SCIENTIFIC AMERICAN

CARGO-HANDLING

SEVENTY-FIVE CENTS

October 1968

TAIN HOWARD K. PLASMAN IN "THE LEFT HAND SEAT". HE FLEW 10 YEARS FOR THE RIGHT TO SIT THERE.

True Pilot Stories.

"I was 22,000 feet over the Atlantic on a training flight, banking into a 360° turn, when it happened.

The FAA Inspector cut my number three engine.

The trick was to shut down the engine, keep the airplane under control, and do it all in a matter of seconds.

As soon as I had things humming again, he failed an electrical system. And when I handled that, he gave me a series of missed approaches, instrument landings and all the other things the government makes an airline pilot do to qualify.

Fortunately for me, the training I'd received at Eastern was so demanding, I didn't have any problems getting my rating. But to be perfectly honest about it, I wouldn't want to face that check ride every day.

It's tough enough going through it every six months."

Captain Adam J. Whitley

"When I joined Eastern last February, I was fresh out of the Marine Corps.

I remember being interviewed and waiting for this fellow to ask about my experience. I thought I shouldn't have any trouble in that area.

I told him I had over 3,000 accident free hours. That I had put in 4 years as a fighter pilot and another 3 years as a test pilot. That I had flown fighters, bombers, submarine chasers and had even spent a year in helicopters, so I figured I knew my way around airplanes pretty well.

Well I guess he figured a little differently. He told me I'd go through Ground School, The Simulator, Flight Training and Engineer Training before they would let me near an airplane. And that if I were as good as it looked, in 7 to 9 years I might make Captain."

First Officer John P. Tristani

"I took my first airplane ride back in 1931.

My father ran a flying school. And one day he pointed to this J-1 pursuit plane, a relic from the First World War, and said, 'What do you say we take her for a little spin, son?'

The next thing I knew we're doing rolls and loops, and I was too excited to do anything but hang on.

I guess I never got over it, because I've been flying ever since. And even though I've handled everything from DC-3's to DC-8's, and learned a lot in 25 years at Eastern, flying has never become routine for me.

It's still my first love, and somehow, I think my Father knew it would be."

Captain Orville B. Bivens

EASTERN

We make it easier to fly.

You're looking at a two-year-old trout

How the original work of a professor at the University of Washington College of Fisheries has resulted in a new breed of superfish that may well provide an important and amazingly convenient new food supply.

Dr. Lauren Donaldson, pictured above, is holding a "baby" two-year-old Supertrout. Tipping the scales at 18 pounds, she is six times as large as any normal trout has any right to be. Donaldson is concerned. "I don't know how big she'll get because she hasn't stopped growing yet."

In the back of the University fisheries lab a high fence encloses eight pools of fingerling Supertrout. The new breed is a hybridization of the migrating Steelhead and the fast-maturing, stay-at-home Rainbow. In crossing the two closely related species, the rapid growth characteristic of the specially selected Rainbow is dominant. The Supertrout become sexually mature in two years instead of the usual four, and at that age are three times larger than a mature four-year-old Steelhead.

The University's "fish ranch" borders on Portage Bay, a fresh water lake in Seattle which connects by way of ship canals and locks with Puget Sound. To insure selection of only the hardiest trout, the lake water is channeled into the breeding ponds without benefit of any purification, aeration or temperature control. The fingerlings who don't make the grade are ground up for plant fertilizer. The ones who do are fed a special fish autosylate (predigested Hake) for six months to build up their mineral balance, and released into the lake to make their way down the ship canal and through the government locks to salt water. When they return to spawn after their abbreviated maturation, the fisheries staff laboriously sifts through half a million fish to select a blue ribbon two hundred for further breeding purposes.

Donaldson's meticulous selective breeding has produced a strapping animal which resists pollution and disease, migrates earlier than normal, matures younger, has a higher survival rate, produces ten times as many eggs, and, according to certain faculty members, tastes better.

The University's research with the Supertrout and migratory Chinook Salmon has profound implications both for the fishing industry and the food supply of the human race. Bred in the artificial environment of the laboratory ponds, the fish make their way to the nearby open seas to mature. Two years later, directed by their infallible homing instinct, the giant hybrids gallantly present themselves to those same ponds for harvesting.

What could be more convenient?

The State of Washington is a fertile field for the exciting new breakthrough industries of the future. In aerospace, agriculture, fisheries, oceanography, nuclear energy and many other areas, the smart money is betting on the State of Washington.

Daniel J. Evans

Daniel J. Evans, Governor

For further information, write: Daniel B. Ward, Director, Department of Commerce and Economic Development, Olympia, Washington

Established 1845 **SCIENTIFIC AMERICAN** October 1968 Volume 219 Number 4

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover shows part of the forward end of a container of the type that is coming into increasingly wide use in the transportation of cargo (see "Cargo-handling," page 80). The multicolored object at the bottom of the photograph is part of the trailer on which the container rests preparatory to transfer aboard a specially designed container ship at the container-ship terminal built by the Port of New York Authority in Elizabeth, N.J. The container is a vanlike, wheelless aluminum structure 35 feet long, eight feet wide and eight feet high. It can hold up to 20 tons of general merchandise of the kind that otherwise would be shipped in separate and comparatively small lots. The container is also equipped in such a way that it can be transferred readily between different modes of transportation, such as from a train to a truck and from a truck to a ship, by highly mechanized procedures that are to a limited but increasing extent automatic.

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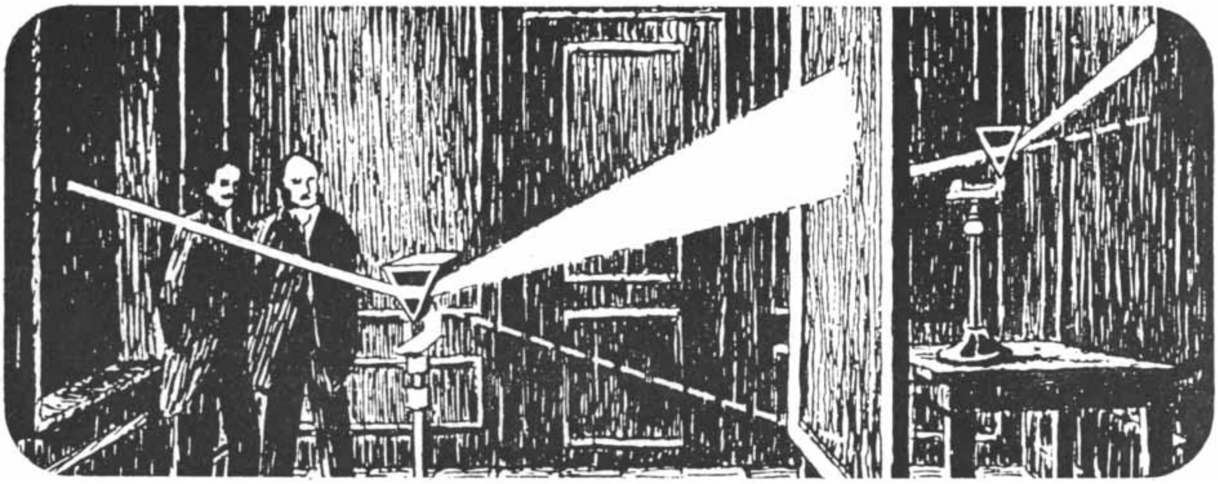


It's a pleasure to see red with the new Plumbicon tube*

In the late 17th Century, Sir Isaac Newton was able to demonstrate that the white light of the sun contained all the colours of the rainbow. He even gave quantitative rules (not very accurate by present day standards) to determine the colour of light obtained by combining rays of some of these colours.

Nearly three hundred years later, our knowledge of human colour perception is virtually complete. But colour TV engineers still wrestle with the problems of transmitting true-to-life colour pictures. Of course, reasonably acceptable results have been obtained for some time, but colour fidelity continues to be difficult to achieve, partly because of problems on the pick-up side. Some TV camera tubes had a good response over the entire visible spectrum, but other properties, such as sensitivity, linearity and stability were poor and they showed spurious signals or time lag.

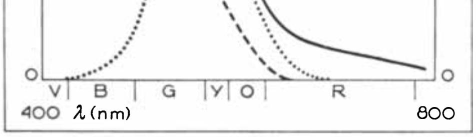
The Plumbicon pick-up tube developed at Philips Research Laboratories, Eindhoven, the Netherlands, was markedly superior in several respects; it was more sensitive, linear, free from colour shading and had no lag. Today, many thousands of these are used in colour TV cameras. The sensitivity of the Plumbicon tube however, was limited at the "red end" of the spectrum. It dropped to zero at a wavelength of 6200 Å. This is not as serious as it might at first appear, as coloured objects tend to reflect fairly wide bands of wavelengths. If they do so, colour processing will ensure good colour rendering in the display. But there are special situations where the loss of a narrow band of long wavelength red causes noticeable colour changes in the magentas or purples. In order to cope with these, we asked a team at the Philips Research Laboratories: "Is it possible to extend the red sensitivity of the tube without harming its good properties?"

From experience in allied fields, they knew that the photo-conductor lead sulphide is noted for its small band gap (0.39 eV, compared with 2.0 eV for PbO the photo conductive layer of the standard Plumbicon tube) and consequently its sensitivity extends far into the infra-red. Unfortunately it is "laggy", that is, its conductivity is slow to disappear when illumination stops, and this precludes its use in pure form for moving TV pictures.

The team therefore set about trying to build just a little PbS into the standard PbO layer to extend its absorption towards the infra-red. Calculations showed that about 1 mol % of PbS was needed. Sulphur can be built in either by doping during the vapour deposition of the PbO layer or by sulphurizing a vapour-deposited pure PbO layer afterwards, using a compound containing sulphur. In principle the first method results in homogeneously doped crystals ; the second provides a dope at the crystal surfaces. It was known from earlier experience that the actual surface area of the layer far exceeds its macroscopic geometrical area of a few cm², due to the "leaflet" structure of the target layer. In fact more than 10% of the PbO molecules are surface molecules. Therefore the two methods can be expected to give approximately the same result. The doping-after-deposition however has less influence on the layer structure and so it was chosen. After extensive studies and experiments in processing, a member of the team, Mr. P. P. M. Schampers, succeeded in working out the proper deposition techniques, using H_2S as the doping compound.

The new layer extends the limiting wavelength to about 8000 Å, without affecting the lag to any extent.

Spectral sensitivity of the eye compared with standard and extended red Plumbicon tubes.



The Plumbicon tube with extended red sensitivity also gains in other respects; improved red absorption plus a higher absorption in the green, increase the overall sensitivity. And the increased absorption reduces the scattering of light in the layer. This results in improved resolution; the modulation depth in the red signal at 400 lines increases from 35 to 50%.

The new Plumbicon tube has no trace of colour blindness.

*** registered trade mark for T.V. camera tubes**

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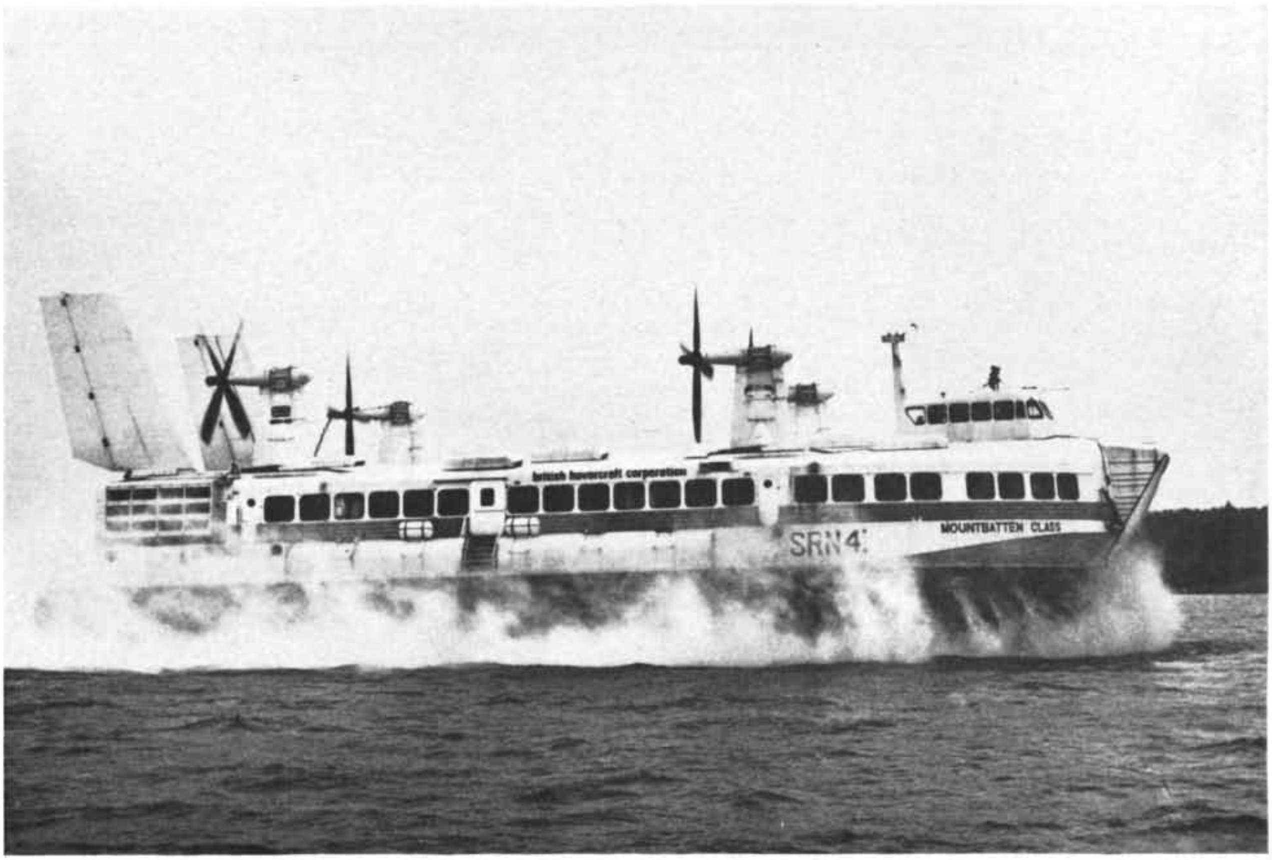
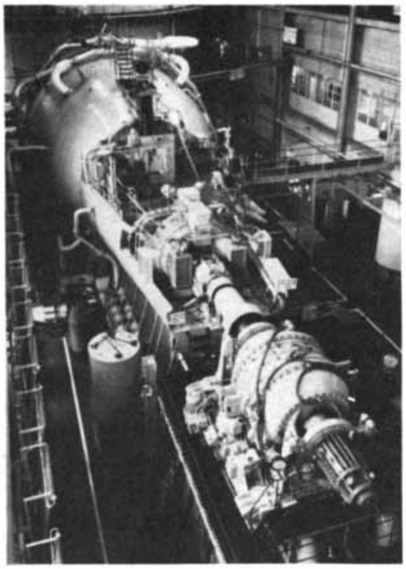


World's fastest ferryboat flies the Channel at an altitude of seven feet.

It looks like a ferryboat, 165 tons squatting in the water, absorbing 254 passengers and 30 cars. But when its four 3,400-horsepower Rolls-Royce Marine Proteus engines come to life, it's no longer just a ferry but the world's largest Hovercraft. It rises on its own cushion of air, surges out into the Channel, ironing out waves as it goes. At 50 miles an hour, it cuts the Channel crossing from a queasy hour and a half to an agreeable 35 minutes.

Hovercraft have a short but spectacular history to date. They can travel over virtually any surface. Case in point: the SRN.6 that recently explored the Amazon River, crossing rocks, rapids and sandbars at an unruffled 50 miles per hour. Canada is testing an SRN.5 for Coast Guard duty. Its 900-horsepower Rolls-Royce engine (actually, all gas turbine Hovercraft have Rolls-Royce engines) gives it a range of 260 miles, and a top speed of 72 miles per hour. Canada is also testing this same craft for Arctic exploration.



LETTERS

Sirs:

Having read with interest the intriguing article on "The Origin of the Olympic Games," by Raymond Bloch, in your August issue, I am minded to contribute some additional information concerning the care and feeding of (and attitudes toward) those ancient forefathers—or forerunners—of our present Jim Ryuns. These little known, long remembered facts are to be found in the book *Greek Athletes and Athletics*, by England's H. A. Harris (Indiana University Press, 1966).

Item: "We are sometimes called on to admire the Greek athletes of antiquity on the ground that they were content to struggle for a worthless crown, and they are held up as paragons of the purest amateurism in sport. The facts hardly support this roseate view. The winner of an event in one of the great 'crown' festivals was on to a very good thing. He expected to be substantially and materially rewarded by his city for the glory his victory had brought it. If Plutarch is to be believed, Solon... laid down maxima for these grants, 500 drachmae for an Olympic victor, 100 for an Isthmian. Even the smaller Isthmian award was almost as much as a year's earnings of a working man." And after the death of Alexander "this pouring of money into athletics" changed the games from "amusement for the enjoyment of the participants" to "entertainment for spectators."

Item: "Plutarch ascribes to trainers and coaches a belief that intelligent conversation at meals spoils the food and gives the diners a headache."

Item: Two of Alexander's generals "carried with them on their campaigns a huge marquee 200 yards long to enable training to be continued under all conditions of weather, perhaps the earliest example of indoor athletics."

Item: "We are apt to think of the frenzied adulation of sportsmen and entertainers as a modern phenomenon, but it was no less marked in antiquity. Oppian, looking for a simile to describe pilot fish crowding round a ship, can find no better picture than the mob of admirers round a popular athlete: 'As an athlete crowned with fresh laurels is beset by boys, youths and men who conduct him to his house and crowd round him in troops until he crosses the threshold of his home.'" Laodamas said to Odysseus: "...nothing brings a man greater renown throughout his life than what he does with his hands and feet." But "at least we in our day have not yet reached a stage at which these darlings of the people are officially granted exemption from military service...."

Item: St. Paul "was a lover of athletics" and "the effects of this are deeply marked in Christian thought and language."

Items: "...our 'agony' is derived from 'agon,' the Greek word for athletic contest." As today, on the track "all turns were made left-handed." With the aid of a thong that gave it a stabilizing twist a superior but unnamed Greek athlete seems to have thrown the javelin "well over 300 feet," which is "slightly longer than the modern world record...." "...wrestling was by far the most popular sport." "If the evidence for men's athletics in ancient Greece is scanty, that for women's is even scantier"—Pausanias said that at the Heraean festival there were "races for unmarried girls"—but the girls' track suits were less scanty: whereas the men competed naked, the ladies, according to Pausanias, wore tunics "reaching to a little above the knee,

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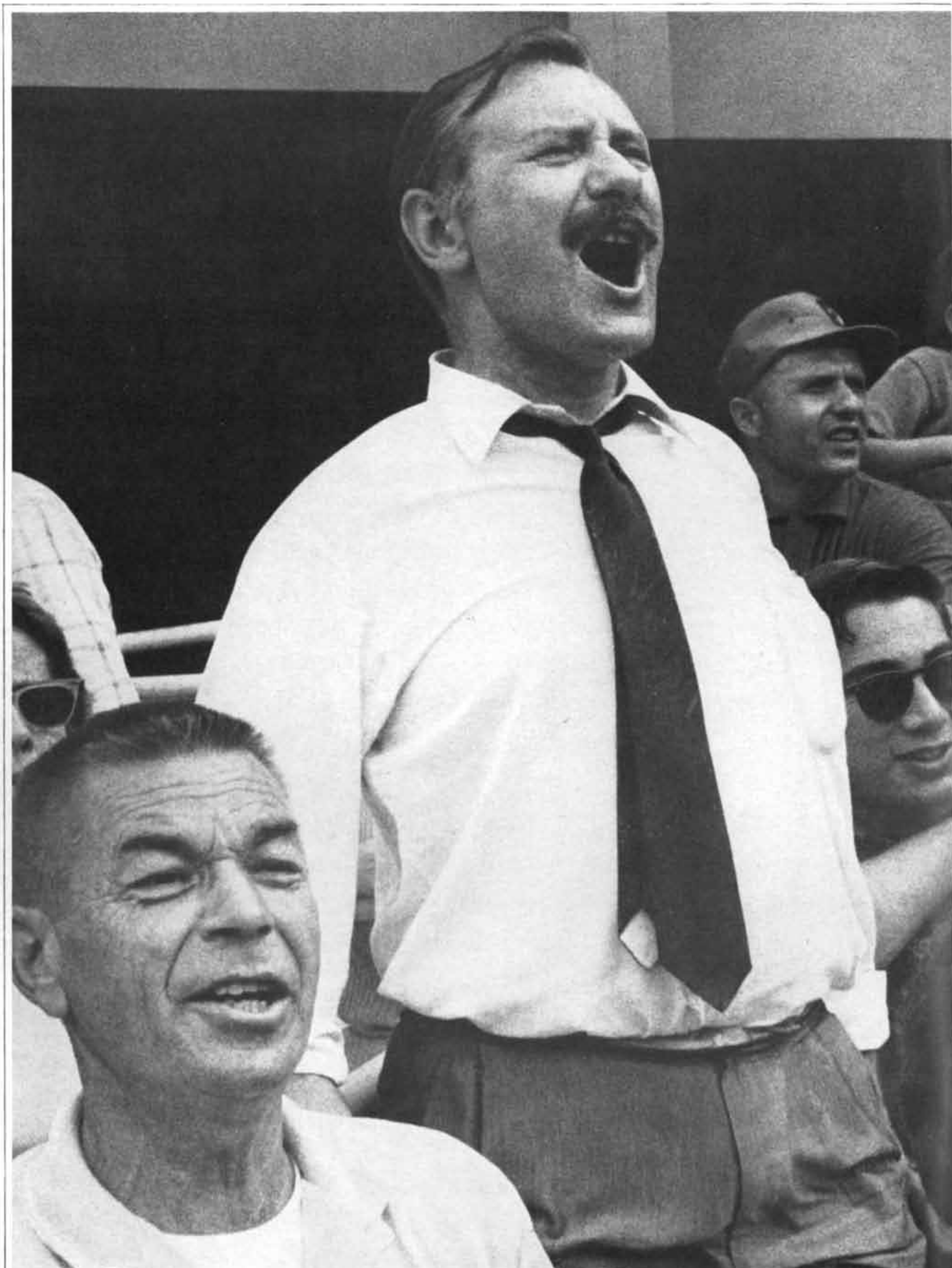


with the right shoulder bare as far as the breast."

JOHN WHITE

Smithsonian Astrophysical Observatory
Cambridge, Mass.

P.S. Once upon a time there was a boxer from Cyrene named Eurydamas, "who after receiving a blow in the face found himself with a mouthful of his own teeth. Reflecting that if he spat them out the sight could not fail to bring comfort and encouragement to his opponent, he swallowed them."

J. W.

Sirs:

Professor Lwoff's review of *The Double Helix* [SCIENTIFIC AMERICAN, July] raises some interesting questions about the nature of truth—not so much of scientific truth as of historical truth. As a historian married to a biochemist, I have some familiarity with the methodology of both fields, and I think the reviewer is not sufficiently aware of the striking differences between the two. He acknowledges that Watson's book is not science but history, and yet his quarrel with it (as has been true of many of the reviewers) centers on that very characteristic which qualifies it for the latter label, namely an awareness of historical process. To take the most striking example, consider Watson's attitude toward Rosalind Franklin. I have read and heard many criticisms of his attack on her, complaining of his injustice and lack of understanding, to say nothing of his snide personal remarks. The critics seem to feel that the reversal of his feelings described in the last chapter and his posthumous apology do not justify the inclusion of the earlier evaluation, since he acknowledges that it was "wrong."

