancestor worship and a reverence for the past in general. It would appear to be no coincidence that both elements were closely linked some three millenniums ago, in the latter part of China's first great dynastic period. In that period, the Shang dynasty, the earliest mature form of Chinese writing began to be employed for a religious purpose: to seek supernatural advice by divination.

The divining technique of the final centuries of the Shang called for the preparation of "oracle bones," most commonly the shoulder blade of an ox or the plastron (bottom shell) of a turtle, in a special way, so that subsequent heating would form cracks on the surface of the material. After the oracle bone had been prepared the diviner engraved his questions on its smoothed surface, exposed the bone (or the shell) to heat and judged from the cracks that appeared whether the oracular answers to his questions were favorable or otherwise.

Today it is hard to believe that this early Chinese writing was unknown even to the Chinese less than a century ago. It was not until 1899 that an ailing scholar in Peking accidentally came on examples of such Shang inscriptions. His name was Wang, his field was etymology and we owe the discovery to his trust in traditional Chinese medicine. Among the scores of folk remedies long applied in China is one that prescribes "dragon bones." These are various bits of bone and shell; the majority of them are ancient and some are actually fossil bones. What they have in common is that one of their major constituents is calcium. Powdered calcium is effective as a coagulant of blood, and so it is not surprising that pulverized dragon bone was often applied to cuts.

For Wang's illness his physician prescribed, among other things, dragon bone. Wang's servant brought back from a pharmacy a packet of folk medicines, including a few pieces of bone. As Wang examined his purchase he was surprised to see that some of the bones were inscribed with what appeared to be a very primitive form of Chinese writing. He immediately sent his servant back to the pharmacy with instructions to buy up all its dragon bones, and thus among the medicinal bones were rediscovered the oracle bones of the ancient Shang.

I say rediscovered because accounts of early Chinese history do mention this Shang system of divination. Until Wang's purchase, however, no one had identified the occasional inscribed dragon bone as being one of the Shang artifacts. Now, as word of Wang's find began to spread, professional collectors of Chinese antiquities developed a new passion. Pharmacies were soon stripped of their supply of inscribed bones, forgeries began to appear and the high prices offered by collectors led to illegal digging in a recognized source of Shang antiquities: the Anyang area of Honan province, some 500 kilometers south of Peking.

The Chinese government put a halt to this private grave robbing, and archaeologists under the direction of the Academia Sinica, the nation's principal scholarly organization, excavated 15 separate Anyang sites between 1928 and 1937, when the Japanese invasion of China brought the work to a temporary halt. During the 10-year campaign the excavators uncovered a total of nearly 20,000 oracle bones. The huge collection proved to be the most important single source of material for the oracle-bone studies of the ensuing decades.

In the same years when the work at Anyang was in progress many foreign scholars in China took up the study of Shang divining practices and shipped home their own collections of oracle bones. For example, the first oracle bones to reach the U.S. are now part of the Couling-Chalfant collection at the Carnegie Institute Museum in Pittsburgh. Frank H. Chalfant, an American, was also the first Western Sinologist to publish studies of oracle-bone inscriptions. Also attracted to this new field of study were scholars in Canada, Britain, France, Germany, the U.S.S.R. and Japan.

Needless to say, many Chinese scholars also did pioneer work in the field. Among them was Kuo Mo-jo, who until his recent death was also a prominent political figure in the People's Republic of China, responsible for archaeological and other cultural affairs. The work of Sinologists both in China and elsewhere in the years since Wang made his purchase in Peking has resulted in the publication of more than 2,000 scholarly books and articles on the subject of oracle bones.

These 80 years of study have greatly enlarged knowledge of early Chinese divining practices. For example, it is now known that the Shang diviners were not the first to heat ox shoulder blades until they cracked and then interpret the cracks in an oracular manner. The practice goes back to Neolithic times, at the end of the fifth millennium B.C. The Neolithic farmers of China had by then been familiar with the shoulder

ORACLE-BONE INSCRIPTION in the photograph on the opposite page is one of several engraved on the shoulder blade of a sheep. It is specimen No. 974 in the Couling-Chalfant collection of Shang oracle bones at the Carnegie Institute Museum in Pittsburgh. The sheep bone was unearthed in the vicinity of Anyang, the last Shang capital. The Chinese writing is in the simple style characteristic of the later Shang dynasty. The divination took place on the 34th day. The paired inquiries are: On the 37th day, will it rain? On the 37th day, will it not rain?

SHANG REALM near the end of the second millennium B.C. extended from what is now Liaoning province in northern China westward to what is now Shensi province and thence southward below the Yangtze River. The southern boundary (*broken line*), like the boundary on the Yellow Sea to the north, is not precise. A recently reported discovery in Kwangtung province (*x*) implies that Shang authority extended 1,200 kilometers south of the capital, Anyang.

blades of oxen for at least 2,000 years: they used them as spades. The Neolithic diviners wrote no questions on their oracle bones. The reason probably was that the number of written characters devised up to that time was small. (Archaeological findings indicate a total of about 40.) The characters seem to have been mostly numerals or clan names. With such limitations it is difficult to frame questions.

For example, what may be the most complex Neolithic written statement discovered so far is incised on a 5,000-year-old pot excavated at Ta Wen K'uo, a site in Shantung province. The inscription combines three characters, which in order from top to bottom appear to represent the sun, fire and mountain peaks. The inscription might be rendered literally as "fire under the sun and on top of the mountain peaks." A freer rendering might be "extraordinary heat" or even "brush fire." In any event the Chinese written repertory in Neolithic times was quite limited.

The Neolithic practice of unwritten divination continued and became even more complex in the shadowy period that precedes the Shang: the Hsia dynasty, which is traditionally dated from the 21st century B.C. to the 16th. The Hsia was believed by many scholars to be only a legendary dynasty, but archaeological investigations in recent years have discovered a number of Hsia sites.

By Shang times the diviners began to write their questions on one side of the oracle bone, having prepared the opposite side of the bone to make sure that the cracks would appear. The diviners also gradually became displeased with shoulder blades, which were irregular in shape and hard to prepare for inscription. A turtle plastron was more symmetrical, more appealing to the eye and easier to handle. By the time oracle-bone divination had reached its peak, during the last three centuries of the Shang, turtle shell had replaced ox bone as the principal material for inscription. This does not mean, however, that other kinds of oracle bones disappeared. The shoulder blades of oxen continued to serve, as did those of goats and sheep, the carapace (top shell) of turtles, pieces of antler and even human cranial bones.

At the height of its power Shang China was one of the great nations of the world. The realm extended from Shensi province in the west all the way to the Yellow Sea and from Liaoning province in the north to beyond the Yangtze River in the south. The last of the Shang kings, however, appears to have been unworthy of his heritage: a fondness for drink contributed to his overthrow in the 12th century B.C. His successors, the kings of the Chou dynasty, were a robust and even rambunctious lot. There is some irony in the fact that the unsettled Chou era (12th to third century B.C.) was the golden age of Chinese philosophy. Confucius, Mencius, Lao Tzu and the less well known Chuang Tzu all flourished in this period. Until recently it was believed divination went out of fashion with the founding of the Chou. Recent discoveries in Shensi province, where the Chou capital was located from the 12th century B.C. until early in the eighth century, demonstrate, however, that divination by oracle bones continued under China's new rulers at least until 1000 B.C. Not long thereafter the practice was for unknown reasons abolished.

The oracle-bone heritage nonetheless remains an enormous one. It is impossible to estimate how many thousands of inscribed bones and shells may have been pounded into powder for medicinal purposes and how many scores or hundreds are still hidden in private collections inaccessible to scholars. Both my own investigations and recent estimates published in China indicate that the number of inscribed specimens recovered from the Anyang sites alone totals about 100,000. The new Chou discovery is said to add 15,000 more oracle bones to the overall total. The study of these artifacts will occupy scholars for generations.

In any discussion of oracle bones two questions soon arise. First, how were the shoulder blades and turtle shells prepared for divination? Second, what kinds of inquiries were inscribed? I have done experiments that throw some light on the first of these questions.

Working with the shoulder blades of steers, I have tried to "flatten" and otherwise prepare the bones to receive an inscription. My instrument was a modern metal saw fitted with a detachable steel blade 17 centimeters long and a quarter of a centimeter wide. The unwanted projections on a shoulder blade are the spine on the reverse side and the higher parts around the shoulder socket. (The obverse side of the bone is naturally smooth.) To rid a single bone of these projections cost me four hours of labor and two broken saw blades.

To engrave an inscription on the obverse side of the bone I worked with a modern stainless-steel engraving knife. Although I am not unskilled in writing Chinese, I found it next to impossible to produce the kind of engraving most commonly seen on the oracle bones. I did not even attempt to make the pairs of pits (one round and shallow and the other *V*-shaped and deeper) that the Shang diviners scooped out on the reverse side of the bone. If I found my task

so difficult, working with steel tools, how much harder must it have been for the Shang, who had only knives or saws of bronze and engraving tools of soft jade?

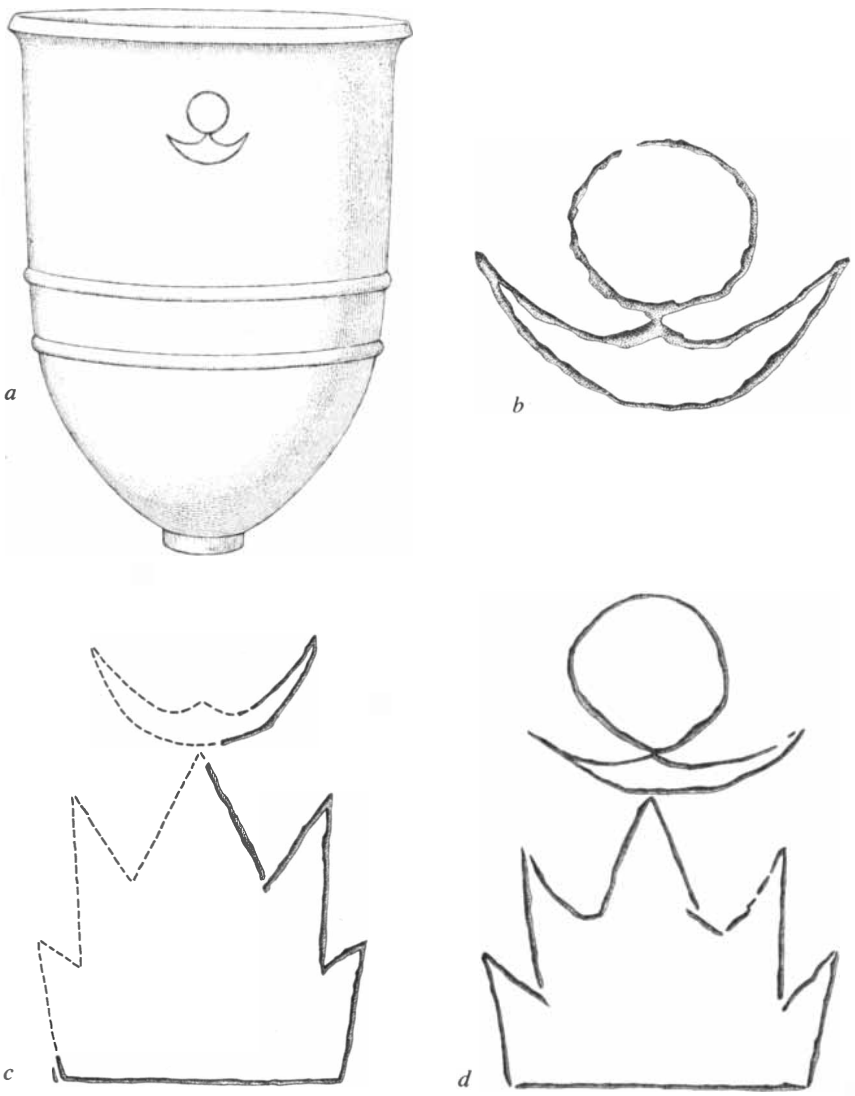
Had the diviners perhaps used only fresh bone? I tried that and found the work no easier. Had they perhaps softened the bones by boiling them? I tried that too, with the same result. Had they softened the bones in some other way? After wrestling with the question for some time I tried soaking steer bone and turtle shell in either wine or vinegar before setting to work. The bones and shells treated in this manner proved to be much easier to handle. Was this how the Shang diviners pretreated their oracle bones? Probably, but more research is needed before a definite conclusion is possible. What fluid was used? Was it rice wine or some other kind of wine? Was it vinegar? If so, what kind? Such studies might also illuminate the early stages of Chinese chemistry.

The pairs of pits the Shang diviners cut into the reverse surfaces of the oracle bones served a very practical purpose. The oracular response the diviners hoped to receive was a pair of cracks that would resemble the written character "pu," that is, a vertical line joined at about the midpoint from the right by a more or less perpendicular line. This simple character still exists in Chinese writing; its meaning is "divination" and its pronunciation (something like the sound "boh!" in English) is thought by some scholars to imitate the popping sound made by an oracle bone when it cracks under the application of heat.

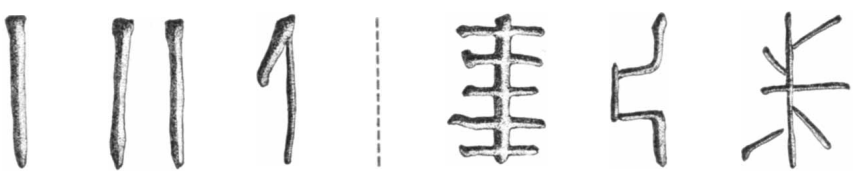
The *V*-shaped vertical gouge in each pair of pits ensured the appearance of the upright element of the "pu." Simple chance entered the divining process with respect to whether the perpendicular crack, ensured by the presence of a circular pit next to the vertical gouge, was perpendicular enough. If the perpendicular crack was more or less at a right angle to the upright crack, that is, within 20 degrees of an exact 90 degrees, the oracular reply to the diviner's question was considered to be affirmative. If the angle of the crack did not fall within this 40-degree range (from 70 to 110 degrees), the reply was negative.

One reason the Shang diviners may have come to prefer turtle shell is that the naturally symmetrical divisions of the shell into plates provide distinct areas for the placement of the paired pits. In practice the pits were made in matching numbers on both sides of the center line of the shell. Therefore, disregarding the single plate that straddles the center line, each half shell could hold a good many paired pits. Because the diviner's inquiries were traditionally presented in the form of antithetical questions this means that one turtle shell could provide responses to numerous inquiries [*see illustration on page 148*]. An ox shoulder blade had room for far fewer paired inquiries.

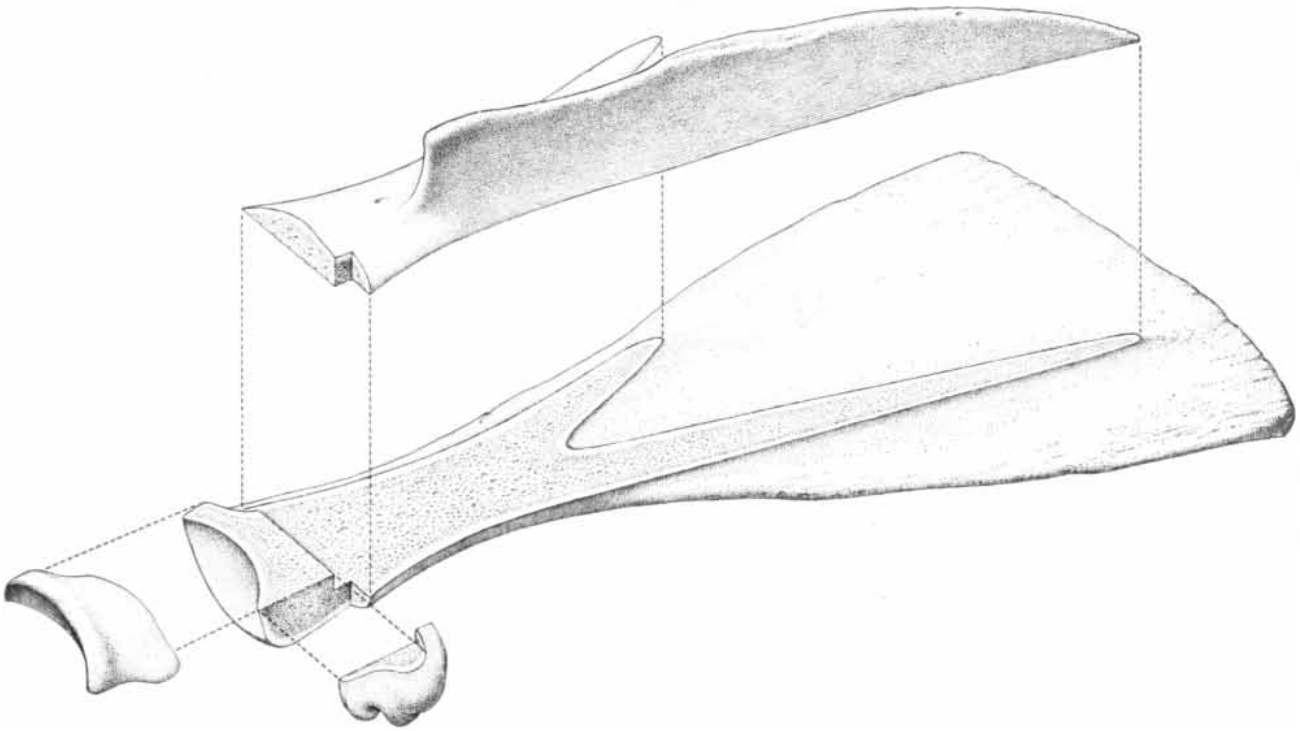
The Shang diviners sought guidance of several kinds. They inquired about future natural phenomena such as rainfall, thunderstorms, snow and fair weather. They also asked for forecasts about crops, hunting trips, travel of other kinds and military ventures. They questioned the advisability of certain kinds of religious ceremonies, the probable outcome of childbirth, the future course



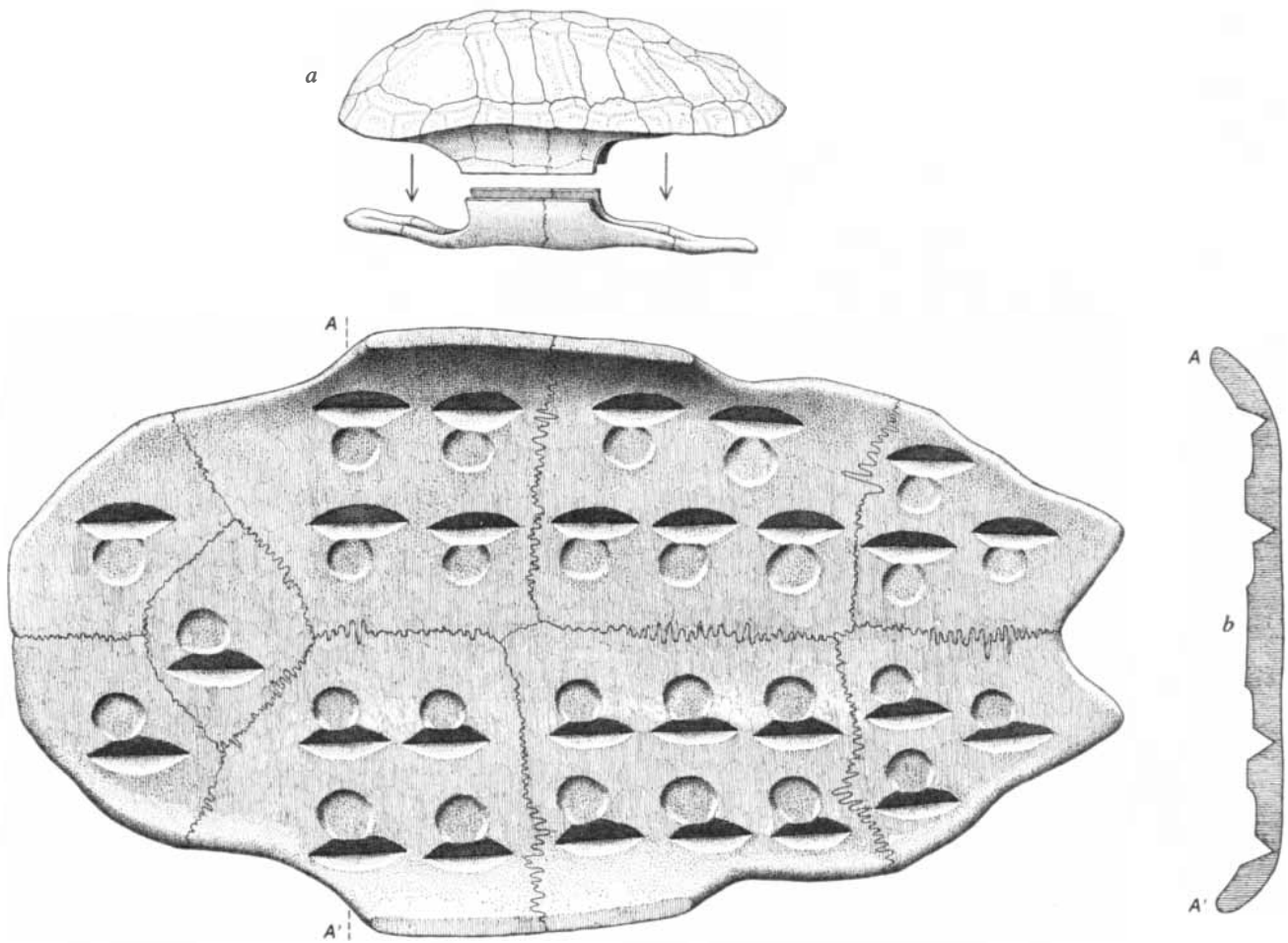
NEOLITHIC POTTERY of the fourth millennium B.C. from sites in Shantung province bears incised pictographs representative of some of the earliest-known Chinese writing. Near the lip of one pot (*a*) are two pictographs repeated in enlarged form at the right (*b*): a circle at the top, representing the sun, and below it a three-cusped crescent, representing fire. Incisions on a potsherd from a second site place the "fire" pictograph above a pictograph with five peaks, representing a mountain (*c*). Still another pot incision (*d*) arrays all three pictographs: "sun" over "fire" over "mountain." The three-character inscription may be read as "extraordinary heat."



OTHER NEOLITHIC CHARACTERS, inscribed on pottery from Pan P'o in Shensi province, are earlier and more cryptic than the Shantung pictograms. The three at left have been interpreted as numerals; the three more complex characters at right may represent clan "totems" or the names of tribes. The total number of Chinese Neolithic characters is less than 40.



OX SHOULDER BLADE was converted into an oracle bone by cutting off parts of the socket end (*left*) and the long protruding spine (*top*) on the back of the blade. The Shang diviners then cut pairs of pits, one deep and one shallow, into the back surface of the blade.



TURTLE BOTTOM SHELL was converted into an oracle bone by cutting through the bridge that connects the top and bottom shells (*a*). The pairs of pits, usually about 30 in number, were cut on the inside of the shell. Cross section (*b*) shows relative depths of four pairs.

of such illnesses as headache and toothache and even the meaning of dreams. Before I give a sample of these inscriptions it will help the reader to know something about the state of Chinese writing toward the end of the Shang dynasty.

It is customary to describe Shang writing as "mature." By this Sinologists mean the Shang made use of all five of the principles whereby a written character in the Chinese language may be invented. The first and simplest of these principles is what is called pictographic: the scribe draws a more or less realistic representation of an object, such as a turtle, a tree or a knife.

The second principle is called ideographic, or "indicative." For example, if the pictograph meaning "knife" is drawn with a mark beside it, this indicates that the meaning of the ideograph is "knife edge." Similarly, if two dots are added in the chest area to the usual pictograph for "female," a kneeling stick figure, this indicates that the meaning has been changed from "female" to "mother," the logic being that a mother feeds her infant from her breasts.

The third principle, called the suggestive compound, applies to somewhat more complex ideographs. For example, the modern Chinese word for "mass" or "masses" (in the sense of crowdedness) was written by Shang scribes as the stick-figure pictograph for a man, repeated three times, with the pictograph for the sun added overhead. Evidently to the Shang scribes the compound representation of three people working under the sun suggested crowdedness. Similarly, the Shang surrounded the pictograph for the sun with four simplified tree pictographs to symbolize a setting sun at the end of the day; the suggestive compound gave rise to the modern Chinese ideographic character for "evening."

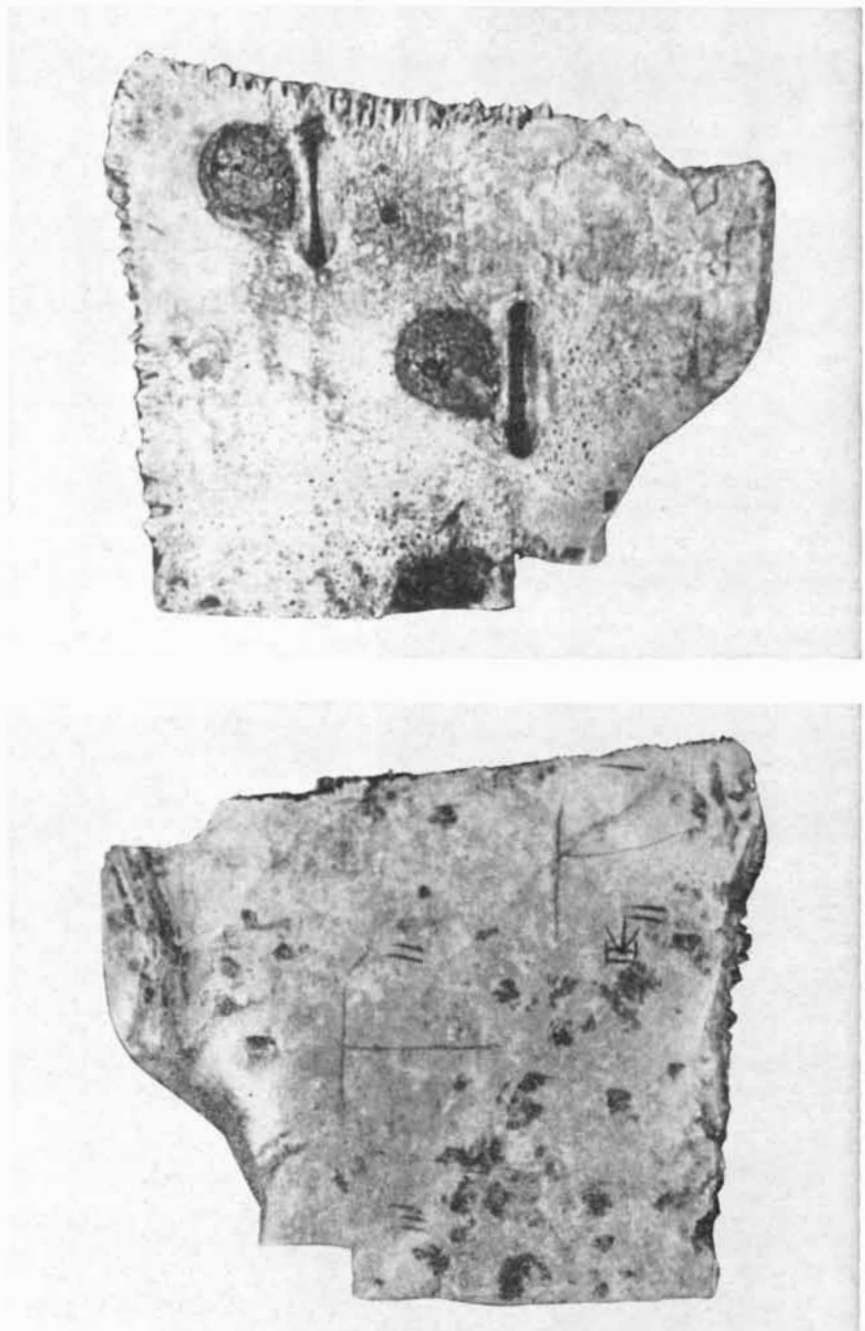
The fourth principle is a variation on the compounding of two or more radicals, as certain indicative ideographs are called. Here one of the components of the written character conveys the meaning intended and the other component indicates how the combination is pronounced. Most of the 50,000 characters in modern Chinese writing were formed according to this principle.

As a modern example take the sound "ch'ing" (the character "green"). This character can combine with the "sun" radical to mean "clear sky," with the "water" radical to mean "clear water," with the "heart" radical to mean "feeling" or "love" and with the "speech" radical to mean "please" or "to invite." All these compounds are pronounced *ch'ing,* although with different tones.

A good Shang example is the character "chiu," meaning "wine." It is a combination of two components: a pictograph of a jar (which is pronounced

"iu") and three cursive strokes representing "(running) water." These represent the liquid (the wine) inside the jar. The first component suggests the sound of the word; the second suggests the meaning.

The fifth principle is a further development of the preceding four. It is needed for the creation of characters to represent abstract concepts that cannot be expressed in pictures. The principle is applied by searching for an existing character that has the same sound as the abstract word. The choice among several like-sounding characters is based on the lowest probability of confusion in context. For example, in Shang times the word meaning "also" was pronounced "yi," but the scribes were apparently unable to invent an abstract character to express this important concept of "too-ness." As it happened, the Shang ideograph for armpits, a stick-figure man with a dot under each arm, was also pronounced "yi." "Armpits" and "also" were unlikely to be misunder-



PURPOSE OF PITS is demonstrated by these views of the back and front of the same fragment of turtle shell. Two pairs of pits appear on the back of the shell fragment (*top*); the dark color of the shallow pits is a result of the application of heat to that area. Visible on the front of the fragment (*bottom*) are two sets of cracks that were produced by applying heat to the back. Each set of cracks is in the general shape of the character "pu," indicating that the response to the diviner's inquiries, which were engraved on the front of the shell, was favorable.

stood in context, and so the anatomical "yi" was pressed into service to represent the abstract "yi."

To judge from the analysis of oracle-bone inscriptions now available, the Shang vocabulary consisted of some 4,000 characters, and most of them were invented in accordance with the five principles I have outlined. The majority of the characters represent nouns, but five of the other seven parts of speech in English (pronouns, verbs, adverbs, adjectives and prepositions) are also represented. The simple sentences the Shang scribes wrote were similar in grammatical structure to modern English. The basic sentence consists of a subject, a verb and an object, although the sentence can be varied rhetorically. An oracular record typically consists of two or three sentences. The average length of the inscription is between 10 and 15 characters; inscriptions that run to more than 50 characters have rarely been reported.

The pair of antithetical questions that compose the typical oracle-bone inscription were addressed to some ancestor, male or female, or to some other kind of supernatural being. The oracular ceremony itself followed the engraving of the questions on the obverse side of the bone or shell. The oracle bone was then turned to expose the reverse surface and heat was applied to the appropriate shallow round pits. A heated bronze rod may have been used for the purpose, but the scorch marks suggest that the instrument was often a burning stick or a glowing piece of charcoal. In any event the application of heat not only caused the adjacent *V*-shaped pits to produce vertical cracks on the obverse of the oracle bone but also caused the shallow pits to produce the matching roughly horizontal cracks.

Here are some examples of diviners' paired questions:

On the 15th day Diviner Cheng inquires: Will it rain tomorrow, the 16th? On the 15th day Diviner Cheng inquires: Will it not rain tomorrow, the 16th?

On the 31st day Diviner Ch'in inquires: Will the eastern region receive a good harvest? On the 31st day Diviner Ch'in inquires: Will the eastern region not receive a good harvest?

On the 27th day Diviner Pin inquires: Should the king conduct a military campaign this spring against the Yi barbarians? On the 27th day Diviner Pin inquires: Should the king not conduct a military campaign this spring against the Yi barbarians?

On the 39th day Diviner Ku inquires: Will Lady Hao be in good health after she gives birth to a baby? On the 39th day Diviner Ku inquires: Will Lady Hao not be in good health after she gives birth to a baby?

[No date or name] inquires: Will a

toothache cause the king trouble? [No date or name] inquires: Will a toothache not cause the king trouble?

Sometimes the outcome of a divined event is also recorded on the oracle bone. An example follows:

On the 55th day Diviner Ku inquires: Will we get [anything] when we hunt at Kuei? Record: On that day we hunted and killed one tiger, 40 deer, 164 wolves and 159 fawns. Also killed were a couple of foxes.

Some Sinologists see in the Shang practice of posing questions in antithetical pairs a foreshadowing of the yin-yang concept that plays a major part in Chinese philosophy. If this interpretation is valid, we can credit the Shang with nourishing still another Chinese tradition that remains honored today. Foremost among these traditions, observed if not initiated by the Shang aristocracy, is ancestor worship.

I have mentioned that the diviners usually addressed their inquiries to ancestors, that is, to the ancestors of those on whose behalf advice was sought. More than 95 percent of the oracle bones analyzed so far were used for this kind of inquiry. Of this large majority almost all were addressed to one or another male or female ancestor from a roster of some 70 different names. Complex ceremonial systems were developed solely for the worship of these 70 forebears, and a number of inscriptions record the ceremonies. This suggests that members of the aristocracy in the Shang period were religiously inclined and favored their own immortal ancestors above all other spirits.

The Shang were not, however, exclusively ancestor worshipers. Some inquiries were addressed to the shadowy eminence Shang-ti (literally "Heavenly Emperor," or "God"). Others were intended for lesser divinities, such as the local deities of rivers and mountains, of the sun, the wind and the clouds, and were even on occasion addressed to insects. One may see foreshadowed in this wide-ranging pantheon another traditional Chinese attitude: tolerance with regard to religious diversity.

SHANG CHARACTERS (*left column*), many of them pictographic in nature, became increasingly stylized as Chinese brush-and-ink writing developed (*left to right*). Shang and succeeding pictographs in the first two rows show a turtle (*first in plan view*) and tree branches and roots (*profile*). The next four rows show how pictographs can be compounded into ideographs. In the third row two dots added to the Shang pictograph for "female," a profile of a kneeling figure, give rise to the ideograph "mother" (a breast-feeding female). In the fourth row the Shang pictograph for "sun" is above the pictograph for "man," a standing figure in profile repeated three times; the combination forms the ideograph for "masses." In the fifth row the Shang pictograph for "sun" is surrounded by simplified "tree" pictographs; the resulting ideograph, implying sunset, evolved into the modern character for "evening." Finally, when the pictograph for "knife" (*first and third*) has a mark added (*second and fourth*), it becomes the ideograph representing "edge of a knife." The left pair are oracle-bone characters; the right pair are modern printed Chinese. The Shang vocabulary included some 4,000 characters.

There is a small fraction of oracle bones that played no role in divination. The inscriptions they bear are of two kinds: calendrical records and records of tribute payment. For reasons not known the calendrical notations were made exclusively on ox shoulder blades. Tribute records appear on both bone and turtle shell; characteristically they were engraved inside the hollow of the shoulder-blade socket, on the stumps of the turtle shell or on its two "tail" scales.

The Shang calendar was a lunar one built around a repeating cycle of 60 days: six weeks, each 10 days long. The cycle of 60 is the result of combining two ancient series of symbols: the 10 "heavenly stems" ("t'ien-kan") and the 12 "earthly branches" ("ti-chih"). This cosmological device may have evolved from the ancient Babylonian zodiac. The cycle of 60 survives in China today, although its main application is in counting a cycle of 60 years rather than 60 days. In any event, because of its lunar base the Shang calendar required readjustment at regular intervals, usually the addition of a leap month (known as the 13th month in oracle-bone inscriptions) every third year.

As for the tribute records, the Shang rulers appear to have been the overlords of a feudal society (although this conclusion remains controversial). At least the inscriptions record payments of trib-

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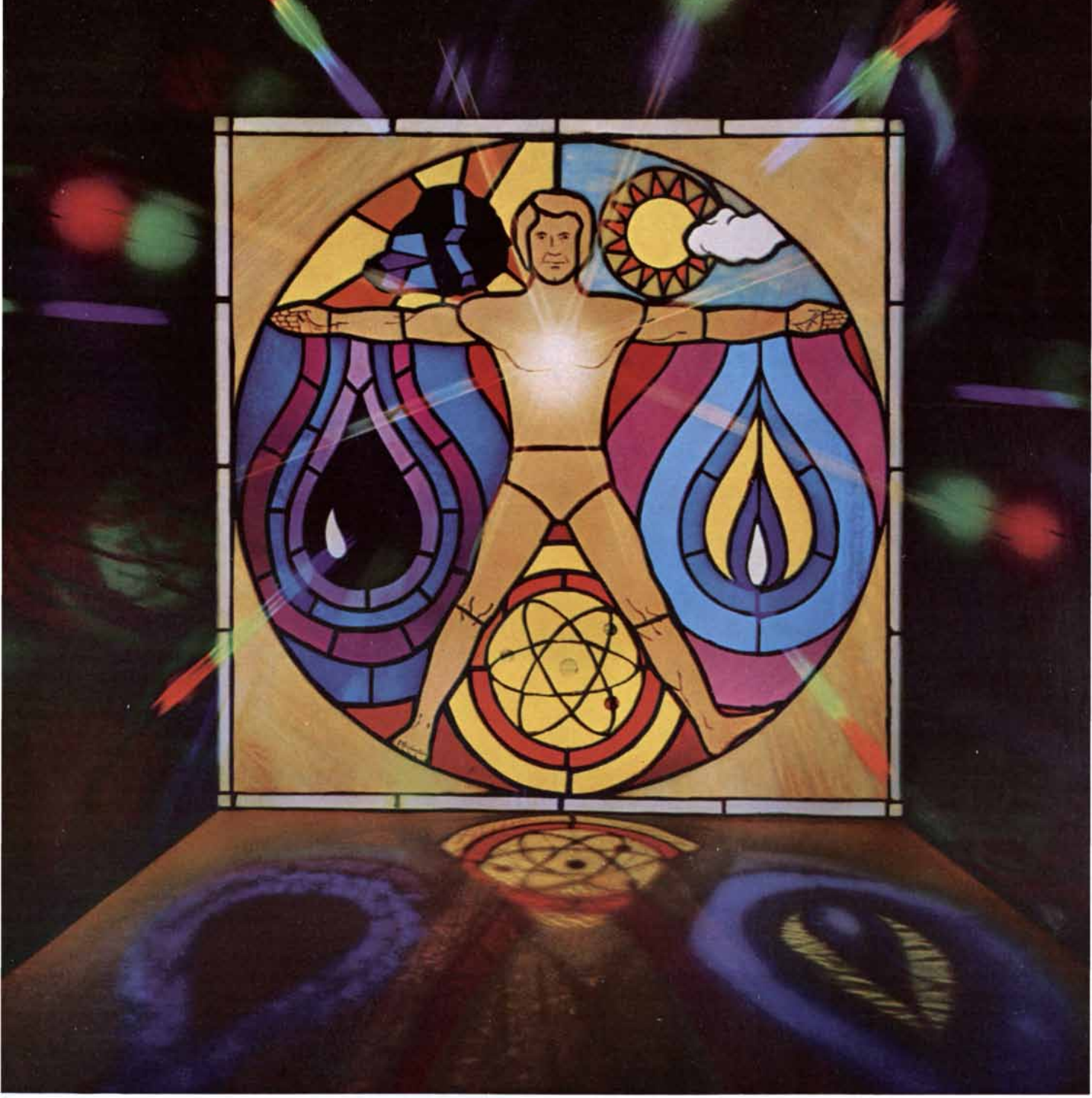
ute to the royal court, and the records include numerous place-names that can be interpreted as the homes of the vassals who offered tribute. Intensive research by a number of scholars has suggested the geographical location of these place-names and others mentioned in the oracle-bone inscriptions. Although the conclusions are tentative, the Shang political domain may have been greater in extent than has been supposed. Recent archaeological findings lend weight to such a conclusion. While I was visiting China last summer I was told that a Shang site had just been unearthed near the east coast of Kwangtung province, some 250 kilometers east of Hong Kong. That location is about 1,200 kilometers south of Anyang, the later Shang capital, and is by far the southernmost Shang site yet discovered.

The nondivining inscriptions, at least for the present, are too few to have more than a limited significance for students of the Shang period. For such topics as the origin of the Shang people, the struc-

ORACULAR CRACKS resembling the written character "pu" are readily visible on this fragment of turtle shell because the crack lines were emphasized after the divination. When the horizontal crack was perpendicular to the vertical crack or within 20 degrees of the perpendicular, the oracular response was deemed favorable by the diviner; outside that range the response was unfavorable. Inset below the photograph is the character "pu" in modern printed Chinese.



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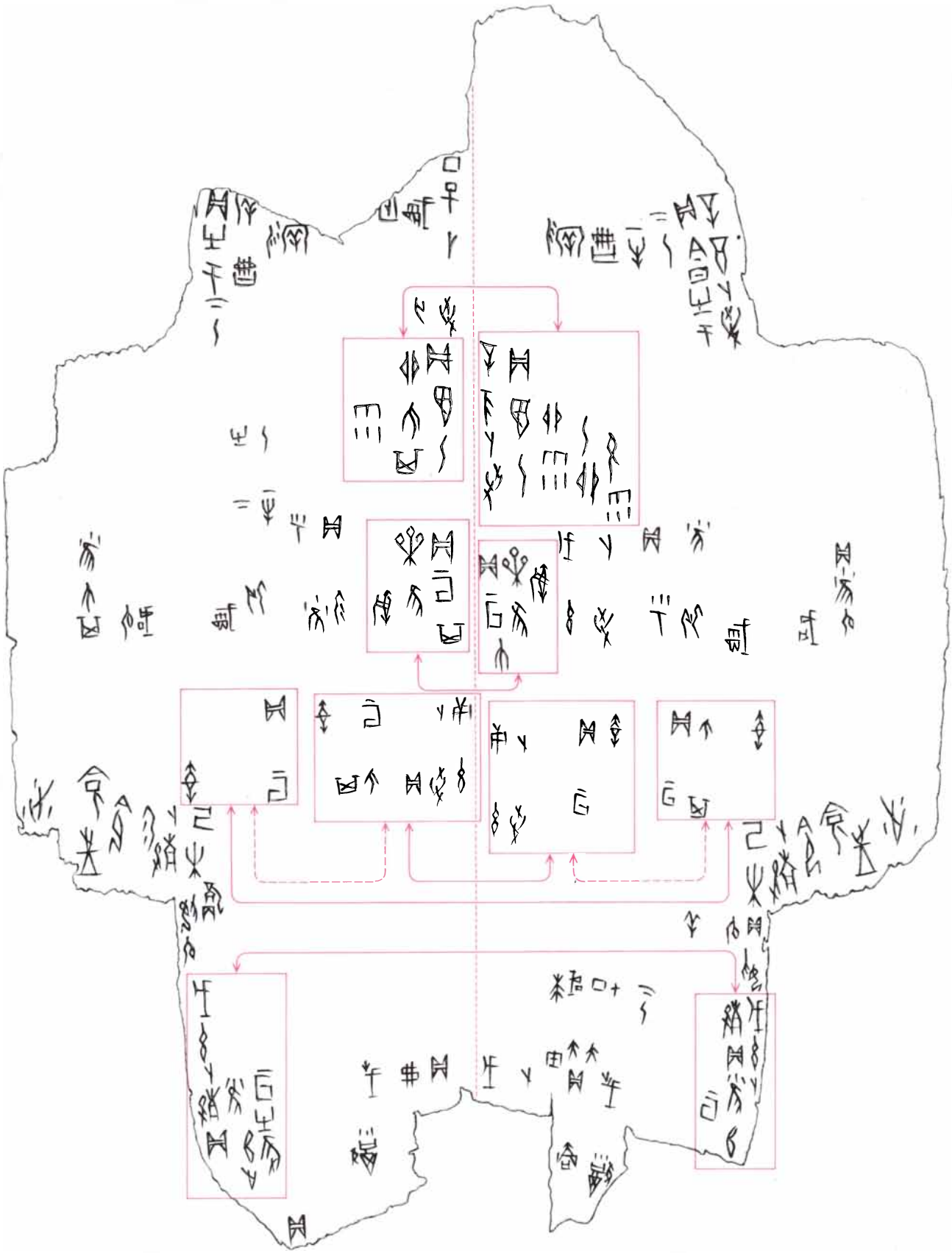


SCORES OF QUESTIONS were inscribed on this single turtle shell, recovered nearly intact from an Anyang excavation. The diviners who inscribed them, Cheng and Ku, wrote their questions in antithetical fashion on opposite sides of the center line of the shell. Boxes and solid arrows identify five such pairs; broken arrows show that four of the questions comprise two independent sets of two questions each.

ture of their government, the relations between the ruling class and the peasants and slaves, the nature of the economy and the varieties of agriculture, and for such social questions as the nature of marriage practices and the relative status of the sexes, students of this era of Chinese cultural emergence must depend almost entirely on the questions asked by the Shang diviners.

As an example of what can be learned, consider the status of women and in particular what scholars have pieced together about that same Lady Hao on whose behalf Diviner Ku inquired about an impending childbirth. The oracle bones suggest that aristocratic Shang women enjoyed a relatively high status. Their lot was certainly better than that of the upper-class women of the Chou, if we may judge by inscriptions on bronze vessels, by historical writings and by passages in the Confucian classics. According to these sources, Chou women were for the most part confined to their chambers and were barred from taking part in public activities.

This was not true of Lady Hao. In the numerous divinations undertaken on her behalf questions are asked not only about childbirth but also about the success of her religious rituals and even about her military enterprises. Some of the inscriptions refer to her as a royal consort, some as a feudal vassal and some as a military commander with the rank of general. On a turtle-shell fragment now in the Gulbenkian Museum of Oriental Art and Archaeology in England it is recorded that Lady Hao commanded one of two columns sent to fight a regional enemy. Her fellow officer, a man, led a force of 10,000 men. Lady Hao's force numbered 3,000. And Lady Hao was by no means the only Shang woman to enjoy such status. The oracle bones mention more than 100 other women by name; many of them actively took part in religious, political and military activities.

In 1976, by a happy coincidence, the archaeologists at work in the Anyang area located and excavated Lady Hao's tomb. The discovery, which has not yet been formally reported, more than confirmed the high status of this Shang aristocrat implicit in the oracle-bone inscriptions. Her tomb contained, according to preliminary accounts, 16 human sacrifices, more than 500 articles of carved stone and jade, more than 400 bone carvings, scores of bronze weapons, tools and mirrors, numerous musical instruments and some 200 bronze vessels, including a square basin of record size.

The example of Lady Hao is only one of the fascinating glimpses into the lives and activities of the people of the Shang that the oracle-bone inscriptions afford us, even though these lives are separated from our own by three millenniums.

The Physics of Karate

A close examination of how the karate expert can break wood and concrete blocks with his bare hand reveals the remarkable capacity of the unaided human body for exerting physical force

by Michael S. Feld, Ronald E. McNair and Stephen R. Wilk

The picture of a karate expert breaking stout slabs of wood and concrete with his bare hand is a familiar one. The maneuver is so extravagant that it is often dismissed as some kind of deception or illusion, but the fact is that there is no trick to it. Even a newcomer to karate can quickly learn to break a substantial wood plank, and soon he would be able to break entire stacks of them. We have investigated in detail how the bare hand can break wood and concrete blocks (and by implication do similar damage to other targets) without being itself broken or injured. The key finding is that the hand of the karateka, or practitioner of karate, can develop a peak velocity of 10 to 14 meters per second and exert a force of more than 3,000 newtons, a wallop of 675 pounds. If the hand is positioned properly, it can easily withstand the resulting counterforce.

The maneuvers of the Japanese style of karate that is practiced today were developed on the island of Okinawa. When the Japanese conquered the island in the 17th century, they stripped it of all weapons and banned their making and importation; even the manufacture of swords for ceremonial purposes was forbidden. To defend themselves the Okinawans developed karate, a system of empty-hand combat based on the weaponless fighting methods of ancient Chinese monks, warriors and physicians. Karate is just one of a wide variety of martial arts that have evolved in the Orient, including tae kwon do, kempo and kung fu.

The techniques of karate differ markedly from those of Western methods of empty-hand combat. The karateka concentrates his blows on a small area of the target and seeks to terminate them about a centimeter inside it, without the long deliveries and follow-throughs of the punches in Western boxing. Whereas the Western boxer imparts a large amount of momentum to the entire mass of his opponent, pushing him back, the karateka imparts a large amount of momentum to a small area of his opponent's body, an amount that is capable of breaking tissue and bone. A well-executed karate strike delivers to its target several kilowatts of power over several milliseconds, quite enough to break blocks of wood and concrete.

Today karate is practiced as a sport and as a potential method of self-defense. The karateka studies many different maneuvers so that he can execute each one in a precisely prescribed manner. The precision demanded of him makes karate not only an excellent physical discipline but also a mental one. Although the breaking of objects is not the point of karate, we shall discuss it here because it is a good way of demonstrating how much energy a well-executed karate strike can deliver. Karate seems to develop to a maximum the capacity of the unaided human body for exerting physical force.

The wood blocks we used in our experiments were standard pieces of dry white pine that weighed .28 kilogram and were 28 centimeters long, 15 centimeters wide and 1.9 centimeters thick. They were cut so that the grain was parallel to the width. The concrete slabs were "patio blocks" that weighed 6.5 kilograms and were 40 centimeters long, 19 centimeters wide and four centimeters thick. The patio blocks were dried in an oven for several hours to remove excess water, thereby making them uniform in content. Under the ends of each block of wood or concrete a support was placed that reduced the effective length of the block by four centimeters.

In a block-breaking demonstration the karateka strikes the top of a block in a range of points near the center. In our experiments we assumed for the sake of simplicity that the force is evenly distributed in that range of points. We also assumed, and experiment subsequently confirmed, that the deflection, or bending, of the block when it is struck is quite small compared with its overall dimensions.

As a first step in understanding the physics of the breaking process, picture a fist moving toward a block supported at its ends. The impact will cause the block to bend in the direction in which the fist is moving. As the block is bent it is deformed: the upper half of the block is compressed and the lower half is stretched. The top surface is compressed the most and the bottom surface is stretched the most. Because wood and concrete are weaker under tension than they are under compression the block starts to crack at the bottom surface. The crack spreads rapidly upward as the fist continues to force the block downward.

The elongation of the bottom surface is caused by the force in the plane of the block that results from the impact of the fist. To put it another way, stress in this plane, or force per unit of cross-sectional area, gives rise to strain, or fractional elongation of the block. The relation between stress and strain is best understood by thinking of the bottom of the block as a horizontal coil spring. The block resists the stress pulling it apart just as the spring does. The spring pushes back with a force that is proportional to its extension. In other words, force equals extension multiplied by the spring constant, which for a given spring is a parameter that characterizes its stiffness. Since stress is analogous to force and strain is analogous to extension, an equivalent relation holds for the block: stress equals strain multiplied by the elastic modulus, which for a given material is a constant that corresponds to the stiffness of the material. When the stress reaches a critical value, called the modulus of rupture, the block breaks.

Since the stretching of a spring until it snaps is analogous to the breaking of a block, equations for the spring that yield formulas for the energy and force at the point of rupture also apply to the block. It turns out that the energy needed to break the block equals its volume (V) multiplied by the square of the modulus of rupture (σ) divided by twice the elastic modulus (E). This formula, $V\sigma^2/2E$, conforms to intuitions about the breaking process. It obviously takes more energy to break larger blocks and blocks that have to be subjected to greater stress. It is also not surprising that the

THREE CONCRETE SLABS are broken by one of the authors (McNair) with the heel of his right palm. Slabs were "patio blocks" that weighed 6.5 kilograms and were 40 centimeters long, 19 centimeters wide and four centimeters thick. The supports under the ends of the blocks reduced their effective length by four centimeters. Bone can resist 40 times more stress, or force per unit area, than concrete.

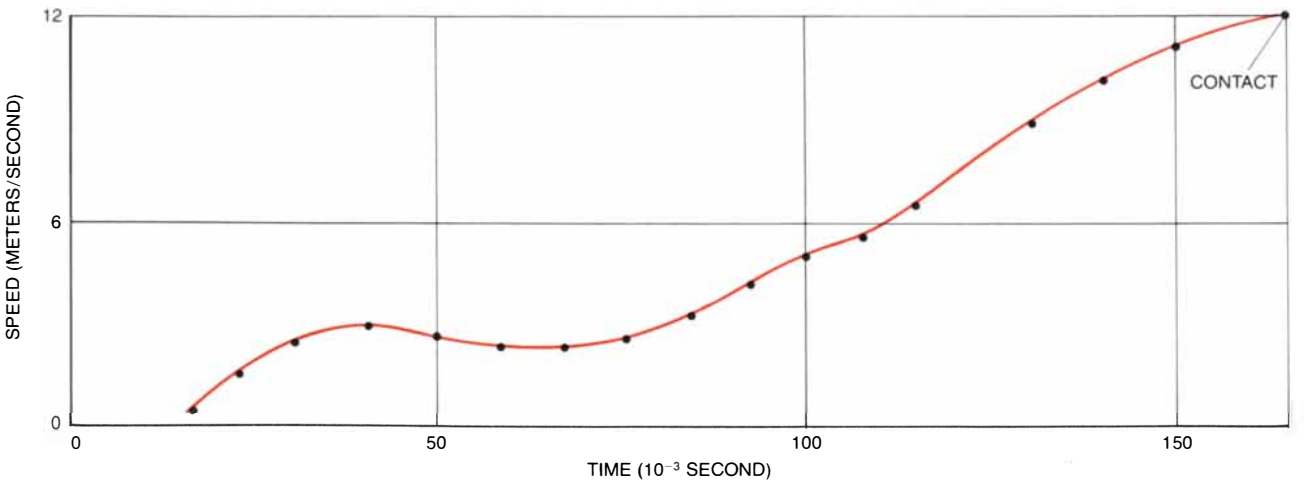
critical energy is inversely proportional to the elastic modulus. The elastic modulus is a measure of the stiffness of the block, and so stiff blocks have a lower critical energy because little energy is wasted in stretching them.

The formula provides only a rough estimate of the critical energy, because the physical properties of blocks are not as simple as those of springs. Nevertheless, it is useful because it indicates which parameters are important in the breaking process and how they are scaled with respect to one another. For example, the formula suggests that the critical energy is proportional to the square of the rupture modulus, and so if two materials have the same properties but rupture moduli that differ by a factor of 2, it takes four times more energy to break the material with the larger modulus.

Before critical energies can be computed from the formula it is necessary to know the modulus of rupture and the elastic modulus of both kinds of block. Because the appropriate values were not tabulated in the literature we measured these moduli ourselves by putting samples of wood and concrete in a hydraulic press and recording their deflection as a function of the applied force. Wood is a fairly elastic material, typically requiring about a centimeter of deflection before breaking. A force of 500 newtons will deflect it to that extent. (One newton is, appropriately, roughly equivalent to the force exerted by the weight of an apple.) A concrete block needs to be deflected by only one millimeter before breaking, but the deflection requires between 2,500 and 3,000 newtons. From these measurements we found the elastic modulus of wood is 1.4×10^8 newtons per meter squared and that of concrete is 2.8×10^9. The rupture modulus of wood is 3.6×10^6 newtons per meter squared and that of concrete is 4.5×10^6.

Putting these modulus values into the

ROTATING-DRUM CAMERA provided simultaneous side and front views of a hammer-fist strike, in which the fist is brought down from above the head in a circular arc. Here the fist is breaking four blocks of dry white pine, each .28 kilogram in weight and 28 centimeters long, 15 centimeters wide and 1.9 centimeters thick. The white-pine blocks were cut so that the grain ran parallel to the width.



SPEED OF THE FIST in the hammer-fist strike was determined by analyzing a sequence of drum-camera photographs, one of which is the photograph at the top. The fist reached a peak speed of 10 meters per second at the point of impact. Other sequences with the same subject yielded peak speeds as high as 14 meters per second. This strike is one of the most powerful karate maneuvers that involve the hand.

energy formula yields a critical energy of 32 joules for wood and 10 joules for concrete. (One joule is the energy needed to lift one kilogram 10 centimeters.) Such rough estimates of the critical energies seem to be the right order of magnitude, because measurements we made indicate that about 100 joules are available in a karate strike. Although these values for the critical energy are unreliable when they are considered individually, when they are considered together, they should give an adequate indication of the ratio of the energy needed to break wood to the energy needed to break concrete. The values suggest that the fist must deposit three times more energy in a wood block.

We made more precise estimates of the critical energy by considering the acoustical properties of the wood and the concrete slabs. When any object is struck, it vibrates, propagating waves through the material and sending sound waves into the air. The same phenomenon happens when the karateka strikes a block: vibrations are generated that sometimes deform the block to the breaking point. The properties of such vibrations can be predicted from a complex equation that describes the sound waves. The equation is a function of both time and the position along the length of the block, so that the vibration of the block depends on the shape it has immediately after the hand of the karateka strikes it.

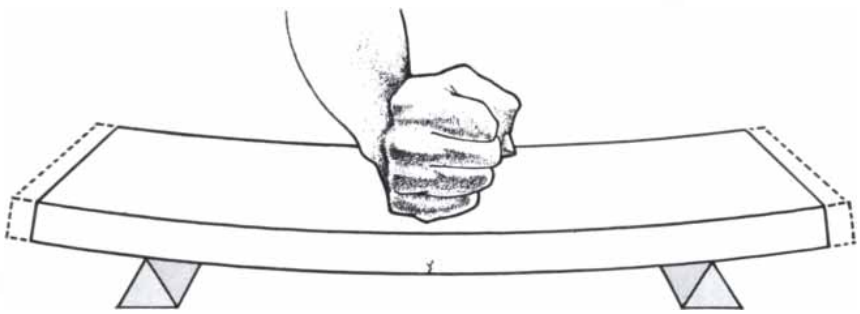
In this respect the block is similar to a violin string. When the string is plucked gently, only the fundamental tone is excited and the resulting motion is simple, but when it is plucked more vigorously, overtones are excited and the resulting motion is more complex. In a karate strike only the fundamental vibration is excited, because the hand and the target interact for several milliseconds. This interaction time is comparable to the period of the fundamental vibration but is much longer than the periods of the overtones. As a result the overtones are not sounded; there is simply not enough harmonic content to excite them.

Since only the fundamental tone is sounded, the equation that governs the motion of the block is simplified considerably. The block acts as if it were a mass, weighing half as much as the block actually weighs, sitting on top of a coil spring. The acoustical model yields a formula for the critical energy of the block. The formula indicates that the earlier rough estimates were six times too high. In other words, it takes only 5.3 joules to break wood and 1.6 joules to break concrete.