Here is precisely where the two fields diverge: the scientist is interested chiefly in the result; the emotions and frustrations he experiences along the pathway to the goal are largely irrelevant. The historian feels just the reverse: he does not deny the importance of the goal, but he is far more fascinated by the process of reaching that goal—by the pathway, in fact. How Watson felt about the group at King's College, and particularly Miss Franklin, who *seemed* at the time to be behaving obstreperously, is of vital interest and importance. To pretend, even by omission, that his later evaluation of her was the one he had always held would have been to falsify the facts seriously. This must be true if one grants that scientists are not "thinking machines" but human beings with emotions, jealousies and competitive feelings, which do affect the kinds of problem they attack and how they attack them—at least to some extent.

Your reviewer does make this latter point, but he seems unable to accept its implications. How often, in writing history, we are faced with the memoirist, writing in the fullness of age, who either from blurred vision or from the need for self-justification unconsciously falsifies the feelings and opinions he had in the past. He says, "This is how I thought." He rarely will say, "This is how I *think* I thought 30 years ago." The result is falsified history, since for the historian the true, contemporary feelings and emotions of the actors are just as much facts as the actions and events. Thus Watson's opinion of Miss Franklin, and his change in opinion, are historical fact.

I do agree with Professor Lwoff's conclusion that not all impressions are worth the pain their publication causes, but this does not gainsay the point made above. No one should infer from my remarks that I think Watson comes out of the book as a completely admirable human being. He appears to have been bumptious, opinionated, tactless and rather offhandedly cruel in his personal judgments—as so many of us are. But he is clearly a good scientist. He also appears to be devastatingly honest, a quality that goes a long way toward balancing the others, and one that is essential to *both* the historian and the scientist.

CYNTHIA F. BEHRMAN

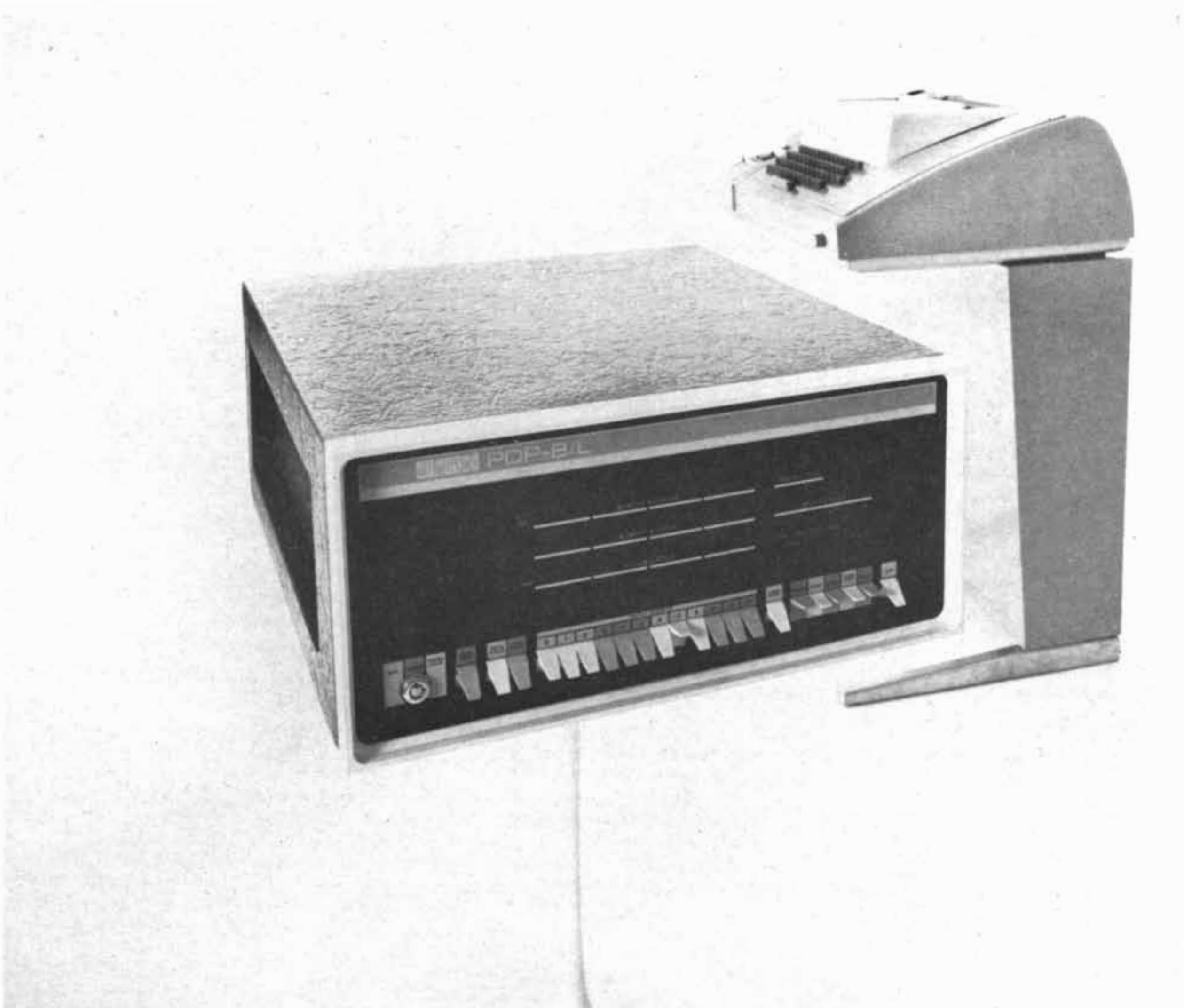
Wittenberg University
Springfield, Ohio

Sirs:

Frederick C. Kreiling's interesting article on Leibniz [SCIENTIFIC AMERICAN, May] states that this seminal thinker proposed the equals sign (=). Some readers may take this to mean that Leibniz was the first to use the sign. Actually it made its debut in 1557 in a work by Recorde and was used independently by Pompeo Bolognetti in 1568. The absorbing story of this universally adopted symbol is recounted by Florian Cajori in his *A History of Mathematical Notations.*

I. G. GROSSMAN

Durham, Conn.



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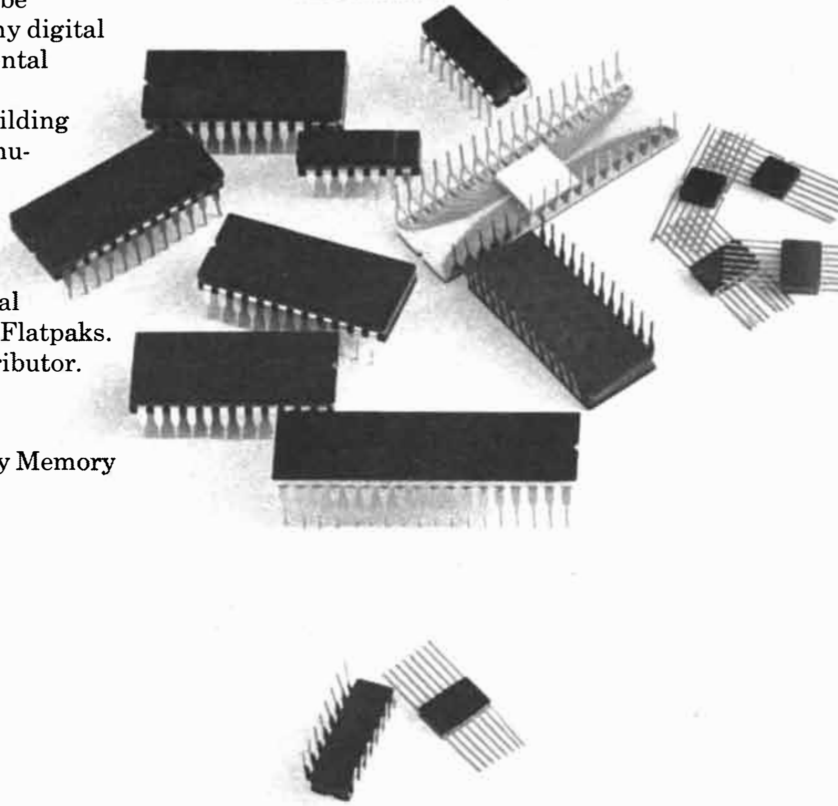

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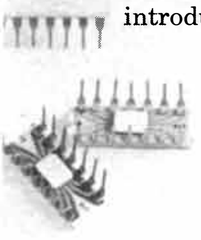

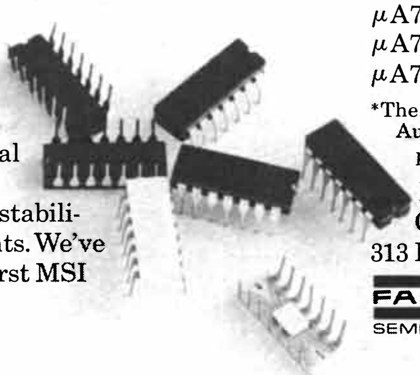

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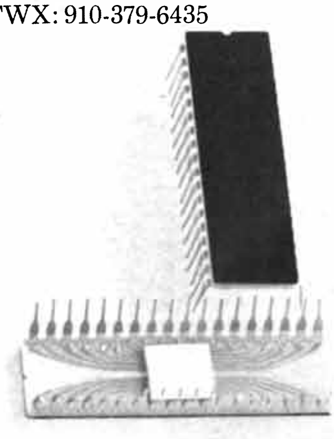


50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1918: "Nothing would please the military masters of Germany more than to create the impression among the civilian population of the Entente nations that the German army is crumbling and that peace will come before Christmas. Staggering under the weight and borne back by the pressure of the Entente attack, the fighting qualities of her troops and the genius of her generals are being strained to the breaking point, no doubt, in the effort to carry through successfully that most difficult of all military maneuvers, a general retreat in the face of, and in close contact with, superior and victorious forces of the enemy. The German armies are not routed; and the way they respond when called upon to hold by counter-attacks such portions of the line as are essential to the orderly retirement of the whole front, proves to the military mind that the discipline and the fighting spirit of the German army as a whole are still intact, and that it may take a season's campaign to bring about a general collapse."

"There have been delays in the aircraft program; we have merely hundreds of planes at the front when too hopeful an attitude from many in authority told us we would by this time have thousands. The fact remains that the United States, the most backward of all civilized countries in developing its aircraft industry, is now forging to the front in such a rush that before very long—certainly before the war ends—it will lead the world in the production of aircraft and of motors, and will possess more factories, more workmen, more capital invested and more flying fields than any other two, and possibly three, countries considered as one."

"The first of several factors through which it is logically possible to explain the life and conduct and customs of the Indians of the Southwest is that of race or heredity, in other words, the inherited tendencies—physical and psychical, bodily and mental—which the people that carry these customs have or might have. The general attitude of anthropologists, at least those who are primarily concerned with modes of life, toward this factor of race or heredity as explanatory of the practices or conduct of peoples, is distinctly negative. If there are such hereditary differences between human groups, we have not yet been able to determine them."

"The first successful experiment on record of jumping from a moving airplane with a parachute was recently made by Capt. Sarrat, a French aviator. This intrepid airman leaped from a height of 800 yards with an umbrella some twelve yards in diameter, and landed safely. He was three minutes in the air, suspended from the parachute. Previous to this test numerous experiments were carried out in France with sandbags, and the practicability of the scheme was established beyond reasonable doubt. But it goes without saying, nevertheless, that it required real courage to be the first to risk his life and limb in an actual test."

"Thirty years ago the foreign commerce of the United States was carried on on the strength of our agricultural exports. Fifty per cent of all the goods sent abroad by this country consisted of foodstuffs, 30 per cent was raw materials, and but 20 per cent was contributed by the factory. Since then matters have changed vastly. The industrial producer has usurped the place of the farmer and the miner. When the war broke out in 1914, half the nation's export consisted of manufactured goods; raw materials accounted for approximately a third; but the farmer's share had declined to 18 per cent of the total. Today the world looks to the United States of America for all that it was accustomed to buy from Europe in former years."

SCIENTIFIC AMERICAN

OCTOBER, 1868: "The theory of the origin of species by natural selection, which was first enunciated by Darwin 10 years ago and which has been so widely discussed, has undoubtedly been gaining ground among the most celebrated naturalists. When this theory was first propounded, it met both vehement opposition and ridicule. It was attacked by philosophers and wits, and formed the subject of many a lampoon and satire. It was denounced as opposed to the teachings of revelation, as a system of guesses which were not sustained by either facts or logic. But there was a vitality in the theory, and the conclusions of a man who fortifies his opinions with such a host of facts as Mr. Darwin brought to sustain his are not easily put aside. One after another the thinkers of the entire world have slowly been accepting the theory, until it may be doubted that any hypothesis is more nearly established upon a permanent basis."

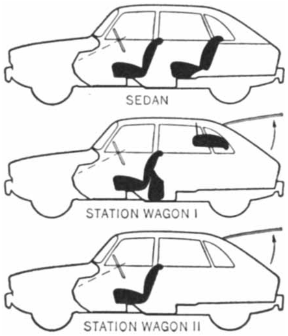
"The Paris *Moniteur* announced officially on Sept. 24 that the Government concession lately granted in favor of MM. Erlanger and Reuter of the Franco-American Telegraph Company, authorizing them to lay a submarine telegraph cable between France and America under certain reserved conditions, has become definite and complete, capital to the amount of 27,500,000 francs—the main condition—having been subscribed for the undertaking. The cable will, as at present proposed, be laid in two sections; the first from Brest to the French island of St. Pierre off Newfoundland; the second from St. Pierre either to New York direct or to a point between Boston and New York, with a special line to New York."

"A remarkable paper has lately been sent to the Royal Society by Mr. Huggins, one of the Fellows. It announces the application of a new and most promising method of inquiry to the determination of the motions of the stars. Mr. Huggins tested this method by the motions of the star Sirius. The spectrum of this star is crossed by a multitude of dark lines, and among others by one known to correspond to a bright line seen in the spectrum of burning hydrogen. The two spectra were brought side by side, and due care having been taken to magnify as much as possible any discrepancy which might exist, it was found that the dark line in the spectrum of Sirius was not exactly opposite the bright line in the spectrum of hydrogen, but was slightly shifted towards the red end of the spectrum. It followed from the amount of the displacement that at the observation Sirius was receding from the earth at the rate of about 40 miles per second. When due account is taken of the earth's orbital motion at the time of observation, it results that Sirius is receding from the sun at the rate of about 28 miles per second, or upwards of 900 millions of miles per annum."

"A man in England recently made 15 miles in one hour on a velocipede."

CHAPTER TWO: THE RENAULT 16 SEDAN-WAGON

YOU'RE ALREADY FAMILIAR WITH CHAPTER ONE, THE RENAULT 10



THE AUTHORS

ANTONY HEWISH ("Pulsars") is a member of the group that discovered the first pulsar during observations made at the Mullard Radio Astronomy Observatory of the University of Cambridge. In addition to his work at the observatory, Hewish is a fellow of Churchill College and a university lecturer in physics. He entered the University of Cambridge as a student in 1942 but soon left for military service at the Royal Aircraft Establishment in Farnborough. There, he writes, he "met Ryle," who is now Sir Martin Ryle, professor of radio astronomy at Cambridge. "Returned to Cambridge 1946," Hewish continues, "graduated 1948 and joined Ryle's research group at Cavendish Laboratory. A natural choice—brand-new subject, prior acquaintance with Ryle, etc. Awarded Ph.D. 1952 and elected research fellow, Gonville and Caius College. Elected Fellow of Royal Society 1968." Describing his work, he says: "Besides pulsars, which came my way rather gratuitously, I am involved in investigations of interplanetary space using the scintillation of quasars. This method gives useful measurements of the solar wind, particularly away from the plane of the ecliptic, where space probes cannot go. Starting from my early days as a research student, when I hacked through piles of brass tubing to make dipoles for Ryle, I have spent a good deal of my time designing feed arrays for the radio telescopes used in the 3C and 4C surveys at Cambridge. Teaching also absorbs a fair proportion of my effort as I am Director of Studies in Physics at Churchill College."

DONALD B. EFFLER ("Surgery for Coronary Disease") is chief of the department of thoracic and cardiovascular surgery at the Cleveland Clinic. He was graduated from the University of Michigan in 1937 and took his M.D. there in 1941. During service in the medical corps of the U.S. Army he received postgraduate training in surgery at Walter Reed Army Hospital, the medical school of George Washington University and the Hospital of the Good Samaritan in Los Angeles. He joined the Cleveland Clinic in 1947.

RICHARD WOLFGANG ("Chemical Accelerators") is professor of chemistry at the University of Colorado and also retains an affiliation with Yale University, where he was on the faculty from 1956 until he went to Colorado this year. Born in Germany, he took his undergraduate and graduate degrees at the University of Chicago. As a candidate for a Ph.D. he worked under Willard F. Libby and was involved in the discovery of tritium in nature. After obtaining his doctorate in 1951 he worked for a time at the Brookhaven National Laboratory and at Florida State University. His interests include isotope geochemistry, nuclear physics, the chemical effects of nuclear transformance and the nature of chemical reactions. He is also attracted to teaching because, he says, "I get most of my good ideas from students, particularly undergraduates." Aside from his work he enjoys sailing and skiing.

ARTHUR KORNBERG ("The Synthesis of DNA") is professor of biochemistry and head of the department of biochemistry at the Stanford University School of Medicine. A graduate of the City College of the City of New York in 1937, he obtained his M.D. at the University of Rochester four years later and remained there for a year as an intern at the university's Strong Memorial Hospital. From 1942 to 1953 he was an officer of the U.S. Public Health Service, holding during the last six years the position of chief of the Enzyme and Metabolism Section of the National Institute of Arthritis and Metabolic Diseases. From 1953 until he went to Stanford in 1959 he was professor of microbiology and head of the department of microbiology at the Washington University School of Medicine in St. Louis. In 1959 he shared with Severo Ochoa of New York University the Nobel prize in medicine and physiology.

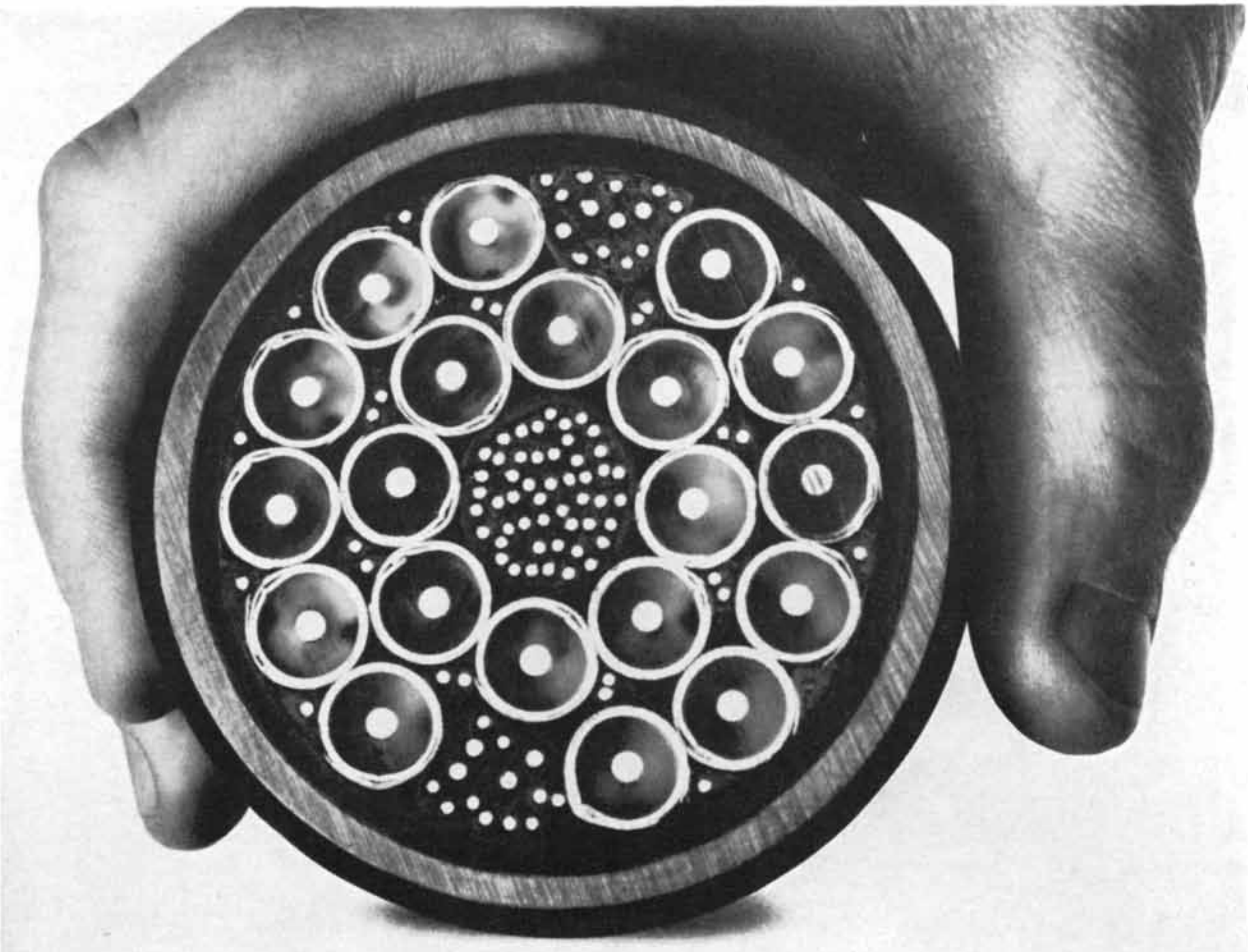
ROGER H. GILMAN ("Cargo-handling") is director of planning and development for the Port of New York Authority. He has been with the Port Authority since 1937, the year after he was graduated from Harvard College with a degree in engineering sciences. For four years during World War II he was with the U.S. Navy, and from 1961 to 1964 he was on loan from the Port Authority to serve as the first executive director of the Tri-State Transportation Committee after its establishment by the governors of New York, New Jersey and Connecticut. He was promoted to his present position, then called director of port development, in 1953.

SHMUEL WINOGRAD ("How Fast Can Computers Add?") is a member of the staff of the Thomas J. Watson Research Center of the International Business Machines Corporation. His early training was in electrical engineering; he received his bachelor's and master's degrees in that subject at the Massachusetts Institute of Technology. Earlier this year he obtained his Ph.D. in mathematics from New York University. He joined IBM in 1961 and has worked in the mathematical sciences department of the Watson Research Center. Concerning his work there Winograd writes: "Was interested in construction of reliable automata from less reliable components, and in particular in the connection between information theory and redundancy techniques. Currently trying to determine the minimum number of arithmetic operations required to compute various functions."

KJELL JOHANSEN ("Air-breathing Fishes") is associate professor of zoology at the University of Washington. He was born and educated in Norway, receiving his doctorate in zoology at the University of Oslo. In 1959 he came to the U.S. as a postdoctoral scholar in the department of physiology and biophysics at the University of Washington. His interest in cardiovascular and respiratory systems has taken him to Brazil, Australia, East Africa, Alaska and Mexico to study special adaptations and environments. "My spare time," he writes, "is used to satisfy my interest in outdoor life such as hiking and cross-country skiing. Art, and painting in particular, is another interest."