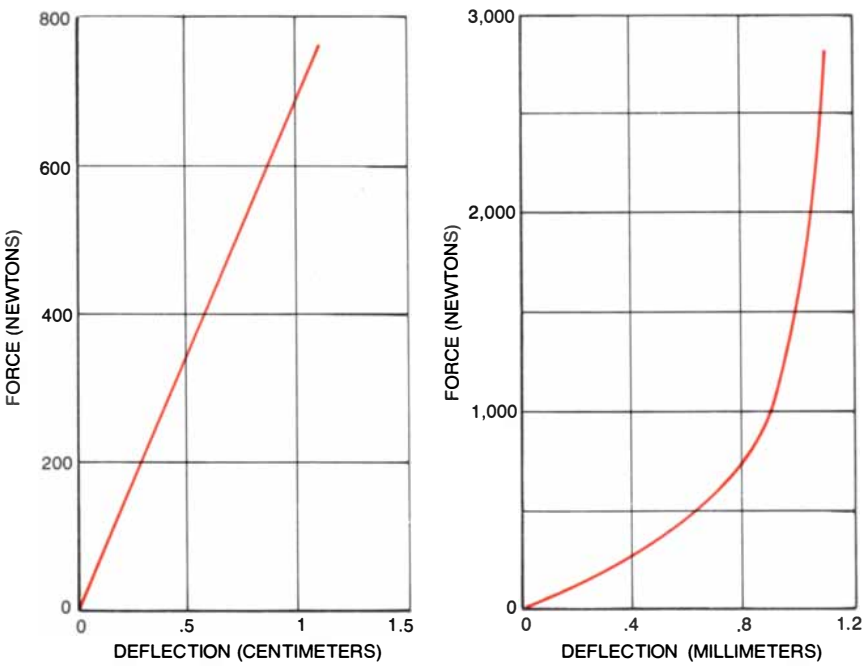
The acoustical model also yields formulas for the critical force needed to break the block and for the periods of the sound waves generated by the karate strike. We verified the predicted periods by lightly tapping blocks with a pen-

MANEUVER	PEAK SPEED (METERS/SECOND)
FRONT FORWARD PUNCH	5.7 – 9.8
DOWNWARD HAMMER-FIST STRIKE	10 – 14
DOWNWARD KNIFE-HAND STRIKE	10 – 14
ROUNDHOUSE KICK	9.5 – 11
WHEEL KICK	7.3 – 10
FRONT KICK	9.9 – 14.4
SIDE KICK	9.9 – 14.4

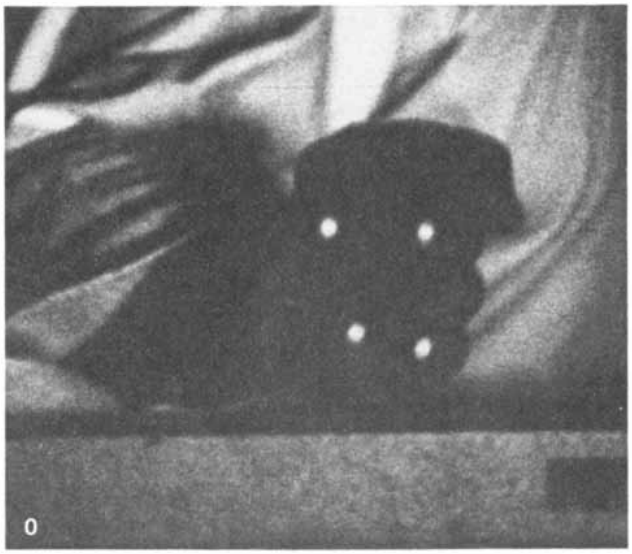
PEAK SPEEDS of karate maneuvers are listed first for empty-hand blows and then for kicks. The knife-hand strike is the "karate chop." In the roundhouse kick the foot moves in a clockwise circle as the opposite hand moves counterclockwise in order to keep the body balanced by minimizing net angular momentum. In the wheel kick the body rotates with the leg extended.

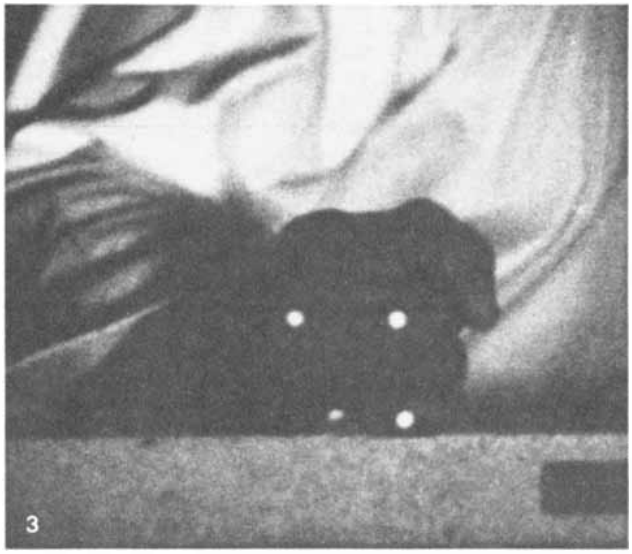


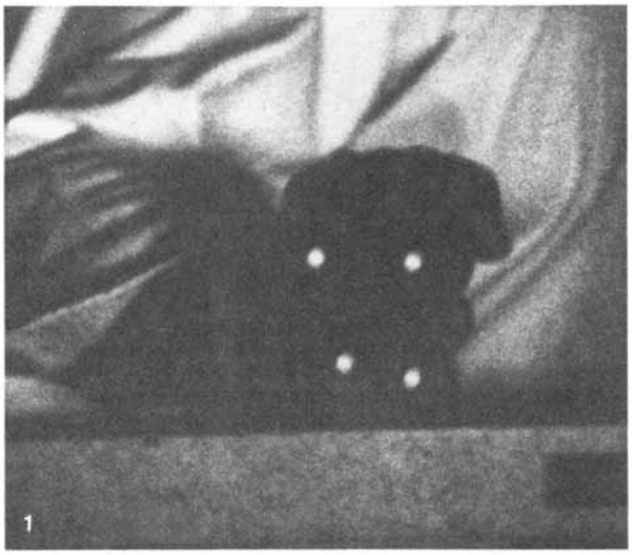
HAMMER-FIST STRIKE breaking a wood block is shown in a highly schematic diagram. In a well-executed strike the fist hits the block along a range of points near the center. The block acts like a coil spring: it pushes back on the hand with a force proportional to its deflection. The top of the block is compressed; the bottom is stretched. Because wood is weaker under tension than it is under compression the block cracks first on the bottom surface (near the center). The crack propagates rapidly upward as the block continues to be pushed downward.

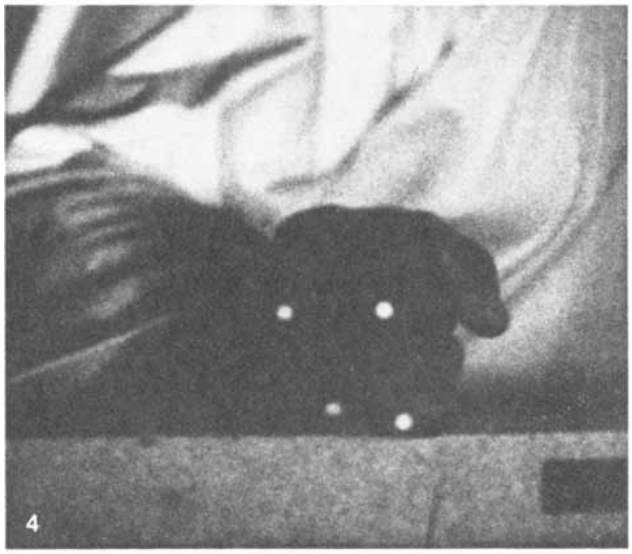


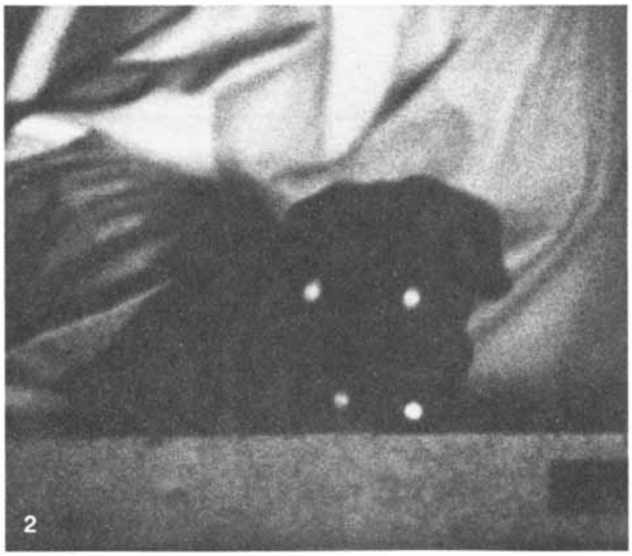
HYDRAULIC-PRESS MEASUREMENTS were made of the deflection of a wood block (*left*) and a concrete block (*right*) as a function of the applied force. Each of these plots yielded values for the elastic modulus, which for a given material is a constant that indicates its springiness, and for the modulus of rupture, which is the minimum stress that causes a block to snap. It is useful to know these moduli in order to find the energy needed to break each kind of block.

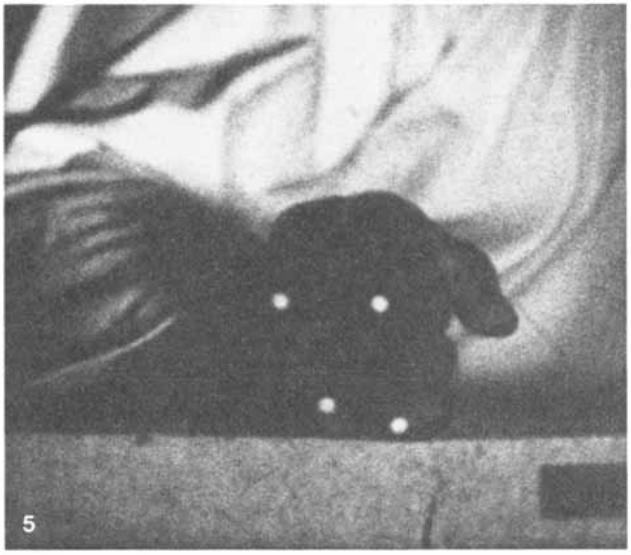












FOUR MARKER DOTS were put on the side of a fist so that the displacement, velocity and acceleration of different parts of the fist during the impact could be determined from these photographs, which were spaced a millisecond apart. Although the fist makes contact with the block at *0*, the crack does not develop until *4*. The fist and the block are in contact for five milliseconds. As the fist strikes the block it decelerates rapidly. The change in the positions of the dots with respect to one another indicates that the fist is compressed and distorted to such an extent that it scarcely acts like a solid object. Hence models of the impact process cannot consider the fist as being solid.

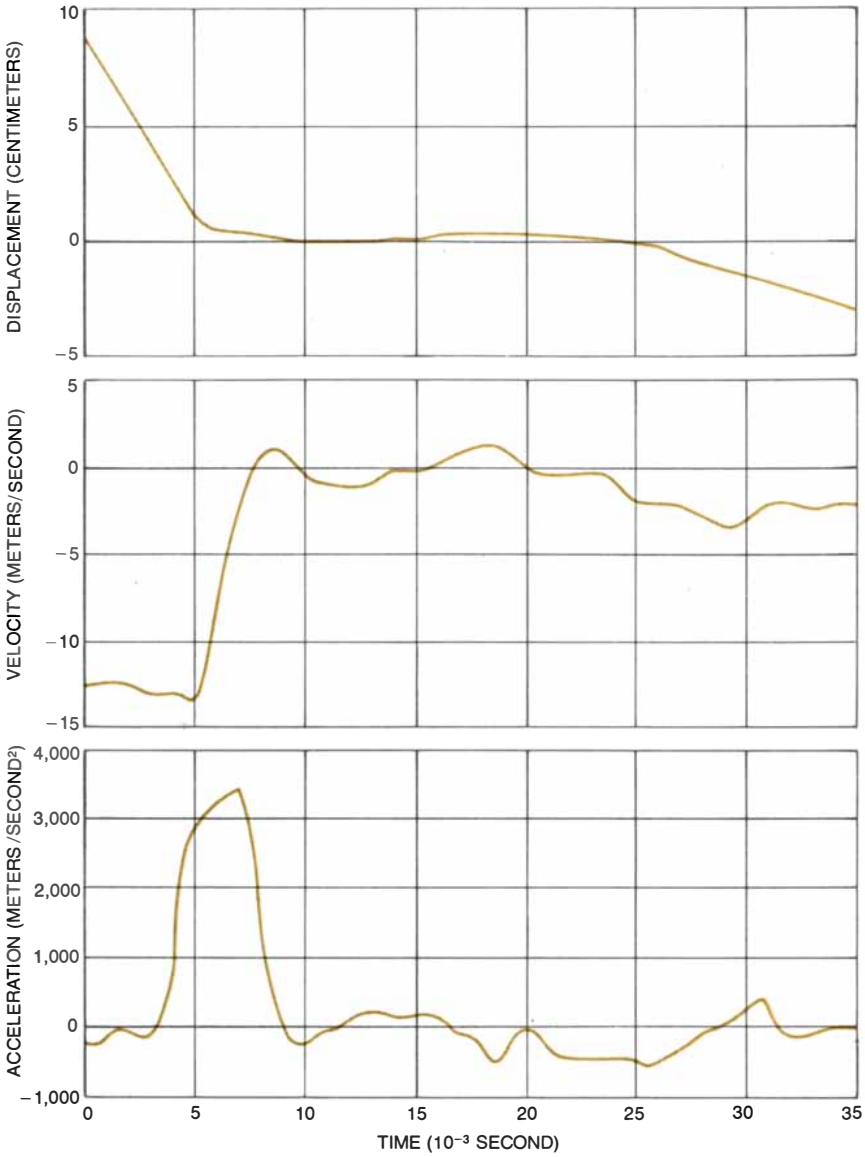
cil eraser and monitoring the resulting sound waves with a microphone hooked up to an oscilloscope. Oscilloscope pictures of the sound waves showed periods that were in reasonable agreement with the predicted values. That confirmed the validity of the acoustical model.

The formula for the critical force yields 670 newtons for wood and 3,100 newtons for concrete. Hence it takes almost five times more force to break concrete than to break wood but only a third as much energy. Energy is the product of force and deflection, and so the fact that wood is deflected 16 times farther than concrete is responsible for wood's having the larger critical energy.

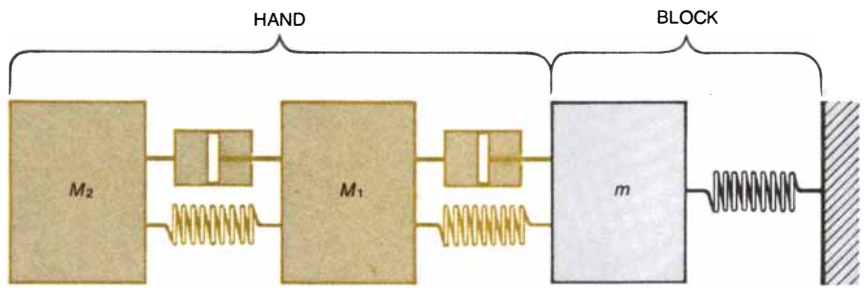
At first glance this result seems puzzling, because the larger critical energy of wood suggests that concrete is easier to break. Experience, of course, indicates the opposite. The puzzle is solved by the fact that not all the energy in the karate strike can be deposited in the target. Each critical energy we had computed represents not the energy of the karateka's hand but the energy that must be transferred to the target in order for it to break. The energy the hand needs depends on how easily energy can be transmitted from the hand to the target, which in turn depends on the relative masses of the hand and the target. When the target is less massive than the hand, as is the case with wood, it accepts most of the energy. When the target is more massive, as is the case with concrete, it accepts only a small fraction of the energy. That explains why wood is easier to break.

The role of mass in energy transfer can be made clearer by considering rubber balls. Think of a rubber ball thrown through the air. If the ball hits an identical ball that is at rest, the first ball stops and the second ball absorbs its energy and continues along the trajectory of the first ball. If, on the other hand, the ball hits a much heavier ball, the first ball rebounds at nearly the same speed and the heavier ball hardly moves. These two instances are examples of an elastic collision; in such a collision kinetic energy, or energy of motion, is conserved. In other words, the kinetic energy the first ball has before the impact equals the kinetic energy it has after the impact plus the kinetic energy the second ball has after the impact.

A karate strike is not an elastic collision. We made high-speed motion pictures showing that the hand and the target are in contact during the entire breaking process. On impact the hand and the block move together. In such an inelastic collision not all the kinetic energy in the hand becomes kinetic energy in the combined system. Some of the energy unavoidably is expended in deformation: the flattening of the hand and the target against each other. The heavier the target is, the less the kinetic



VERTICAL DISPLACEMENT, velocity and acceleration are plotted for the dot at the lower right on the fist in the photographs on the opposite page. The peak deceleration of the dot was 3,500 meters per second squared; that of the other dots was 4,000 meters per second squared.

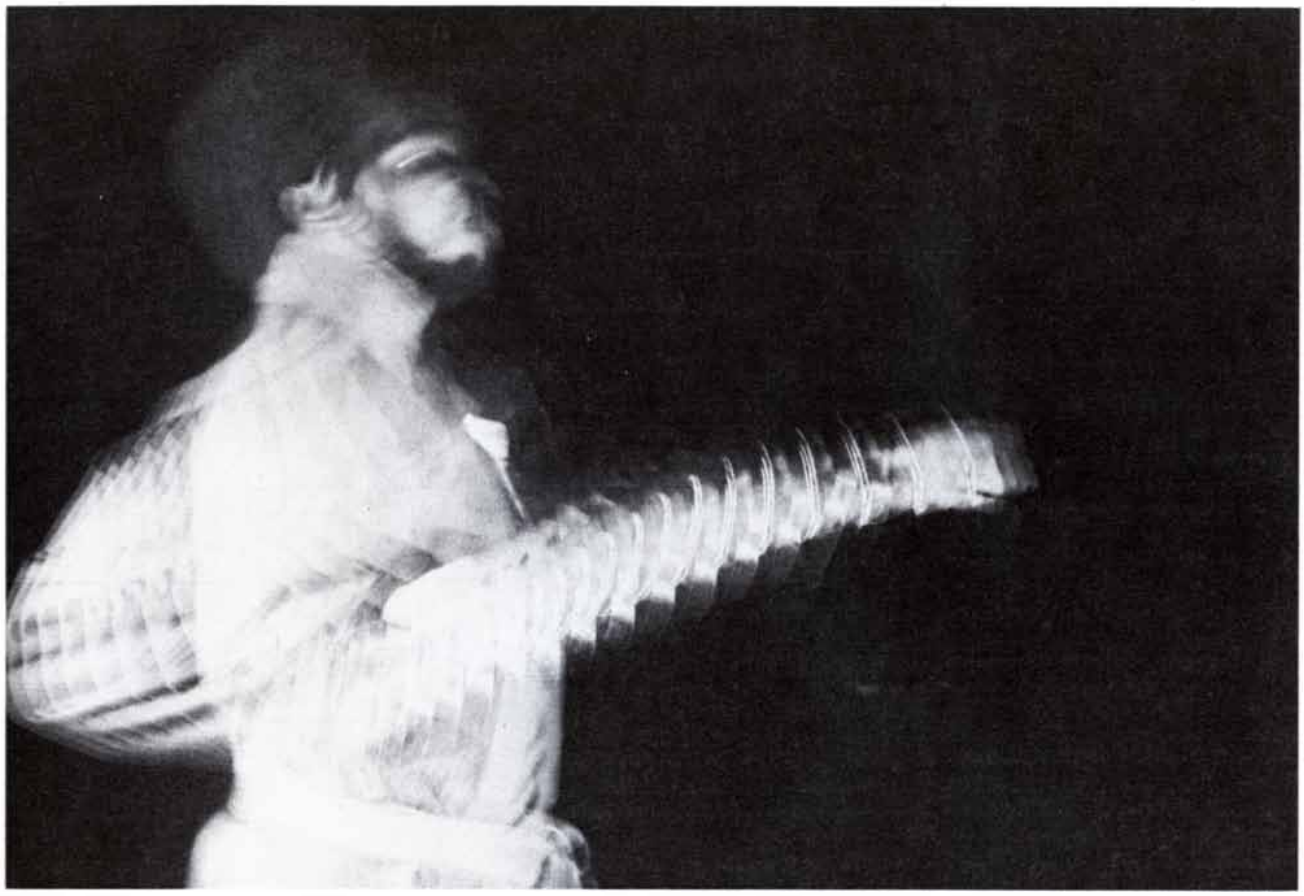


IMPACT PROCESS is represented by a dynamic model that regards the hand and the lower forearm as consisting of two masses, the first (M_1) corresponding to the surface hand tissue and the second (M_2) to the rest of the hand and the lower forearm. The masses are linked by springs and dampers. In modeling the karate strike the hand, represented by the coupled masses, hits the block, represented by a mass (m) on a spring. When the coupled equations governing the interaction were solved, it was found that the hand needs 12.3 joules of energy to break wood and 37.1 joules to break concrete. The dynamic model is a slight modification of one that John W. Mishoe and Charles W. Suggs of North Carolina State University developed to study the response of the hand and forearm to vibrations generated by industrial machinery.

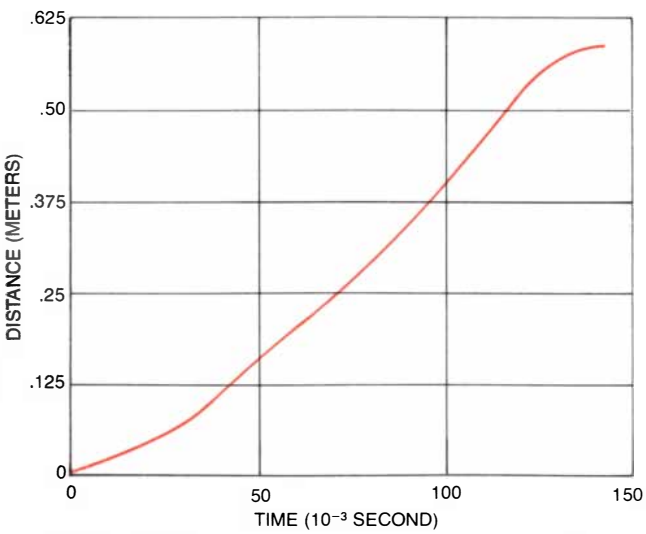
energy goes into motion and the more it goes into deformation. With wood most of the kinetic energy is conserved, but with concrete a substantial fraction goes into deforming the hand.

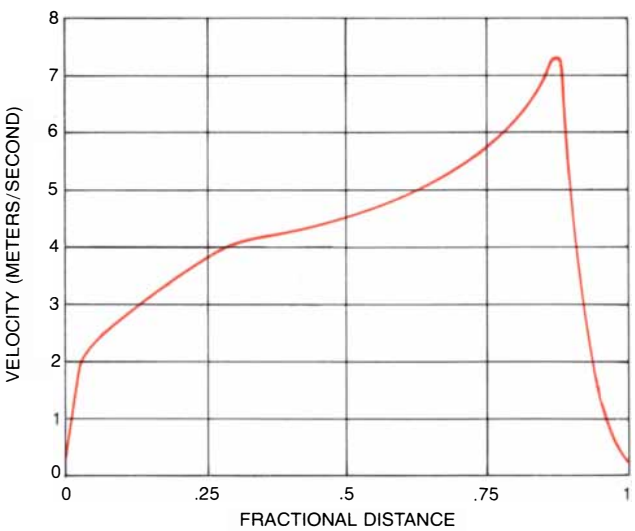
A simple estimate of the energy transferred in a karate strike can be made by assuming that the collision between the fist and the block is perfectly inelastic. From kinematic laws describing the motion of objects colliding inelastically and from the critical energies we have computed it is easy to determine the energies a hand would need in order to break the blocks: 6.4 joules for wood and 8.9 joules for concrete. The inelastic-collision model confirms the obvious: wood is easier to break.

It is time to put the theoretical model aside and see how much energy, velocity and acceleration are actually available in the karate strikes. We determined these quantities primarily from multiple-flash stroboscopic photographs,



STROBOSCOPIC PHOTOGRAPH of a forward karate punch, in which the karate expert was illuminated by 120 flashes per second, indicates that the fist reaches maximum speed shortly before the arm is fully extended. The karate expert focuses his punch just inside the target, so that his fist reaches maximum speed at the point of contact. As a result the punch imparts a large amount of momentum to target.





MAXIMUM SPEED of about 7.5 meters per second was achieved by the fist shown in the upper illustration on this page. From the distance between each position (*left*) the velocity of the fist was plotted as a function of the fraction of the total distance it traveled (*right*).

made with the shutter of the camera left open as the karateka executed a maneuver. The karateka was illuminated by 120 flashes per second, so that his position at the time of each flash was recorded in the photograph. From measurements of the distance between each position the velocity and acceleration of the hand of the karateka could be easily calculated. The stroboscopic photographs showed peak velocities of between 10 and 14 meters per second for the hammer-fist strike (in which the fist is brought down from above the head in a circular arc) and the knife-hand strike (the "karate chop"). In the forward punch of karate the hand reaches speeds of between 5.7 and 9.8 meters per second, and in various kicks the foot reaches speeds of between 7.3 and 14.4 meters per second. The peak speeds in the hammer-fist strike correspond to energies of between 50 and 100 joules, much more than the 6.4 joules the hand needs to break wood and the 8.9 joules it needs to break concrete as calculated from the inelastic-collision model.

In spite of this encouraging result the inelastic-collision model only roughly approximates the interaction of the hand and the block. The model erroneously assumes that the collision is completed before the block begins to break. Our high-speed motion pictures show that the hand and the block are still interacting while the block is fracturing. Another shortcoming of the model is that it yields no insight into the dynamics of the fracture process or into the forces acting on the hand and forearm during the strike.

The motion pictures were made at 1,000 frames per second. That made it possible to observe the impact process in slow motion and to study the frames individually to see what happens from one millisecond to the next. One sequence of frames recorded a hammer-fist strike impinging on a concrete block. We put four marker dots on the side of the fist so that we could study the velocity and acceleration of different parts of the fist during the collision. As the fist strikes the block it decelerates rapidly, reaching a maximum deceleration of 3,500 meters per second squared for the lower right-hand part of the fist (when the blow was struck with the right fist) and 4,000 meters per second squared for the rest of the fist. The fist is compressed and distorted to such an extent that it scarcely behaves like a solid object. The impact lasts for five milliseconds, with the slab starting to break at the bottom after having been deflected only a millimeter.

The data gathered from the motion pictures can be utilized to estimate the peak force exerted on the fist during the impact. The peak force is the product of the mass of the fist and its deceleration. For a mass of .7 kilogram the force is between 2,400 and 2,800 newtons, which is about 400 times greater than the force of gravity. Similar motion pictures were made of a hammer-fist strike impinging on a wood block, but here the deceleration was much too small to measure accurately.

For a better description of the impact process we turned to a dynamic model that John W. Mishoe and Charles W. Suggs of North Carolina State University had developed to study the response of the hand and forearm to vibrations generated by industrial machinery. Unlike the inelastic-collision model, the dynamic model does not treat the hand as a solid object; it regards the hand and lower forearm as consisting of three masses (corresponding to the skin of the hand, the hand tissue immediately under the skin and the remaining 90 percent of the mass of the hand and lower forearm) linked by springs and dampers. For our purposes it is necessary to represent the hand by only two of the three coupled masses, because the mass corresponding to the skin is negligibly small.

In modeling the karate strike the hand, represented by the coupled masses, hits the block, represented by a mass on a spring, whose parameters were determined from the acoustical analysis described above. When the complex equations governing this interaction were solved with the aid of a computer, it was found that the hand needs 12.3 joules of energy to break wood and 37.1 joules to break concrete. These values are somewhat higher than those predicted by the inelastic-collision model.

Although it is not clear that the dynamic model precisely describes the karate strike, in which the forces are much larger than those encountered in the operation of vibrating machinery, the results are encouraging. The model indicates that the hand must reach a speed of 6.1 meters per second to break wood and 10.6 meters per second to break concrete. Such speeds agree with our observation that beginners can break wood but not concrete. A hand velocity of 6.1 meters per second is within range of the beginner, but a velocity of 10.6 meters per second calls for training and practice. The dynamic model also predicts correctly that a concrete block fractures in less than five milliseconds.

How is it that the hand of the karateka is not shattered by the force of the karate strike? Part of the answer lies in the fact that bone is much stronger than concrete. Consider how easy it would be to shatter a piece of concrete the size and shape of a bone. Indeed, the rupture modulus of bone is more than 40 times greater than that of concrete. If a cylinder of bone two centimeters in diameter and six centimeters long were simply supported at its ends, it could withstand a force exerted at its center in excess of 25,000 newtons. Such a force is eight

times greater than the force concrete exerts on the hand in a karate strike. The hand can actually withstand forces much larger than 25,000 newtons because it is not a single piece of bone but a network of bones connected by viscoelastic tissues. Furthermore, the hand is not supported at the ends and struck in the middle, as a block of concrete or wood is.

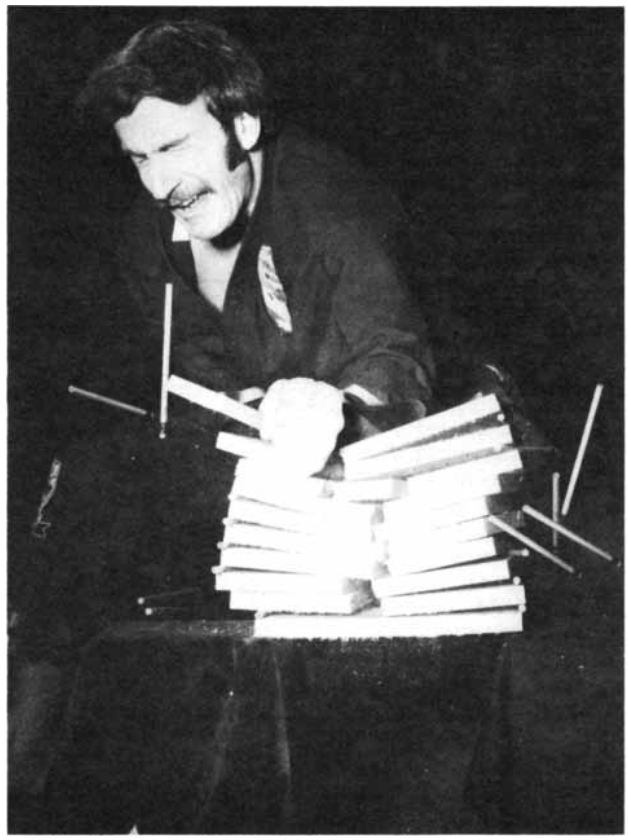
Under impact the bones move and transmit part of the stress to the adjoining muscle and other tissue. Some of the stress is absorbed by the skin and muscles that lie between the point of impact and the bones. Moreover, much of the force is rapidly transmitted to other parts of the body. Work remains to be done to determine what fraction of the stress is absorbed where.

In the hammer-fist strike the fifth metacarpal, the bone at the bottom of the fist and the one most vulnerable to the impact of the blow, is protected by the muscle called the abductor digiti minimi. As the fist is tensed the abductor muscle stiffens and thickens. The first line of defense against the blow is the skin. The next is the abductor, which acts as padding in absorbing some of the impact force. Then the tendons in the wrist absorb some of the blow as the fist bends back at the wrist. Finally the energy transmitted to the arm is absorbed by muscles and other tissues in the forearm and the upper arm.

In karate the proper positioning of the hand, and of the foot when it is used to deliver a blow, is critical. In many maneuvers, such as the open-hand strike and the side kick, contact is made with the edge of the hand or the foot. These techniques concentrate the force on a small area of the target, thereby reducing the likelihood of deflecting a bone to the point of fracture. In fact, if the striking part of the body is oriented properly, the force required to break it is much greater than the force required to break the target. For example, we have estimated that in a well-placed side kick the foot can withstand roughly 2,000 times more force than concrete can.

So far we have discussed only the breaking of a single block, and karatekas can also break stacks of wood and concrete blocks. With a well-executed strike or kick the karate expert can demolish several concrete blocks placed directly on top of one another. Even higher stacks of concrete blocks (and of wood blocks as well) can be broken if the blocks are not stacked flush on top of one another but are held slightly apart by dowels placed between them. The dowels ensure that the critical force is reduced by a favorable effect of angular momentum. When the first block breaks, it absorbs energy from the fist. As the two halves of the broken block move downward, they acquire angular momentum. The angular momentum and linear momentum of the broken pieces are often large enough to break the second block, which in turn breaks the third block, and so on. Hence the peak force needed to break, say, eight wood blocks is less than eight times the peak force needed to break only one block.

All the karateka has to do is properly hit the first block hard enough near the center. An off-center strike may fail to break the entire stack. Photographs show that in such a strike each successive block that breaks does so at a point that is closer to its center. Thus part of the energy of the hand is lost to the horizontal motion of the fracture wave. When too much energy is lost to such motion, there may not be enough left to break the bottom blocks.



EIGHT WOOD BLOCKS (*left*) are broken by the hammer-fist strike of one of the authors (Feld). Originally the blocks were not stacked flush on top of one another but were kept slightly separate by pencils placed between them. The pencils ensured that the critical force was reduced by a favorable effect of angular momentum. When the first block broke, it absorbed energy from the fist. As the two halves of the broken block moved downward, they acquired enough angular momentum to break the second block, which in turn broke the third block, and so on. Hence the force needed to break the eight blocks was much less than eight times the force needed to break one block. An off-center strike (*right*) failed to break the bottom block in a stack of 10. The fracture wave traveled toward the center, where the blocks are most easily broken. Much energy was lost to this horizontal motion, so that not enough was left to break the bottom block.

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Finding new ways to

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Though a new feature, the system isn't just for new planes; it can easily be added to existing L-1011s. And the savings, over the life of each plane, could total millions of dollars.

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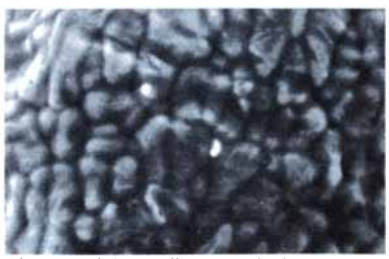
Since the 1930s, most aircraft have been structured of strong, lightweight aluminum. Future generations of aircraft may also be made mostly of aluminum, but of a very different nature.

A new technology being explored by Lockheed uses powdered aluminum, alloyed with such elements as iron, lithium or cobalt, to create lighter, stronger and stiffer metals than can be achieved with conventional aluminum technology.

Results indicate this 'new aluminum' could reduce present-day jetliner weight by 10%. That in turn means savings of millions of gallons of fuel over each aircraft's life, a big benefit in energy-short years.



Aluminum lithium alloy magnified 1,000 times.

For this new-material process, Lockheed scientists even had to employ astonishing techniques for turning the powdered aluminum and alloys into superior metal. After heating and melting, for example, the mixture is rapidly cooled *a million times faster* than the cooling rate used with standard aluminum ingots.

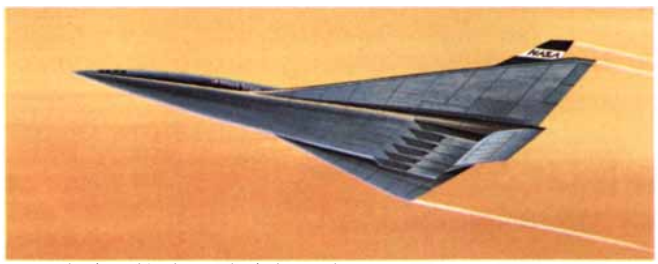
Down the road: liquid hydrogen.

Lockheed scientists are deep into a NASA-sponsored study of a future aircraft, powered by a clean-burning liquid hydrogen, that could cruise at a flashing hypersonic speed of about 4,000 mph, or six times the speed of sound.

Because liquid hydrogen can be made from coal or even water, its future use in aircraft could eliminate the need for scarce, expensive petroleum.

The aircraft would cruise at altitudes as high as 120,000 feet and have ocean-spanning range. Its 200 passengers

save fuel in flight.



Design for liquid hydrogen fueled aircraft

could be whisked from New York to London in under two hours, and could make the Los Angeles/Tokyo flight in a mere two hours, 18 minutes—takeoff to landing.

Fine-tuning the flight plan.

When a pilot calls Lockheed's JetPlan, he's in touch with a computerized encyclopedia of information affecting his proposed flight. And the benefit he gets is eye-opening economy—savings of both time and fuel.

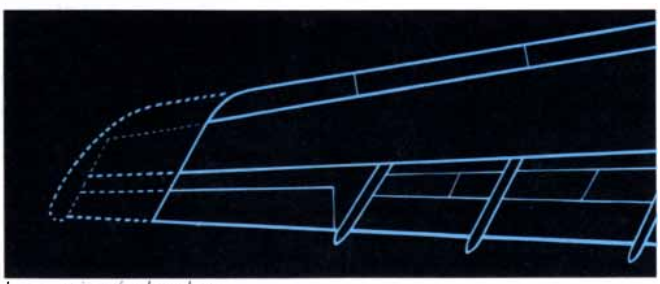
To tap a constantly updated reservoir of data, a pilot makes preflight contact via telephone and a small printer terminal. In minutes, he gets back his most efficient flight plan. Given origin, destination, and type of aircraft, JetPlan reckons its answer from such factors as route analysis, current weather, recommended fuel load, cruise altitude, speed and shortest route.

How well does it work? Over a recent 12-month test period, U.S. military and corporate aviation saved more than 30 million gallons of fuel, or better than $1.5 million. But that's just the beginning. The number of JetPlan users and the savings are both growing steadily.

Stretching wings.

Longer wings mean reduced drag and consequently a substantial cut in fuel use. But among big wide body jetliners, only the Lockheed L-1011 TriStar can add nine feet of wingspan without costly structural redesign.

That's because of the L-1011's advanced technology, in this instance an exclusive system of Active Control ailerons. Controlled by computers, these ailerons will act automatically to reduce the structural loads on the lengthened L-1011 wings.



Longer wings for less drag.

The longer wings and Active Control ailerons will mean a healthy savings of fuel when they enter airline service in 1980. And they'll also help the L-1011 have the smoothest ride of any jetliner through gusts and turbulence.

When it comes to devising farseeing programs to meet the growing fuel crisis, Lockheed knows how.

Lockheed

Ink-Jet Printing

Minute drops of ink, squirted from a nozzle and steered in flight, can be made to form printed characters. The ink-jet technology is particularly well suited to printing at the command of a computer

by Larry Kuhn and Robert A. Myers

The invention of movable type more than 500 years ago transformed the art of printing by decomposing the written word into its basic elements: the letters of the alphabet. Several new printing technologies have taken a further step in the same direction: they break down each character into an array of dots. Both innovations bring the advantage of increased versatility. With movable type the same set of characters can be reassembled over and over to form new texts; with dot-matrix printing the size and form of the characters themselves can be changed at will.

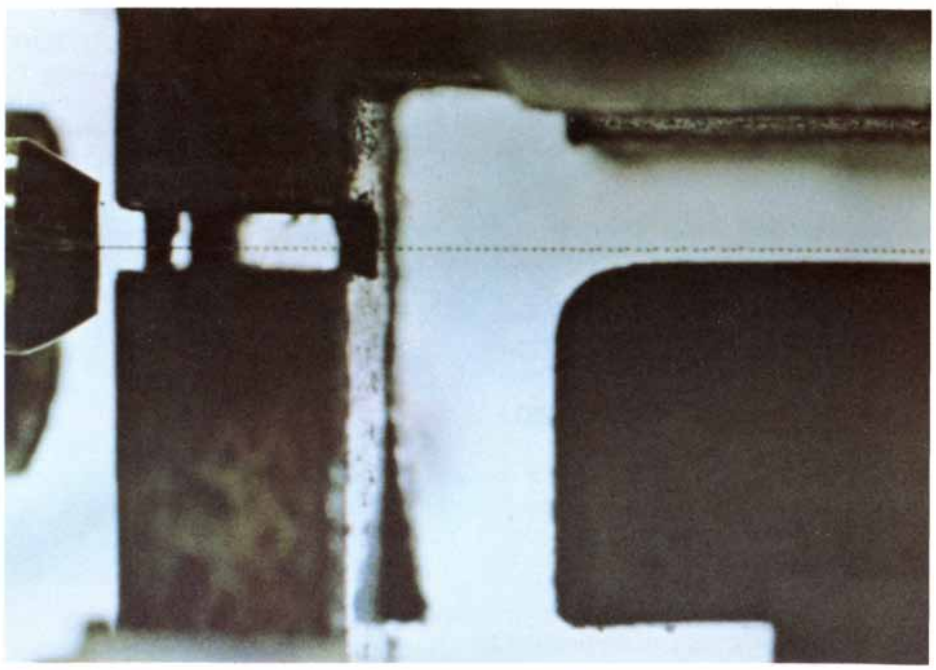
Ink-jet printing is one of the new dot-matrix technologies. Whereas most traditional printing devices work by pressing an inked image of the letter against the paper, the ink-jet printer "paints" each character. A stream of ink issuing from a microscopic nozzle is broken up into small drops that are then directed to specified positions on the paper. The only preexisting image of the character is an electronic one, which is employed to control the drop trajectories.

In principle one might construct an ink-jet press, where many thousands of independently controlled jets would print a magazine or newspaper directly from an electronic representation of the text and illustrations. For now, however, the technology is confined to printing on a more modest scale. The ink-jet printer serves as an output device for a computer or a word-processing system. It is in applications of this kind that versatility is most important. Thousands of identical copies of a single text are seldom needed; instead the machine is called on to make one copy or a few copies of many different documents.

Most computer-output printing is done by machines that have a strong functional resemblance to the ordinary typewriter. They are called impact printers, and they all share the same fundamental mechanism: a preformed image of a letter is made to strike the paper, usually through an inked ribbon. The letters can be mounted on individual type bars, as in the conventional typewriter, or they can be arranged on a disk, on the surface of a ball or on a belt. Most machines print a single character at a time at rates of from 15 to about 50 characters per second. Faster machines print a full line at a time and can produce as many as 50 lines per second.

The dot-matrix printer employs a significantly different mechanism. In an electromechanical version of the matrix printer seven or eight closely spaced wires of tungsten carbide are arranged in a vertical line. Each wire is coupled to a solenoid magnet that can drive the tip of the wire into an inked ribbon and the paper. In operation the line of wires is swept across the page as various combinations of solenoids are energized, forming letters, other characters and the spaces between them.

In an ink-jet printer the dots that compose the matrix are marks left by individual drops of ink. Because the drops are generally much smaller than the wires of an impact matrix printer the resolution of the printed image can be much higher. In the commonest kind of impact matrix printer each character is formed by selecting some of the 35 dots in a five-by-seven array, with the result that many familiar letter forms can only be approximated. Because the wires cannot ordinarily be packed any closer than three or four per millimeter the individual dots remain distinct. The drops generated by an ink-jet printer are small enough and can be placed accurately



DROPS IN FLIGHT were photographed as they moved through the deflection apparatus of an ink-jet printer. The ink emerges from the nozzle at the far left as a continuous jet, which quickly breaks up into drops with a diameter of about 60 micrometers. At the point where the jet breaks up, selected drops are given an electrostatic charge by the electrode immediately to the right of the nozzle. The large metallic structures in the center of the photograph are deflection plates to which a potential of some 3,000 volts is applied. In the electric field between these plates the drops that have acquired a charge are deflected upward by an amount propor-

enough to yield a resolution equivalent to a matrix of 1,000 dots per character. They can be spaced as closely as 10 per millimeter and they overlap slightly, so that no white space is left between the dots. The quality of the resulting printed image is comparable to that produced by a typewriter with a fabric ribbon.

Another potential advantage of ink-jet printing is its quietness. Noise was not an important consideration when a computer and its peripheral devices were large enough to require a room of their own, but today a computer is often installed in an ordinary office, where the noise of most impact printers can be disruptive. The ink-jet mechanism is virtually silent. Because it is mainly an electronic device it also promises greater reliability than the electromechanical components of an impact printer. It should be pointed out, however, that much of the noise and many of the mechanical failures in a printer can be attributed to the machinery that transports the paper, and that machinery is essentially unchanged by the adoption of ink-jet technology.

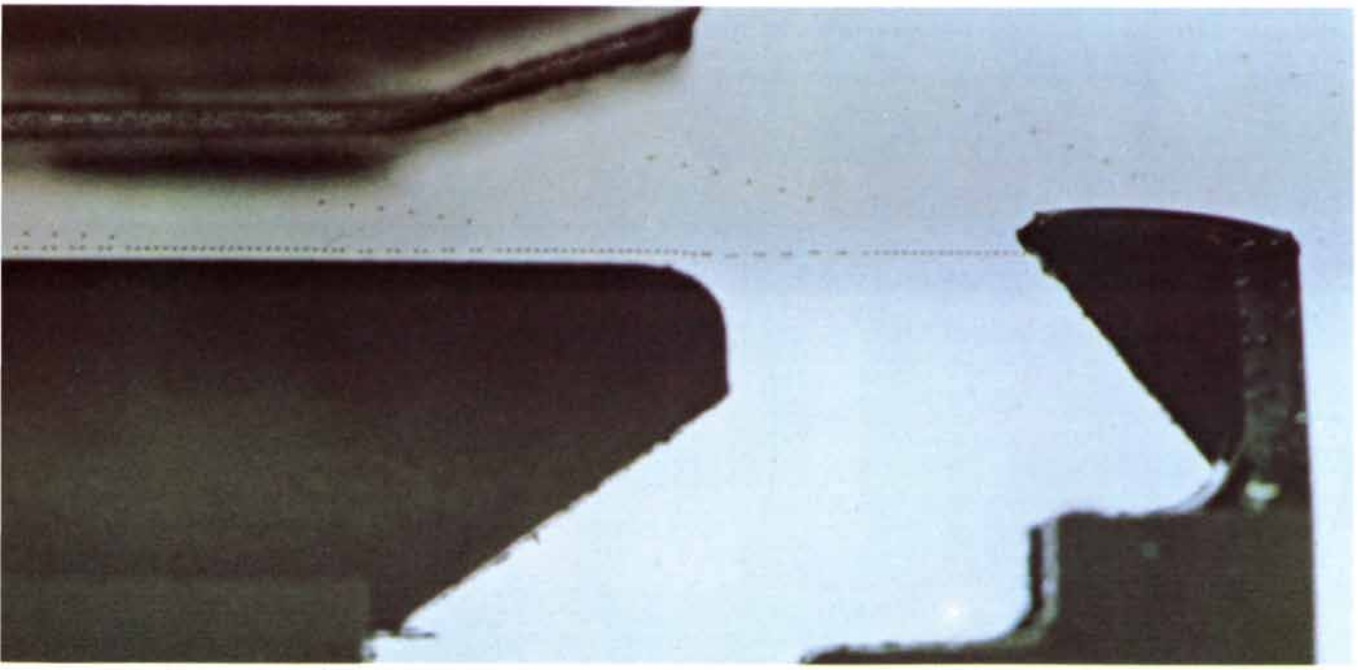
Perhaps the most impressive advantage of the ink-jet printer is its ability to change almost instantaneously the size or style of the type being printed. It would be no more difficult to print Greek or Arabic characters than it is to print the Roman alphabet, and even nonalphabetic languages such as Chinese can be reproduced. Indeed, there are almost no limitations on the form of the material to be printed. Any given point can be either marked with a drop or left blank; to borrow a term from another realm of computer science, the printer is capable of "addressing" all points on the page.

Several methods of ink-jet printing have been devised, of which we shall discuss three. In the first method a single stream of drops is steered electrostatically and in the second the steering is electromagnetic. The third scheme employs multiple ink jets, which are independently directed onto the paper or into a gutter where the unused ink is collected. All three of these technologies rely on a continuous, synchronized stream of drops. There are other methods of ink-jet printing in which the drops are issued on demand, but we shall not discuss them here.

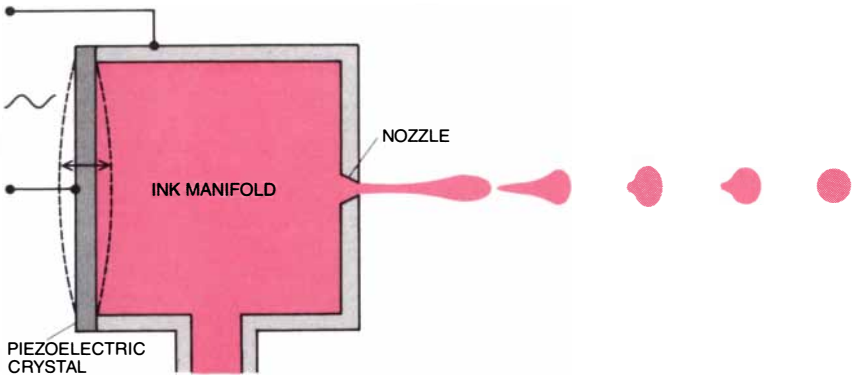
Most of the physical principles underlying the operation of an ink-jet printer were understood in the 19th century. It was not until the early 1960's, however, that the ingenious idea essential to the construction of a practical printer was demonstrated by Richard G. Sweet of Stanford University. In an extended series of experiments Sweet showed that an electric charge could be impressed on the drops that form out of a continuous stream of fluid. What is more, he found that even when the drops were generated at the rate of 100,000 per second, the charge on each drop could be determined independently. The trajectory followed by each drop could then be controlled by passing all the drops through a uniform electric field.

Sweet's immediate aim in these experiments was the construction of a high-speed oscillograph, an instrument for recording rapidly changing electrical signals. The technique has since found other applications, including some that are rather far afield, such as the sorting of cells in blood specimens. The printing of alphabetic characters is one of the more obvious applications, which Sweet himself was among the first to investigate. One way to build a printer, for example, is to mount the drop generator and the various electrodes for charging and deflecting the drops on a movable carriage: the print head. The deflection field then steers the drops to various positions along a vertical line while the entire print head is swept across the page horizontally. If the drops are formed at a rate of 100,000 per second and a typical character is made up of roughly 100 drops, then the maximum printing rate should be about 1,000 characters per second. Actual rates are much slower, however, because not every drop can be utilized; indeed, in a practical printer only about 2 percent of the drops reach the paper.

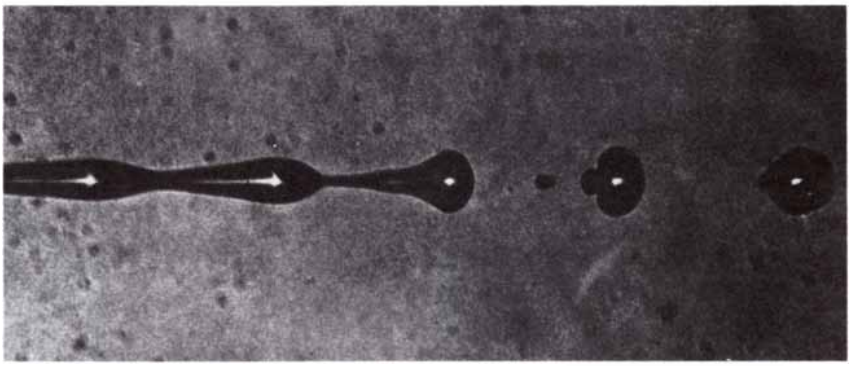
A printer of this kind was first offered commercially by the A. B. Dick Company. The International Business Machines Corporation has since introduced



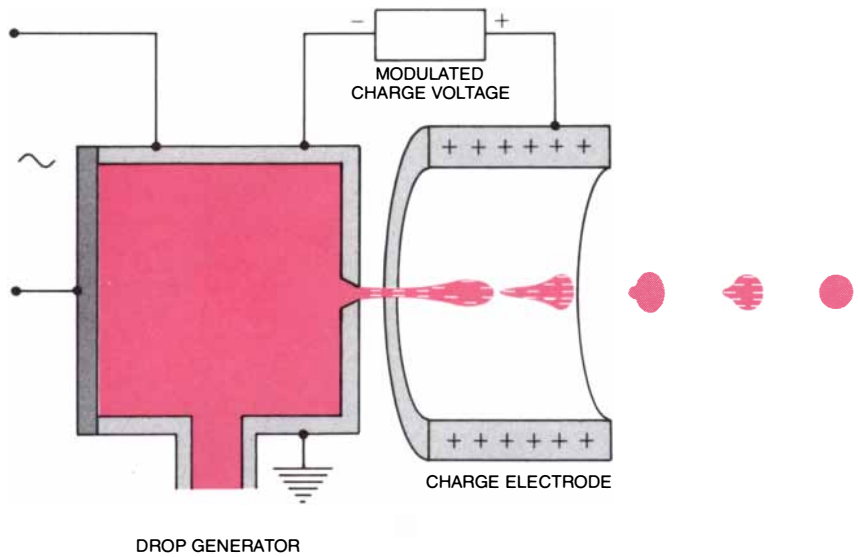
tional to their charge. The uncharged drops continue undeflected to a gutter at the right, where unused ink is collected for recirculation. Only the deflected drops reach the paper, which in an operating printer would be positioned to the right of the gutter and at right angles to the plane of the image. The drops are emitted at a rate of 117,000 per second and move with a speed of about 18 meters per second. Deflected drops fall behind their original positions in the sequence because of aerodynamic drag. Although the photograph appears to show a single set of drops, it actually superposes the images of several hundred sets illuminated at the same positions in their trajectories by successive flashes of a stroboscope. The photograph was made by Carl E. Lindberg of the Office Products Division of the International Business Machines Corporation in Lexington, Ky. It shows components of the IBM 6640 printer mounted on a laboratory test bench.



DROP GENERATOR emits a continuous jet of ink whose breakup into drops is synchronized by an external signal. The ink is forced through a nozzle some 20 to 40 micrometers in diameter under a pressure equal to a few times atmospheric pressure. Ordinarily such a jet would disintegrate into a random spray, but the synchronizing signal creates drops that are uniform in size, velocity and spacing. The synchronization is most commonly brought about by a periodic pressure variation applied by a piezoelectric crystal mounted on one wall of the ink manifold.



FORMATION OF DROPS is governed by surface tension, which amplifies the slight undulation in the surface of the jet created by the synchronizing signal. In the regions where the jet is narrowest the forces resulting from surface tension are greatest, and so they further reduce the diameter until the stream breaks apart into separate drops. The photomicrograph was made by Jean-Claude Chastang of the IBM Manufacturing Research Laboratories at Yorktown Heights, N.Y. Small drops between the major ones are "satellites" that must be suppressed.



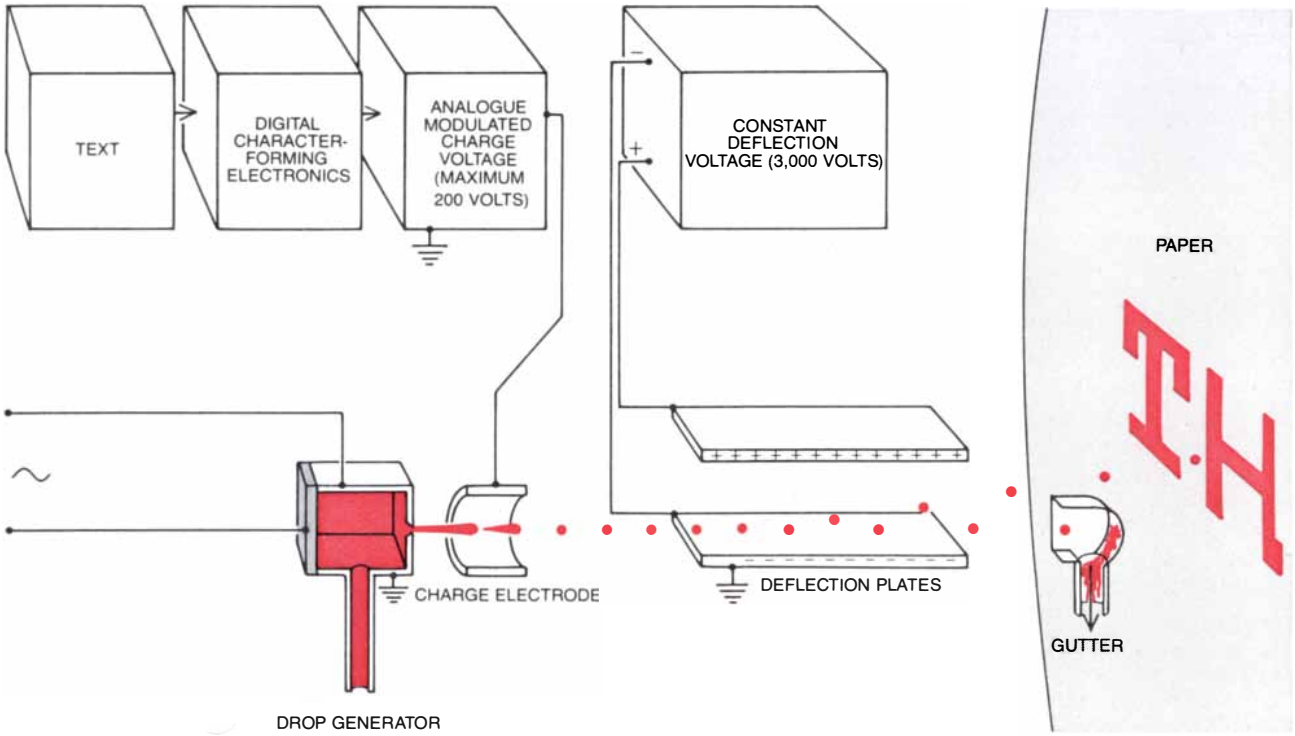
ELECTRIC CHARGE acquired by each drop in a stream can be controlled independently. A positive potential applied to the charge electrode draws electrons (*denoted by minus signs*) through the ink to the tip of the jet. When a drop breaks off, a charge proportional to the voltage on the electrode is trapped on the drop. Charges of nearby drops, however, can alter the charge of a drop that is forming, and voltage must be adjusted to compensate for these effects.

a printer that employs the same means of drop steering to achieve a character image of typewriter quality. Because we are most familiar with the development of the IBM printer, which is now designated the 6640, we shall refer to it as an example in much of the discussion that follows.