ANNEMARIE DE WAAL MALEFIJT ("Homo monstrosus") is associate professor of anthropology at Hunter College of the City University of New York. A native of Amsterdam, she came to the U.S. in 1951 and studied anthropology at Columbia University, where she received a bachelor's degree in 1955 and her Ph.D. in 1959. She has spent the summers of 1967 and 1968 at the Aruba Research Center recently established by the City University of New York at Aruba in the Netherlands Antilles; in addition to studying patterns of fishing on the island she has worked with students receiving field training in anthropological research. Among her writings is *Religion and Culture: Anthropology of Religion,* a recently published book dealing with the religions of nonliterate peoples.

ROBERT M. ADAMS, who in this issue reviews *The Huxleys,* by Ronald W. Clark, is professor of English at the University of California at Los Angeles.



Cross-section of new cable: the twenty coaxial tubes can handle up to 32,400 simultaneous telephone calls.

Development of a transmission system

The Long Lines Department of the AT&T Co. recently announced that a new coaxial cable system was placed in service between Washington, D.C., and Miami, Florida, and that the system would later be extended to Boston.

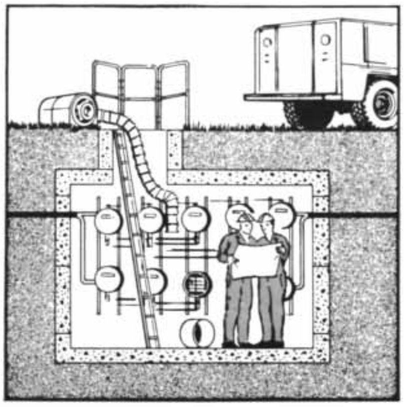
Behind this simple statement lie decades of research and development, millions in investment, years of planning and of efficient manufacture . . . and the constant desire to improve telephone service.

Service, in fact, is the beginning of the story. The demand for communications along the east coast has risen by about 2500 new circuits per year. More important, forecasts warned that this rise would continue, and at an even greater rate.

Why not, then, merely install additional systems of the types already developed? The answer is that communications technology has advanced greatly in the fifteen years since Bell Laboratories developed a major new coaxial system. Here was a chance to use this new technology for better service and lower cost.

But what type of system? Why not microwave radio, so important in modern telephony? Coaxial cable systems require a high initial investment. Cable, rights-of-way, and installation add up to large sums of money, even though only part of the cable may be used at first. Microwave radio also requires heavy investment, but with the difference that some expenditures may be deferred until service is needed.

In other words, you don't use coaxial unless you have a reasonable expectation of "rapid fill"—the rapid use of communications circuits to justify the expense of making them available.



Underground "repeater" or amplifier hut of the new system. Reliable transistors and related devices, plus new designs, let advanced electronic equipment work in such environments without excessive maintenance.

But if you can expect this rapid use, as on the east coast route, coaxial cable becomes very attractive. It is not inherently limited by frequency space. And coaxial cable is "exploitable": new systems, when developed, can be added to in-place cable.

So the problem reduced to developing the right coaxial system at the right time to meet the rising needs for service at a reasonable cost.

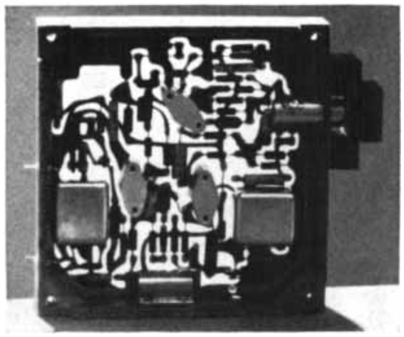
The "right" coaxial cable system was an all-solid-state system. For several years transistors and related devices had been available. They had the desired bandwidth but had neither the required linearity nor the power-handling ability for amplifiers that could transmit several thousand voice signals.

The technical problem, then, was to improve transistors, to design efficient circuits, and to organize circuits and subsystems into a working whole . . . that is, to plan and develop a large communications system.

The new system had to be—and is—better than older coaxial systems. Cost per channel mile has come down. Noise has been reduced (required because better telephone instruments are now used and because of very long, continental, and even intercontinental, circuits). A high degree of monitoring and control is built in; adjustments that once required a trip to a remote amplifier site can now be made from a main station. Maintenance visits to amplifier stations along the route are to average one per year or less.

New prefabricated "manhole" structures house the amplifiers. These are much easier to construct and install—and are more secure against damage—than the previous above-ground "huts."

In all, the new system typifies the complex, essential jobs that are the reason for Bell Laboratories . . . research, development and systems engineering organization of the Bell System.



Basic solid-state amplifier of the new transmission system.

The new transmission system between Washington and Miami. The cable contains ten pairs of coaxials; one pair is reserved for emergency service. Each pair can carry 3600 telephone channels; nine pairs can carry up to 32,400 simultaneous telephone calls, or the equivalent in mixed telephone, data, telephoto, and other services. About every two miles, there is an amplifier whose basic solid-state circuit handles the very wide range of 0.564 MHz to 17.548 MHz. The circuit's amplification characteristic is carefully shaped to give more gain at the high-frequency end of the band, where cable loss is greater. Most amplifiers are of this simple type, with fixed gain. Others incorporate the basic circuit but also include more complicated circuits to compensate for temperature and other effects on transmission. Main stations (major terminals from which remote adjustments can be made) are used about every 150 miles along the route. In addition to self-regulation, the new system includes fault-locating equipment to identify any failed repeater. These and other sophisticated design techniques give stable and reliable transmission. Noise is 4 dB less than in earlier coax systems.

Bell Telephone Laboratories

Research and Development Unit of the Bell System

How to squeeze 6-hours and 24-minutes into a 2-hour and 8-minute reel.

For longer stretches of sound, it's the new skinny recording tapes. Super-thin, they let you put up to 3600 feet on a standard 7-inch reel. Twice—even three times—the playing time you used to get. And all on a normal tape machine!

Many of the best of the new skinny tapes are based on polyester formulas using DMT (Dimethyl Terephthalate) or TA (Terephthalic Acid) from Amoco. They're strong. More resilient. (Skinny tapes absorb tension by stretching.)

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Pulsars

These newest astronomical mystery objects emit radio pulses with a spacing so regular they could be used as clocks. They may be fuel-depleted stars that are pulsating or rotating

by Antony Hewish

It is ironical that astronomy's latest discovery, the pulsars, should have been stumbled on unexpectedly during an investigation of quasars, those starlike radio sources whose origin is still one of the outstanding problems of astrophysics. Almost exactly a year ago a small group of workers operating a new radio telescope at the University of Cambridge were surprised to find that weak and spasmodic radio signals coming from a point among the stars were, on closer inspection, a succession of pulses as regularly spaced as a broadcast time service. With skepticism bordering on incredulity, the Cambridge group began systematic observations intended to reveal the nature of these strange signals even as they undertook to explain them away in terms of man-made radio interference. After all, seasoned radio astronomers do not make the mistake of supposing that every queer signal on their records is truly celestial; in 99 cases out of 100 peculiar "variable radio sources" turn out to be some kind of electrical interference —from a badly suppressed automobile ignition circuit, for example, or a faulty connection in a nearby refrigerator.

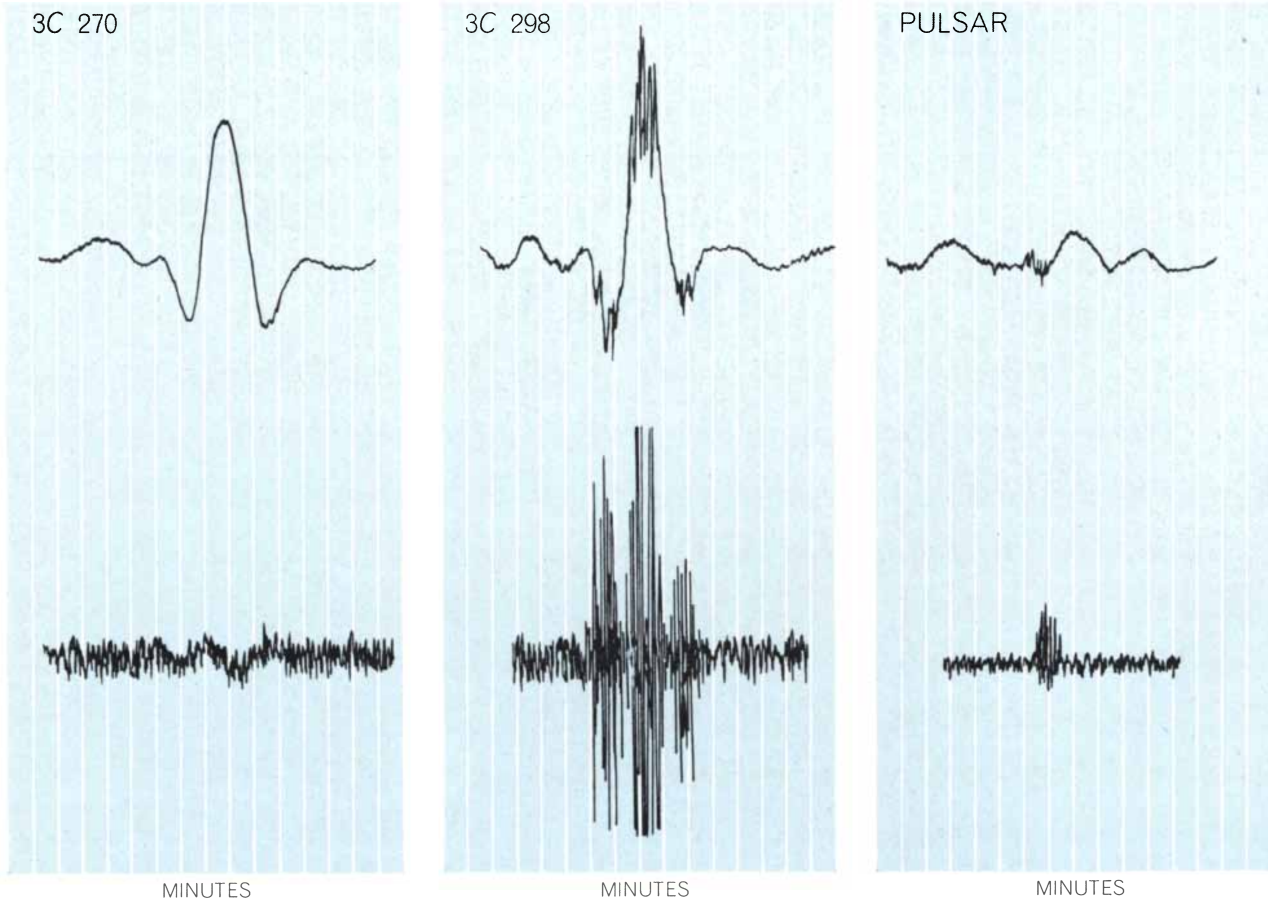
As the days went by excitement rose when we found that the pulses were coming from a body no larger than a planet situated relatively close to us among the nearer stars of our galaxy. Were the pulses some kind of message from another civilization? This possibility was entertained only for lack of an obvious natural explanation for signals that seemed so artificial. It soon declined in attractiveness with the discovery of similar pulses coming from three other directions in space, and with the absence of any planetary motion associated with the sources. (Presumably another civilization would have to occupy a planet.) We finally concluded that the only plausible explanation for these mystifying radio sources was that they were caused in some way by the vibrations of a collapsed star, such as a white dwarf or a neutron star.

The publication of these findings, about eight weeks after the pulses were first detected, stimulated intensive theoretical and observational work at research centers the world over. Whereas the true nature of the pulsars is still far from clear, it may be an opportune moment to take stock of the situation.

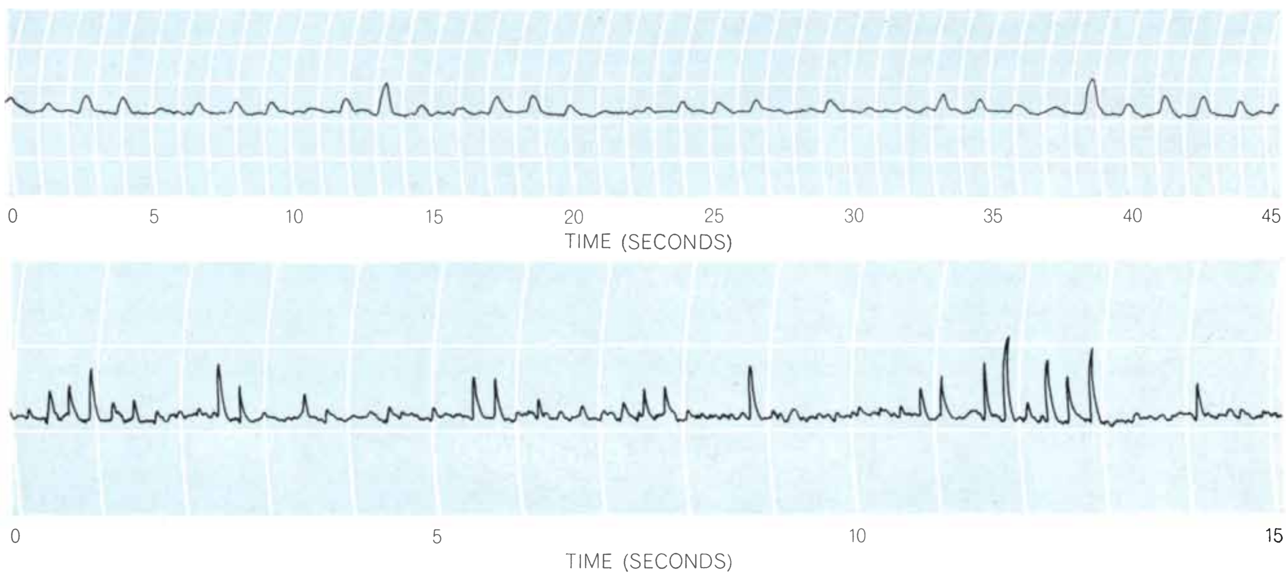
One obvious question to ask is why pulsars remained undiscovered for so long although powerful radio telescopes have been in operation for at least 10 years. The short answer is that the signals are not only very weak but also have an energy that falls off at the shorter wavelengths that radio astronomers mostly work with—wavelengths from a few centimeters to a meter. To find the pulsars it is necessary to use a sensitive radio telescope operating at meter wavelengths with the additional requirement that observations of the same areas of sky must be repeated with a recording system that has a sufficiently rapid response to show up the radio flashes. By a lucky coincidence these instrumental facilities were just those planned for a quasar hunt at Cambridge. The search was also designed to exploit the phenomenon of interplanetary scintillation.

The scintillation phenomenon was first observed in 1964. We found that the radio waves from very compact radio galaxies—objects whose angular dimensions are less than one second of arc—showed a characteristic rapid and irregular fluctuation of intensity. This effect, similar to the twinkling of visible stars, is caused by the distortion of the incoming radio waves as they pass through clouds of the electrically charged particles sprayed out by the sun (the "solar wind"). These "plasma clouds" cause scintillation only if the radio waves are sufficiently coherent, that is, if their source has extremely small angular dimensions. Ordinary radio galaxies have angular dimensions considerably larger than quasars and do not scintillate; therefore the effect gives a first-rate indication of whether a radio galaxy is likely to be a quasar or not. Now, just as the earth's ionosphere bends long wavelengths more than short ones, so do the plasma clouds in space. This means that scintillation is more pronounced at meter wavelengths than it is at the centimeter and decimeter wavelengths for which most radio telescopes are designed.

The radio telescope built at Cambridge for seeking possible quasars by the scintillation technique operated at a



CHARACTERISTIC RECORDINGS show how interplanetary scintillation can be used to distinguish between a radio source of very large size, such as a normal radio galaxy (*left*), and sources that are the size of stars or even smaller (*middle and right*). The recordings were made by the author and his co-workers with the large array radio telescope of the Mullard Radio Astronomy Observatory at the University of Cambridge. Such a telescope can be adjusted only for elevation; the rotation of the earth then carries the radio source past the antenna's field of view. The normal radio galaxy 3*C* 270 produced the smooth "envelope" curve at the top left. The lower trace is an amplified version of the fluctuations of the upper trace. The middle pair of traces was produced by 3*C* 298, a quasi-stellar radio source, or quasar. Interplanetary scintillations are clearly visible. They are produced when the coherent waves from a compact source travel through the nonuniform clouds of electrically charged particles emitted by the sun, the "solar wind." The pair of traces at right provided the first indication of radio emission from an object later identified as the first pulsar, CP 1919.



EARLY PULSAR RECORDS show the regular but variable-strength emissions of CP 1919 (*top*) and CP 0950 (*bottom*). In the trace of CP 1919, 15 pulses can quite clearly be distinguished in each 20-second interval, corresponding to one pulse approximately every 1.3 seconds. The exact pulse interval is now established as 1.33730113 seconds. CP 0950 emits a pulse every .2530646 second.

wavelength of 3.7 meters (equivalent to a frequency of 81.5 megahertz). Unlike many other radio telescopes, which are paraboloidal dishes, our instrument has a rectangular array of 2,048 dipole antennas spread over an area of 4.5 acres. By utilizing phase-scanning to steer the reception beam in elevation (declination) and the rotation of the earth to sweep the sky from west to east (right ascension) it was possible to survey a large fraction of the sky in one week.

Observations were begun in late July, 1967. Thereafter the task of analyzing the 400 feet of recorder chart paper that rolled from the equipment each week fell to a young graduate student, Jocelyn Bell. For the first time in the history of radio astronomy a large area of sky was repeatedly surveyed with an extremely sensitive radio telescope tuned to meter wavelengths. The sky was soon found to be liberally scattered with radio galaxies that exhibited plasma-cloud scintillation. These radio sources were carefully studied week by week to ascertain how the phenomenon changed in magnitude as the position of the sources shifted with the motion of the earth around the sun. Since the plasma clouds are embedded in the solar wind, which blows outward past the earth, scintillation becomes more intense as the line of sight to a radio source moves closer to the sun.

The recordings were mostly as we had expected, but one day in August, Miss Bell noticed something odd. What looked like rapid scintillation involving a very weak source was taking place in the middle of the night, a time when scintillation is usually low [*see top illustration on opposite page*]. Another curious feature was that the signals were present for only a fraction of the time required for the reception beam of the antenna to swing past a source in the sky. Had this happened only once we would undoubtedly have disregarded it and supposed that some interfering signal was present. By the end of September, however, the same thing was clearly apparent on six different occasions, although at other times it simply failed to show up. The constancy of position exhibited by the signals showed that they were probably from a true celestial source, which led us to imagine that we had found some kind of flare star. When the sun is active, its radio emission is often enormously enhanced; we calculated that if such a burst of activity occurred in a nearby star, it would be just about detectable with our radio telescope.

Now that we were really interested the source responded by virtually disappearing from the records for the next six weeks. One day late in November, Miss Bell undramatically announced: "It's back." We immediately arranged to make high-speed recordings to see if the signals had the same characteristics as signals from the sun. To our amazement the signals came as a regular succession of pulses at intervals of just over one second [*see bottom illustration on opposite page*]. It was simply unbelievable that such signals could be from a genuine astronomical object, but repeated observations showed that there could be no doubt about it. Naturally this mysterious radio beacon rather dominated our lives for the next few weeks as we carried out more observations in an effort to understand the true nature of the source.

One of our earliest surprises was the discovery that each pulse was associated with radio signals of continuously changing wavelength: the signals swept through the one-megahertz pass band of the telescope's receiver from high frequencies to low. This was revealed when two receivers tuned to slightly different frequencies were operated simultaneously and each pulse arrived a fraction of a second earlier in the receiver tuned to the higher frequency. A measurement of the instantaneous bandwidth of the radiation then showed that the actual duration of the pulse was only from 10 to 20 milliseconds.

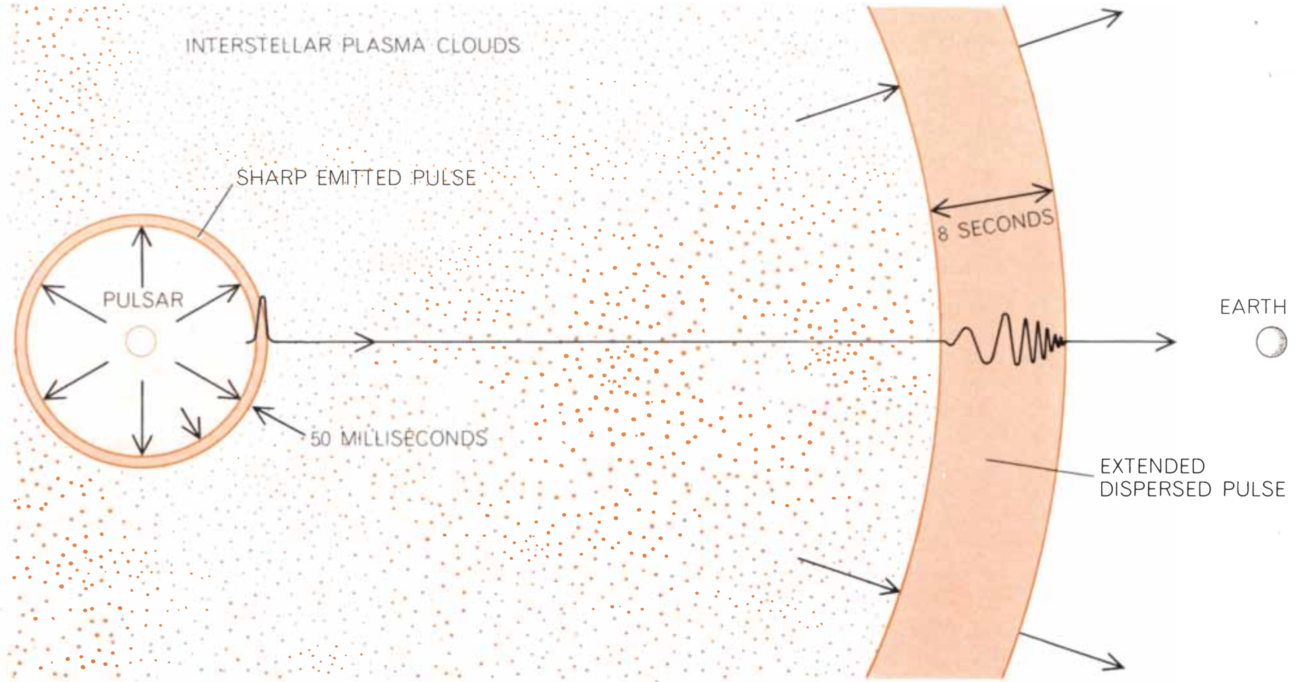
This provided the first vital clue to the source itself: the body emitting the pulses had to be extremely small. Its radius could not be larger than a few thousand kilometers. The reason is that a large body cannot emit a pulse of radiation in a time shorter than the time required for light to travel across it. Suppose, for example, the sun could be instantaneously switched off; how would it look from the earth? First we should see a dark spot at the center of the sun, since this is the part nearest to us. The dark area would then enlarge outward until the sun was a bright ring; finally even its outer edge would disappear. The entire sequence would take about two seconds, so that if the sun were to flash on and off like a pulsar the flashes could not have a duration shorter than that.