The first requirement of an ink-jet printer is a well-defined stream of drops. The interval between drops must be uniform, the drops must all be the same size and they must all be moving in the same direction at the same speed. Almost any jet of liquid, such as the water from a garden hose, will spontaneously break up into drops, but ordinarily the drops are random in size and spacing. For reliable printing the stream must be synchronized, but that is not difficult to achieve. All that is necessary is to impress a periodic rippling on the surface of the emerging jet; the drops then appear at the ripple frequency.

In the IBM 6640 the ink jet is created by forcing ink under moderate pressure (a few times atmospheric pressure) through an opening about 35 micrometers in diameter. It was found convenient to apply the synchronization signal as a small pressure variation. One wall of the manifold that confines the pressurized ink is coupled to a piezoelectric crystal; when an electrical signal of the selected frequency is applied to the crystal, it vibrates rather like a drumhead. The synchronizing frequency is roughly 117,000 cycles per second. The jet emerges from the nozzle at a speed of 17.5 meters per second, and so the interval between drops is about 150 micrometers.

It is not immediately obvious why a stream of liquid should break up into drops at all. The explanation lies in the concept of surface tension, which forces any free liquid to assume the shape of minimum surface area. Simple calculations show that a cylinder of fluid with a fixed volume can reduce its surface area by forming drops if the interval between drops is greater than the circumference of the cylinder. If the surface of the jet is slightly rippled, the force that arises from surface tension is greatest in regions of high curvature. As a result regions that are slightly swelled tend to swell further and regions that are constricted tend to become narrower, forming a neck that finally breaks off. In effect the fluid jet is an amplifier of very high gain that greatly magnifies any perturbation impressed on the stream. In an unsynchronized jet, random drops result from the amplification of random vibrations and variations in fluid flow. Because the amplifying mechanism has high gain the stream can be synchronized by a signal of very small amplitude, one that yields a surface perturbation of a few tenths of a micrometer.



ELECTROSTATIC PRINT HEAD steers each drop to a position on the paper determined by the charge on the drop. The text to be printed is stored in electronic form and is ultimately converted into a sequence of voltages that are applied to the charge electrode. Hence each drop in the stream is given a charge corresponding to one of these voltages. After leaving the drop generator and the charge electrode the drops pass between deflection plates that bear a steady high voltage. In the electric field between the plates a drop is deflected by an amount proportional to its charge. In this way a drop can be directed to any position along a vertical line segment whose length is equal to the height of a character. Movement in the horizontal dimension is provided by transporting the entire print head across the page.

The behavior of fluid jets was studied by a number of 19th-century investigators, and the subject was given a particularly elegant analysis by Lord Rayleigh. The 19th-century theorists were unable, however, to analyze certain subtle effects that cannot be ignored in the design of a printer. In particular, nonlinearities in the amplification process distort the surface of the jet and give rise to much smaller droplets, called satellites, between the desired drops. Because satellite droplets can contaminate the print head or cause misplaced marks on the paper they must be suppressed. In the past few years several attempts to explain satellite formation theoretically have been undertaken but without complete success. Hence the design of a drop generator is carried out mainly by cut-and-try methods.

Electric charge is applied to the drops by a small electrode that surrounds the region where the drops break off from the jet. A voltage is applied between this charge electrode and the drop generator. If the voltage is positive, electrons are drawn to the tip of the ink stream by electrostatic attraction, and when a drop breaks free, it carries some of these electrons with it. Once the drop has separated from the jet it is electrically isolated and the charge cannot leak away, even when the voltage on the charging electrode changes. The charge on a drop is proportional to the voltage on the charge electrode. That voltage is limited to a few hundred volts; if it were much greater, repulsion between adjacent charged drops would become unmanageable. Furthermore, as the voltage increases, repulsion between charges within a drop eventually exceeds the surface tension of the liquid and the drop explodes.

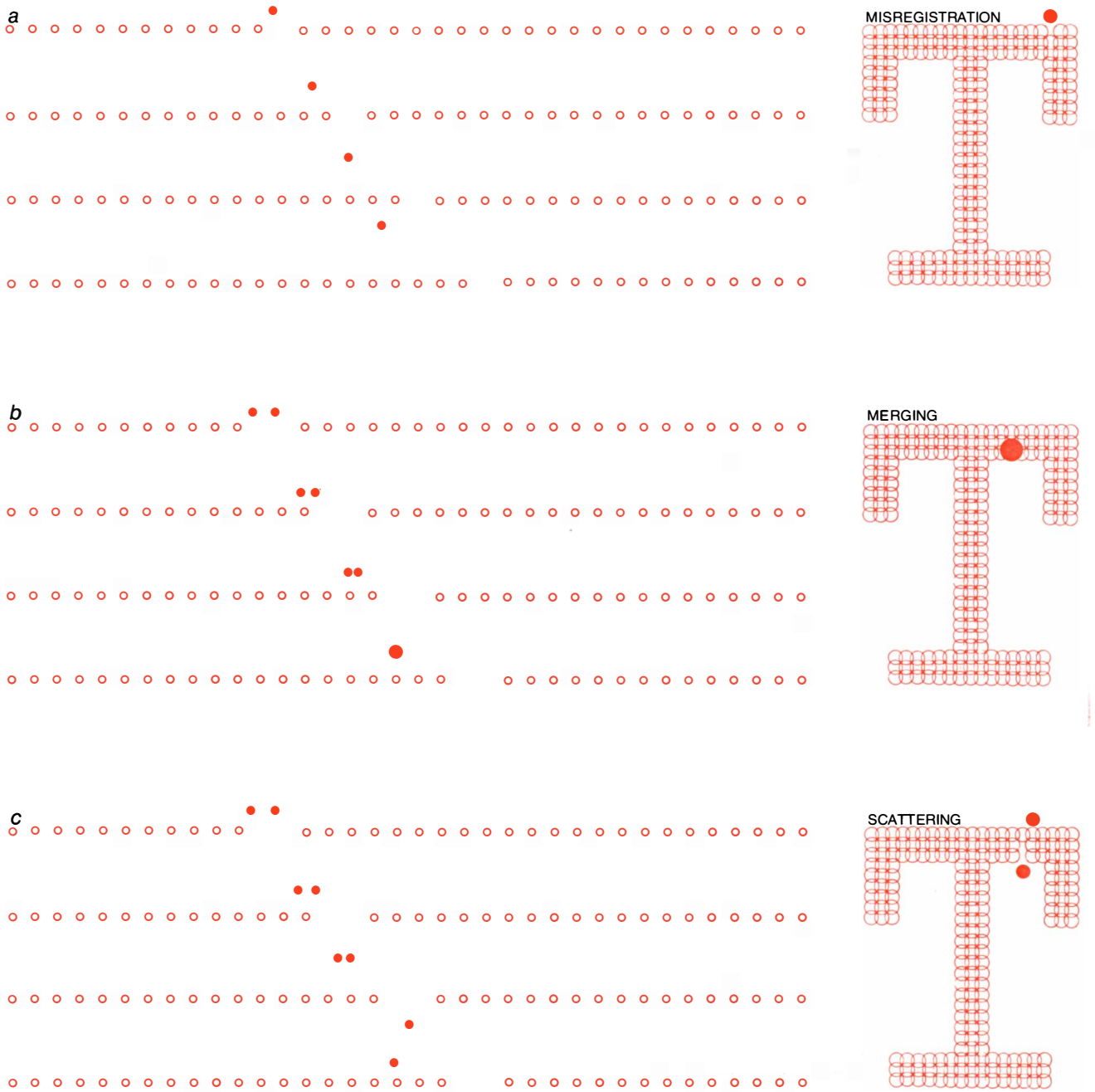
After leaving the charge electrode the drops pass into the electric field of the deflection plates. The magnitude of the field is determined by the distance between the plates and by the voltage applied to them; an upper limit is the field strength at which there is arcing between the plates. In principle drops could be given either positive or negative charges, so that they would be deflected either up or down by the fixed voltage on the deflection plates. In practice it is simpler to design drive circuits that give all the drops a charge of the same polarity so that they are all deflected in the same direction. Here we shall assume that all drops have a negative charge (or zero charge) and that the deflection plates are arranged in such a way that all charged drops are deflected upward.

Character generation begins with an electronic specification of the positions on the paper to be marked by drops. The specification can be stored in a semiconductor memory device such as a read-only memory and called up on demand. The pattern of binary numbers in the memory is then decoded and employed to specify the sequence of voltages applied to the charge electrode. If the print head moves across the page from left to right, the first signals applied to the charge electrode must result in deflections appropriate for the column of dots at the left edge of the character. As the print head moves, signals must be supplied at the proper moment for each succeeding column. Because the stream of drops cannot readily be turned on and off, where blank spaces are needed some drops must be discarded.

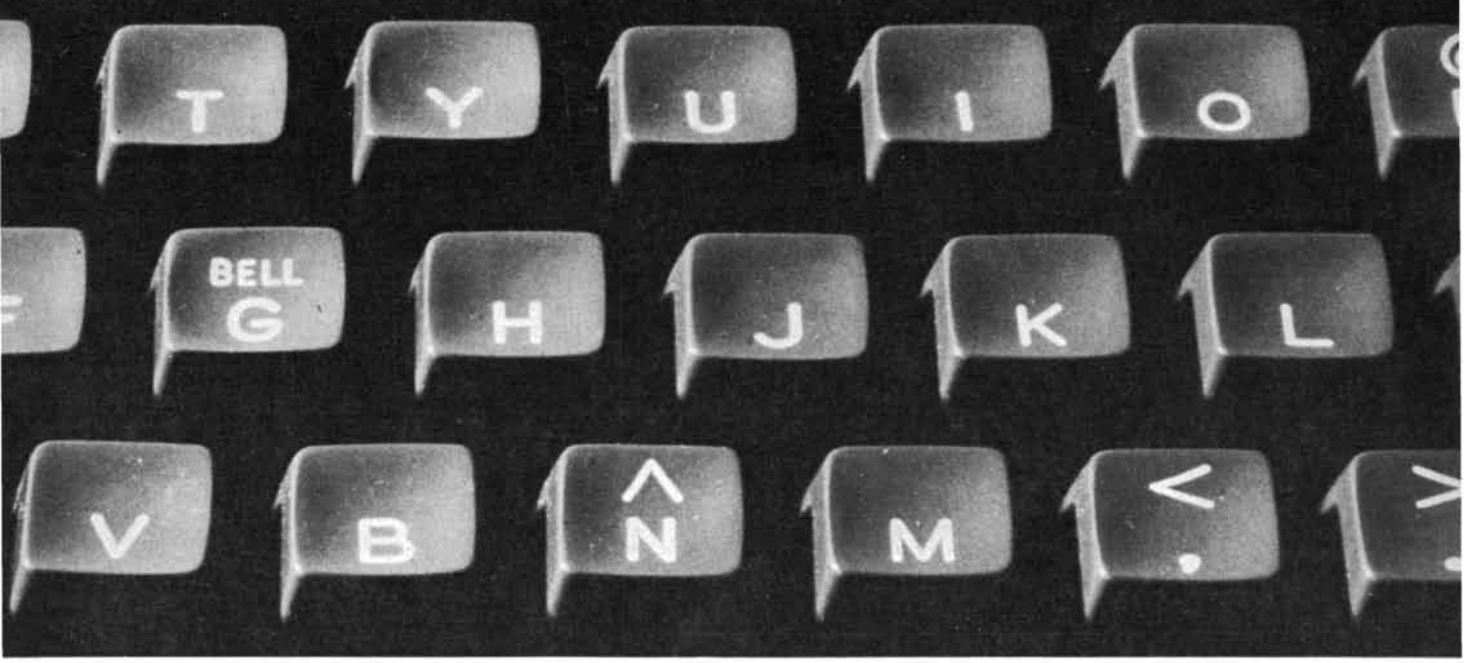
The trajectory of a drop can be calculated in a first approximation by assuming that the deflection is proportional to the voltage that appeared on the charge electrode at the time the drop formed. If the voltage is zero and the drop acquires no charge, its path will be unaffected by the electric field between the deflection plates. The drop will continue in a straight line. In the IBM 6640 and in other printers of similar design these undeflected drops are not allowed to reach the paper; instead they are collected in a gutter. Ink from the gutter is

returned to a reservoir and is ultimately recirculated to the print head. When a voltage is applied to the electrode, the drop acquires a charge and is deflected onto the paper. The greater the voltage, the greater the charge and the more sharply the drop is deflected.

The idea of varying the charge on the drops and passing them through a constant deflection field, which was Sweet's innovation, may seem somewhat out of the ordinary. It may appear more natural to give every drop the same charge and to vary the voltage on the deflection plates. That is the method employed, for example, in the cathode-ray tube of an oscilloscope or a television receiver, where the deflected objects are not charged drops but individual electrons. The reason such a system would not work in an ink-jet printer can be understood by considering the forces acting on a drop or on an electron in the deflection field. A typical drop has a charge that corresponds to a million excess electrons, and the electrostatic force acting on the drop exceeds the force on a single electron by the same factor. The deflection induced by that force, however, depends not only on the charge but



MISPLACEMENT OF DROPS is caused mainly by aerodynamic and electrostatic disturbances while the drops are in flight. In a continuous stream of drops directed to the same point, such as the gutter, each drop moves in the wake of the preceding ones; all the drops are therefore subject to the same drag, which is less than that acting on a leading drop. If a single drop is deflected out of this stream (*a*), it is no longer sheltered by the preceding drops and so it slows down. Because the deflected drop spends a longer time in the field of the deflection plates, it is deflected through a larger angle and its trajectory takes it to a higher position on the paper than the intended trajectory. When two consecutive drops are deflected, the leading drop leaves a wake that allows the trailing drop to catch up. If the two drops are not highly charged (*b*), they can merge, so that a single oversize blob appears where two smaller dots were intended. If the two drops are highly charged (*c*), they approach each other and then scatter as a result of electrostatic repulsion, ultimately landing at unpredictable positions.



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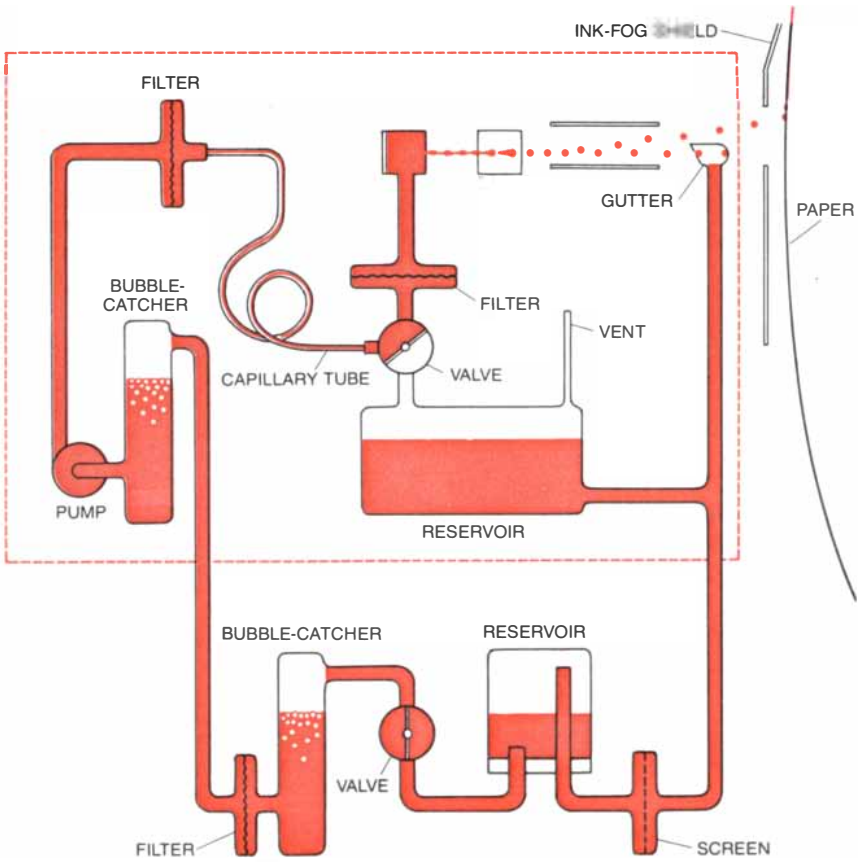
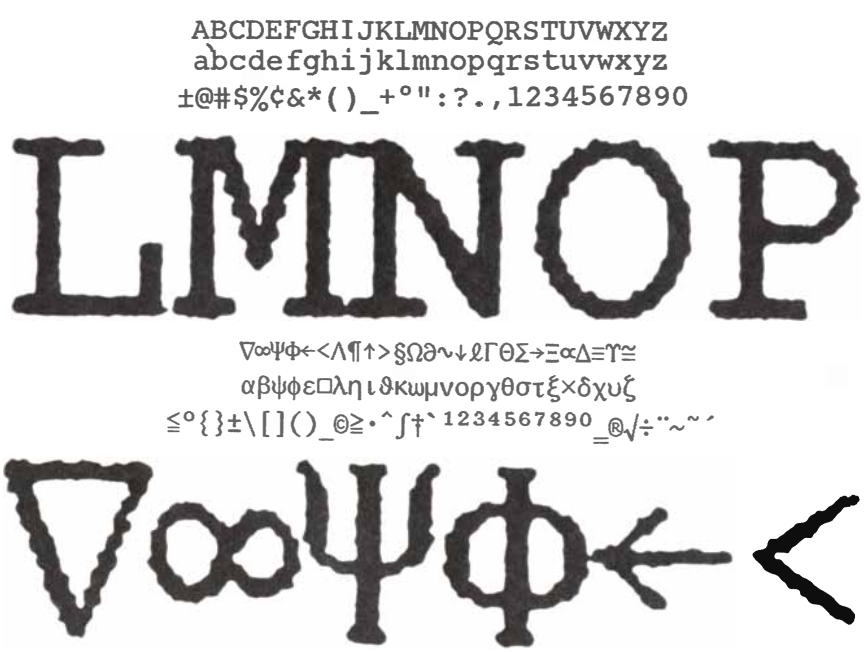


RECIRCULATION OF INK is necessary in an ink-jet printer because most drops never reach the paper but instead are collected in the gutter. The ink-handling circuit shown is that of the IBM 6640 document printer. Components within the broken-line rectangle are mounted on the moving print head. Several filters are included in the circuit in order to trap contaminants that might clog the nozzle. The jet must be started and stopped quickly to avoid dribbling ink on the charge electrode or the deflection plates; to that end the print head is equipped with a fast-acting valve that shunts excess ink to a reservoir. The components are not shown to scale.



SPECIMEN OF TYPE printed by the IBM 6640 is comparable in quality to that produced by a typewriter with a fabric ribbon. The type is shown at actual size above. In the enlarged characters below, the individual dots are clearly distinguishable, particularly in curves and diagonal lines, where the rectilinear array of deposited drops gives rise to a "stairstep" imperfection.

also on the mass. For the electron the ratio of charge to mass is 1.76×10^8 coulombs per gram, whereas for an ink drop it is about 10^{-6} coulomb per gram. Hence for a given field strength the deflection of a typical drop is smaller than the deflection of an electron by a factor of about 10^{14}.

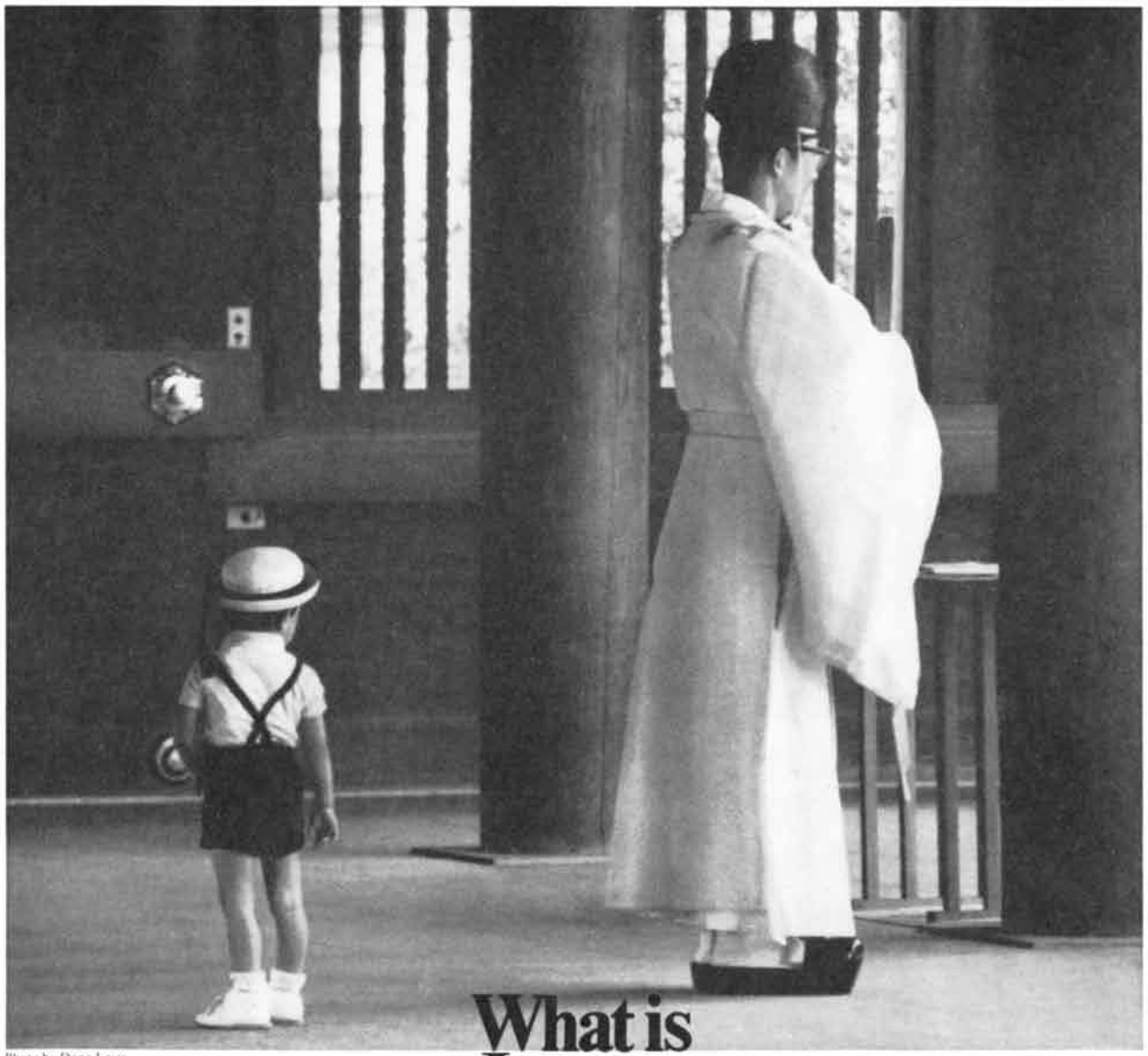
Because of the small ratio of charge to mass an ink drop is an extremely sluggish projectile and is difficult to steer. Characters of adequate size can be formed only by making the deflection plates as long as possible, so that each drop spends sufficient time under the influence of the deflecting field. The separation between drops is small, however, so that many drops are in the deflection field at the same time. It follows that if the drops were to be steered by altering the deflection voltage, their trajectories could not be determined independently.

The assumption made above that drop deflection is proportional to charging voltage is only an approximation, and in many instances it is not a very good one. Several factors can alter the trajectory of a drop. The most important ones are related to interactions between nearby drops.

One kind of disturbance takes place at the charge electrode, where the charge acquired by one drop can be influenced by the charges of the drops that precede it in the stream. The charge on a given drop is determined by the total electric field surrounding the drop. The major influence on this field is the positive voltage applied to the charge electrode, but any other charge in the vicinity will also exert an effect. In particular, if the preceding drop has a large negative charge, it will reduce the net positive voltage acting on the newly forming drop. As a result the charge carried away by the new drop will be smaller than what was intended. The corrective is to alter the applied voltage to compensate for the inductive interactions between nearby drops. Thus in order to calculate the correct charging voltage it is not enough to know where a drop is meant to strike the paper; the history of preceding drops must also be taken into account.

A more troublesome distortion of the printed character results from aerodynamic influences on the drop trajectory and from electrostatic repulsion between drops that carry a charge. These effects have proved to be important factors limiting the speed and resolution of ink-jet printing.

For a drop moving through still air aerodynamic drag is a force hundreds of times stronger than gravity and is comparable in magnitude to the electric forces created by the deflection field. When all the drops in a continuous stream are aimed at the same point (such as the gutter), each drop leaves



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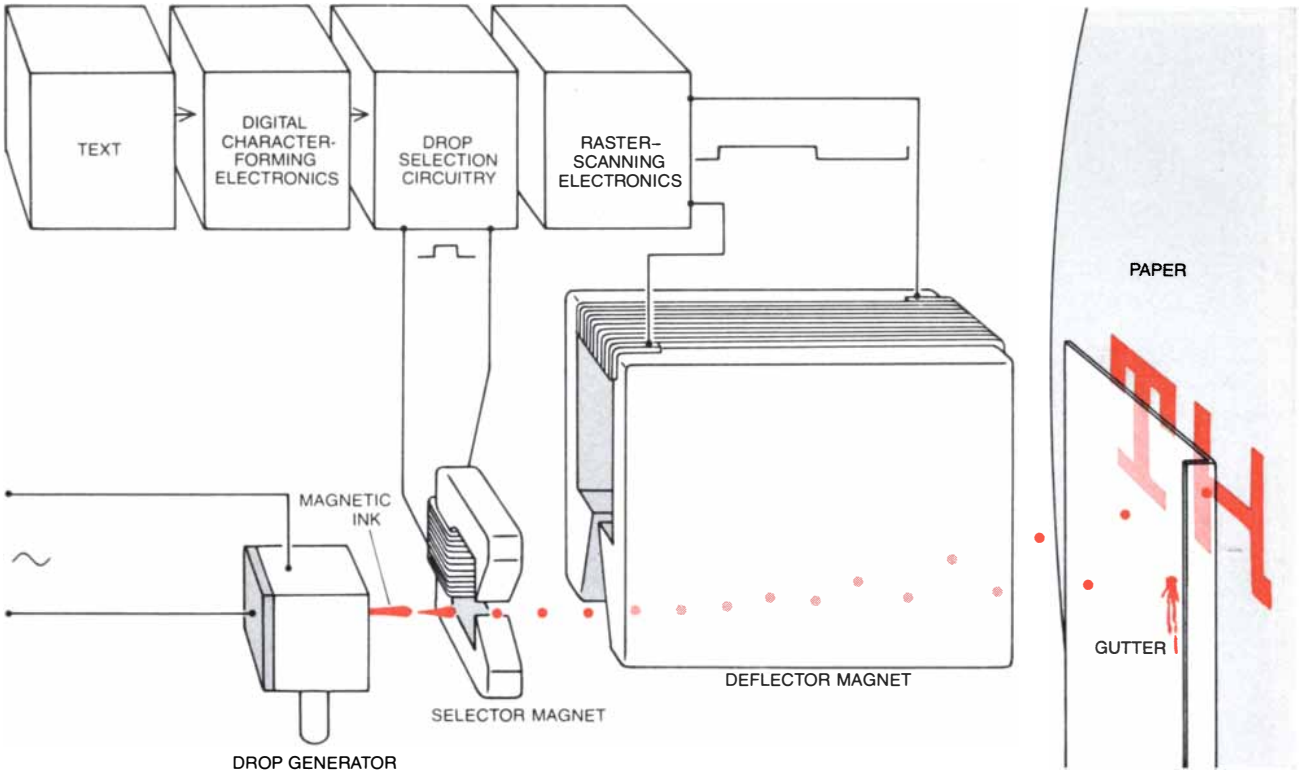
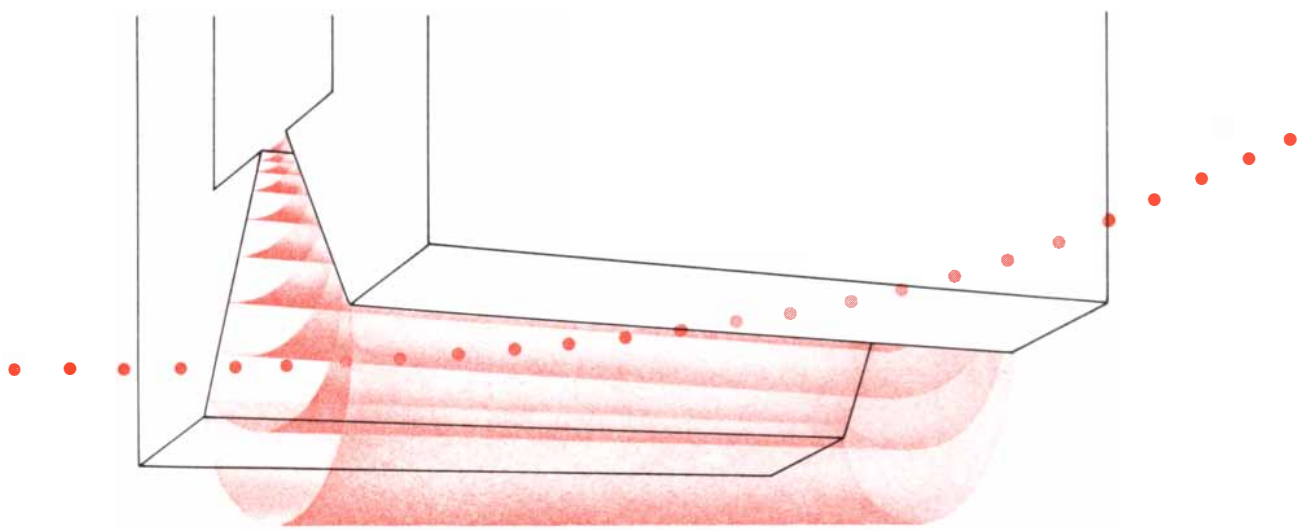


MAGNETIC INK-JET PRINT HEAD employs a ferromagnetic fluid as its ink. Drops of the ink can be steered in two dimensions by nonuniform magnetic fields, or field gradients. Vertical position is controlled by the field gradient of the deflector magnet; because this magnet is quite long several drops are under its influence at any given moment. Deflection in the horizontal plane serves merely to select which drops are allowed to reach the paper and which ones are intercepted by the knife-edge gutter. The selector magnet is short enough for it to affect only one drop at a time. As in an electrostatic printer, characters are formed by moving the print head across the page.

a wake that shelters the drops behind it and thereby reduces the drag acting on them. When a single drop is deflected out of the stream, however, it must make its own way through still air and is therefore slowed substantially. One result of this deceleration is that the drop spends a longer time in the deflection field than it would otherwise and reaches the paper above its intended position.

The distortion of the printed image can be more serious when two successive drops are deflected out of a continuous stream. The first drop in the pair feels the full effect of aerodynamic drag, but the wake it leaves shields the second drop and allows it to catch up with the first one. If the two drops are not highly charged (or to be precise if the product of their charges is not large), they may merge. As a result where two drops were meant to be placed in vertical alignment a single, larger blob appears at an intermediate position. If the two drops are highly charged, then as they approach each other electrostatic repulsion builds up. Instead of merging the drops bounce



MAGNETIC-FIELD GRADIENT is needed to deflect a drop of ferromagnetic fluid. In a uniform field (one with a gradient of zero) a drop would be subject to equal forces pulling in opposite directions. In a field gradient the drop is drawn toward the region of greater field strength. A nonuniform field can be generated by a magnet with beveled poles. The field is stronger where the poles are closer.

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apart, landing at unpredictable positions often a considerable distance from the intended ones.

In principle it might be possible to compensate in part for these effects by adjusting the charging voltage, but the adjustment for any one drop depends in a complicated way on the trajectories of many other drops. Because the present theoretical understanding of the drop interactions is limited it has been necessary to rely on empirical methods. The commonest expedient is to leave uncharged "guard" drops, which go into the gutter, between pairs of drops that are charged and deflected. By throwing away at least half of the available drops this technique reduces misregistration, but it also reduces printing speed.

There is much more to building a workable ink-jet printer than the physics of drop generation and placement. For example, the formulation of the ink is not a trivial exercise. The ink must be electrically conductive; it must also be free of particulate matter, since that might clog the nozzle. As a result of evaporation and temperature fluctuations the properties of the ink change, which makes necessary periodic adjustments to the ink pressure and to the timing of electronic events. In the IBM 6640 these adjustments are made automatically by a system that senses both the aimpoint of the jet and the instant of drop formation. Whenever the jet is started or stopped, there is a risk that a dribbling or drooping jet will contaminate the electrodes of the print head, a risk that is minimized by a fast-acting valve. A particularly difficult requirement is that the ink, the ink-supply system and the nozzle not interact chemically. Engineering considerations of this kind are the dominant factors in the design of a machine that must operate reliably in commercial service.

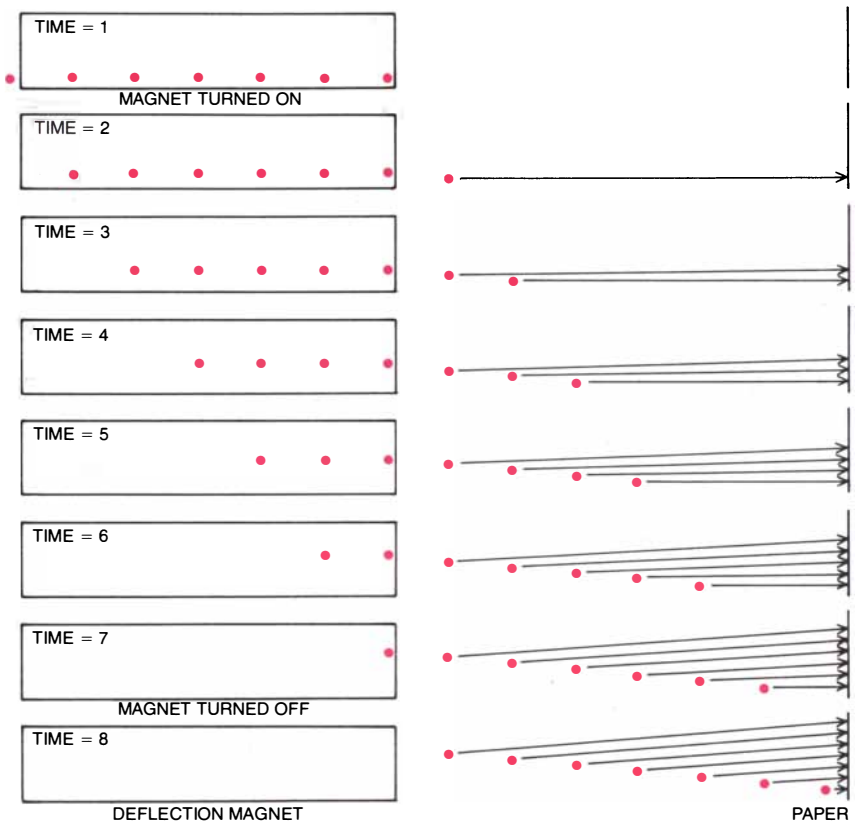
An alternative ink-jet technology that might avoid some of the complexities of the electrostatic device is a magnetic drop-deflection system devised by George J. Fan and Richard A. Toupin, who work in our laboratory at the IBM Thomas J. Watson Research Center at Yorktown Heights, N.Y. An essential component of the system is a magnetic ink, one of a class of liquids called ferrofluids developed in the 1960's by workers at the Avco Corporation. Such a fluid is a suspension of minute particles of magnetite, the magnetically active form of iron oxide. The fluid cannot retain a permanent magnetization, but it is strongly attracted by a magnet.

A moving drop of ferrofluid ink can be deflected by passing it through a magnetic-field gradient. The path of the drop would be unaffected by a uniform field, but in a nonuniform one the drop is drawn toward the region of greater field strength. It is an easy matter to create such a field gradient; in a *C*-shaped magnet with beveled pole pieces, for example, the field is stronger where the poles are closer together.

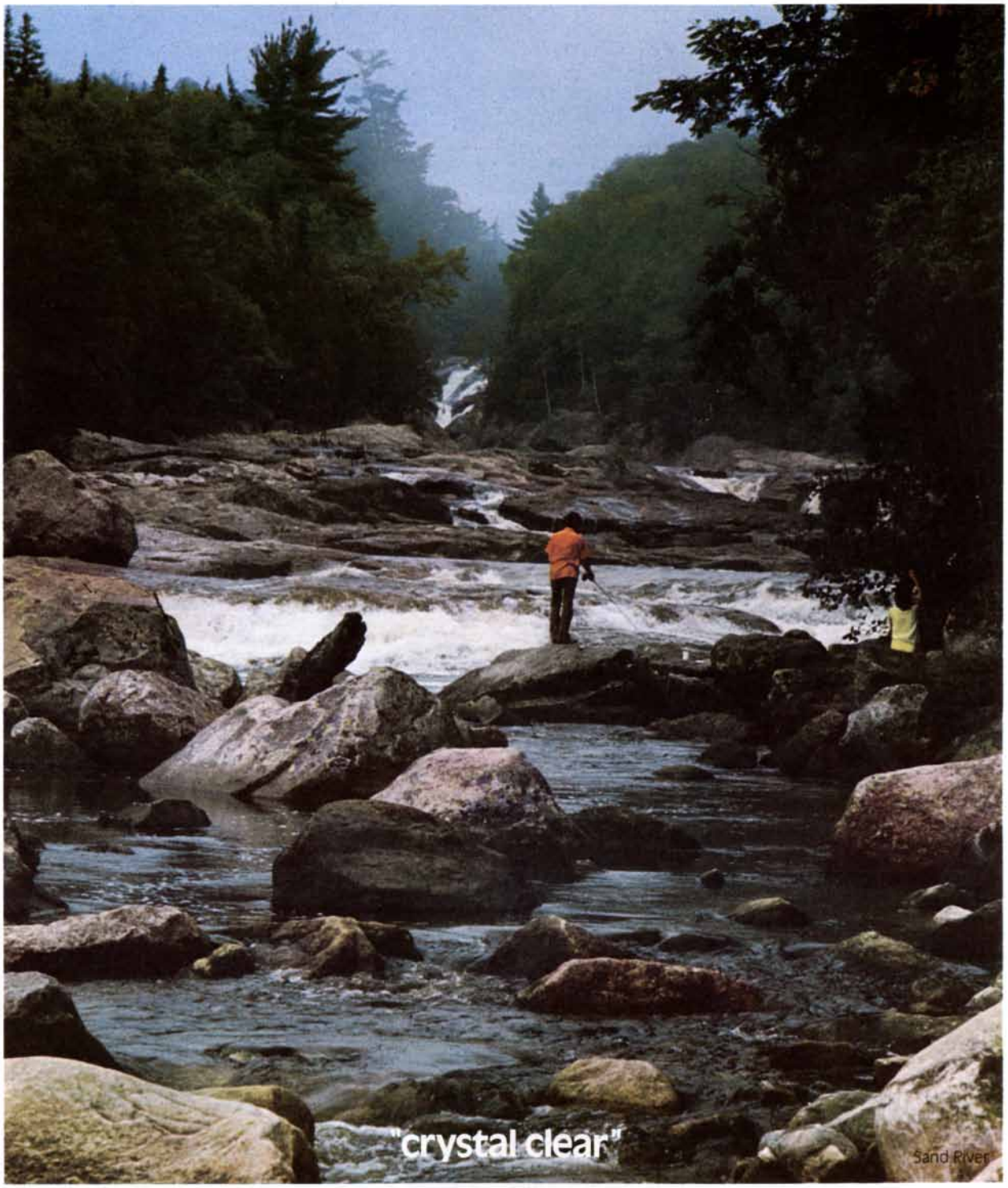
A magnetic ink-jet printer employs a synchronized drop generator much like the one in an electrostatic printer, but the generator usually operates at about half the drop frequency. The apparatus for deflecting the drops and forming characters is quite different from the corresponding electrostatic devices. For a given field gradient deflection is proportional to the net magnetic moment of the drop, which cannot be controlled independently from drop to drop; the magnetic moment per unit volume of fluid is a fixed property of the ink. For this reason drops cannot be individually selected for deflection. One alternative to the aiming of individual drops is to create a raster of drop positions, much like the pattern of electron scan lines in a television picture, and to provide a means for "blanking" selected positions.

Suppose the drops pass through a field gradient created by an electromagnet whose pole pieces are exactly seven drop periods long. The gradient is arranged so that drops exposed to the field will be deflected upward before proceeding to the paper. If the field is turned on just as a drop is leaving the influence of the magnet, the drop will continue on its original trajectory unaffected by the field. The next drop will have been exposed to the field gradient for one drop period before it leaves the magnet, and so it will be deflected through a small angle. The next drop will have been exposed to the gradient twice as long, and so it will be deflected twice as much. The deflection increases uniformly for each succeeding drop through the eighth one; for the eighth drop the field is on the entire time the drop is between the pole pieces, and so its deflection is the maximum possible.

On the printed page this sequence of eight drops creates a vertical line made up of eight uniformly spaced spots; by moving the print head across the page horizontally the pattern can be repeated



RASTER OF DROPS is created by the magnetic deflection system. Here the length of the deflection magnet is assumed to be six times the drop spacing and the magnet is actuated cyclically, so that it spends seven drop periods on followed by seven periods off. When the magnet is turned on (*1*), the drop just emerging from between the poles is unaffected by the field gradient and proceeds directly to the paper. When the next drop emerges (*2*), it has spent one drop period under the influence of the field gradient, and so it receives a small deflection. The next drop (*3*) spends two periods in the field, and so it is deflected twice as much. With each succeeding drop through the seventh one the deflection grows by the same increment; for the seventh drop the field is turned on the entire time the drop is between the pole pieces, so that no greater deflection is possible. The result of the progressively increasing deflection is a vertical column of dots on the paper. In order for the column to form a character selected drops are deleted by diverting them into a gutter that would lie outside the plane of the illustration.



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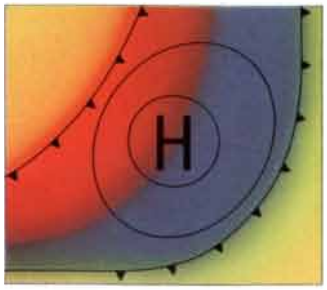
Since then, however, air quality studies have revealed frequent rural violations of that standard. The suspected sources of ozone are the stratosphere, drift from urban areas, and, indirectly, natural vegetation. To evaluate each source, scientists at the General Motors Research Laboratories analyzed air at five rural sites.

Average Beryllium-7 Concentrations in High Pressure Systems at Busick, N. Carolina



■ ^{7}Be = 372 disintegrations/min.
■ ^{7}Be = 261 disintegrations/min.

What did they find? Not only was the ozone standard violated at all five sites, but *average* ozone levels at those sites exceeded average levels in urban areas previously monitored (although *peak* urban levels were higher).

Furthermore, using beryllium-7 as a tracer of stratospheric ozone, our scientists found that such ozone is distributed *throughout* high pressure weather systems and, in fact, is most concentrated in the trailing sector.

This evidence refutes the assumption that stratospheric ozone contributes only near the leading edge of these systems, where measurements show lower ozone levels. And it thus indicates that the stratospheric contribution to ground-level ozone has been seriously underestimated.

The results aren't all in. But enough has been learned to question a goal requiring cleaner air than what nature itself provides.

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indefinitely. All that is needed in order to create characters is a means of selectively discarding some of the drops. The drops at positions to be left blank must be intercepted before they reach the paper; so must the six drops that follow each upward vertical scan. The reason for catching the six trailing drops is that when the magnet is turned off after the eighth drop, the deflection does not immediately return to zero. When the field is removed, it has already influenced the ninth drop for six drop periods, the 10th drop for five periods and so on. Drops eight through 14 are therefore discarded and a new scan begins with drop 15.

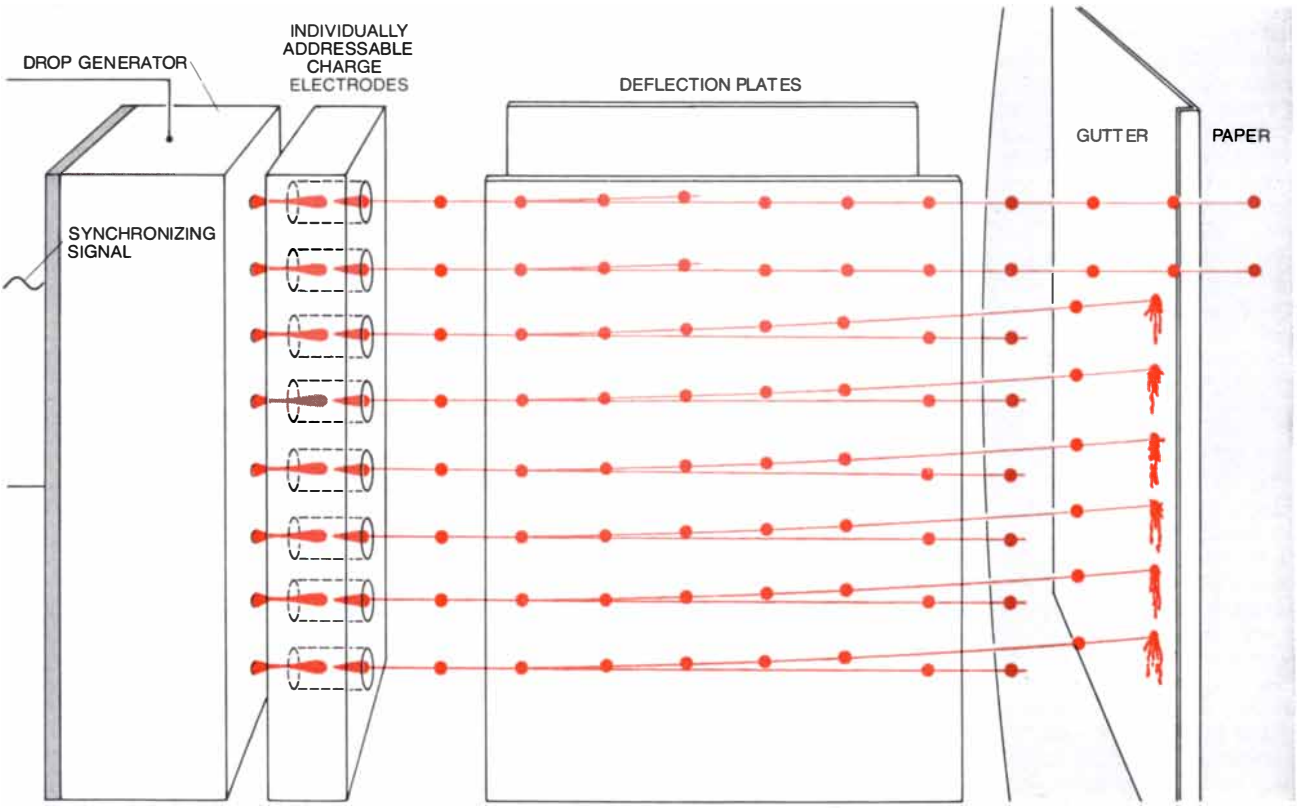
The means for eliminating selected drops from the sequence is another magnetic deflector. Since individual drops are to be selected, the length of the pole pieces must be shorter, less than one drop period, but that is acceptable because little deflection is needed. The small selector magnet is oriented at right angles to the deflection magnet so that the drops it designates are pulled out of the plane of the raster scan. The selector is positioned upstream of the deflector magnet, and so the drops it influences still pass through the deflecting gradient; before they reach the paper, however, they are intercepted by a knife-edge gutter and recirculated. The drops that remain in the plane of the raster pass the gutter and go on to the paper.

An important feature of the magnetic printer is that the maximum possible deflection is essentially independent of drop size. In an electrostatic printer a larger drop has more mass but can accommodate little additional charge, so that it is deflected less. The force acting on a magnetic drop, on the other hand, is proportional to the drop's mass since a larger drop has more magnetite in it. For this reason a magnetic ink-jet printer might operate efficiently with the large drops needed for a low-resolution matrix printer.

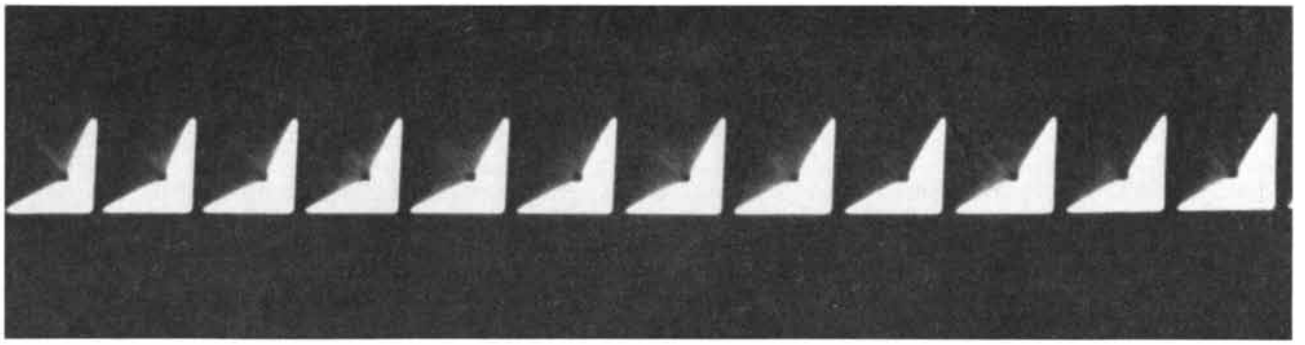
Another capability of the magnetic printer is the deflection of each drop in two dimensions. A printer with two axes of deflection could form characters not by selecting dots from a fixed array but by drawing curves and line segments. Fan and his co-workers have demonstrated a magnetic printer that draws characters in this way.

In an effort to improve the speed of the ink-jet process we have also investigated printers in which an array of nozzles operate in parallel, another configuration foreseen by Sweet. The technology employs electrostatic deflection; it has been called binary printing or nozzle-per-spot printing. The print head consists of many closely spaced nozzles supplied with ink from a common manifold and synchronized by a single piezoelectric element. The jet from each nozzle passes through a charge electrode that can be individually addressed; then the drops from all the jets pass between a common pair of deflection plates. Each charge electrode has only two possible states; it is either on or off. If a drop is charged, it is deflected into a gutter and the ink is recirculated; otherwise the drop passes undeflected to the paper. It is because a drop has only these two possible destinations that the printing is called binary.

The Mead Corporation has built a high-speed printer on these principles. Some 600 nozzles are lined up across the width of the page (about five inches) and the paper is continuously drawn under them. Each charge electrode is turned on and off in the proper sequence to form an entire line of dots. The device is capable of printing up to 45,000 lines per minute but has comparatively low



BINARY PRINT HEAD employs multiple ink jets and steers each drop to one of only two possible destinations. If a drop is uncharged, it proceeds straight to the paper; if the drop is given a charge, it is deflected into the gutter. The nozzles are arranged in a vertical column and share a single pressure manifold and synchronizing signal. Each ink stream, however, is provided with a separate charge electrode, so that drops can be selected individually for printing or for deletion. All the drops pass through a common pair of deflection plates, where drops that have been labeled with an electric charge are pulled into the knife-edge gutter. Because the printing is done with uncharged drops most electrostatic interactions between drops in flight are eliminated. Moreover, because only small deflections are needed voltages applied to the electrodes can be reduced and so can the distance between nozzles and paper, thereby minimizing aerodynamic effects.



ROW OF NOZZLES for a binary print head was etched in silicon by techniques similar to those employed in making microelectronic devices. In this scanning electron micrograph the nozzles are seen from the ink-manifold side. The shape of the nozzles is determined by the orientation of the planes of atoms in the single-crystal wafer of silicon and for that reason can be precisely controlled. Each nozzle has the form of a truncated pyramid; the ink issues from the smaller base. The square shape of the aperture has no effect on the drop stream.

resolution. So far it has been employed mainly for the printing of "computer letters": mailed advertisements that include names or other information that is different in each copy.

At IBM Research we have investigated the design of a nozzle-per-spot printer in which a moving print head would reproduce characters serially at high resolution. Such a binary printer offers a number of advantages over the analogue electrostatic printer described above. The drops from a binary array of nozzles are less affected by electrostatic and aerodynamic interactions, so that drop placement is more easily controlled. The circuitry needed for drop control is also greatly simplified. On the other hand, the fabrication of the nozzles and the charge electrodes becomes a formidable challenge.

The replacement of analogue devices by binary ones is a well-established trend in the electronics industry as a whole, made possible by the discovery that even very complex circuitry can be manufactured cheaply when it is represented as a pattern on the surface of a wafer sawn from a single crystal of silicon. We and our associates adopted the same techniques for the fabrication of the essential components of the binary print head.

The fabrication of the nozzle array demands great precision. In a typical array some 40 nozzles, each from 20 to 40 micrometers in diameter, must be packed together in a line whose length is roughly equal to the height of a typewriter character. The spacing of the nozzles must be uniform; what is more important, the jets issuing from them must be parallel to within high accuracy. For example, if the paper is only one centimeter from the nozzle, a deviation from parallel alignment of less than .1 degree would result in a drop misplacement of about 20 micrometers, which is roughly the maximum error that can be tolerated in high-quality printing. Uniform velocity is as important as uniform direction, and it is harder to achieve. If the drops do not have equal transit times between the nozzle and the page, then the motion of the print head with respect to the paper gives rise to errors in drop placement.

Several approaches to nozzle fabrication have been investigated, including drilling holes with laser light or an electron beam and assembling a bundle of fine glass capillaries. The nozzle for the IBM 6640 is made by mechanical drilling. For the binary array we formed the nozzles by chemically etching holes through a silicon wafer, a method that had been proposed in a somewhat different form by Charles Chiou and his collaborators at the IBM Laboratory in San Jose, Calif. Many copies of the pattern to be etched can be defined on a single wafer by photolithography. The etching itself can then be carried out in batches of several wafers each. In a final step the wafers are cut into chips, each chip bearing a nozzle array. Silicon was chosen not because of any intrinsic property that makes it a particularly suitable material for the nozzles but because there is a highly developed technology for the fabrication of precise microscopic structures out of silicon.

An etched nozzle has the form of a truncated pyramid, the large base forming the nozzle entrance on one side of the wafer and the smaller base the exit. The sides of the pyramid are defined by planes of atoms in the crystal, and hence their orientation is in principle fixed to within a few atomic diameters. For protection against corrosion a thin film is applied to the array, such as a layer of silicon dioxide.

The jet emerges from the nozzle with a square cross section but quickly relaxes to a circular one. At the outset it was not known what effect the square orifice might have on the formation of the drop stream, but the shape turned out to be unimportant. The corners of the square, having high curvature, are immediately flattened by surface tension. Because of inertia there is some overshoot, so that each corner of the square develops into a concavity, but the ensuing oscillation is damped too quickly for it to influence drop formation. For the purposes of the printer the jet from a square nozzle is virtually identical with one from a round nozzle.

Arrays of as many as 40 nozzles have been fabricated and tested. The jets have excellent directional characteristics, which can be attributed to the crystal structure of the silicon, which determines the shape and orientation of the nozzles. The sharp edge of the opening also contributes to uniformity by creating a stable point of detachment for the fluid. The closely matched velocities of the jets are an indication that all the nozzles are the same size.

The fabrication of the charge electrodes also presents considerable difficulties. The reason is that each electrode in the array must be electrically isolated so that it can be turned on and off independently of all the other electrodes. Moreover, attaching a separate wire to each electrode and connecting it to a distant electronics module could be awkward. One of us (Kuhn) therefore suggested that the array of charge electrodes also be made in a single chip of silicon. Integrated circuits could be created on the same chip as the electrodes themselves and during the same processing steps. Signals intended for the various electrodes could then be sent over a single wire in encoded form. An on-chip circuit would decode the signals and distribute them to the proper destinations.