The second clue was provided by the frequency distribution of the pulses, which gave an important indication of the distance of the emitter. It is known that interstellar space is filled with very-low-density gas consisting predominantly of hydrogen atoms. Light from hot stars ionizes, or dissociates, some of these atoms, giving rise to free electrons. In a perfect vacuum radio waves of all wavelengths travel at the same speed—the speed of light—but this does not hold in an ionized gas. In such a gas the longer the wavelength, the lower the velocity. Thus a sharp pulse of radio waves containing a spread of wavelengths becomes stretched out as it travels through the ionized interstellar gas, with the short wavelengths arriving at the earth slightly before the longer ones [*see top illustration on next page*].

This effect, called dispersion, is a general property of wave motion. It happens, for example, with the ripples in a pond into which a stone has been dropped, and with the seismic waves that travel outward from an earthquake. If the density of electrons in interstellar space were accurately known, the difference in arrival time of a pulse at different wavelengths would give the distance of the source immediately. Unfortunately the density is not easily measured, but it is probably around one electron in a volume of 10 cubic centimeters. If this estimate is adopted, the distance of the first pulsar to be discovered is about 130 parsecs. (One parsec is 3.26 light-years.) When one considers that the diameter of our galaxy is about 30,000 parsecs, it is evident that this pulsar must be regarded as one of our neighbors in space.

The next big surprise came when we began timing the pulses and the truly staggering accuracy of the pulse rate became apparent. We found that from day to day the arrival of the pulses could be predicted to better than a tenth of a second, but we also observed that the interval between pulses was gradually decreasing. The explanation is that during this period the orbital motion of the earth was carrying us in a curving path toward the source. Thus there was a progressive decrease in period resulting from the Doppler effect. When due allowance was made for the Doppler variation, the pulses kept time within the experimental accuracy of about 10 milliseconds for several weeks.

We now know that the regularity of the pulses exceeds one part in 100 million, so that the pulsar can be regarded as a very good clock indeed. The period of the first pulsar is, in fact, 1.33730113 seconds. This period differs slightly from the value we originally gave; we had made a counting error of one pulse per day because we were unable to track the source for long periods. Our mistake was soon revealed when the large steerable radio telescopes at Goldstone in California and at Parkes in Australia were trained on the source. Just what the true

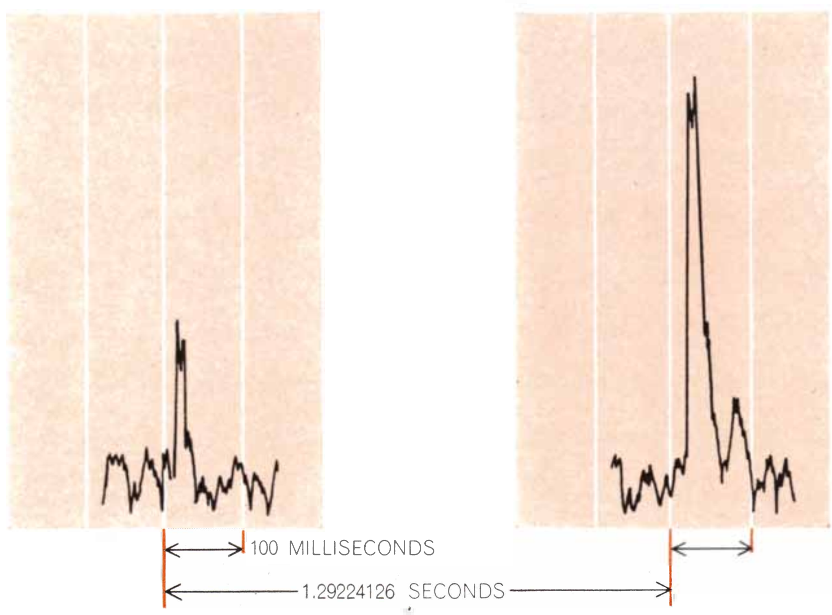


INTERSTELLAR CLOUDS OF ELECTRONS retard the velocity of radio waves in direct proportion to their wavelength: the longer the wave, the lower the velocity. Thus the broad-spectrum pulse that may be emitted within 50 milliseconds by a pulsar is stretched out by electrons in space so that the longest waves may lag as much as eight seconds behind the shortest when received on the earth. By measuring this delay and making reasonable assumptions about electron density one can estimate the distance to the source.

regularity of the pulses is we shall not know until timing experiments have been conducted for several years; the present accuracy is limited by irregularities in the shape of the pulses. The first pulsar is now designated CP 1919, which stands for Cambridge pulsar at right ascension 19 hours 19 minutes.

Faced with the problem of accounting for pulsed radio emission from a body no larger than a planet stationed relatively close to us in the galaxy, the possibility of communication from another civilization cannot be ignored. There is strong evidence, however, that the signals are not radiated from a planetary body in orbit around a star. Just as the orbital motion of the earth gives rise to a Doppler variation of period, so would any planetary motion of the source itself. We searched carefully for such effects, but when the orbital motion of the earth had been allowed for, no additional Doppler variation could be detected. Although it would be possible for an orbit to lie in a plane perpendicular to the line of sight, thus giving rise to no Doppler effect, we felt that this was rather unlikely.

If the source is a natural emitter, possibly a collapsed star, we reasoned that there should be others like it in the sky. A careful inspection of all the records made in the quasar survey was undertaken from which we obtained a number of positions where pulses were possibly present. The radio telescope was trained on these places, and after some weeks three more pulsars had been added to the list. By this time we felt reasonably confident that the pulsars were a natural phenomenon. We published our findings on the first pulsar while checking the properties of the other three. One of the three has a pulse interval of only .25306 second, the briefest period yet observed. Nine pulsars are now known. The fifth was found by Harvard University radio astronomers working with the 300-foot



CONSECUTIVE PULSES FROM CP 0808 show marked differences in fine structure at the recording frequency of the large Cambridge antenna array: 81.5 megahertz. This corredish at the National Radio Astronomy Observatory in Green Bank, W.Va., two more have been turned up at Cambridge and two have been located in the southern sky by a team at the Cornell–Sydney University Astronomy Centre at the University of Sydney. One of the southern pulsars, PSR 2045, has the longest period yet observed: 1.9616633 seconds [*see top illustration on page 35*].

During the past six months strenuous efforts have been made at radio and optical observatories throughout the world to penetrate the pulsar mystery. It is now known that pulsars radiate over a very wide band extending from 40 megahertz to 3,000 megahertz. The spectrum of the radiation is difficult to establish because of large pulse-height variations that are quite unrelated at the different wavelengths. It appears that the radiation is strongest at low frequencies and drops off steeply at frequencies above 1,000 megahertz. The rapid and irregular fluctuation of pulse strength from instant to instant is an important property of pulsar radiation and shows up in all the sources [*see illustration below*].

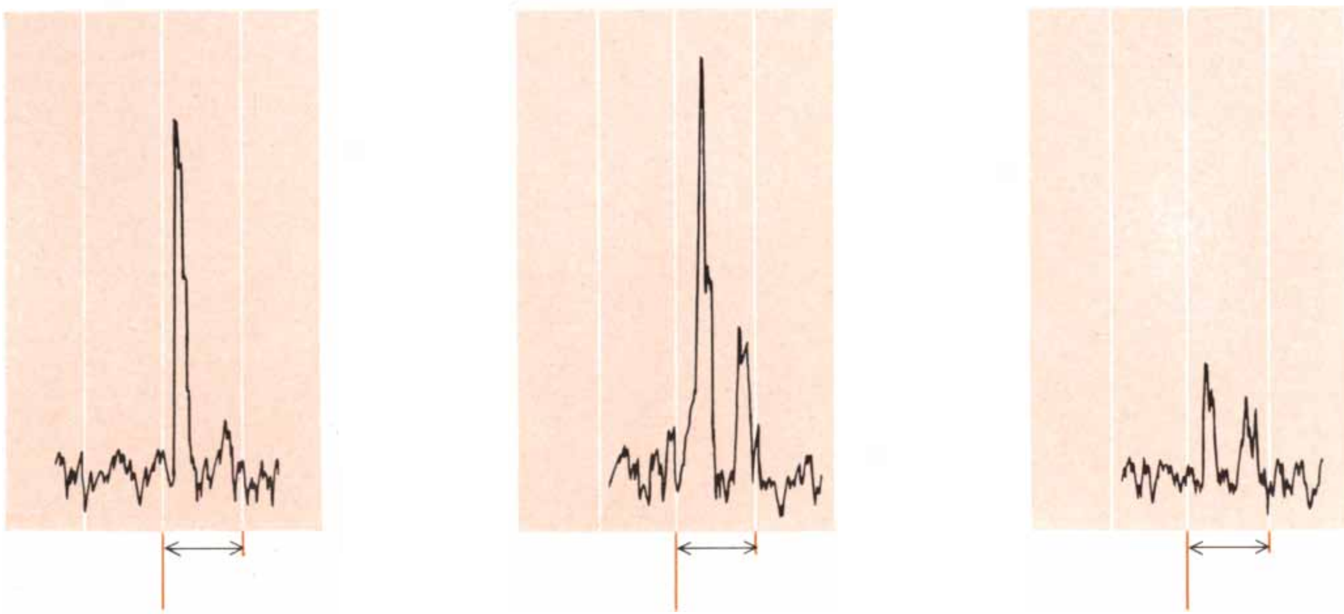
Pulse trains have been carefully studied to see if any kind of strength pattern is present, but without success. Amplitude modulation of the pulses would, of course, be an obvious method of coding a message if the signals were an attempt at communication by another civilization. One feature common to all the pulsars is that the amplitude variations are more rapid at lower frequencies. For example, at 81.5 megahertz CP 1919 radiates relatively strong pulses for only about one minute at a time, whereas at 408 megahertz the bursts of strong signals last for about half an hour. It has been suggested that these fluctuations arise from scintillation caused by plasma clouds near the pulsar, and it does seem quite likely that such clouds would be blown out from the source.

When individual pulses are examined in detail, they show a remarkable complexity of structure. Each pulse is found to consist of a number of subpulses, the exact form of which may change radically between one pulse and the next [*see bottom illustration on next page*]. Subpulses lasting only .2 millisecond have been reported from a group working with the giant 1,000-foot paraboloid at Arecibo in Puerto Rico. Since this figure is at the detection limit of the Arecibo receiving system, it may be that even finer structure exists.

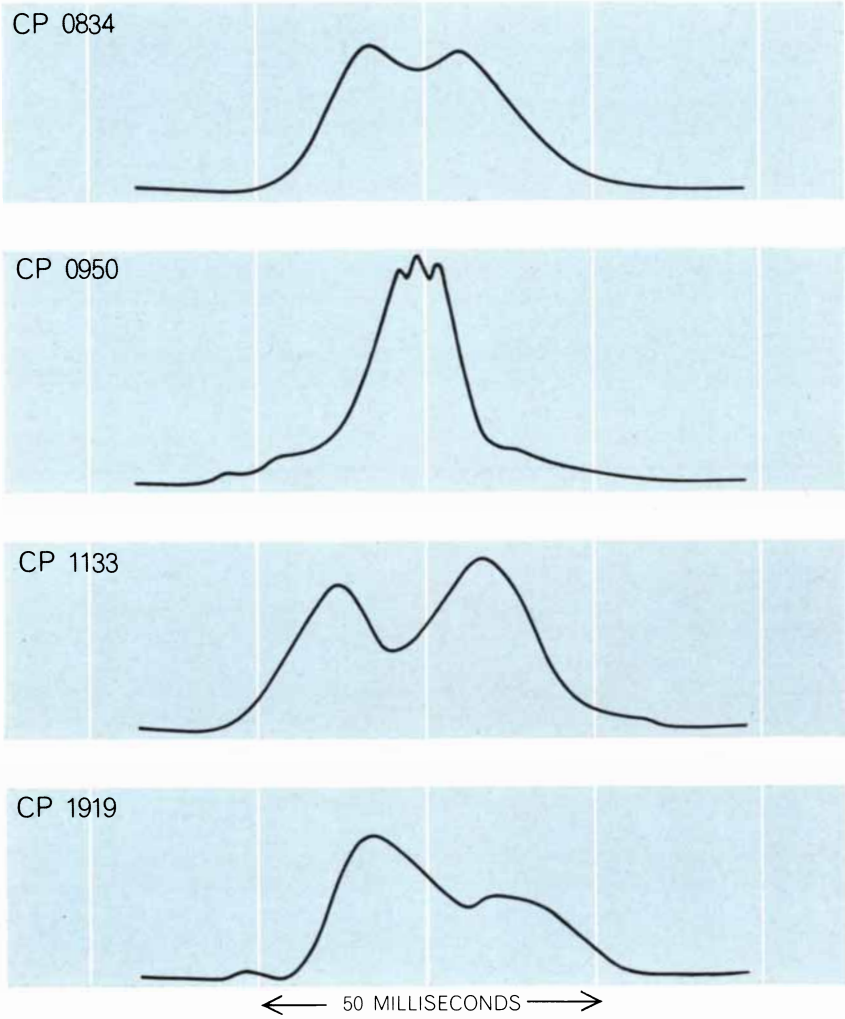
An important property of the subpulses is that they often exhibit considerable polarization. Strong circular polarization with the sense of rotation varying rapidly from one subpulse to the next has been observed at Arecibo, and long-lived linear polarization has been detected at the Jodrell Bank radio observatory in England. At Cambridge we have also found that the sweeping radio-frequency signal that constitutes the pulse has a complicated spectrum. The energy in a single pulse may be quite different at frequencies separated by only 300 kilohertz.

Although the shape of individual pulses varies considerably, it turns out that the "envelope" of the pulse—a smoothed-out form of its detailed trace obtained by superposing pulses for a minute or so—settles down to a characteristic form that is different for each source [*see top illustration on next page*]. CP 1133 has a double-humped envelope, whereas CP 0950 shows a slow rise followed by a rather narrow peak. It is interesting, however, that all the pulse-envelope traces last about 50 milliseconds. Referring back to our earlier consideration of the physical size of the pulsars, this shows that in all cases their diameter cannot exceed about 15,000 kilometers. The subpulses must of course be emitted from bright patches that are even smaller than this upper limit.

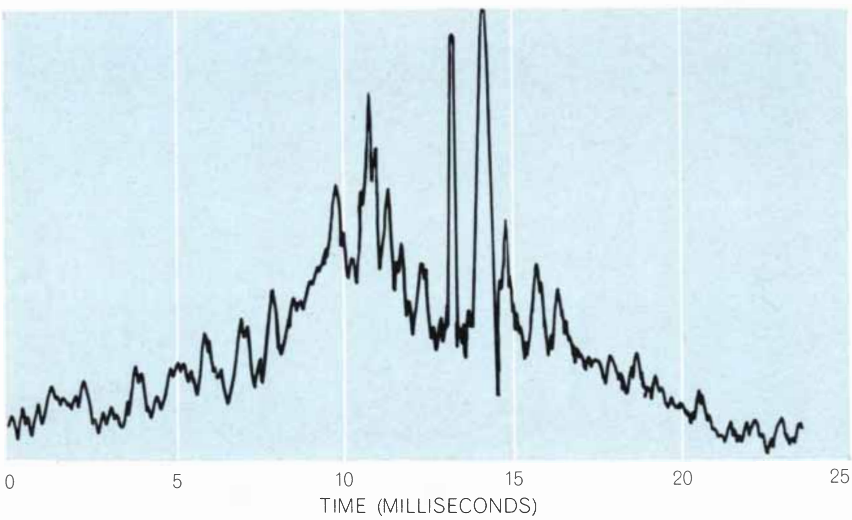
Radio astronomers will clearly be busy for some time searching for more pulsars and unraveling the properties of those already found. Another line of investigation is the possibility of observing pulsars with optical telescopes. The trouble here is that the sky is so densely packed with stars that very precise radio positions are necessary in order to be sure of identification. The Cambridge dipole array that originally detected the pulsars was not designed for accurately pinpointing sources, but at the same observatory Sir Martin Ryle operates a large radio telescope system that employs the principle known as aperture synthesis. Using three 60-foot dishes, one of which is mounted on rails, and feeding the radio signals into a computer,



sponds to a wavelength of about 3.7 meters. At centimeter and decimeter wavelengths the emissions from pulsars are much weaker, which explains in part why they were not discovered earlier by the large radio telescopes that usually work at the shorter wavelengths.



AVERAGE PULSE ENVELOPES of four pulsars were determined by A. J. Lyne and B. J. Rickett with the 250-foot dish telescope at the Jodrell Bank observatory of the University of Manchester. The fact that all emit pulses of roughly the same duration, 50 milliseconds, suggests that the emitting objects are all close to the same size. CP 0950 may be the smallest.



FINE DETAIL IN CP 0950 was recorded at a frequency of 195 megahertz (1.55 meters wavelength) with the 1,000-foot dish telescope at Arecibo, Puerto Rico, operated by Cornell University. J. M. Camella, H. D. Craft, Jr., and Frank D. Drake made the recording.

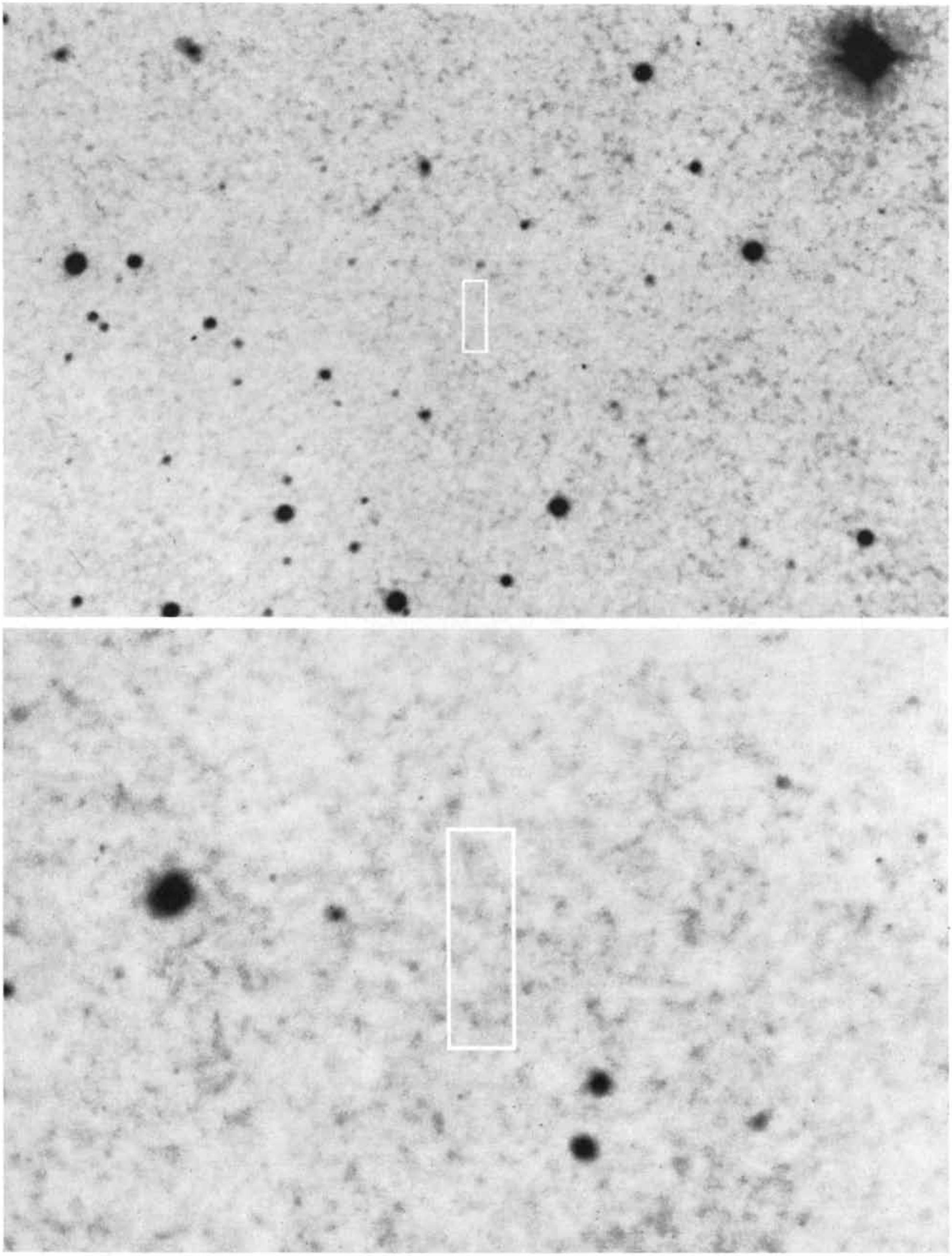
the system constitutes an instrument equivalent in capability to a steerable dish a mile in diameter [*see bottom illustration on page 35*].

Accurate positions have now been obtained with this instrument for CP 1919, CP 0950 and CP 1133. Inspection of prints from the National Geographic Society–Palomar Observatory Sky Survey reveals no object within the rectangles of probable pulsar position except for CP 1919 [*see illustration on page 32*]. The pulsars CP 0950 and CP 1133 radiate no visible light down to the limit of the photographic plates. In the case of CP 1919 a faint yellow star is seen near the pulsar position, but we cannot be sure that this is not a coincidence.

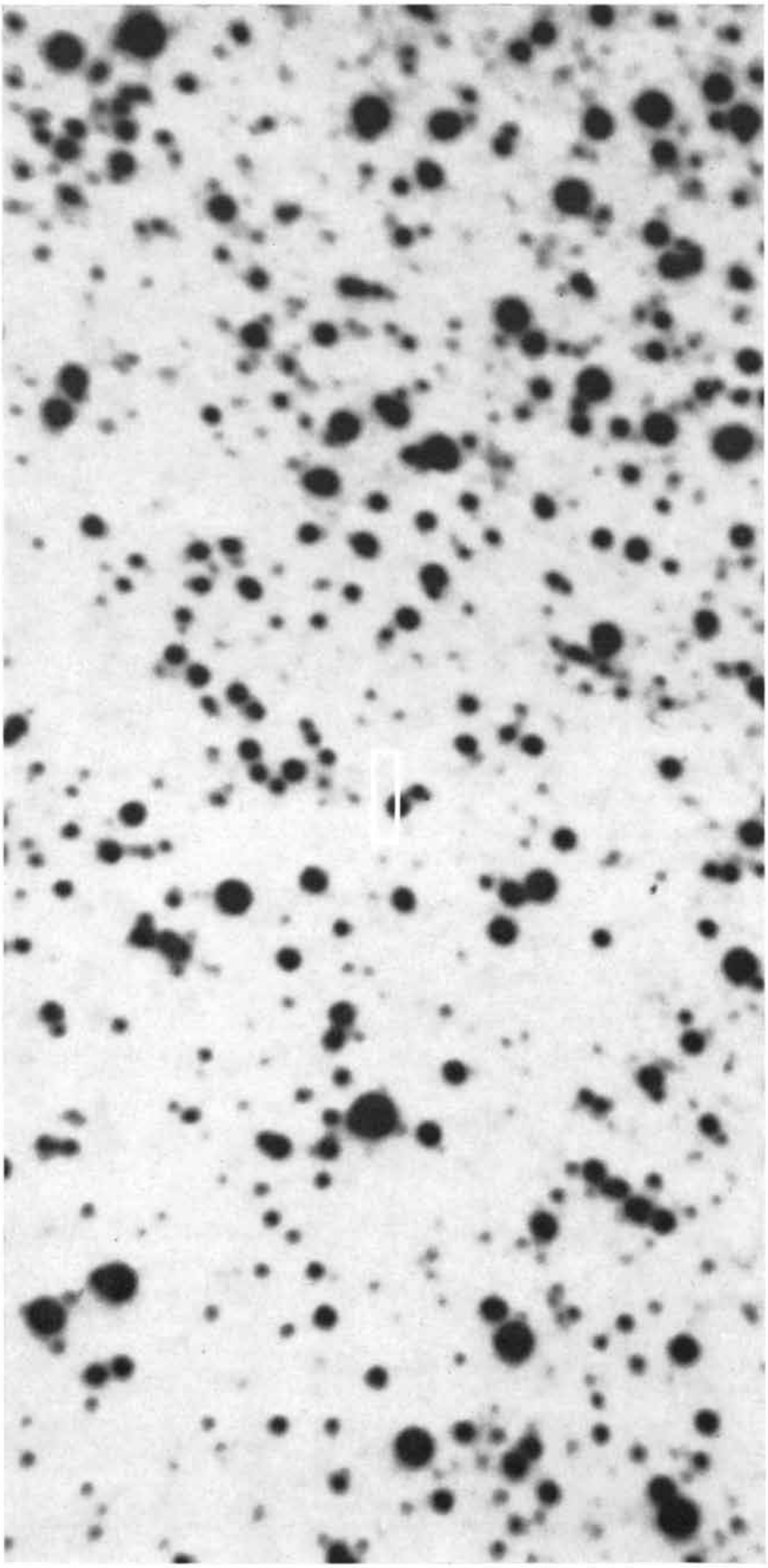
Much effort has been expended in attempts to detect light flashes from this star. Observers at the Kitt Peak Observatory in New Mexico report that they have found a small optical variation at, curiously enough, *twice* the pulsar period. A similar result was also reported from the Lick Observatory in California, but the report was subsequently withdrawn. Other observations have failed to show any fluctuation of light from the star. In view of the absence of light from at least two of the pulsars, and their close similarity in all other respects, the optical evidence obtained so far must be treated with caution.