The pyramidal holes employed as nozzles are not suitable for charge electrodes, but holes of other shapes can be created by etching silicon with a different crystallographic orientation. We chose to etch long slots with the long walls parallel. The holes were etched in thick wafers of silicon that had been doped with an electron-donor impurity, converting the material into an *n*-type semiconductor, which has an excess of electrons. The walls of each slot were then treated with another dopant to make them *p*-type semiconductors, which have a shortage of electrons or an

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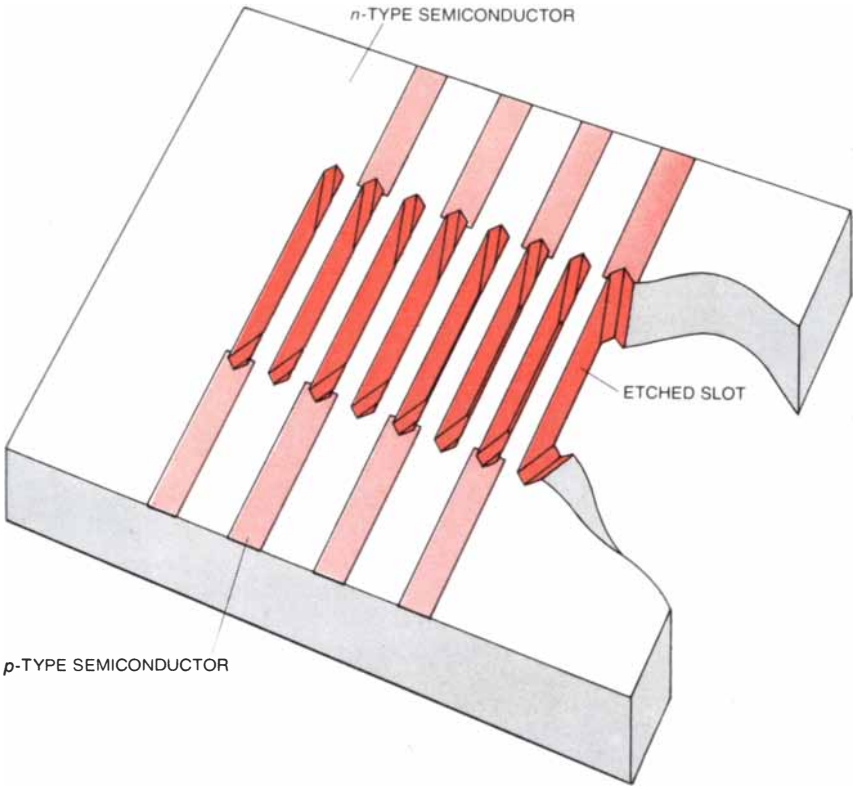
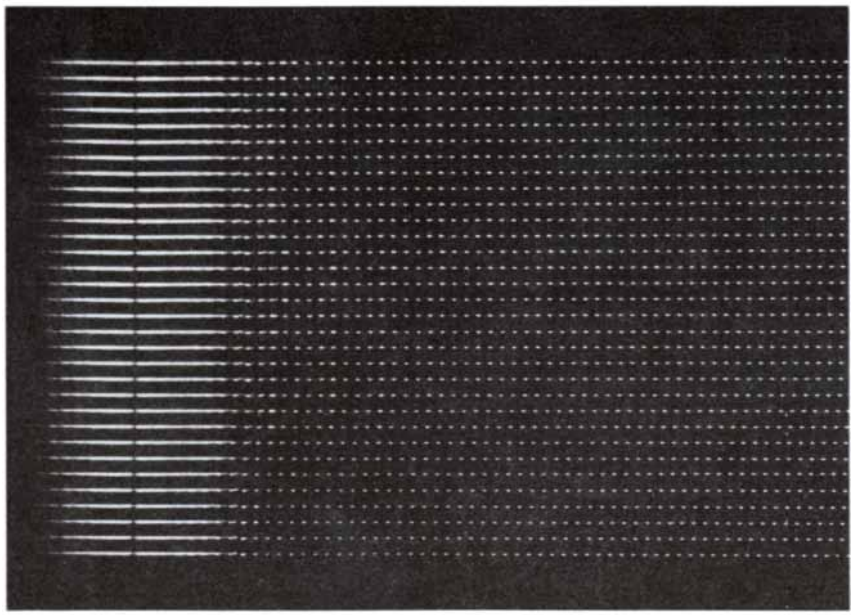


ARRAY OF CHARGE ELECTRODES was also etched in silicon, but in material with a different crystallographic orientation. As a result the holes have a different shape: they are slots instead of pyramids. Because each stream of drops must be steered independently of the other streams, each charge electrode must be electrically isolated. That is accomplished by treating the walls of the slots to make them *p*-type semiconductors, whereas the bulk material is an *n*-type semiconductor. When a bias voltage is applied, each slot acts as a diode and no current can flow from one electrode to another. Ultimately it should be possible to fabricate an integrated circuit on the surface of the chip for the purpose of decoding signals to the electrodes.



MULTIPLE STREAMS OF INK DROPS emerge from an etched-silicon nozzle array. The image is greatly magnified, the actual size of the array being roughly the height of a typewriter character. The streams of drops exhibit several properties that are important in a binary, or nozzle-per-spot, printer. The drops are uniform in size and spacing, and the streams are parallel to within high accuracy. The velocity of the drops is also nearly uniform, the only significant distortion being a tendency for drops at the periphery to move slower than those at the center.

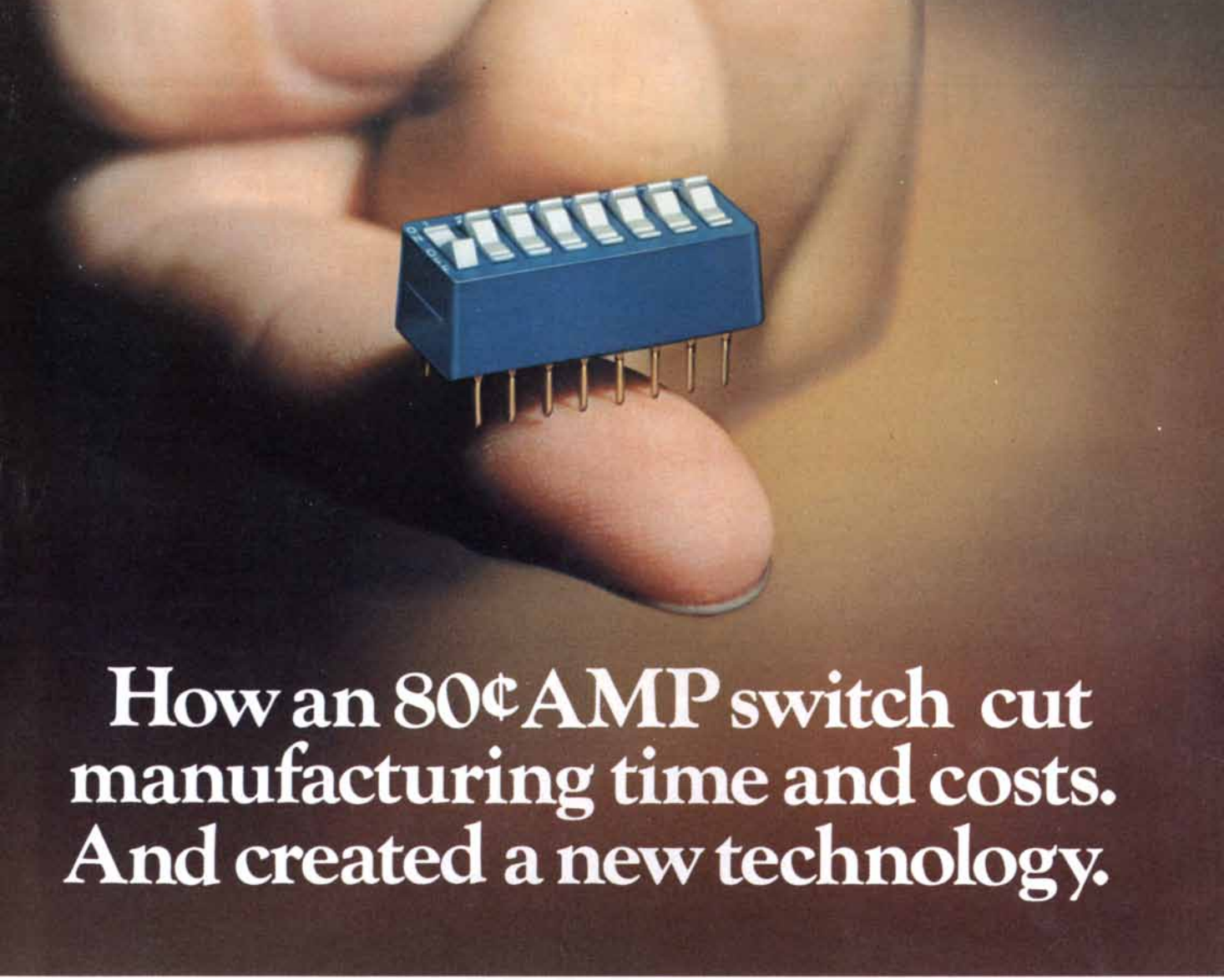
excess of "holes." The junction between the *n*-type and *p*-type layers represents a diode; when an appropriate voltage is applied across the junction, each slot is electrically isolated from its neighbors. In addition the *p*-type surface serves as a conducting layer for the electrode.

A print head can be assembled from these components by mounting the nozzle array on a manifold with a piezoelectric driver to provide the synchronization signal. The charge-electrode array is then bonded to a printed-circuit board, which holds the array in proper alignment with the nozzles and also carries the drive signals to the electrodes. Rudimentary printing experiments have been carried out with such prototype assemblies. Both the nozzles and the charge electrodes are spaced on centers .3 millimeter apart. The jet diameter is about 25 micrometers, and the jet velocity is about 12.5 meters per second.

It may well be possible to extend silicon fabrication methods to still another component of the binary print head. Synchronization of the drop stream by an electromechanical transducer such as a piezoelectric crystal is unsatisfactory for very long arrays of nozzles because distant nozzles may not receive the same mechanical excitation. The problem can be avoided by direct, nonmechanical synchronization of the stream with an electrical signal. If an oscillating voltage is presented on an electrode near the emerging jet, a mirror image of the electrode's charge is induced in the fluid jet, which is therefore attracted to the electrode. The result is a periodic deformation in the surface of the jet, which is precisely the kind of signal needed for synchronized drop formation.

One way to provide such a synchronizing signal is by fabricating an electrode for each nozzle in the silicon substrate of the nozzle array. Synchronization has been demonstrated with such nozzle arrays, but in our experiments it was not strong enough for reliable printing. The limiting factor is the electrical strength of the insulating oxide layer on the surface of the nozzle chip, which limits the voltage that can be applied to the synchronizing electrode. With an improvement in coating technology the all-electronic ink-jet print head should become possible.

There is a satisfying symmetry in the development of all-electronic printing. It was the proliferation of computers in the past 15 years, and more recently of microelectronic devices, that created the need for machines that quickly and legibly print a document on demand. Electronic technology is essential to all such printers, including even the electromechanical ones, and it is the very basis of the ink-jet mechanism. With the adoption of semiconductor processing methods for the fabrication of the printing machinery the cycle has fully closed.



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THE AMATEUR SCIENTIST

More on boomerangs, including their connection with the dimpled golf ball

by Jearl Walker

Last month I described the basic mechanism that makes a boomerang return to the person who throws it. My account left some of the stranger aspects of the design and flight of boomerangs unexplained. This month I shall first deal with these aspects and then explain how you can experiment with the boomerangs you have made according to the techniques I described last month.

One interesting feature of certain older boomerangs is that they have a rough surface. Some of the ancient boomerangs found in Australia have this characteristic, as if the person who made the boomerang thought a rough surface would make it go farther. Although the idea seems implausible, it might be correct. One's initial reaction is that roughening would increase the friction between the surface and the passing air, so that the boomerang would lose forward velocity sooner and fall to the ground earlier. If a rough surface is desirable, the reason certainly has nothing to do with friction. Something else must be going on.

Many familiar objects have surfaces that have been made rough to increase their flight time. The dimpled golf ball is the best-known example. In the early days of golf all the balls were smooth, as intuition would suggest. Eventually someone noted that a ball scarred and pocked by use seemed to travel farther than a smooth one when both were struck in essentially the same way. Thereafter balls were pitted on purpose. Ascher H. Shapiro once did experiments comparing a dimpled golf ball with a smooth one. He found that the dimpled ball traveled more than four times farther than the smooth one, notwithstanding the difference in air friction.

Why would dimples aid an object in its flight? The answer lies in the behavior of the air flowing around a dimpled golf ball or a roughened boomerang. For the sake of simplicity first consider the flow pattern around a classic airfoil. Most of the air passing the airfoil is unaffected by the viscosity of the air, that is, by the friction between two layers of air or between a layer of air and the surface of the airfoil. Next to the surface, however, is a layer of air called the boundary layer that is affected by viscosity in an important way. The air closest to the surface does not move at all, being held in place by the friction between it and the surface. The next layer of air has a low velocity. As one considers more of these imaginary thin layers of air at greater distances from the surface one finally reaches layers moving with a speed that is unaffected by friction with the surface of the airfoil. The thickness of the boundary layer is defined as the distance from the surface to the level where the friction can be neglected. The clue to the behavior of dimpled golf balls and roughened boomerangs lies in the movement of the air in the boundary layer.

The air pressure around a classic airfoil is high in front of the airfoil and behind it, relatively low over the top of it and relatively high below it. Last month I explained that the pressure difference between the top and the bottom is due to the Bernoulli principle. That pressure difference gives lift to the airfoil. This month I shall examine how the air moves from the front to the rear over the top of the airfoil.

Consider two small parcels of air, one parcel traveling inside the boundary layer and the other one just outside it. When they approach the airfoil, they are slowed to a stop by the high-pressure area just in front of the airfoil. When they reach the top of the airfoil (because it is moving), they must accelerate as they are pushed by the pressure difference between the front and the top. The parcel in the boundary layer must act against the viscous forces extending outward from the surface of the airfoil, however, and so it does not accelerate as much. When the two parcels pass over the top of the airfoil, the one outside the boundary layer is moving faster.

As the parcels then move toward the rear of the airfoil they encounter an increase in pressure and so slow down. The parcel outside the boundary layer will be brought to a stop by the time it reaches the rear of the airfoil and then will be accelerated farther rearward by the high pressure there until it regains the speed it had before it began to pass the airfoil. The parcel inside the boundary layer begins the trip to the rear with a lower speed, so that it may stop before it reaches the rear of the airfoil. If it does stop, the high pressure at the rear may even push the parcel back toward the top of the airfoil, forcing air emerging from below the airfoil up to replace it. The air of the boundary layer will be pushed away from the airfoil by this influx, an effect that is termed separation and is an important factor in the drag on the airfoil.

Part of the drag comes from the friction between the passing air and the surface of the airfoil. One can call this contribution skin-friction drag. Another contribution comes from the difference between the average pressure on the front and that on the rear of the airfoil. If the average pressures are about equal, this contribution is small and one need consider only the skin-friction drag. In some cases, however, the pressure difference is even larger than the skin-friction drag. Such a situation may arise when the boundary layer separates from the surface, leaving a relatively wide wake of turbulent air replacing what initially was high pressure. The pressure of the turbulence is intermediate between the low pressure on top of the airfoil and the high pressure in front of it. Thus the pressure difference between the front and the rear may be large, creating a strong drag on the airfoil. The earlier the separation develops in the passage of air over the top of the airfoil, the stronger the drag from the pressure difference will be. With an earlier separation the pressure in the wake is lower and the wake is wider; both effects reduce the average pressure on the rear of the airfoil.

A smooth golf ball is a blunt object from which the boundary layer separates early, perhaps even before the air has gone halfway to the rear. A normal golf ball is dimpled in order to delay the separation. (Streamlining would accomplish the same result, but a golf ball shaped like an airfoil would be unlikely to roll well on the green.) At first the effect of the dimples seems counterintuitive because the dimpling surely also increases the skin-friction drag. The reduction in the pressure-difference drag is so large, however, that the overall drag is decreased and the golf ball travels considerably farther.

The dimples are designed to create a turbulent boundary layer that will rapidly mix the air in the boundary layer and the air outside the layer. As a result the air in the boundary layer does not have a chance to slow down with respect

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to the outside air because it is always receiving momentum from the outside air. When boundary-layer air passes over the top of the ball and heads toward the rear, it does not slow to a stop before it reaches the rear and the high pressure at the rear does not push it away from the surface. The wake is therefore relatively narrow, and the pressure difference between the front and the rear of the ball is not as large as it would have been if the ball had been smooth.

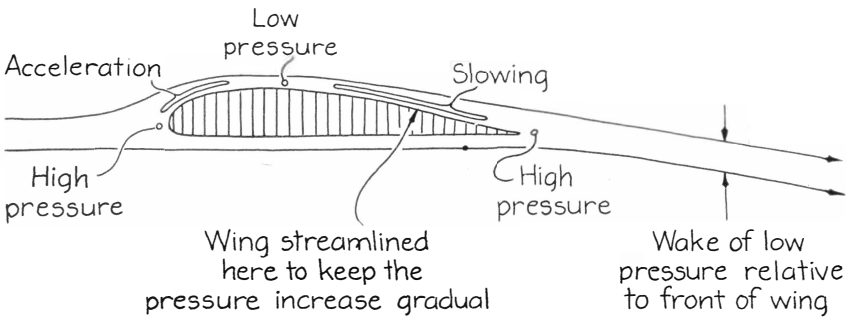
For the past several years a golf ball with a new dimple design has been offered by Uniroyal. The regular arrangement of circular dimples is replaced with a random arrangement of hexagonal dimples. Based on the research of John Nicolaides of the University of Notre Dame, the ball reportedly travels an average of six yards farther than the conventional ball. I am not sure why, but the cause is likely to be the creation of a better turbulent boundary layer.

Recently I saw a demonstration of the effect of dimpled golf balls at the Ontario Science Centre in Toronto. One smooth ball was attached to a vertical rod hinged at the top so that the ball could move when an airstream was directed at it. A dimpled ball was mounted in the same way. When the airstream was turned on, the ball with the lesser drag would be displaced less and its rod would swing less from the vertical. When I turned on the air, I found that the dimpled ball was displaced the least. The dimpled ball has less drag.

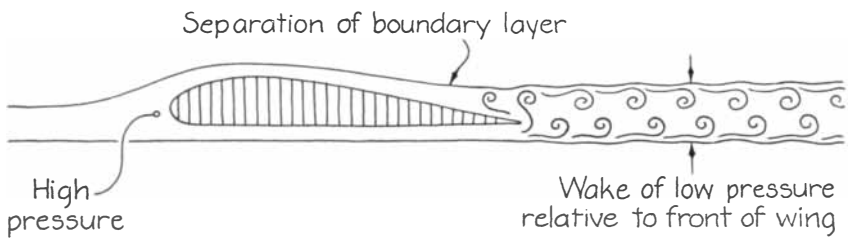
Should a boomerang be roughened or dimpled? Maybe. One must bear in mind the likelihood of separation on an airfoil traveling at moderate speed, as a boomerang does. When investigators study the flow of a fluid past objects, they must be able to compare the likelihood of separation and turbulence even though they are using different fluids (having different densities and viscosities) and different objects (having different sizes). To make the comparison a dimensionless number called the Reynolds number is computed. Named for Osborne Reynolds, who contributed greatly to the analysis of fluid dynamics in the 19th century, the number is calculated from the density and speed of the fluid multiplied by a typical length of the object and divided by the viscosity of the fluid. When the Reynolds number is high, separation and turbulence are likely, the boundary layer is turbulent and the flow is said to be only slightly viscous. The fluid may actually have a high viscosity, but under the circumstances of the high Reynolds number the flow is almost as it would be if there were no viscosity. A given pressure difference propelling a parcel of the fluid will create an acceleration of the parcel that depends on the density of the fluid rather than on the viscosity.

When the Reynolds number is low, separation and turbulence are unlikely, the boundary layer is laminar and the flow is said to be viscous. Again the behavior does not depend directly on the actual value of the viscosity, which may in fact be low. Under the circumstances of the low Reynolds number the pressure difference attempting to propel a parcel of the fluid is almost matched by the opposing viscous forces, with the result that acceleration is minimal.

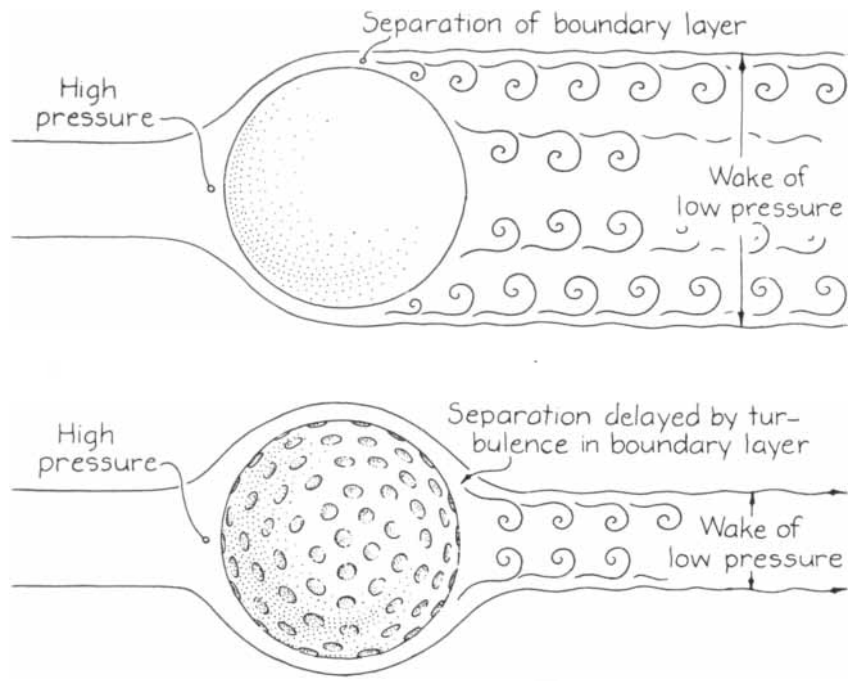
For a golf ball the Reynolds number is in a middle range, high enough to make separation and wake turbulence likely but not high enough to create a turbulent boundary layer. Dimpling the surface (even at the cost of increased skin-friction drag) is justified. What about a boomerang? Unfortunately the Reynolds number of a typical boomerang also lies in a middle range of values, making the effect of roughening unclear. If the performance of a particular boomerang is not much affected by early separation of the boundary lay-



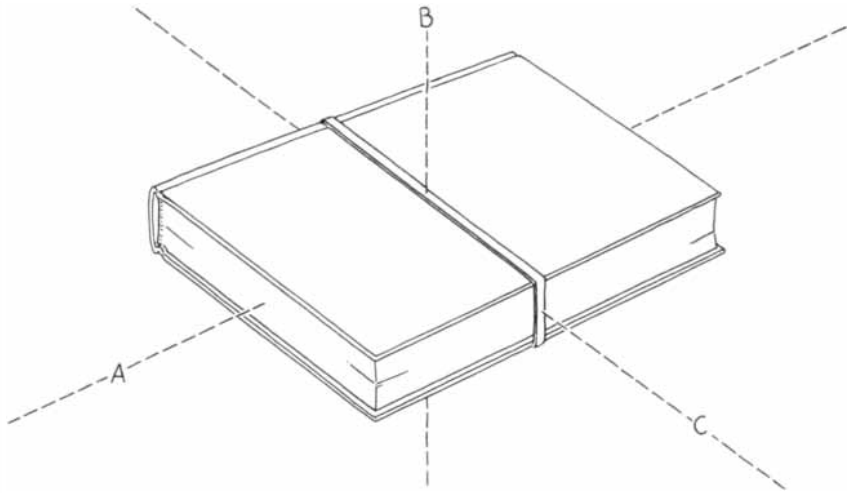
The distribution of air pressure around a classic airfoil



Separation of the boundary layer



How air flows around a smooth golf ball and a dimpled one



The principal axes of rotation of a book

er, roughening the surface is inefficient because the overall drag is increased by the additional drag of skin friction. On the other hand, if the performance of a boomerang is considerably affected by early separation, a roughening of the surface may increase its flight time.

A related consideration in reducing the chance of separation is whether or not the object should be streamlined. Airplane wings are streamlined to reduce separation and the drag caused by pressure difference. Should the arms of a boomerang be streamlined too? For the sake of simplicity again consider a classic airfoil. When air in the boundary layer moves over the top and toward the rear, it meets a progressive increase in pressure that threatens to stop its progress and force a separation. If the path to the rear is short, the pressure increase is sudden and separation may be unavoidable. Hence an object such as an airplane wing has a tapered rear to make the pressure increase gradual. The tapering also increases the distance over which the passing air rubs against the surface, thereby increasing the skin-friction drag. Still, the avoidance of separation is worth the increased drag.

Shapiro gives an example of streamlining in his book *Shape and Flow: The Fluid Dynamics of Drag*. He compared the overall drag on a cylindrical wire and a streamlined airfoil when air passed them at 210 miles per hour. The wire had the same drag as the airfoil, which was almost 10 times the width of the wire. Intuition suggests that the much thicker airfoil should have the greater drag, but intuition does not always take into account the subtle effects of boundary-layer separation and pressure-difference drag. At high Reynolds numbers it is better to streamline the object.

Suppose the fluid passes the object at a Reynolds number that is low enough to make separation unlikely. Streamlining the object (at the cost of increased skin-friction drag) would then be wrong. Instead the object should be blunt, presenting as little surface as possible for the air to pass.

Should the arms of a boomerang be streamlined? They probably should be, but I have not found conclusive evidence to verify my guess. Once again the Reynolds number for a typical boomerang is in the awkward middle region, and I do not know if separation is sufficiently common to justify the increased skin-friction drag the boomerang would have if the arms were streamlined.

You may wonder why none of the boomerang shapes is just a straight stick. Even if a straight stick is suitably curved on one side and flattened on the other so that it presents a classic airfoil to the passing air, it will not serve as a boomerang. The reason is a bit subtle, because it involves the stability of a rotating object against the small perturbations it encounters as it rotates.

Suppose you bind a book with a strong rubber band so that the book remains closed and flip it into the air. As is shown in the illustration above, the book can rotate about three principal axes. Rotation about two of them (either *A* or *B*) is stable, but around the third axis (*C*) the book wobbles vigorously.

The axes are characterized by the distribution of the book's mass with respect to an axis. With rotation about axis *A* the book has its mass distributed as close to the axis of rotation as possible. The book's moment of inertia is the lowest for this axis. The moment of inertia is the highest for axis *B* because then the book has its mass distributed as far as possible from the axis. About axis *C* the moment of inertia is intermediate and the rotation of the book is unstable.

The stability depends on what the angular momentum of the book does

when it deviates slightly from being exactly parallel to the principal axis about which the book is rotating. (The book's angular momentum is a vector with a magnitude that is the spin rate multiplied by the moment of inertia and with a vector direction that is perpendicular to the plane in which the book is spinning.) For two choices of a principal axis (*A* and *B*) a wandering angular-momentum vector is quickly rotated (precessed) back to being parallel to the principal axis. For axis *C* a wandering angular-momentum vector is rotated away from being parallel. If you could carefully spin the book around the wobbly axis with the angular-momentum vector exactly parallel to the axis, the book would spin stably. Any deviation from that parallel condition (a likely development) will increase quickly during the flight and the book will be unstable. If the greatest moment of inertia and the intermediate one are almost equal, as they would be for a square book, the spins around both of the axes associated with them will be unstable.

The standard banana-shaped boomerang spins around the axis about which it has the greatest moment of inertia, and so its spin and flight are stable. With a straight boomerang, however, the greatest moment of inertia and the intermediate one would be almost equal, and the boomerang would be unstable. The wobbling would prevent the boomerang from meeting the air at the proper angle of attack, and so the device would get no lift. In short, a straight boomerang does not boomerang.

A curious feature of a regular boomerang is the tendency for it to "lie down," that is, for its spin plane to rotate from being almost vertical to being horizontal. At the beginning of a flight the boomerang's forward velocity is great enough so that the spin plane needs only a slight tilt from the vertical to have enough upward lift to counter the weight of the boomerang. As air drag slows the forward velocity, progressively more of the lift has to be upward to hold the boomerang up. By the time the boomerang returns to the thrower the spin plane is almost horizontal.

Two possible causes for lying down can be identified. One, which is true for all types of boomerang, involves the air deflected by the arm that is turning forward of the boomerang's center of mass. Whenever an arm rotates through the forward position, it deflects the passing airstream, which (slightly later) flows around the other arm as the boomerang travels forward. Hence the trailing arm does not meet undisturbed air and does not experience the same lift as the leading arm.

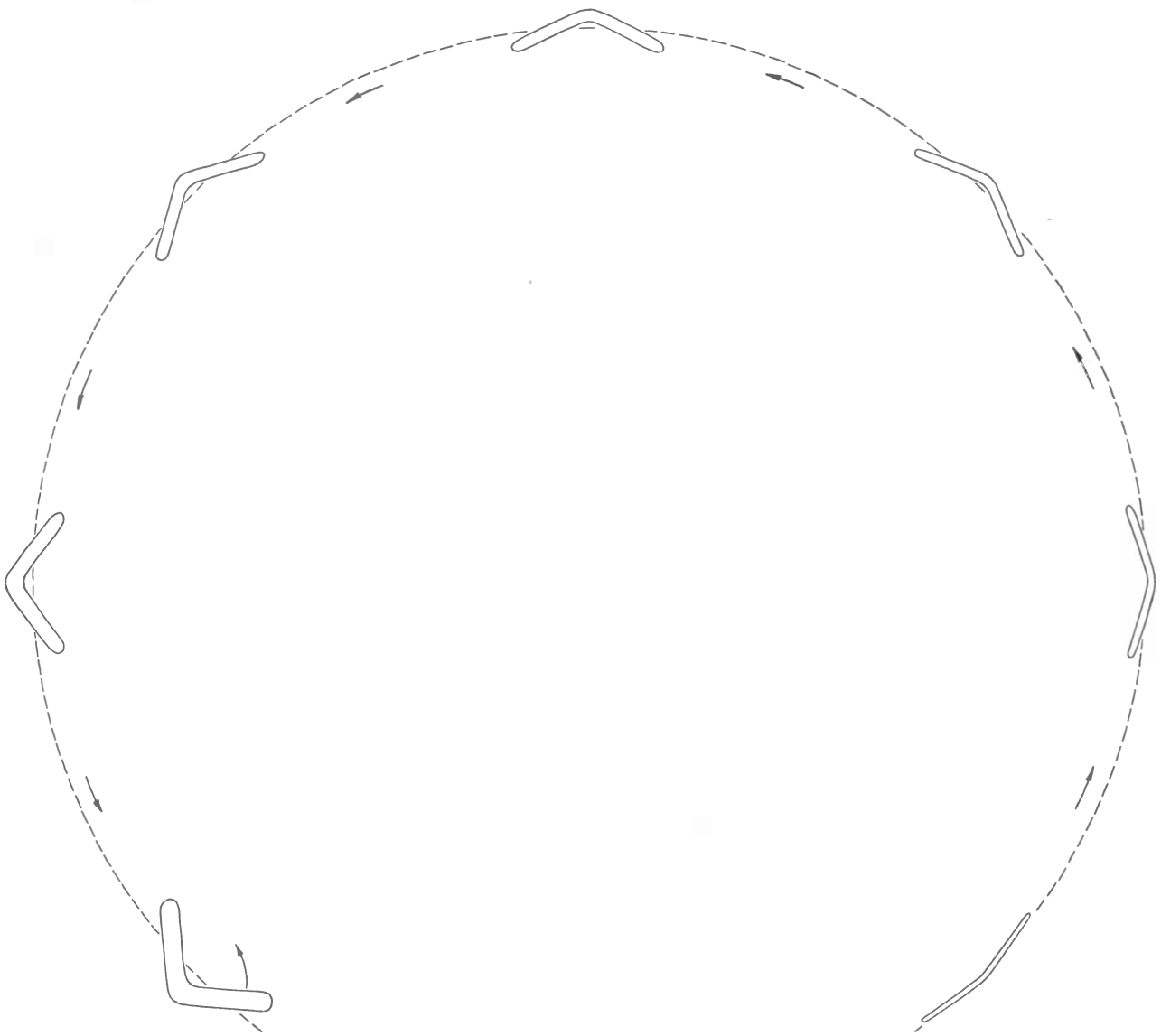
For example, just after a throw by a right-handed thrower the boomerang has a horizontal lift to the left of the

thrower. When the air leaves the leading arm, it must be deflected to the right of the thrower. (According to Newton's laws of motion, every action has an equal and opposite reaction. If the boomerang is forced to the left by the air, the air must be forced to the right by an equal amount.) As the trailing arm turns into air that is already flowing to the right it has a bit less lift than the leading arm because the air does not flow past the leading arm at the best attack angle. (The attack angle may even be negative.) The result is that as a boomerang spins, the leading arm always has a bit more lift than the trailing arm.