No satisfactory explanation for the pulsars has yet been suggested. The energy requirement, combined with the immense stability of the timekeeping mechanism, implies that some object with the mass of a star is involved. We are currently aware of only two types of star, white dwarfs and neutron stars, that are as small as the pulsars must be [*see top illustration on page 33*]. White dwarfs are stars that have collapsed after exhausting their nuclear fuel. Their mass, roughly equal to the mass of the sun, is packed into a volume the size of a planet. Neutron stars have been proposed on theoretical grounds, but none has yet been found. They would have roughly the same mass as white dwarfs, but their diameter would be only on the order of 10 to 100 miles. Calculations indicate that neutron stars might be hot enough to emit detectable X rays.

The nature of these compact stellar bodies and the reason why only the two types are plausible depends on the properties of matter at enormously high density. A typical star such as the sun maintains its size by balancing internal pressure against gravity; the pressure results from the large amounts of radiant energy



OPTICAL SEARCH for pulsars has so far been unrewarding. The rectangles in these two sky photographs delineate the radio positions of CP 0950 (*top*) and CP 1133 (*bottom*). The long side of the rectangle equals two-thirds of an arc minute in the case of CP 0950 and one arc minute for CP 1133. One would expect that if either pulsar were a normal white dwarf it would be visible in such pictures if it were as nearby as the radio evidence indicates. The prints are from the National Geographic Society–Palomar Observatory Sky Survey.



OPTICAL SEARCH FOR CP 1919, first pulsar to be discovered, has been conducted in the region defined by the rectangle. Unconfirmed reports from optical astronomers suggest that some object in this region is emitting light in a fluctuating and possibly regular manner. But the star lying on the boundary of the rectangle exhibits no unusual properties.

released by nuclear reactions deep inside the star. As the nuclear fuel is used up the radiation pressure must eventually decrease and gravity will then contract the star to a smaller volume. A new equilibrium becomes possible, even for a cool star, when the pressure due to the motion of electrons balances gravity. For a star as massive as the sun this happens only when gravity has shrunk the material into a sphere with a radius of some 6,000 miles. The visible white dwarfs are presumed to be old, burned-out stars of about this mass and size.

We can imagine a star much more massive than the sun collapsing in the same way, but an interesting situation arises when gravitational forces compress the spent matter into too small a volume. Quantum effects, and the "degeneracy" of the electrons resulting from the Pauli exclusion principle, dictate that the electrons weaving in and out among the atomic nuclei can be packed into a smaller volume only if their energy is increased. The more massive the star, the greater the inward gravitational force and the greater the electron energy. Eventually the energy is so great that the electrons react with protons to form neutrons—the reverse of the normal process, in which a free neutron decays into a proton and an electron within a few minutes. When the electrons disappear, so does the pressure caused by their motions; gravity then contracts the star still further until it becomes a neutron star. According to current ideas a heavy star is likely to explode before it reaches the white-dwarf stage, leaving a neutron star at its center. Attempts to find neutron stars in the debris of supernovas, however, have not succeeded.

Since the time of Sir Arthur Eddington astrophysicists have contemplated the possibility of pulsating stars that alternately expand and contract over their entire surface. These ideas are of interest in the theory of variable stars such as the cepheid and RR Lyrae types. As we groped for some explanation for the pulsars we were impressed by the fact that the pulsation periods calculated for white dwarfs and neutron stars came fairly close to the observed periods of the pulsars. For the neutron star it had also been calculated that considerable quantities of energy could be stored in the vibrations, implying that the pulsation might persist for a long time. It therefore appeared that the pulsation of an entire star might provide just the required clock mechanism for triggering the emission of the radio pulses.

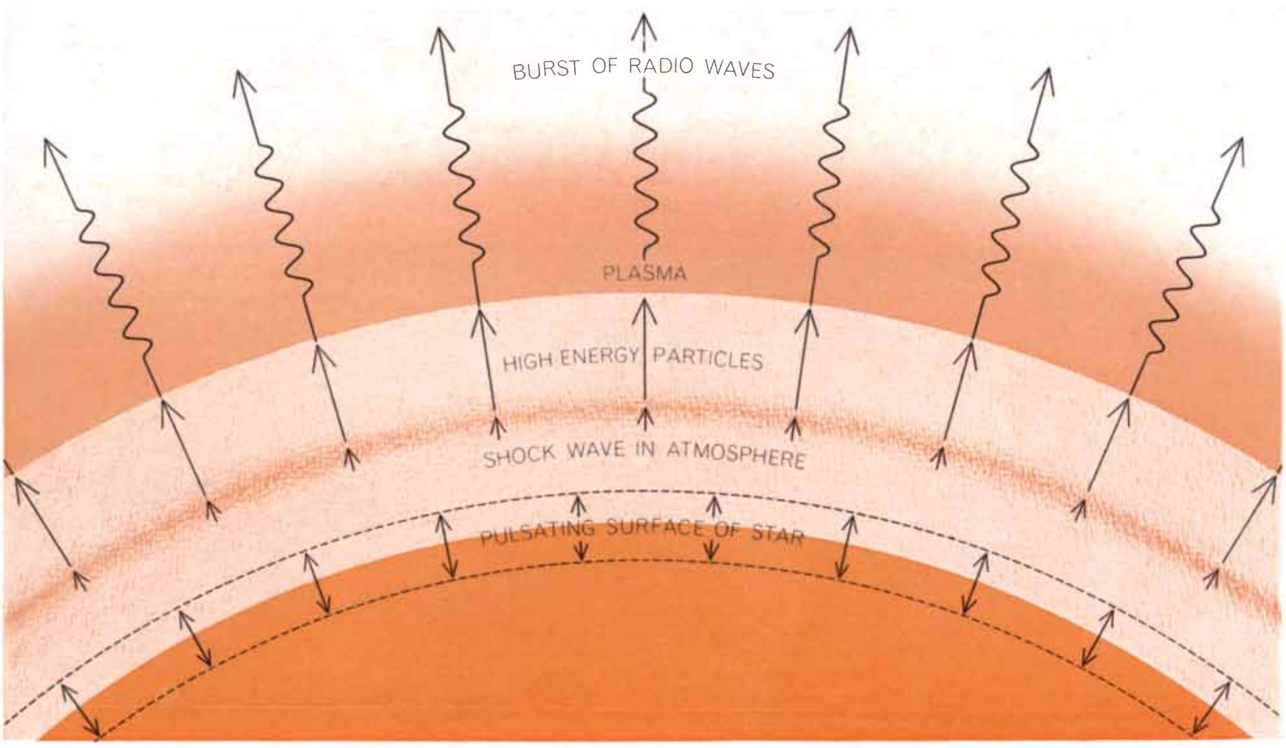
Precisely how an up-and-down vibra-

CONJECTURED SIZE OF PULSARS is compared with relative sizes of the sun, the earth, white dwarfs and neutron stars. The sun is 864,000 miles in diameter, the earth not quite 8,000 miles. White-dwarf stars incorporate a mass roughly equal to that of the sun in a volume of planetary dimensions. Hypothetical neutron stars also have a mass roughly equal to that of the sun but a diameter of only 10 to 100 miles. The brief pulse interval suggests that pulsars fall somewhere in size between neutron stars and white dwarfs.

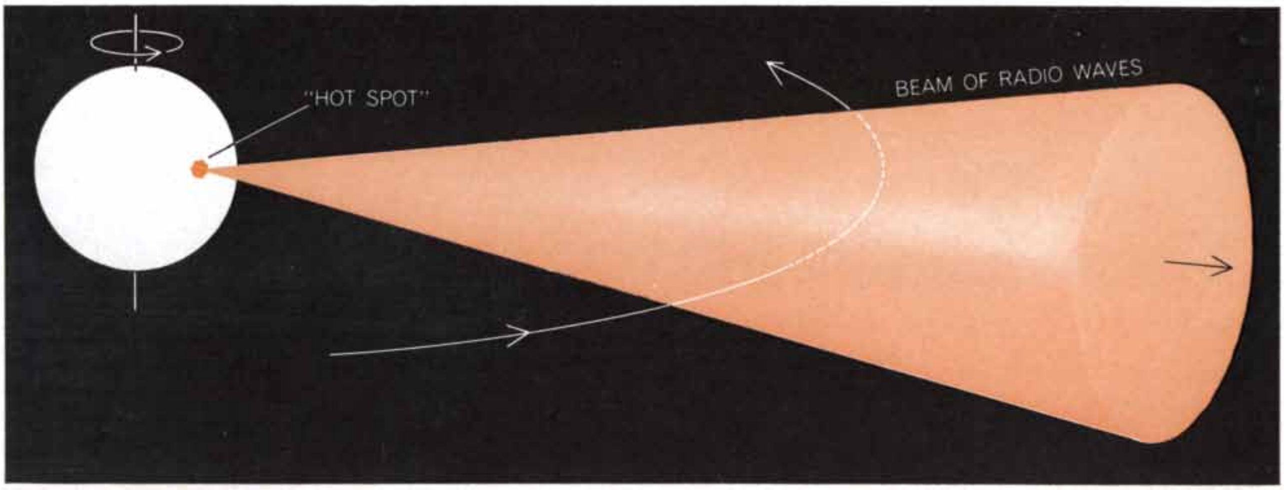
tion of the surface of a star would give rise to radio pulses is far from clear. One can, however, visualize a pressure wave being launched into the atmosphere by the heaving surface; then, as the atmosphere thinned out, the pressure wave would be transformed into a shock wave. The outward-moving shock front might accelerate electrons to high speeds and the electrons in turn might generate radio waves as they rushed out through the ionized gas surrounding the star [*see illustration below*]. Events of this kind certainly occur in the solar atmosphere, giving rise to radio outbursts. We may imagine that similar activity, linked to a pulsating surface, accounts for the regular radio flashes from a pulsar.

When we first considered this possibility, there was one important snag. Calculations indicated that neutron stars would pulsate rather too rapidly, with periods of milliseconds. White dwarfs, on the other hand, would pulsate too slowly; if they were compressed sufficiently to vibrate with periods shorter than a few seconds, they would be collapsed by gravity. Faced with this challenge, several theorists have recently calculated that a spinning white dwarf can be made to vibrate considerably faster, particularly if the interior of the star rotates more rapidly than its equatorial region does. Periods as short as .1 second are reported for this model, which would certainly account for the known pulsars. Other modifications of white-dwarf theory assume that the star pulsates at some overtone of the fundamental period, or that the atmosphere vibrates at some fairly high rate that is coupled to a slower vibration of the interior.

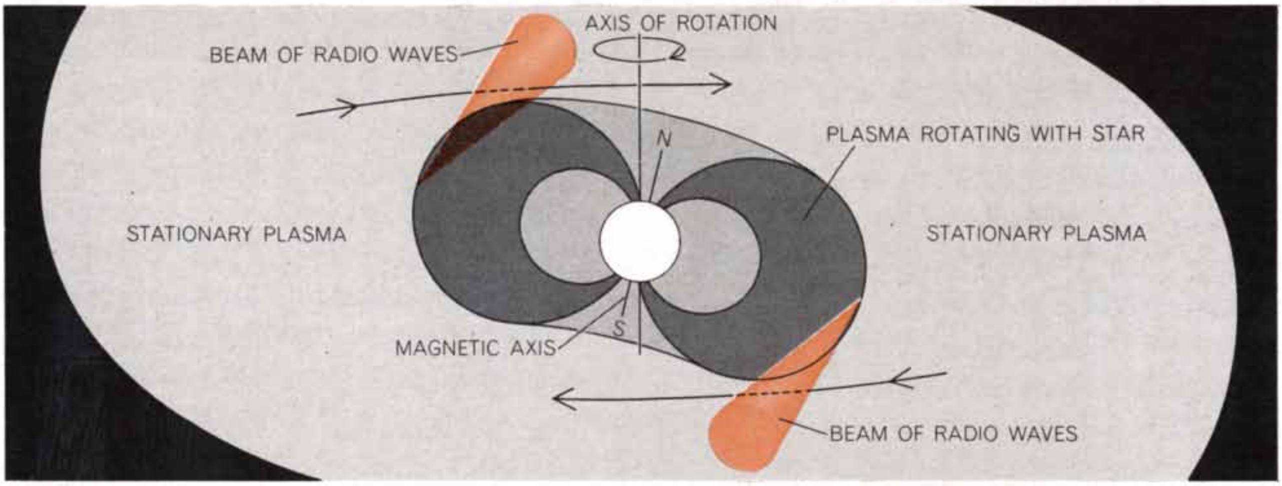
Many other ideas have been suggested to explain pulsars, some of which can be classified as "lighthouse" theories. If radio waves continuously emitted from some active region on a rotating star are suitably formed into a beam, regular flashes at the rotation period of the star will be observed on the earth [*see top illustration on next page*]. This picture presents difficulties if the star is a white dwarf; if the star spun fast enough to account for the most rapid pulsations, it



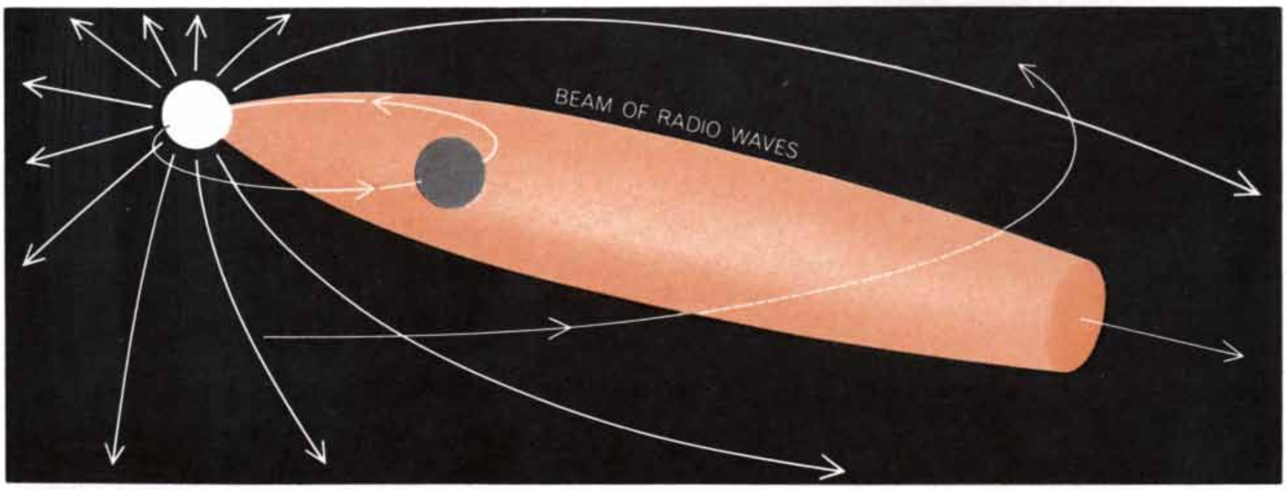
MODEL OF PULSATING STAR assumes that the entire surface of a white dwarf (or possibly a neutron star) is oscillating at the frequency characteristic of the pulsars so far observed. The regular motion of the surface sends out shock waves that generate bursts of radio waves in all directions when they strike the plasma, or electrically charged envelope of gas, in the star's upper atmosphere.



ROTATING WHITE DWARF is one of several "lighthouse" models put forward to explain the frequency and extreme regularity of pulsar signals. In the model illustrated, proposed by J. P. Ostriker of Princeton University, radio waves are continuously emitted from some active region, or hot spot, on the surface of a white dwarf that is rotating at a rate equivalent to the pulse interval.



ROTATING NEUTRON STAR is a lighthouse model proposed by Thomas Gold of Cornell University. It presupposes that the star's magnetic field is sufficiently powerful to grip the star's envelope of plasma out to a great distance, forcing it to rotate at the same rate as the star itself. At the periphery where the spinning plasma finally breaks away, highly directional radio beams will be emitted.



PAIR OF NEUTRON STARS traveling rapidly in orbit around each other provides still another lighthouse theory. The gravitational field of a neutron star is so immense that it would bend and focus radio waves if they were being continuously emitted by the companion star. The various lighthouse theories require that the earth be fortuitously located in line with the rotating radio beams.

might fly apart or rotate so unevenly over its surface that accurate timekeeping would be impossible. Neutron stars, however, could spin at more than 600 revolutions per minute before centrifugal forces disrupted them.

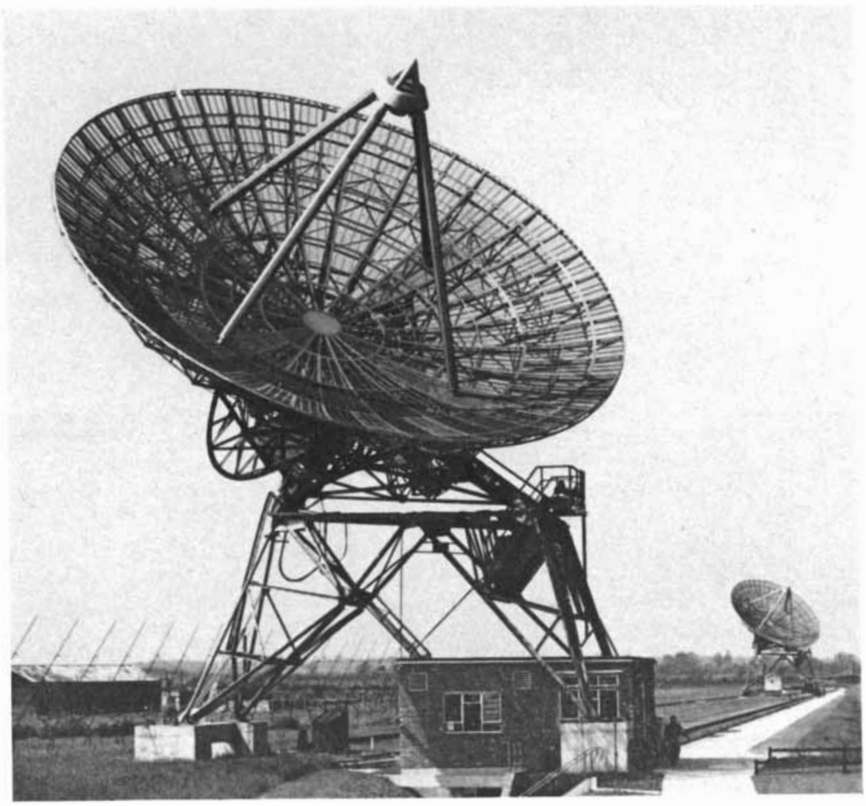
Neutron stars are also likely to have a powerful magnetic field, and such a field would provide the basis for another lighthouse theory. The magnetic field would cause the ionized atmosphere of the star (if there is one) to whirl around with the star, even if the atmosphere were quite extended. Thomas Gold of Cornell University has suggested that the far reaches of such an atmosphere might move at a speed approaching the speed of light before it became disconnected from the magnetic field. At the point where the spinning atmosphere broke away, radio waves would be generated and formed into a beam by relativistic effects [*see middle illustration on opposite page*].

Still another lighthouse model, proposed by W. C. Saslaw, J. Faulkner and P. A. Strittmatter of the University of Cambridge, calls for a pair of neutron stars in orbit around each other. Many typical stars exist in pairs held together by gravitational attraction; if neutron stars exist at all, they too may exist in pairs. Now, the gravitational force near a single neutron star would be immense, which means that light waves (and therefore radio waves as well) would be bent toward the star as they pass by. Consequently if one of the neutron stars is continuously emitting radio waves, some of them would be focused by the companion star: its gravitational field would act like a gigantic lens. The result would be a rotating beam that might extend in the direction of the solar system [*see bottom illustration on opposite page*]. A severe difficulty with this idea is that the orbital velocity of the neutron stars would be slowed down rather rapidly by the loss of energy to gravitational radiation. It may be, however, that bodies in free fall do not radiate gravity waves; that would save the theory.

One could continue to describe many other pulsar models that have been proposed. Difficulties arise with most of them, and clearly theoreticians have much work to do before the truth about pulsars is known. Current opinion seems to be about equally divided between white dwarfs and neutron stars as the source of the periodic emission. Quite apart from what pulsars actually are, however, they are likely to become important in widely different realms of astronomy. For example, there is considerable interest in the question of whether or not the astronomical time derived from the motion of celestial bodies remains in step with the atomic time derived from atomic clocks in terrestrial laboratories. It may be that pulsars are sufficiently accurate astronomical clocks to supply the answer. Already the constancy of pulsar timekeeping is almost good enough to provide a direct test of the theory of general relativity. Pulsars are exciting objects and we can expect a great deal from them.

PULSAR	RIGHT ASCENSION	DECLINATION	PERIOD (SECONDS)	DISTANCE (PARSECS)
CP 0328	03h 28m 52s	54°23′	0.714518563	268
CP 0808	08h 08m 50s	74°42′	1.29224126	58
CP 0834	08h 34m 22s	06°07′	1.2737642	128
CP 0950	09h 50m 29s	08°11′	0.2530646	30
CP 1133	11h 33m 36s	16°08′	1.187911	49
HP 1506	15h 07m 50s	55°41′	0.739677626	196
CP 1919	19h 19m 37s	21°47′	1.33730113	126
PSR 1749	17h 49m 49s	−28°06′	0.5626451	509
PSR 2045	20h 45m 48s	−16°28′	1.9616633	114

POSITION, PERIOD AND DISTANCE of nine known pulsars are listed. The hour and minute values of the position in right ascension provide the four-digit number that follows the designation CP (for Cambridge pulsar), HP (for Harvard pulsar) or PSR (simply for pulsar). The last designation was suggested by the group in Sydney, Australia, that recently discovered the two pulsars in the Southern Hemisphere. The distance estimates are based on an assumed mean electron density in space of one electron per 10 cubic centimeters.



APERTURE-SYNTHESIS TELESCOPE at the Mullard Radio Astronomy Observatory of the University of Cambridge employs three 60-foot dish telescopes, of which only two are shown here. One of the three is mounted on rails. The signals from the three dishes are fed into a computer, where they are synthesized into a signal equivalent to that obtainable from a steerable dish telescope a mile in diameter. The instrument has been used by Sir Martin Ryle and his colleagues to establish the precise positions of pulsars in the northern sky.

Surgery for Coronary Disease

There are three main surgical approaches to coronary artery disease: (1) providing the heart muscle with an alternative supply of blood, (2) repairing the diseased artery and (3) repairing the damaged heart

by Donald B. Effler

The effort to save lives with heart transplants illustrates the increasingly aggressive strategies to which medicine has turned in recent years to deal with acquired heart disease, the greatest single hazard to the health and life of modern man. External heart massage, once thought to be perilous and of little value, is now taught routinely to policemen, firemen, ambulance attendants and others who administer first aid. Operations are performed on the heart and its blood vessels almost as freely as they were on less vital organs a generation ago. It has been found that the risks involved in these procedures are relatively small compared with the number of lives that can be saved by their rational and timely use. This article is an account of the results we have obtained at the Cleveland Clinic over the past 10 years with new diagnostic and operative techniques for surgical repair of the heart and its blood supply in coronary arterial disease.

Of the four chambers of the heart, the most important in terms of function and vulnerability is the left ventricle, which pumps oxygenated blood into the body's arterial system. As the heart's basic work unit the left ventricle comprises the main bulk of the heart muscle and requires most of the coronary blood supply. It is fed by the two principal coronary arteries: the right and the left. When these arteries are substantially narrowed by atherosclerosis, the reduced blood flow to the heart muscle leads to the symptom of distress known as angina pectoris (pain in the chest). The pain arises from a metabolic deficit in the heart muscle that in turn results from a severe blood-vessel spasm. It is most likely to occur during physical or emotional stress. (Nitroglycerin relieves anginal pain because it is a potent dilator of blood vessels.) At a certain critical point in the narrowing of a coronary artery by atherosclerosis (usually reduction of its bore by 75 percent or more) the danger of coronary occlusion becomes acute, either by spasmic closing of the vessel or by thrombosis (clotting).

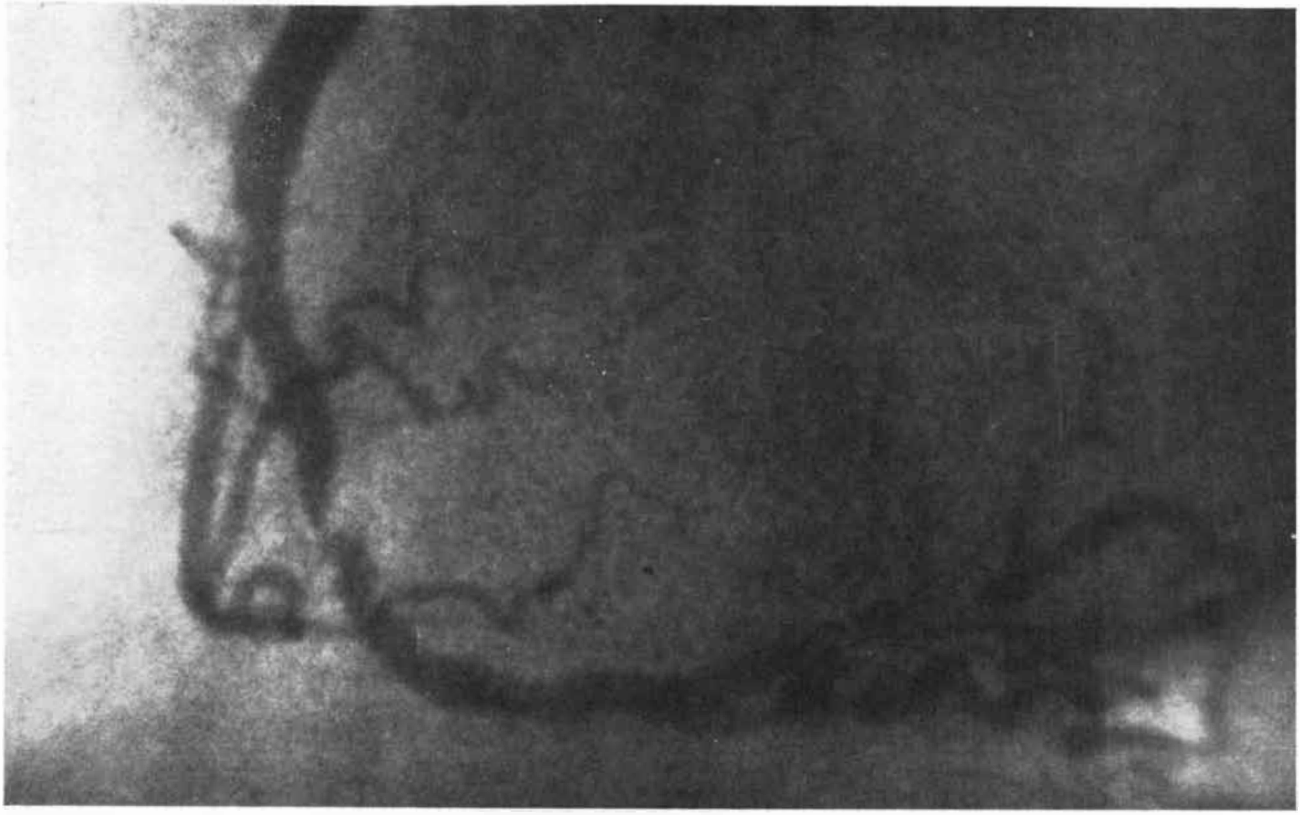
The consequent shutoff of the blood supply to a significant portion of the left ventricle ("heart attack") will destroy the muscle, but it may kill the victim even before that happens by producing ventricular fibrillation, a disruption of the coordinated contractions of the muscle cells. Fortunately the prompt application of artificial resuscitation or electrical stimulation can often restore the heart's coordinated pumping action [see "Intensive Heart Care," by Bernard Lown; Scientific American, July]. An individual's recovery from a heart attack depends on maintenance of the heart's electrical stability and on quick restoration of the blood flow to the heart muscle. Sometimes the heart suffers little damage; more often the survivor is left with permanent impairment of the functioning of the left ventricle and perhaps damage to other structures of the heart.

The treatment of heart patients and of coronary arterial disease has depended on rather vague and often controversial criteria. To begin with, the diagnosis of disease of the coronary arteries has itself been highly uncertain. Traditionally it has been based on electrocardiograms and on general information such as the patient's ethnic background, age, weight, occupation and subjective symptoms. These clues are so inconclusive that it is not uncommon for persons to have a heart attack shortly after they have been given a clean bill of health in a thorough examination. Nor is it unusual, on the other hand, for a healthy person to be condemned by his physician to an unnecessarily restricted life on the basis of an incorrect diagnosis of coronary disease.

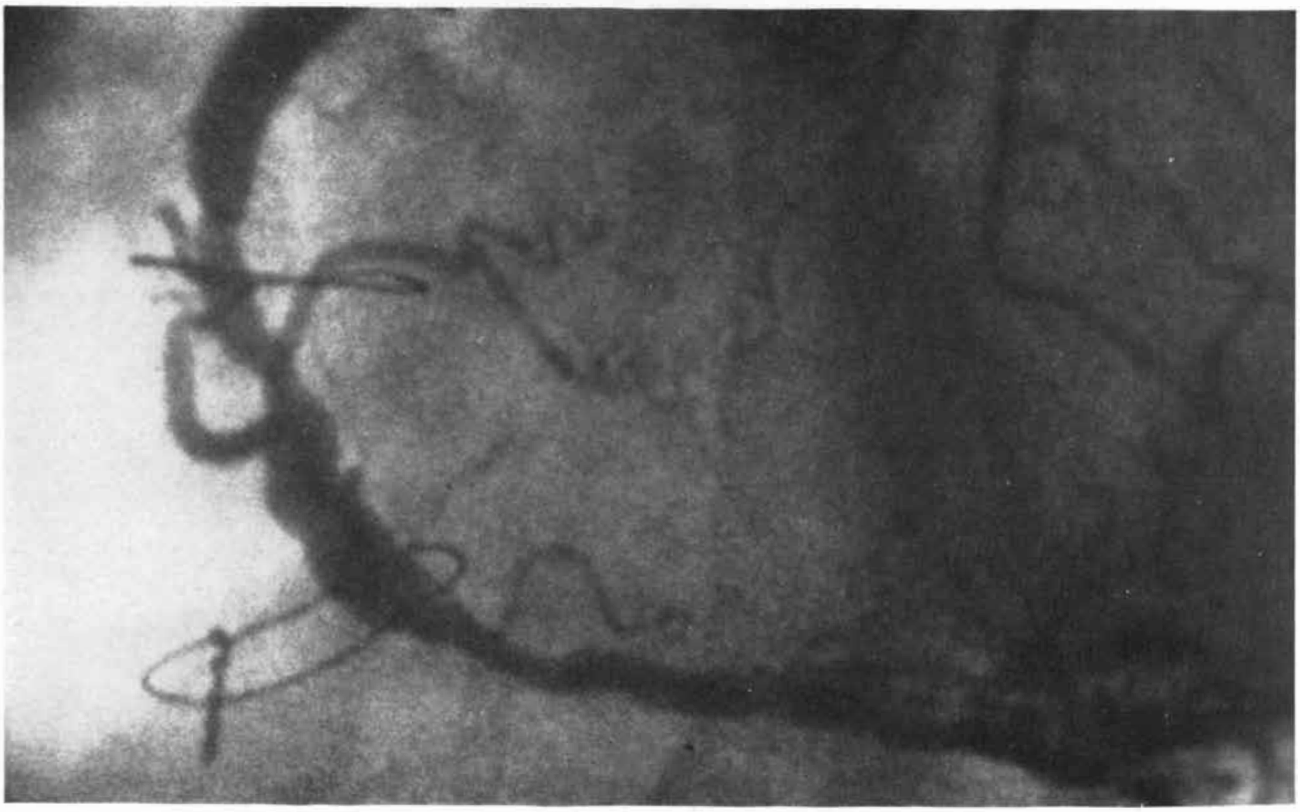
A similar lack of specificity characterizes the treatments usually prescribed for coronary patients: dieting fads of one kind or another, reduction of weight, graded exercise, drugs such as blood-vessel dilators and so forth. Helpful as these prescriptions may be, they do not directly attack the patient's prime need for improvement of the blood supply to the heart muscle.

Attempts to achieve that purpose by surgery were started many years ago. Before World War II, Claude S. Beck of the Cleveland Clinic and Laurence F. O'Shaughnessy in England pioneered experiments in supplementing the coronary blood supply by attaching blood vessels from the abdomen to the heart. They abraded the heart surface and then wrapped a segment of the abdominal tissue called the omentum around the heart in the hope that the abdominal arteries would adhere to the heart and thus nourish the muscle. Many attempts to provide the heart with vascular adhesions by one means or another were made. In 1946 Arthur M. Vineberg of the McGill University Faculty of Medicine tackled the objective in a direct and rational way. He proposed that an artery from the chest be implanted in the left ventricle of the heart.

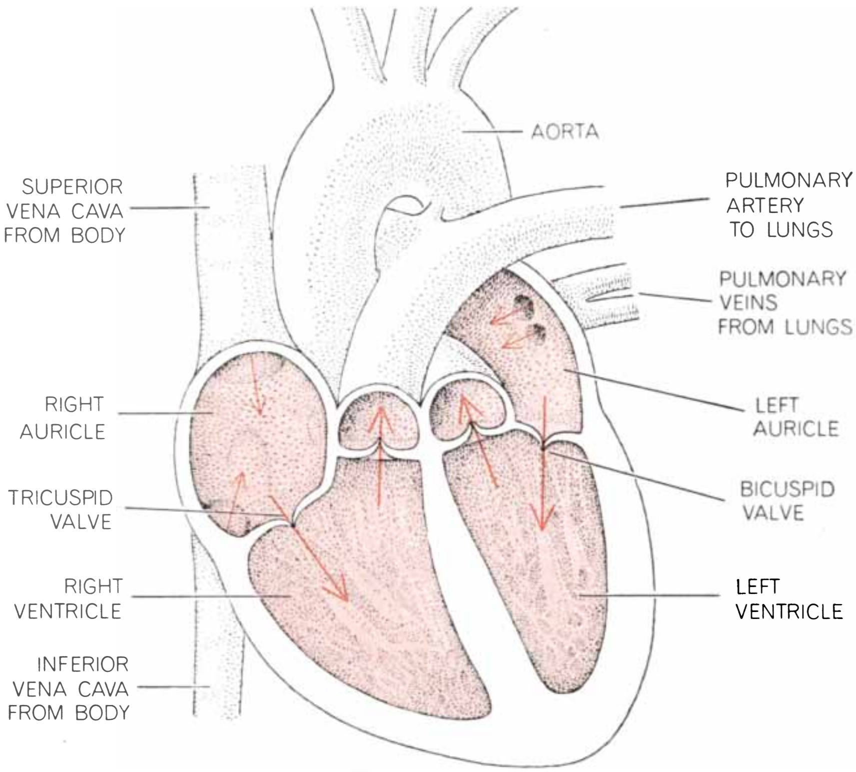
Unfortunately these novel attacks on the problem of coronary artery disease were not notably successful. The results of clinical tests were disappointing, and the medical profession dismissed the concept of surgical revascularization of the heart as being too exotic. Indeed, Vineberg's operation was seriously compromised at the time because it was not supported by a diagnostic technique that



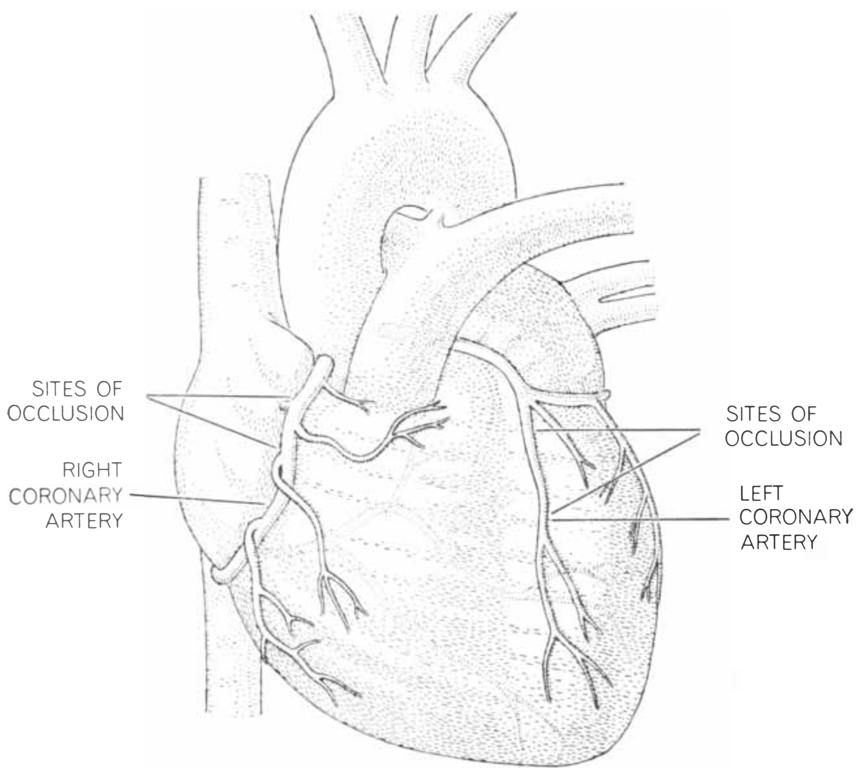
CORONARY ARTERY describes an irregular semicircle near the left side and bottom of an arteriogram. It has been severely narrowed by atherosclerosis (*eight o'clock position at lower left*), impairing blood supply to the left ventricle, the heart's main pump.



REPAIRED ARTERY is seen in a second arteriogram, made five months after the narrow segment was replaced by a length of vein taken from the patient's leg. Many branches of the artery are more prominent, evidence of a better blood supply to the left ventricle. A pair of loops, one seeming to surround the vein graft, are the surgical wires used to close the chest wall after the operation.



FOUR CHAMBERS OF THE HEART comprise two receiving areas and two pumps. Oxygen-poor venous blood, received in the right auricle, is pumped by the right ventricle to the lungs for oxygenation. The left auricle receives the returning oxygen-rich blood from the lungs and the left ventricle pumps it by way of the aorta into the arteries. The left ventricle makes up the bulk of the heart's muscle and uses most of the coronary blood supply.



RIGHT AND LEFT CORONARY ARTERIES do not share equally in the task of carrying blood to the heart muscle. In 60 percent of cases the right artery is dominant, as seen here. The right artery supplies the rear of the left ventricle with blood, whereas the left artery supplies the front and side. Narrowing of the arteries usually occurs at the points shown.

could show precisely under what circumstances the arterial implantation should be made. In medicine it is axiomatic that specific diagnosis must precede therapy.

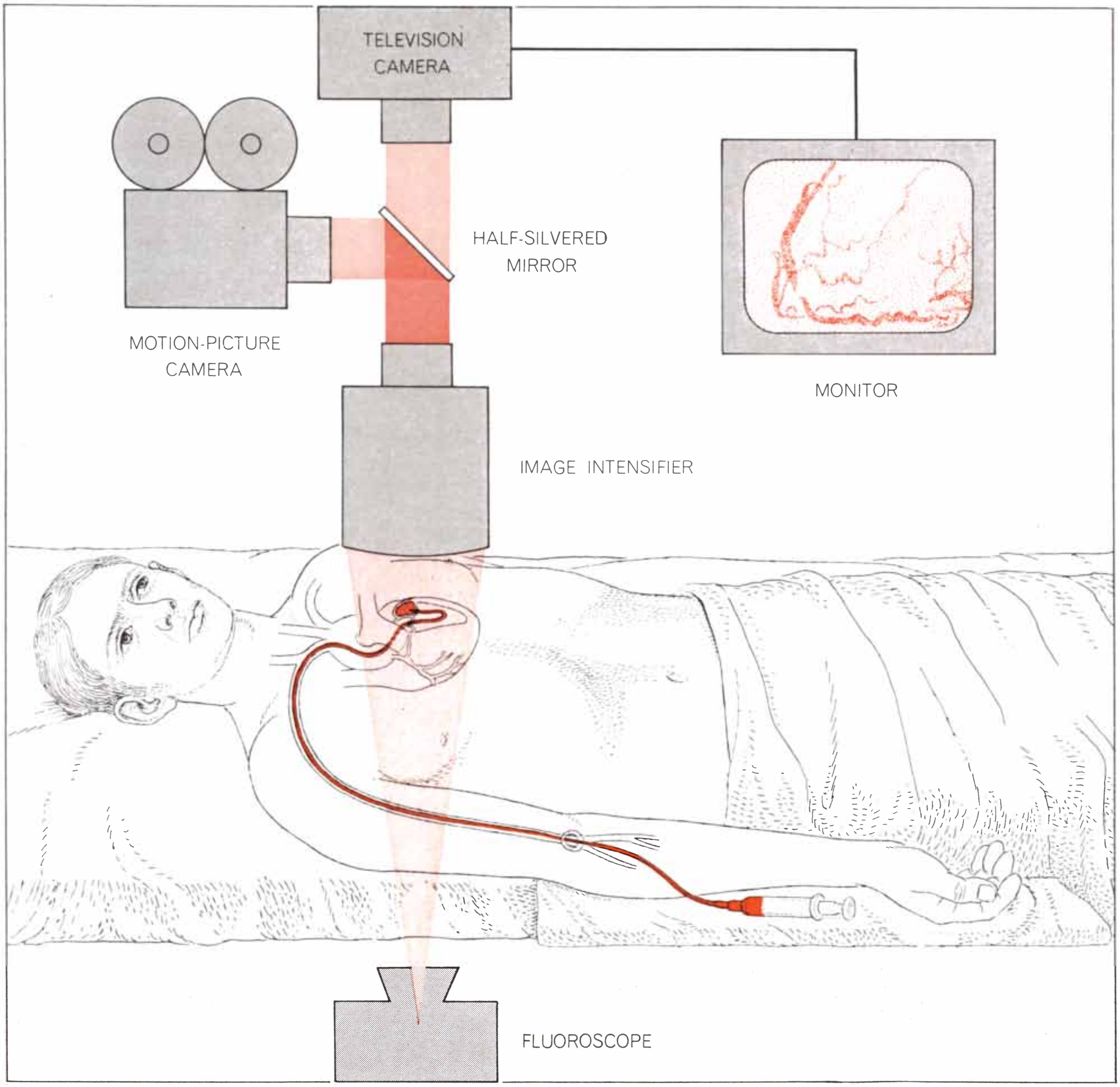
The diagnostic problem was solved in 1958, when F. Mason Sones, Jr., of the Cleveland Clinic developed a technique that made it possible to examine the coronary arteries and even the left ventricle to determine whether they were healthy or diseased. He succeeded in applying X-ray photography to this purpose. Radiography had long been employed to map and examine arteries in more accessible parts of the body, but no safe or effective way had been found to explore the coronary arteries by this means. Sones resorted to a flexible catheter, inserted through a brachial (upper arm) artery so that it reached the heart by way of the aorta, to inject the necessary opaque dye into the coronary arteries. With an image-intensifier and high-speed motion-picture photography he obtained pictures of the coronary arteries showing their condition in precise detail. Moreover, by the selective injection of opaque dye into the left ventricle the same technique produced a "ventriculogram" that showed the contractions and expansions of the ventricle and thus indicated whether or not the muscle was performing normally.

Sones's technique of selective coronary arteriography produced a leap forward in our ability to read coronary disease that can fairly be likened to the impact of the invention of the printing press on the written word. More than 11,000 patients have had their coronary arteries "read" in his laboratory, and the findings have been a revelation. (The procedure is relatively simple, extremely safe and, done under local anesthesia, causes little discomfort to the patient.) Among other things, the examinations showed that among patients who had been diagnosed as having coronary artery disease, a substantial proportion (15 to 35 percent) actually had normal arteries. On the other hand, the radiographic examination detected diseased arteries in a number of patients whose electrocardiograms were normal. The technique has brought certainty to the diagnosis of coronary artery disease. More important, it shows precisely what repairs are needed and thus has initiated a new era in heart surgery.