The difference in forces attempts to tilt the spin plane so that the rear of the boomerang would swing to the right (as viewed by the thrower) and the front would swing to the left. As I argued last month, this simple tilting does not appear because the boomerang is spinning and so has angular momentum. Instead what happens is that the torque resulting from the forces causes the spin plane to precess, that is, to rotate about a horizontal axis until the spin plane is horizontal by the end of the flight.

To make sense of the lying down imagine an overhead view of a right-handed boomerang that you have just launched with its spin plane vertical and therefore with its angular-momentum vector to your left. On the average the lift in front of the center of mass is more than the lift behind the center of mass because of the deflected air met by the rear of the boomerang. For the sake of simplicity consider the lift on the rear to be zero. (The results of my argument are the same even if you give that lift its proper value.) The change in angular momentum is due to the torque caused by the average lift on the forward section. To locate the direction of the change you should employ a rule I gave last month: Point the index finger of your right hand from the center of the boomerang toward the place where lift is applied on the boomerang's arm, point your middle finger parallel to the lift and then stretch your thumb perpendicularly to both fingers. Your thumb shows you the direction of the change in angular momentum: it is upward, perpendicular to the existing angular momentum.

Since the initial angular momentum is to the left and the change is upward, the angular-momentum vector rotates to be more upward, with the result that the spin plane of the boomerang is also rotated, turning from the vertical toward the horizontal. The boomerang has begun to lie down. This rotation, called



How a boomerang "lies down" in flight

Hughes is one of two AMRAAM finalists selected by the Joint System Program Office at Eglin Air Force Base to participate in the validation phase of the Advanced Medium-Range Air-to-Air Missile program. The Hughes design provides track-while-scan, multi-shot, and launch-and-leave capabilities, even against severe electronic countermeasures. AMRAAM will replace the AIM-7 Sparrow, now in use with the U.S. Air Force and U.S. Navy. It will outperform Sparrow. yet be half the size and weight, and cost less. AMRAAM will be used with the F-14, F-15, F-16, and F/A-18 aircraft. The validation phase is expected to last 33 months, at which time the winning design will be carried into full-scale engineering development.

Hughes Missile Systems Group has many openings for engineers in every phase of missile production -- from design through manufacturing -- for its facilities in Canoga Park, California, and Tucson, Arizona. For immediate consideration, send resume to: August Chiary, Engineering Employment, Hughes Aircraft Company, Canoga Park, CA 91304. Or call (213) 883-2400, Ext. 2424.

Vast amounts of data gathered by the Pioneer Venus mission in just 90 minutes last December, though still being analyzed, have given scientists a dramatic glimpse of Earth's nearest planetary neighbor. Teams of investigators already are using their discoveries to refine their theories on the evolution of the solar system and on the forces that drive Earth's weather.

The mission consisted of two spacecraft designed and built by Hughes for NASA's Ames Research Center. One, the Multiprobe, sent four probes to the surface, one of which survived for more than 67 minutes before succumbing to the searing environment. The other, the Orbiter, continues to provide pictures and other data as it circles Venus every 24 hours.

Many of the Pioneer Venus findings confirmed scientists' predictions. The planet's intense surface temperature (850°F) and atmospheric pressure (91 times that of Earth's) seem certainly to be due to a formidable greenhouse effect caused by thick cloud layers trapping solar energy. Various instruments revealed that Venus has global weather patterns. Cloud temperatures are warmer at the equator and colder at the poles. There is even a whirlpool-like vortex in the polar clouds that provides down-motion of the atmosphere.

There were, however, surprises. Probe instruments detected several hundred times more primordial argon and neon gases than Earth has. They also found the smog-like atmosphere is free of particles from an altitude of 19 miles to the surface. Two night probes saw an unexpected glow, perhaps due to "chemical fires" caused by reactions of sulfur compounds in extreme heat near the surface.

precession because it is a rotation of the angular-momentum vector, continues throughout the flight. By the time the boomerang has returned to the thrower the spin plane is almost horizontal and the lift on the boomerang is almost entirely upward.

The second possible cause of lying down is similar. Perhaps one arm has a shape that gives more lift than the other arm. (In the illustration on the opposite page the arm with more lift is labeled *A* and the other arm is labeled *B*.) Both arms have the most lift when they move into the upward position (as I noted last month) because the air speed past the arm is highest when the arm is turning into the oncoming airstream. When *A* is in its best position, it happens to lie in front of the center of mass. When *B* is in its best position, it is behind the center of mass. If the greatest lift exerted on *A* is always greater than that exerted on *B*, as will be determined by the cross-sectional shape of the arms, the lift on the average will be greater in front of the center of mass than it is behind it. Once again a difference between the force in front of the center of mass and the force behind it creates a torque that tilts the spin plane. Just as in the argument about the deflected air, the torque rotates the angular-momentum vector of the boomerang from being initially horizontal to being finally upward, causing the boomerang to lie down.

If the boomerang did not lie down, its flight would be shorter and far less interesting, because at some point during the flight the forward velocity would be too low to provide enough upward lift to support the boomerang. If a boomerang lies down so quickly that it is horizontal about halfway through the flight, it might continue to precess, swinging its angular-momentum vector out of the vertical and thereby dipping its spin plane below the horizontal. The boomerang would then begin to curve in the opposite direction and might even follow a figure-eight path on its return to the thrower.

It takes as much effort to build a boomerang that flies straight as it does to build one that returns. The horizontal lift must be almost eliminated, but enough vertical lift must remain to hold the boomerang up against its own weight. The horizontal lift is removed by twisting the arms to give a negative angle of attack near the tips of the arms and a positive angle of attack near the center. The overall lift is greatly reduced, but not quite to zero. The boomerang is thrown with its spin plane nearly horizontal, so that the net lift is almost vertical.

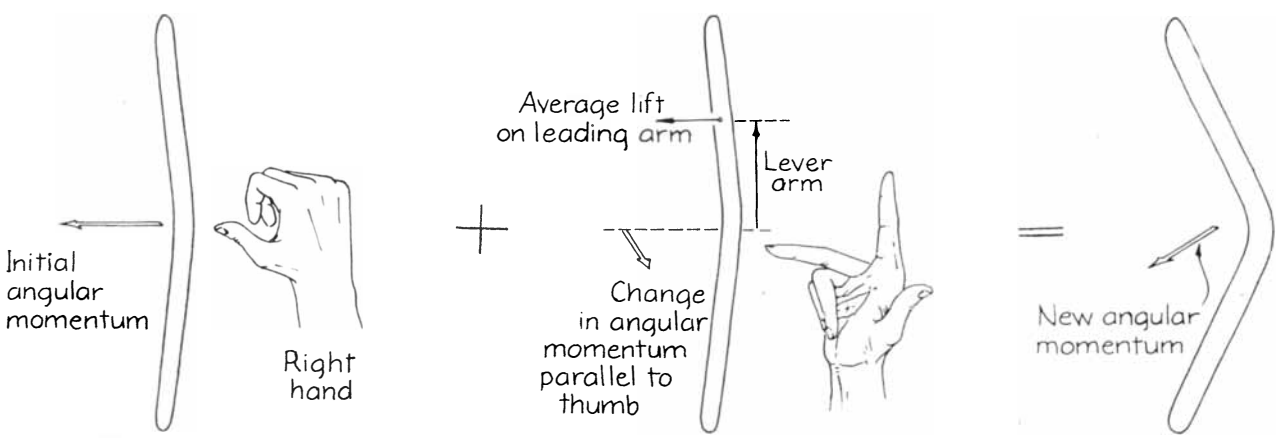
If the boomerang is launched with its spin plane about 20 degrees above the horizontal, a small horizontal lift causes it to fly in a straight line toward the thrower's left. The small amount of lying down makes the spin plane rotate until it is horizontal and then makes it dip below the horizontal. Afterward the boomerang veers somewhat to the thrower's right. Since the path is not perfectly straight, the thrower must know the boomerang well if a distant target is to be hit.

Explanations of the flight and return of boomerangs have been put forward for many years, but much of the early work was erroneous and lacking in experimental verification. Except for a modern understanding of airfoil theory, the basic mechanics of boomerang flight were known as early as 1837, but apparently the information was ignored or misunderstood by later writers. A classic theoretical explanation was given by G. T. Walker in his article "On Boomerangs" in the *Philosophical Transactions of the Royal Society of London* in 1897.

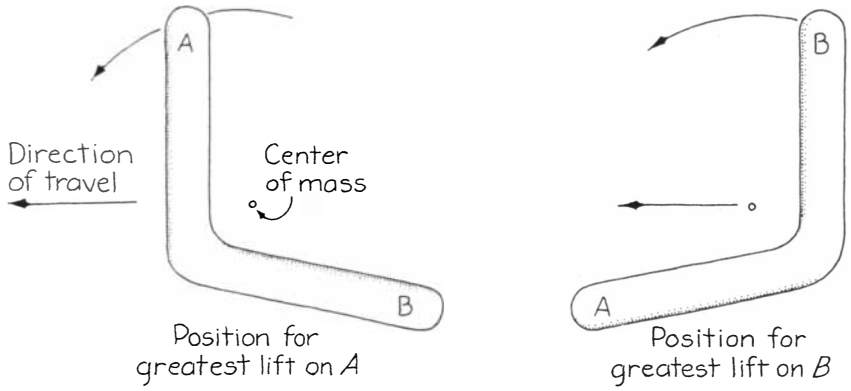
The most exhaustive modern treatment of the subject of boomerangs is the doctoral dissertation by Felix Hess listed in the bibliography for this month [*page 190*]. Hess reviews virtually all the older information and then examines boomerangs himself both experimentally and theoretically. Some of his earlier information was published in this magazine [see "The Aerodynamics of Boomerangs," by Felix Hess; SCIENTIFIC AMERICAN, November, 1968]. Much more information is available in the dissertation, including several interesting three-dimensional illustrations of computer-simulated flights that the reader examines through a stereoscope viewer provided in the back of the book.

A certain amount of research on boomerangs is carried out in wind tunnels in which investigators study the paths of airflow around a stationary boomerang. Much can still be done by amateurs throwing carefully constructed boomerangs. If you pursue this research, your first problem will be to determine what your boomerang does during the flight, because you will be at only one end of the flight and can easily misjudge distance and height. To determine the distance you can station several observers along the flight path. To determine the height you can measure the angle the path makes in your field of view. By knowing both the distance and the angle you can calculate the height the boomerang attains.

Some investigators have chosen to attach a light to the boomerang and throw it in darkness while leaving the aperture of a camera open. The result is a trail of light on the photograph marking the boomerang's path. Examples of the technique were shown in Hess's article in this magazine. With a single camera, however, the three-dimensional nature of the path is difficult to appreciate. Even if you position two cameras to photograph the path from different perspectives, you will still have trouble combining their separate information to get the three-dimensional trajectory. Better results might be obtained if you photograph the lighted boomerang with the stereoscopic technique I described in this department last December. When



Change of angular momentum as a boomerang lies down



Positions of maximum lift on the respective arms of a flying boomerang

the resulting two photographs are put in a stereoscope, one sees a combined image that has depth.

Hess and others have lighted boomerangs by attaching a small circuit composed of batteries, an electric oscillator and a small light. The arrangement is convenient, but unless you sink the objects into the wood (as Hess did) it has the disadvantage of distorting the airflow around the boomerang. The batteries and the oscillator are fastened to the center of the boomerang with only the small light bulb out on an arm, so that the boomerang's moment of inertia is altered as little as possible. A sparkler of the kind that celebrators light on the Fourth of July would also show the flight path.

Many variables stand ready for investigation if you would like to experiment with boomerangs. Although Hess has done a marvelous job in simulating boomerang flight with his computer programs, even he has not ascertained the variables to the point of designing the best boomerang or turning a bad one into a good one by some small change in construction. The major variables are those of the launching and those of the construction. A boomerang you bought would serve for a study of the variables in launching, but you would have to build one to examine the variables in construction.

To investigate launching try to find a large, open space with little wind. Choose one variable and then keep all the others constant as closely as you can. I know that holding the launching conditions constant is difficult because you will never make two successive tosses in exactly the same way. Photographing the launching with a motion-picture camera would enable you to objectively compare the launch angle, the spin and the forward velocity from one trial to another. How do the flight time, the total distance traveled and the maximum height depend on the direction of launching (normally you throw toward the horizon), the angle between the spin plane and the vertical (the greater the angle, the steeper the climb), the spin rate and the forward velocity?

With your homemade boomerangs how does the flight depend on the cross-sectional shape of the arms, the amount of twisting and the weight? I would be particularly interested to know if streamlining the arms is always advantageous. Should the tips of the arms be tapered or rounded? Should the boomerang be narrow in the center and wider at the tips of the arms? Does the flight change if the leading edge is sharp instead of blunt?

Since the effect of surface roughness is unresolved, you might want to explore it. Instead of cutting holes or grooves in a wood boomerang, try attaching cellophane tape that is sticky on each side. The tape itself might create a turbulent boundary layer, or you could create turbulence by sprinkling sand on the sticky stuff. Some researchers have investigated the effect of turbulence by mounting a thin wire just in front of the leading edge of each arm. Hess's results in such an experiment were inconclusive.

Some boomerang enthusiasts have discovered that by adding ballast to the arms near the tips they can greatly increase the distance of the outward flight of a returning boomerang. In 1972 Herb A. Smith, whose "Gem" design for a boomerang I described last month, threw such a boomerang for an outward distance of 108 yards. According to the *Guinness Book of World Records,* that is the longest outward flight ever recorded. Smith suggests adding ballast amounting to as much as a third of the boomerang's weight and countersinking the ballast (usually pieces of lead) in holes drilled about an inch from the tip of an arm. Weight added at the center will probably keep the boomerang in a more level flight, but more distance might be achieved with the ballast near the tips because then the boomerang's moment of inertia is also increased. You might see how much effect ballast has on your homemade boomerangs. If world records interest you, you might try to beat Smith's throw.

BIBLIOGRAPHY

Readers interested in further explanation of the subjects covered by the articles in this issue may find the following lists of publications helpful.

MATHEMATICAL GAMES

POLYOMINOES. Solomon W. Golomb. Charles Scribner's Sons, 1965.

GRAPH THEORY. Frank Harary. Addison-Wesley Publishing Company, 1969.

EXTREMAL ANIMALS. Frank Harary and Heiko Harborth in *Journal of Combinatorics, Information & System Sciences,* Vol. 1, No. 1, pages 1–8; 1976.

PARTICLE-BEAM WEAPONS

HIGH-ENERGY PARTICLES. Bruno Rossi. Prentice-Hall, Inc., 1956.

THE PHYSICS OF FULLY IONIZED GASES. Lyman Spitzer, Jr. Interscience Publishers, 1956.

CLASSICAL ELECTRODYNAMICS. Pages 309–390 and 429–463. John David Jackson. John Wiley & Sons, 1962.

ANTI-BALLISTIC-MISSILE SYSTEMS. Richard L. Garwin and Hans A. Bethe in *Scientific American,* Vol. 218, No. 3, pages 21–31; March, 1968.

A TIMEKEEPING ENZYME IN THE PINEAL GLAND

PINEAL GLAND BIORHYTHMS: *N*-ACETYLTRANSFERASE IN CHICKENS AND RATS. Sue Binkley in *Proceedings of the Federation of Societies for Experimental Biology,* Vol. 35, No. 12, pages 2347–2352; October, 1976.

THE PINEAL. R. J. Reiter. Eden Press, 1977.

THE PINEAL GLAND: A BIOLOGICAL CLOCK IN VITRO. Sue A. Binkley, J. B. Riebman and K. B. Reilly in *Science,* Vol. 202, No. 4373, pages 1198–1201; December 15, 1978.

THE EVOLUTION OF DISK GALAXIES

SPIRAL STRUCTURE, DUST CLOUDS, AND STAR FORMATION. Frank H. Shu in *American Scientist,* Vol. 61, pages 524–536; 1973.

GALAXIES AND THE UNIVERSE, VOL. 9: STARS AND STELLAR SYSTEMS. Edited by Allan Sandage, Mary Sandage and Jerome Kristian. The University of Chicago Press, 1975.

THE FORMATION OF GALAXIES. Richard B. Larson in *Galaxies: Sixth Advanced Course of the Swiss Society of Astronomy and Astrophysics,* edited by L. Martinet and M. Mayor. Geneva Observatory, 1976.

CLUSTERS OF GALAXIES. Neta A. Bahcall in *Annual Review of Astronomy and Astrophysics,* Vol. 15, pages 505–540; 1977.

THE ORIGIN OF GALAXIES. Richard B. Larson in *American Scientist,* Vol. 65, pages 188–196; 1977.

THEORIES OF SPIRAL STRUCTURE. Alar Toomre in *Annual Review of Astronomy and Astrophysics,* Vol. 15, pages 437–478; 1977.

CLAY

CLAY MINERALOGY. Ralph E. Grim. McGraw-Hill Book Company, Inc., 1953.

DIE SILICATISCHEN TONMINERALE. Karl Jasmund. Verlag Chemie, Gmbtt., 1955.

APPLIED CLAY MINERALOGY. Ralph E. Grim. McGraw-Hill Book Company, Inc., 1962.

MINÉRALOGIE DES ARGILES. Simonne Caillère et Stéphane Hénin. Masson et Cie., 1963.

GÉOLOGIE DES ARGILES. Georges Millot. Masson et Cie., 1964.

TERATOMAS AND CHIMERAS

COMPARATIVE DEVELOPMENT OF NORMAL AND PARTHENOGENETIC MOUSE EMBRYOS, EARLY TESTICULAR AND OVARIAN TERATOMAS, AND EMBRYOID BODIES. Leroy C. Stevens in *Teratomas and Differentiation,* edited by Michael I. Sherman and Davor Solter. Academic Press, Inc., 1975.

TOTIPOTENCY AND NORMAL DIFFERENTIATION OF SINGLE TERATOCARCINOMA CELLS CLONED BY INJECTION INTO BLASTOCYSTS. Karl Illmensee and Beatrice Mintz in *The Proceedings of the National Academy of Sciences of the United States of America,* Vol. 73, No. 2, pages 549–553; February, 1976.

TERATOCARCINOMA CELLS AND NORMAL MOUSE EMBRYOGENESIS. Christopher F. Graham in *Concepts in Mammalian Embryogenesis,* edited by Michael I. Sherman. The MIT Press, 1977.

CHIMERIC MICE DERIVED FROM HUMAN-MOUSE HYBRID CELLS. Karl Illmensee, Peter C. Hoppe and Carlo C. Croce in *The Proceedings of the National Academy of Sciences of the United States of America,* Vol. 75, No. 4, pages 1914–1918; April, 1978.

GENETIC MOSAICS AND CHIMERAS IN MAMMALS. Edited by Liane B. Russell. Plenum Press, in press.

CHINESE ORACLE BONES

THE BIRTH OF CHINA. Herrlee Glessner Creel. Frederick Ungar Publishing Co., 1937.

BONE CULTURE OF ANCIENT CHINA. William Charles White. The University of Toronto Press, 1945.

FIFTY YEARS OF STUDIES IN ORACLE BONE INSCRIPTIONS. Tso-pin Tung. Center for East Asian Cultural Studies, 1964.

COMPUTER MATCHING OF ORACLE BONE FRAGMENTS. Hung-hsiang Chou assisted by David G. Opstad in *Archaeology,* Vol. 26, No. 3, pages 176–181; July, 1973.

SOURCES OF SHANG HISTORY. David N. Keightley. University of California Press, 1978.

THE PHYSICS OF KARATE

STRENGTH. R. McNeill Alexander in *Animal Mechanics.* University of Washington Press, 1968.

ASIAN FIGHTING ARTS. D. F. Draeger and R. W. Smith. Kodansha International, Ltd., 1969.

PHYSICS WITH ILLUSTRATIVE EXAMPLES FROM MEDICINE AND BIOLOGY, VOL. 1: MECHANICS. George B. Benedek and Felix M. H. Villars. Addison-Wesley Publishing Company, 1974.

KARATE STRIKES. Jearl D. Walker in *American Journal of Physics,* Vol. 43, No. 10, pages 845–849; October, 1975.

INK-JET PRINTING

THE THEORY OF SOUND. John William Strutt, Baron Rayleigh. Macmillan and Co., Ltd., 1929.

HIGH FREQUENCY RECORDING WITH ELECTROSTATICALLY DEFLECTED INK. Richard G. Sweet in *The Review of Scientific Instruments,* Vol. 36, New Series, No. 2, pages 131–136; February, 1965.

INK JET PRINTING NOZZLE ARRAYS ETCHED IN SILICON. E. Bassous, H. H. Taub and L. Kuhn in *Applied Physics Letters,* Vol. 31, No. 2, pages 135–137; July 15, 1977.

IEEE TRANSACTIONS ON ELECTRON DEVICES. Special Issue on Three-dimensional Semiconductor Device Structures. Vol. ED-25; October, 1978.

THE AMATEUR SCIENTIST

SHAPE AND FLOW: THE FLUID DYNAMICS OF DRAG. Ascher H. Shapiro. Anchor Books, Doubleday & Company, Inc., 1961.

MANY HAPPY RETURNS. Peter Musgrove in *New Scientist,* Vol. 61, No. 882, pages 186–189; January 24, 1974.

BOOMERANGS, AERODYNAMICS, AND MOTION. Felix Hess. 1975 dissertation available from the author, c/o Dr. H. Rollema, Eikenlaan 51, Peize, Netherlands.

PROJECT BOOMERANG. Allen L. King in *American Journal of Physics,* Vol. 43, No. 9, pages 770–773; September, 1975.

This 4-speed has something no other 4-speed has.

Stick shift fanciers. Economy car devotees. You're both going to love this one.

It's called TWIN-STICK. Devilishly clever. And exclusively yours when you choose the Mitsubishi-built 1979 Dodge Colt or Plymouth Champ Hatchbacks. Here's how it works. Release the clutch and push the lever into ECONOMY mode, and you've selected the four-speed range designed to deliver optimum fuel efficiency. Choose POWER, and you get livelier performance. For running through the gears, you use the regular H-pattern lever. Averaging the mileage achieved in both POWER and ECONOMY ranges resulted in EPA estimates of 32 EST. MPG, 44 EST. HWY. with the 1.4 liter MCA-Jet engine. Use the EST. MPG number for comparison purposes. Your mileage may differ depending upon speed, weather and trip length. Actual highway mileage will probably be lower than the HWY. EST. Calif. estimates are lower.

TWIN-STICK is standard on the new 1979 Dodge Colt or Plymouth Champ Hatchbacks.

You get the benefit of a total of eight speeds to play with. Which means you can get the optimum gear for just about any driving situation that comes along. City or country. Uphill or down. Or passing gas stations.

Mitsubishi cars and pickup trucks are sold in the U.S. by Chrysler Corporation.

MITSUBISHI MOTORS CORPORATION

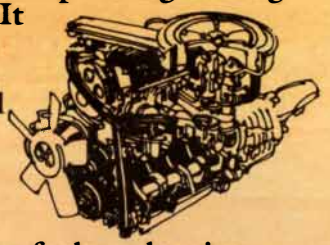
Dodge: Colt • Challenger • D-50 pickup truck.
Plymouth: Champ • Sapporo • Arrow pickup truck.

THE TECHNOLOGICA JAPANESE IMPOR

The ten little imports you see here offer a combined total of utility and technology you're not going to find on other Japanese imports.

BESTTHING FOR ENGINES SINCE HIGH COMPRESSION.

The Mitsubishi Clean Air engine is a pure engineering jewel. It comes with a special "jet" valve for more efficient fuel combustion.



ABOVE-AVERAGE ESTIMATES.

MILEAGE CHART	EST. MPG*
Champ Custom & Colt Custom Hatchback	33
Colt 2- & 4-doors	30
Colt wagon	26
Arrow GT Hatchback	26
Challenger & Sapporo	26
D-50 & Arrow Sport pickups	21

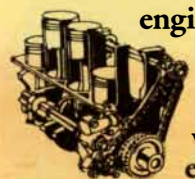
*EPA estimates. Use this number for comparisons. Your mileage may vary depending on speed, trip length, and weather. California estimates lower for Champ Custom and Colt Custom Hatchback, Colt two- and four-doors, D-50 and Arrow Sport pickups.

SLICK NEW TWIN-STICK.

See that little lever at the left? Use it to select either PERFOR-MANCE or ECONOMY range. Then shift gears with the lever at the right. Kind of like two four-speeds in one. It's exclusive on our new Champ and Colt Hatchback.

SAY GOOD-BYE TO THE SHAKES.

Silent Shaft design (an MCA engine exclusive) gives you two counter-rotating shafts to help dampen the vibrations expected of a normal four-cylinder engine.

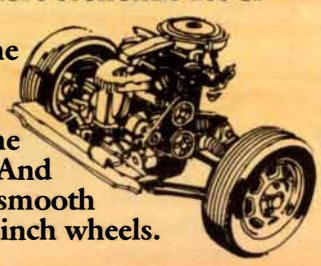


A LITTLE SOPHISTICATION NEVER HURTS.

Our Challenger and Sapporo GTs offer power discs on all four wheels on the optional 2.6 liter Basic Package models.

SOME UP-FRONT THINKING ON ROOM AND RIDE.

Champ and Colt Hatchback are front-wheel-driven. The engine is placed transversely to permit more economic use of interior space. The track is wide to help in the corners. And we offer smooth riding 13-inch wheels.



BUILT BY MITSUBISHI. SOLD EXCLUSIVELY BY

MOST
LLY ADVANCED
TS YOU CAN BUY.

MAKING 'EM EASIER TO DRIVE.

This much-desired automatic speed control option is also available when you select our Colt wagon, Challenger, or Sapporo with the optional 2.6 liter engine and automatic transmission.

Standard driving equipment also includes such gems as adjustable steering column (a rarity among other imports) and trip odometer.

NO CHARGE FOR HANDLING.

Independent rear suspension on Champ and Colt Hatchback is the kind of technology you find on Mercedes or BMW. In addition, MacPherson-type struts at front are on the Champ, Colt Hatchback, Challenger, and Sapporo.

THE COMPLETE SEAT.

Seats on Challenger and Sapporo are orthopedic marvels. They offer lateral and adjustable lumbar support, recliner features, adjustable headrests built into seat, and walk-in passenger seat "memory" adjuster feature.

LITTLE TRUCKS. BIG DIFFERENCES.

They're specially designed for American-size folks and jobs. With a half-ton payload. If

you'd like more, see the Sport model with an interior that looks like tomorrow's sports car. And the biggest engine in its class with its 2.6 liter four.

"...MORE TRICKS THAN A SWISS ARMY KNIFE."

That's what *Car and Driver* magazine says of our Champ and Colt Hatchback.

And why not. They're full of engineering and people features like "Twin-Stick," front-wheel drive, and transverse engine.

Dodge | CHRYSLER | Plymouth

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(Pronounced Do-ers "White Label")

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S. ALLEN COUNTER

HOME: Cambridge, Massachusetts

AGE: 32

PROFESSION: Professor, neurobiologist

HOBBIES: Jungle exploration, film making, archery.

MOST MEMORABLE BOOK:" Origin of Species" by Charles Darwin

LATEST ACCOMPLISHMENT: While continuing neurobiological research in the South American jungle, he discovered a little known Bush Afro-American tribe, the first black slaves in the Americas to gain independence.

QUOTE: "I am thrilled that my research and films have enabled me to contribute to the enlightenment of American culture. Only by being aware of our past can we deal with the present and future."

PROFILE: Energetic, warm, penetrating. Driven by a thirst for new knowledge that may lead to new truths.

HIS SCOTCH: Dewar's "White Label"®