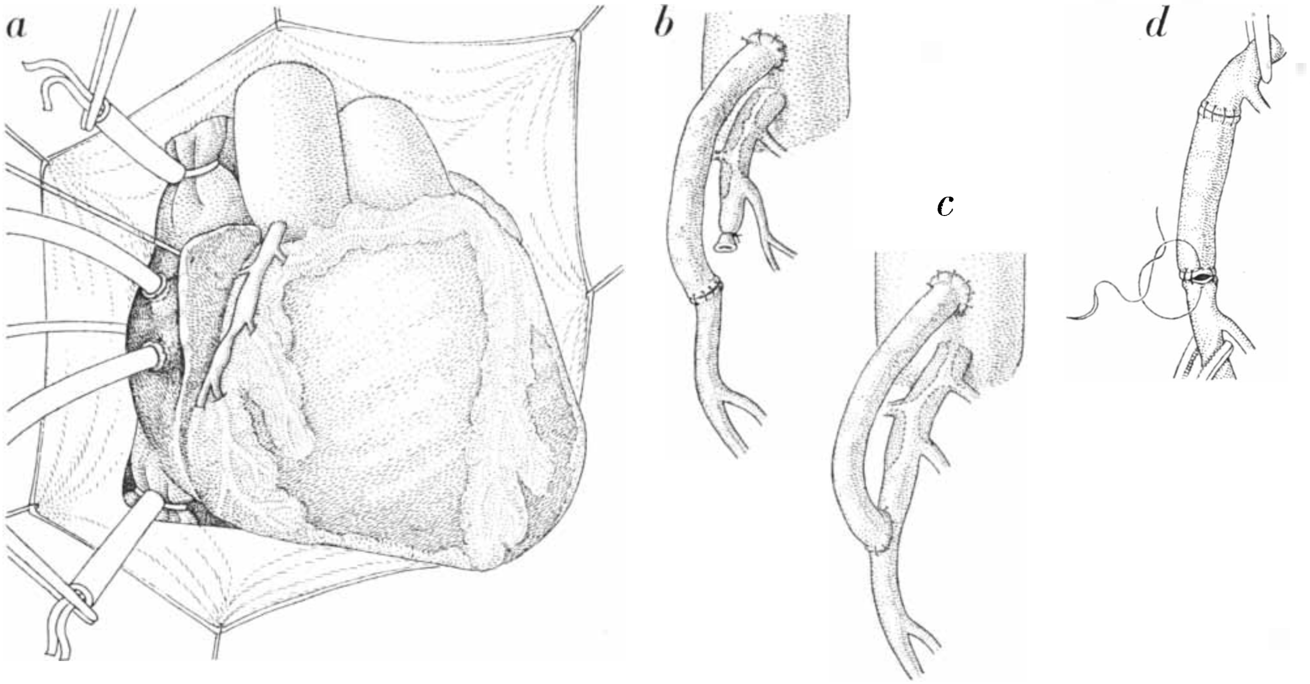
Examination of a large number of coronary patients at the Cleveland Clinic Hospital established that surgery could usefully be undertaken for several different purposes. There are three basic approaches in coronary artery surgery today: (1) to provide an extracardiac source of blood (indirect revascularization) for patients with seriously diseased coronary arteries, (2) to open obstructed coronary arteries by the removal of occluded segments where these are the only serious impediment to blood flow and (3) to reconstruct or repair a left ventricle already damaged by coronary artery disease.

Vineberg had noted that two distinctive aspects of the coronary anatomy and physiology would favor revascularization from a source outside the heart. In the first place, the incoming artery need not be connected to a vein for the outflow of the circulating blood. Unlike skeletal muscle, the heart muscle is a spongy structure riddled with tiny sacs (called sinusoids). Blood percolating into these spaces readily escapes into the venous bed and runs off without producing swelling such as occurs when an artery bleeds in skeletal muscle (causing a "charley horse"). Secondly, it is well known that, in response to the heart's demand for blood, new arterioles will develop naturally to provide collateral circulation. Vineberg pointed out that by this process an artery implanted in the heart could grow arterioles from its side branches to produce a network feeding a substantial area of the muscle.

Vineberg observed that the two mammary arteries in the chest wall immediately in front of the heart were ideally located for the implanting operation he had in mind. At least three of his implan-



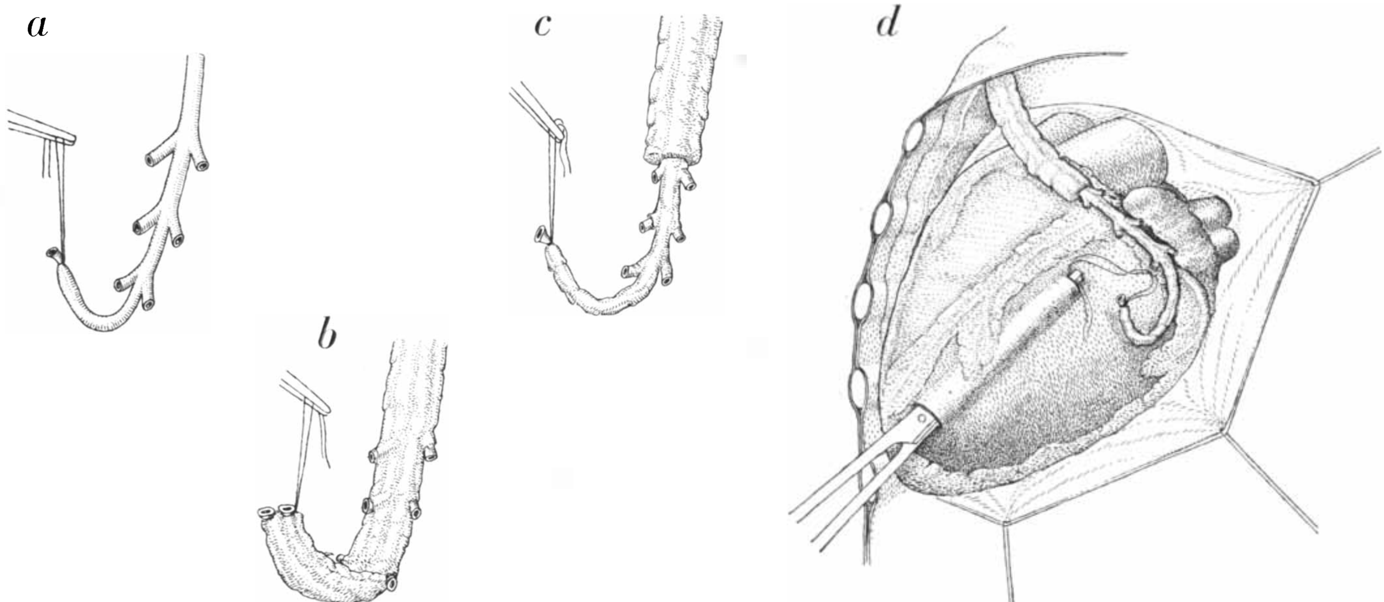
VISUAL DIAGNOSIS of coronary disease requires insertion of a flexible catheter through an artery in the patient's arm up to a point where it is possible to inject a dye opaque to X rays into the coronary arteries. A fluoroscope is in place under the patient; the image formed by its X rays is displayed to the physician on a cathode-ray-tube monitor after image intensification and is also recorded by a motion-picture camera. The technique, which makes possible diagnosis with an unprecedented degree of accuracy, was devised by F. Mason Sones, Jr., of the Cleveland Clinic. Arteriograms on page 37 were made during examinations using the technique.



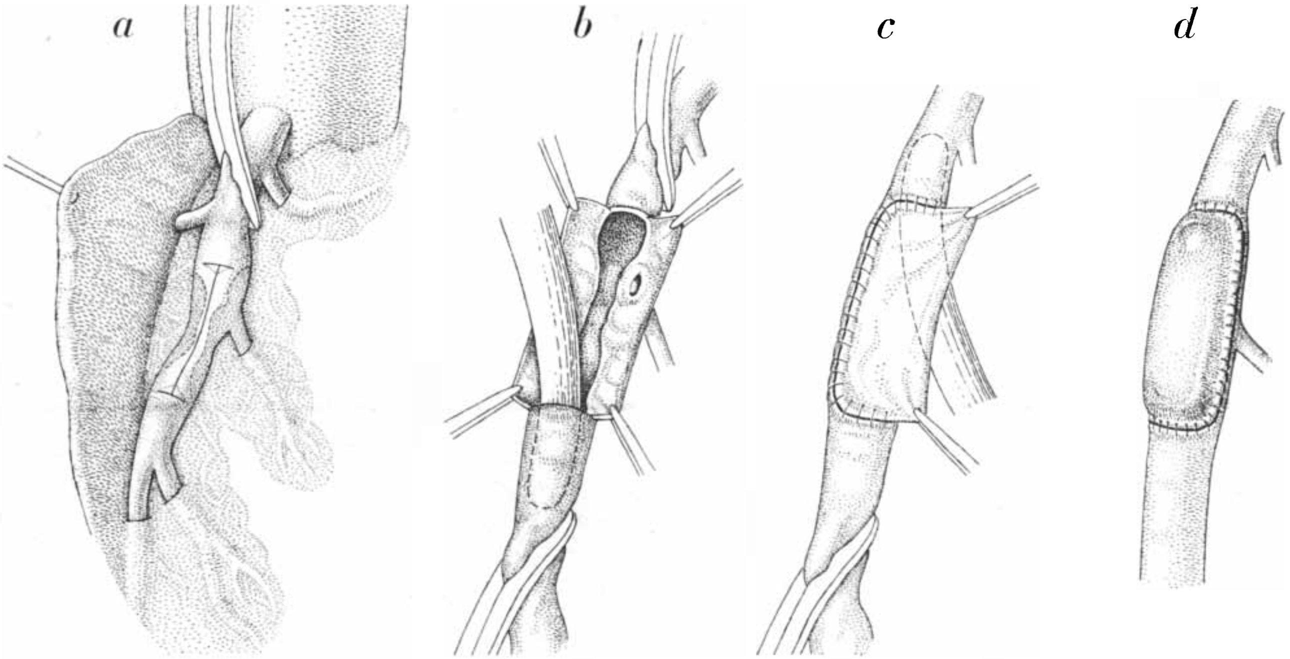
RESTORATION OF BLOOD SUPPLY to the left ventricle is accomplished in several ways. First (*a*) the patient's blood supply is bypassed through a heart-lung machine, permitting work on the coronary artery. When the coronary obstruction lies close to the aorta, a bypass graft is used to connect the aorta and the healthy part of the artery beyond the obstruction. The link is end to end (*b*) or into the side of the artery (*c*). More commonly the diseased length of artery is removed and the vein graft put in its place (*d*).

tations of a mammary artery in the heart were in fact found to produce the predicted result; Sones, who examined the patient's heart by radiography five years later (in 1962), observed that the implanted artery was supplying blood to the heart muscle.

Meanwhile William H. Sewell of the Guthrie Clinic in Sayre, Pa., had discovered a more effective technique for the operation. Instead of the naked artery, he implanted in the heart muscle a pedicle of chest tissue containing not only the artery but also its vein, communicating blood vessels and supporting tissue. This operation could be performed more rapidly, reduced the chances of damage to the artery, eliminated the tendency of the unsupported artery to shorten and enabled the surgeon to place implants on the side and rear of the left ventricle



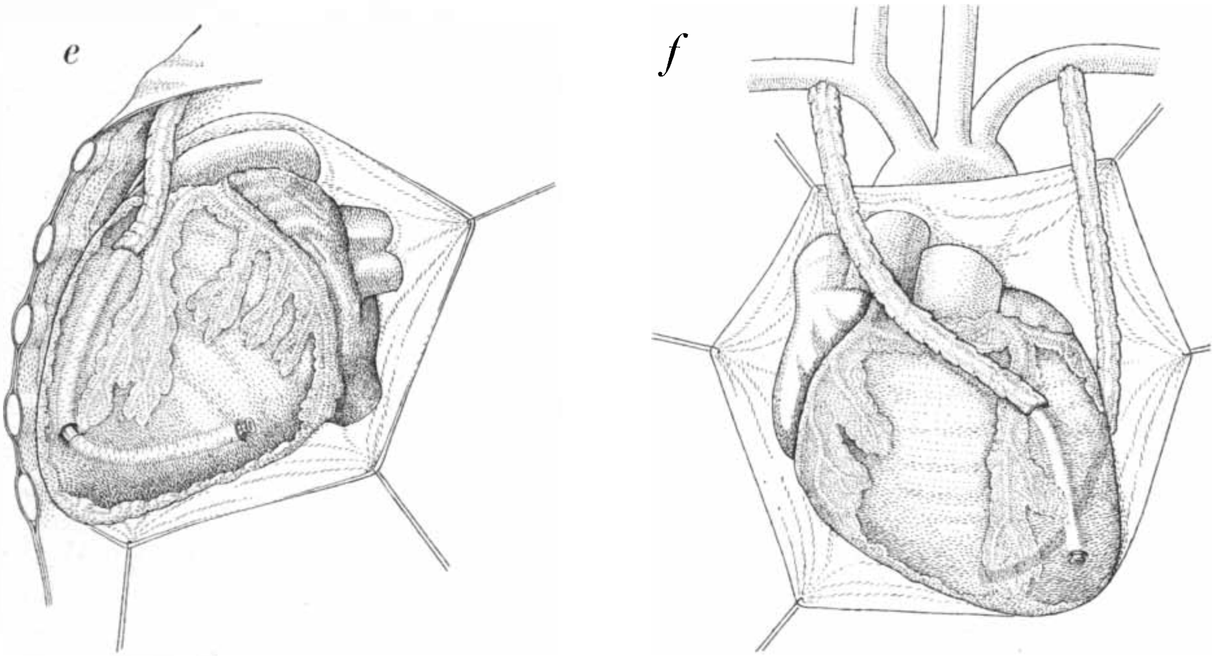
NONCORONARY BLOOD SUPPLY has also been used for the nourishment of heart muscle. A nearby blood vessel, the mammary artery, is generally chosen. In the pioneer method developed by Arthur M. Vineberg of the McGill University Faculty of Medicine (*a*) the mammary artery was stripped bare before implantation in heart muscle. In a later refinement, developed by William H. Sewell of the Guthrie Clinic (*b*), a pedicle of chest tissue, containing the artery, the vein, connecting vessels and supporting tissue,



"VISTA DOME" PATCH provides another means of eliminating a dangerous narrowing of the coronary artery. An incision is made along the narrowed artery segment (*a*) and the crosscut made at each end is rounded (*broken lines*). When the incision is opened (*b*), a probe is used to dilate the artery at each end of the narrowed segment. A patch cut from the pericardial membrane is then sewed in place along the edges of the incision (*c*). When patching is completed (*d*), a gentle bulge replaces the previous narrowing.

as well as on the front. Sewell's procedure considerably improved the clinical results of the revascularization operation.

Combining the useful features of Vineberg's operation and Sewell's elaboration of it, a team of surgeons at the Cleveland Clinic developed a standard operative technique. More than 2,000 coronary patients have been treated with mammary artery implants at the Cleveland Clinic Hospital since the program was inaugurated in 1962. The extent of the operation is based on the patient's need as shown by a radiographic examination of the coronary arteries. When the deficit in the blood supply to the heart is moderate, a single implant is made; in cases of extensive disease of the coronary arteries both mammary arteries are used, the right pedicle being placed in the left



was implanted. The present practice at the Cleveland Clinic is to prepare a pedicle of tissue but to trim the tissue away from the part of the mammary artery to be implanted (*c*). The length of artery is then pulled into a tunnel previously prepared in the tissue of the left ventricle (*d*). When circumstances require it, more than one tunnel can be prepared (*e*). When implantation of only one artery would not provide an adequate supply of blood, two can be implanted, supplying both the front and the rear of the muscle (*f*).

ventricle's front wall and the left pedicle in the side and rear walls of the ventricle. The fatality risk in the operation is not great; even in the group of very sick people who have required the double implant the mortality rate has been less than 10 percent.

The beneficial results of our revascularization operations have exceeded expectations. More than 400 patients have been examined a year or more after the surgery, and in more than 92 percent of these cases it was found that the implanted arteries were supplying blood to the heart muscle. The best results were obtained in patients whose radiographic pictures before the operation had shown that the heart muscle was in good condition but required a better blood supply. In these patients the implanted arteries were functioning well, anginal pain had diminished or disappeared and the tolerance for exercise had increased.

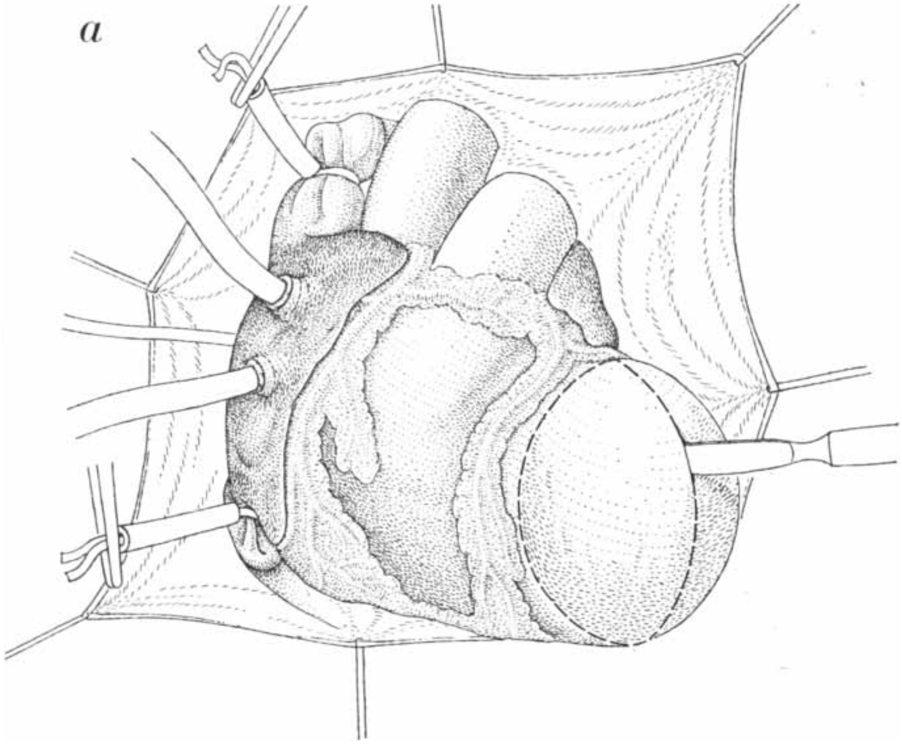
Localized obstructions in the coronary arteries present a different surgical problem from the foregoing. Such obstructions occur much less frequently than general narrowing of the artery does because atherosclerosis is a diffuse process that usually involves the entire artery. Nevertheless, many cases do arise in which a particular segment of the artery is narrowed by disease, and in such cases the indicated remedy is simply removal of the obstruction. Among the advantages of that attack is the fact that a normal flow of blood is restored immediately, without any need for the development of collateral arterioles.

The Cleveland Clinic surgeons first tried the procedure of reaming out the narrowed segment of artery. This was quickly found to be ineffectual, because the reaming operation sheared off side branches and sometimes actually reduced the blood flow through the artery. The surgeons then turned to an old stratagem used by seamstresses to widen a sleeve or similar structure: opening a seam and inserting a gusset, or strip of cloth, to enlarge the diameter. The obstructed segment of the artery was slit lengthwise and a "patch graft" of tissue from a leg vein or the pericardium around the heart was inserted to widen the artery's bore. Approximately 140 such operations were performed at the clinic, and follow-up studies as long as five years later showed that this type of operation could produce a lasting remedy for the arterial obstruction, improving blood flow to the patient's heart. The procedure was not always satisfactory, however; it was ill suited for the repair of lengthy obstructions and in any case it left in place the diseased portion of the artery, which could produce turbulence in the flowing blood and thus lead to eventual trouble.

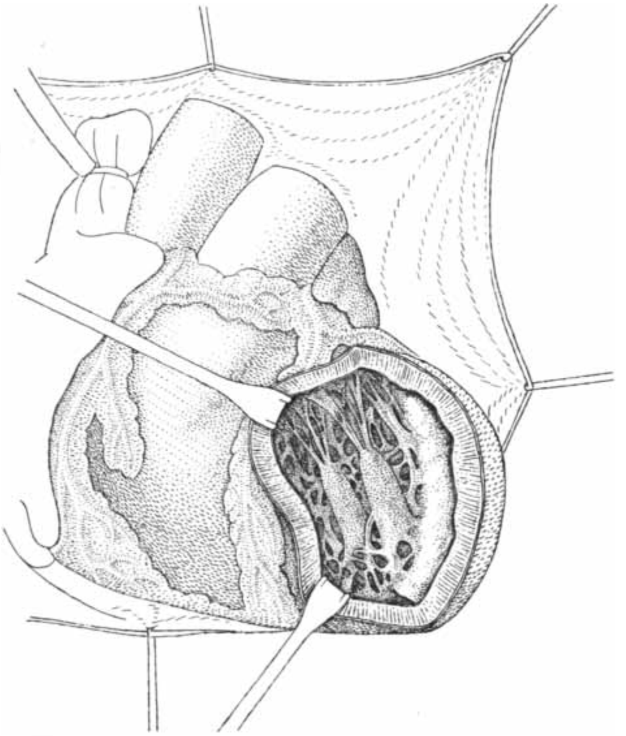
A year ago the Cleveland Clinic team adopted a new technique introduced by Rene G. Favaloro of the clinic. Its rationale is elegantly simple: the diseased segment of the artery is cut out entirely and replaced with a spliced-in section of leg vein (taken from the patient's groin). The operation itself requires a total bypass of the heart by the circulation during the surgery; this is taken care of by the use of an artificial heart machine while the surgeon excises the diseased portion of the coronary artery and grafts in the connecting segment of vein. The results of this technique have proved highly gratifying so far. The obstructing section of artery is replaced by a fine, smooth-walled vessel. Although it is too early to tell what the long-term effects will be, the radiographic examinations of patients made in the 14 months since the technique was inaugurated show that the improvement in the artery's functioning and in the coronary blood supply is far greater than the improvement obtained by the patch-graft operation.

All together more than 300 patients have been operated on for coronary arterial obstructions (by the methods I have mentioned) over the past six years. We have found that the operation is most useful for the right coronary artery (usually the dominant one), which feeds the side and rear walls of the left ventricle. This artery is the most accessible and has relatively few side branches, so that the danger of injury to blood vessels during the operation is minimized. The mortality risk of the current procedure in replacing a diseased segment of the right coronary artery is low—about 5 percent. Our experience has shown, however, that operations for the relief of coronary obstruction, like the other operations on the coronary system, are useful and safe only for patients who have been carefully selected on the basis of their clinical condition and radiographic examination of the difficulty in need of repair.

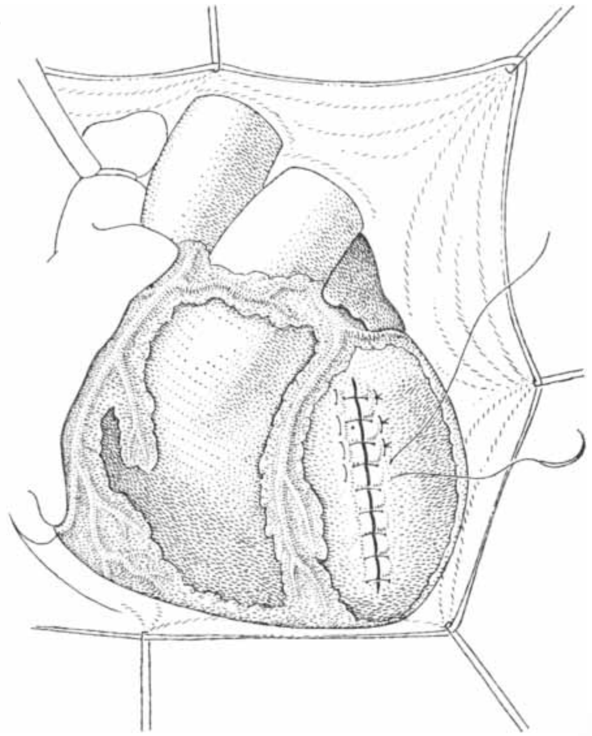
The third type of operation on which the Cleveland Clinic has been working is plastic surgery on the damaged heart itself. The procedure is usually undertaken only on patients who have suffered a major heart attack and have a critical impairment of heart function. The damage may consist in extensive tissue death and scarring of the left ventricle that interferes with its pumping capacity and with conduction of the electrical impulses necessary for the coordinated contractions of the muscle. The attack may have ruptured the septum, or partition, separating the left ventricle from the right, so that blood leaks into



PLASTIC RECONSTRUCTION of a heart damaged by a major attack is another Cleveland Clinic technique. Surgery begins (*a*) after connection to a heart-lung machine allows b



c



suspension of heartbeat. The ventricle's scarred muscle is removed (*b*), along with any underlying blood clot, and the incision closed (*c*). The reconstruction immediately improves the heart's pumping efficiency, dramatically rehabilitating the chronic postattack invalid.

the right ventricle instead of being pumped into the arterial system. Or the mitral valve between the left ventricle and the left auricle may be incapacitated by damage to the muscle operating it. In each of these cases we have found that under suitable conditions repairs are feasible.

During the operation the beating of the heart is suspended and the circulation of blood through the body is powered by a heart-lung machine. For repair of the left ventricle, the dead, scarred tissue is completely removed and the wall is reconstructed by plastic surgery. In the case of a perforated septum between the left and right ventricles, the gaps are closed by surgery. Similarly, plastic surgery can rebuild the mitral valve so that it functions normally.

More than 130 reconstructive operations on the heart have been performed in the past five years. We have been encouraged to find that 90 percent of the critically sick patients who undergo these operations survive the surgery, and 75 percent of the survivors have recovered sufficiently to return to gainful living. Considering these results and the alternative that faces such patients, it seems highly desirable that every victim of a major heart attack who lives on the border of heart failure should be examined for the possibility of rehabilitation by reconstructive surgery.

Recovery after any of these surgical procedures (revascularization or reconstruction) may be a slow process. Moreover, surgery does not remove the underlying causes that bring about the degeneration of the arteries through atherosclerosis. The surgery must therefore be accompanied by such medical measures as are available to check the disease. Before we operate on our patients we insist that they shed excess weight and discontinue cigarette smoking. After the operation they are put on a medical program that includes vasodilating drugs, careful weight control, a diet low in animal fats and graded regular exercise. How effective these measures are in controlling atherosclerosis is difficult to assess, but they do appear to be based on rational grounds.

The Cleveland Clinic is now exploring the possibilities of surgical treatment of the acute phases of the heart attack itself. Prompt radiographic diagnosis and surgical intervention within a few hours after the onset of an attack might in many cases be effective in removing an arterial obstruction and thus limiting damage (infarction) of the heart muscle. Prompt excision of the freshly destroyed muscle tissue and plastic repair of the myocardium could also save many lives; this procedure has been applied successfully in a few patients who, when the heart attack took place, had the good fortune to be in a hospital where aggressive therapy was available. In cases of patients dying of heart failure a heart machine might be employed to take over the pumping function and tide the patient over the critical period until the heart repaired itself. And finally, the surgical implantation of a new heart, either living or artificial, now seems within the realm of eventual feasibility for wide application.

Coronary artery disease kills more than 500,000 Americans each year. Approximately 3.5 million persons are estimated to be more or less incapacitated by this disease, and upward of 20 million suffer some degree of insufficiency of blood supply to the heart. The disease appears to mark out the most active and responsible groups in society for attack; the heart attack is so common among professional people, executives and men in public office that it has become almost a status symbol. If all the men in these groups who have had coronary attacks were forced to retire (as airline pilots automatically are), the shortage of manpower at the top levels of government, industry and the professions in the U.S. would cripple the nation. All in all, coronary disease has become so prevalent and ominous in modern society that heroic measures to deal with it seem not only appropriate but essential.

CHEMICAL ACCELERATORS

The nature of chemical reactions at all energies is opened to study by these new devices. They produce beams of molecules, atoms or ions that are made to react under precisely controlled conditions

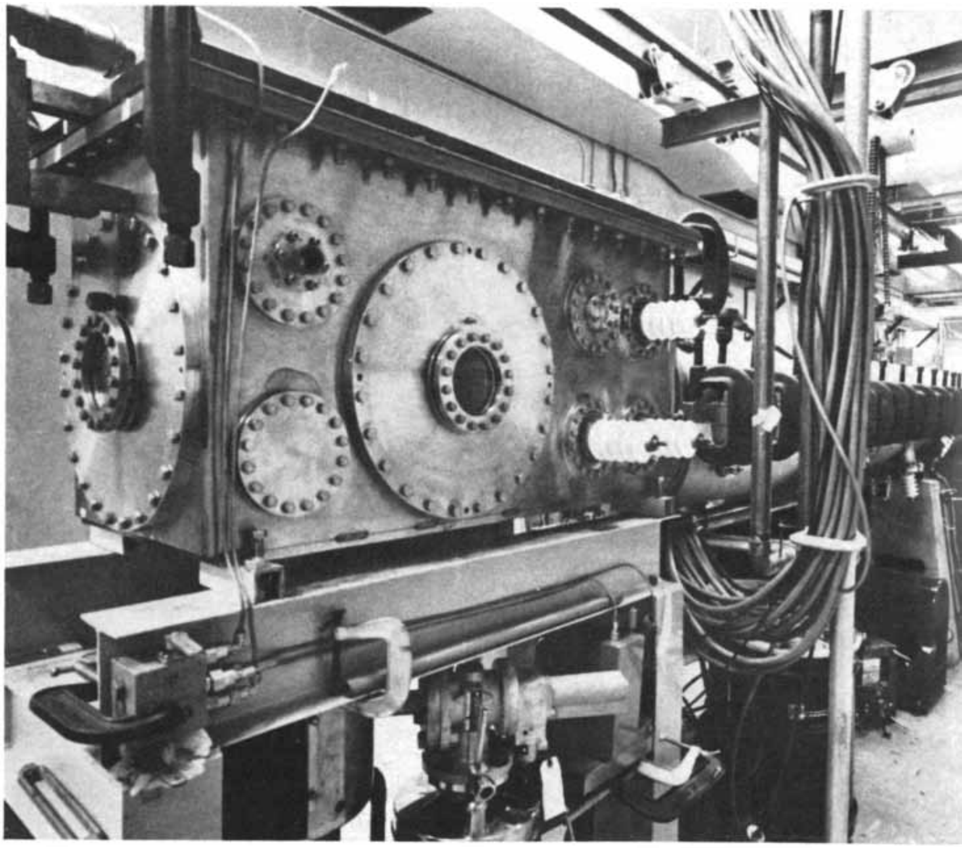
by Richard Wolfgang

The chemist's basic concern is with the structure of molecules and the nature of the reactions in which these structures change. In the 1920's and 1930's the concepts of structural chemistry were profoundly altered. Now our understanding of chemical reactions—of chemical kinetics or dynamics—is in a comparable period of upheaval. A significant aspect of this revolution is the advent of the chemical accelerator: a device for producing beams of atoms, molecules or ions with a controlled and variable velocity whose interactions reveal the detailed nature of reactive collisions and how they depend on energy. Much as particle accelerators have provided physicists with most of their understanding of nuclear reactions, chemical accelerators are beginning to extend the range of reactions with which the chemist can deal and to increase his insight into the process of chemical change.

The classical method of chemical kinetics developed in the 19th century is simply to heat chemicals and note what changes occur and how long they take. From this information one attempts to deduce the actual pathways by which the atoms have rearranged themselves to form new molecules from the old. The energy required to break the chemical bonds and form new ones is supplied by thermal motion. When a substance is heated, its atoms move faster and faster until at some point certain bonds are ruptured and reaction takes place.

The energy yardstick of chemistry is the strength of the chemical bond, which usually measures between two and 10 electron volts. At a given temperature there is a wide spread of kinetic energies of collision between two potentially reactive molecules, but even at high temperatures only relatively low energies (below one electron volt) are accessible [*see illustration on page 46*]. Thermal techniques can therefore sample only those chemical reactions occurring at the lowest energies.

In the past decade a number of new nuclear, photochemical and mass-spectrometric methods have made accessible a part of the vast domain of chemical reactions above thermal energies [see "Chemistry at High Velocities," by Richard Wolfgang; SCIENTIFIC AMERICAN, January, 1966]. Unfortunately these new techniques for studying high-energy chemical reactions, or "hot chemistry," have some of the same drawbacks as the classical techniques of thermal chemistry. For one thing, the exact energy at which a reaction takes place remains hard to estimate. Moreover, after the products are formed the multiple collisions they undergo before they are detected alter their properties, so that one cannot know how they actually emerged from the reaction. In particular, vital



CHEMICAL ACCELERATOR built at the University of Chicago by Lennard Wharton will produce beams of molecules at an energy of about two electron volts, making possible studies of energy-conversion processes that lead to chemical reactions. The photographs

information on the energy and angular distribution of the freshly formed products is lost.

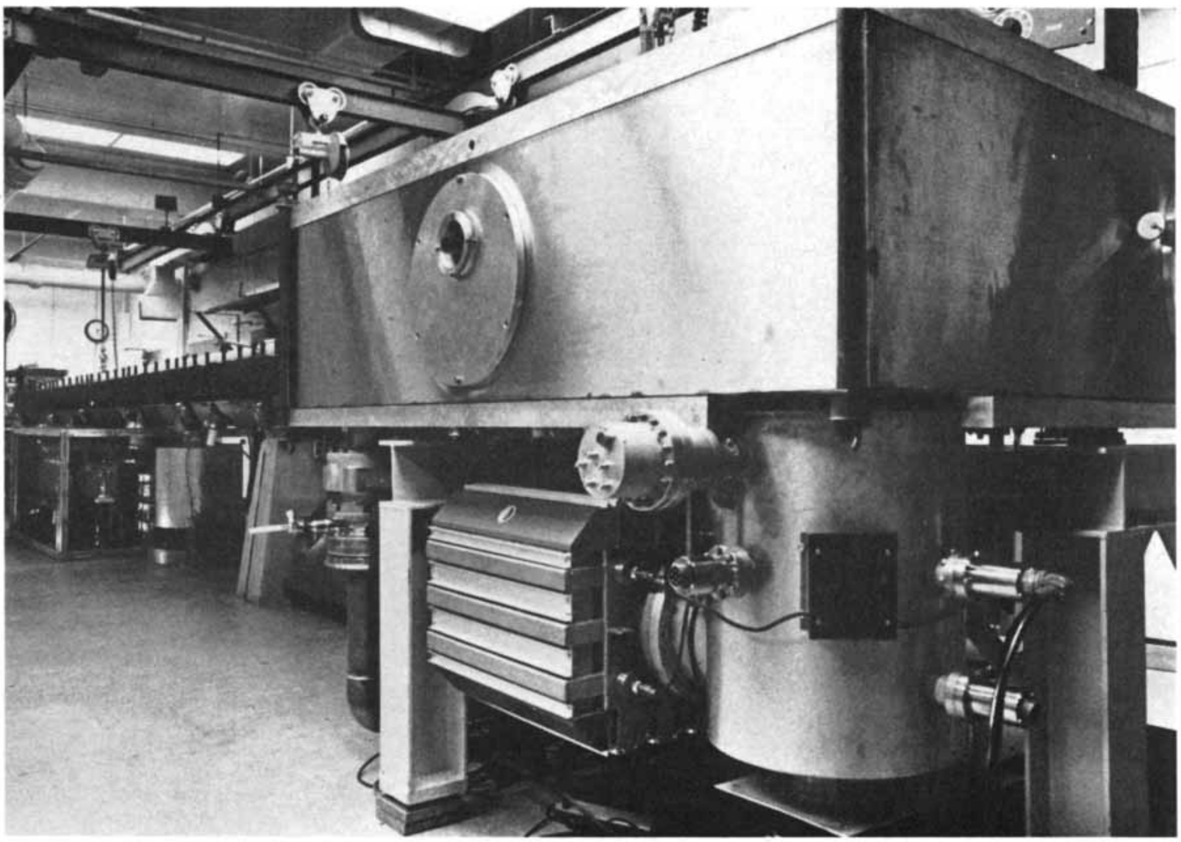
These difficulties can be overcome by making one or both of the reactants into a beam traveling at a known energy through a vacuum. Reaction occurs when such a beam strikes either another beam or a stationary target. One can then measure not only the nature of the products but also their probability of being formed in a collision at any given energy. Furthermore, if the target is a gas so thin that a product is unlikely to be subjected to further collisions, the energies and angular distribution of the product particles can be measured.

In 1955 Sheldon Datz and Ellison H. Taylor of the Oak Ridge National Laboratory made the first successful molecular-beam studies of a chemical reaction. At thermal energies this technique has yielded much new information on the nature of certain simple reactions. It also indicates the potential value of apparatus that would operate over the entire range of chemical energies, from zero to 30 electron volts and higher. It is these devices that one may call chemical accelerators. Clearly they call for a technology very different from that of nuclear accelerators, which operate in the energy range of the bonds in nuclei: about 10 million electron volts.

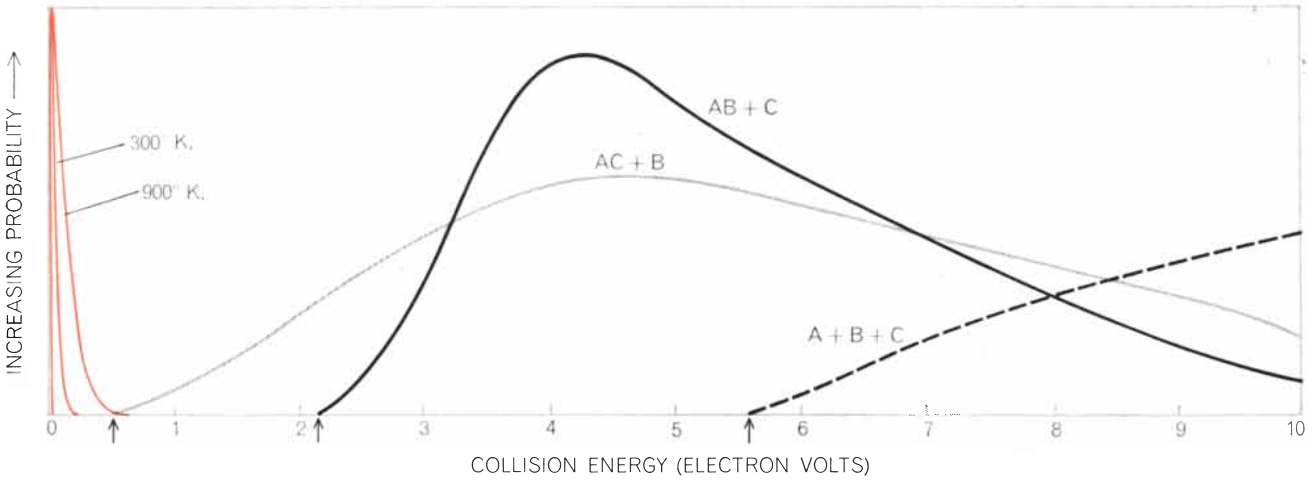
The realization that the concepts of high-energy chemistry should be joined with the molecular-beam method to give us the chemical accelerator is a recent and rather sudden development. One might think that such a simple concept would long since have become the standard method of studying chemical reactions. The fact is that producing chemical beams of the appropriate energies is technically quite difficult, and to detect the reactions they bring about can also be a subtle problem. The design and construction of chemical accelerators is a fast developing field that lends itself to innovation, and new approaches and techniques are being suggested even as the early results obtained with the first devices are being reported.

The simplest imaginable way to accelerate a molecule into the electron-volt range is mechanical—by batting it like a baseball. This was actually done by T. H. Bull and P. B. Moon at the University of Birmingham about 15 years ago in what appears to have been the first attempt to build a chemical accelerator [see "Molecular Beams," by O. R. Frisch; SCIENTIFIC AMERICAN, May, 1965]. In their device a rotor blade revolving at an extremely high speed knocked molecules of carbon tetrachloride through a hole to form a beam. On traversing another chamber containing a little cesium vapor some of the molecules reacted with the cesium to form cesium chloride, which was detected by surface ionization: the molecules donate electrons to the surface of a hot tungsten filament, become positive ions and are measured as a current flowing between the filament and a negatively charged cylinder surrounding it. The energy that can be obtained by this primitive but rather charming method is limited by the rotor's velocity, which in turn is limited by its strength, since above a certain velocity it would simply fly apart. Given existing materials, the energy of carbon tetrachloride molecules obtained by Bull and Moon was about as high as seems readily feasible—about .5 electron volt, or barely beyond the thermal range. The possibilities opened by this pioneering experiment therefore seemed rather limited, and not much more was done about chemical accelerators for a decade.

The next step was to take advantage



show the long dipole accelerator from both ends. Molecules produced by heating in an oven (*left*) are accelerated down the C-clamped tube by electric fields (*see illustration on page 51*). After colliding with target atoms the beam molecules and any reaction products are detected and analyzed (*right*). Apparatus under tube includes radio-frequency switching equipment and vacuum pumps.



CLASSICAL THERMAL TECHNIQUES are inadequate for reaching any but the lowest chemical energies. The black curves indicate probabilities that hypothetical chemicals *A* and *BC*, on colliding at given energies, will yield three different combinations of products; each reaction has a threshold energy (*arrows*). The energy distribution of collisions between *A* and *BC* at 300 degrees Kelvin (room temperature) and 900 degrees is shown (*color*). Even at 900 only a small fraction of the collisions exceed the lowest reaction threshold. At the highest temperatures attainable in classical chemistry, reaction still occurs predominantly at relatively low energies.

of the fact that an ion—a charged molecule or atom—is much easier to move around than a neutral species. Positive ions traveling from a grounded plate to one that is negatively charged acquire an energy corresponding to the potential difference between the plates. If there is a hole in the negative plate, a beam of ions will stream through it. To get an intense and well-collimated beam of ions a somewhat more sophisticated system is needed [*see top illustration on opposite page*]. Bombarding gas molecules with high-energy electrons knocks electrons out of them and makes them into positive ions. A negatively charged plate extracts the ions and charged plates or cylinders form the beam in a process analogous to the focusing of light.

Most of the early work on the energy dependence of reactions between ionized molecules was done with slightly modified mass spectrometers by workers in the U.S. and several European countries. These were not chemical-accelerator experiments—no beam was formed and reactions took place over a wide range of energies—but they led to the development of "tandem mass spectrometer" devices. Here the first mass spectrometer produces an ion beam that reacts with gas molecules to yield products that are analyzed in the second one. A further step toward the chemical-accelerator ideal was a device built by A. Henglein and his co-workers in Berlin, in which the energies as well as the identities of the products could be determined. Then Morton A. Fineman, R. F. Stebbings and B. R. Turner of the General Dynamics Corporation built the first crossed-beam apparatus in the hot-chemical range, which made it possible to measure the angular distribution of the products.

An odd aspect of ion accelerators is that they are easier to operate at high energies than at low energies. The reason is that ions with the same charge repel one another, so that a beam containing many ions tends to "blow up." The slower the ions, the more readily this occurs. Yet the most interesting energy for chemistry is around the energy of the chemical bond, five electron volts or less. At Yale University in 1964 Zdenek Herman of the Institute of Physical Chemistry in Prague, Timothy Rose, James Kerstetter and I started building a chemical accelerator that would operate from high energies down to less than one electron volt and yield products whose angular and velocity distribution could be measured.

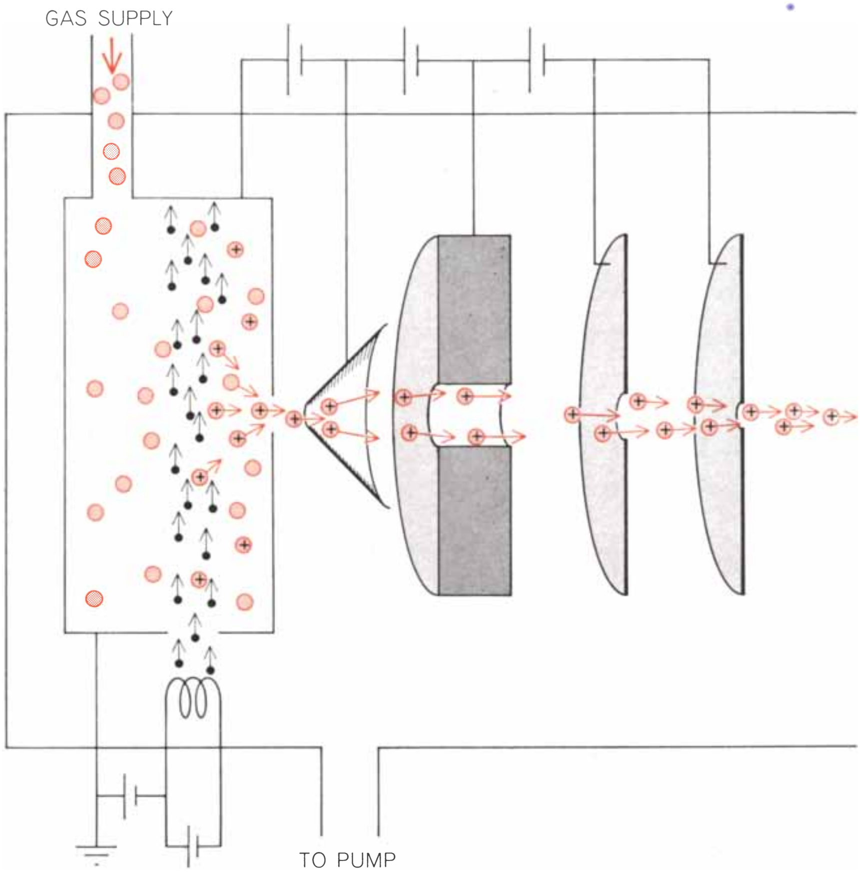
In our EVA (short for Evatron, a name inspired by the billion-electron-volt particle accelerator at Berkeley called the Bevatron) an ion beam of quite high energy is produced as described above. The beam goes through a small mass spectrometer that transmits only ions with the desired mass [*see bottom illustration on opposite page*]. The resulting beam is slowed down to the desired energy by a complex system of ion lenses. The target consists of a beam of neutral low-energy molecules that emerge from a bundle of tiny tubes and are collimated by a slit. The two beams cross at right angles, and the resulting particles are detected by a mass spectrometer. The crossing beams can be rotated around their intersection so that angular distributions can be measured. Ions entering the mass spectrometer are confronted by a series of electrically charged grids that allow only those above a certain energy to pass, so that their energy distribution can also be measured. Finally, ions of the proper mass hit a surface and cause electrons to spray out of it, and the amplified current of these electrons is measured.

The first reaction we studied with EVA, although it is apparently about as simple as a chemical process can be, showed us how much there was to learn. This reaction was the formation of argon hydride ions (ArH^+) from argon ions (Ar^+) and hydrogen ($Ar^+ + H_2 \rightarrow ArH^+ + H$). Two mechanisms had been suggested for the reaction. One was indirect, by way of an intermediate complex. If this complex, ArH_2^+, has a lifetime long enough to enable it to rotate a few times on its axis, then the ArH^+ product it eventually forms will have most of the momentum of both the Ar^+ and the H_2, and it will be scattered through a relatively large angle. Other possible mechanisms are direct, with the final products formed on initial impact. In one direct mechanism proposed by Henglein, "spectator stripping," the Ar^+ simply picks up one hydrogen atom, leaving the other to go on at the same velocity apparently "unaware" that its partner has been stripped away. In this case the ArH^+ product would have the momentum of the Ar^+ and half the momentum of the H_2, and would therefore appear at about half the average angle expected for the intermediate-complex mechanism [*see illustration on page 49*].

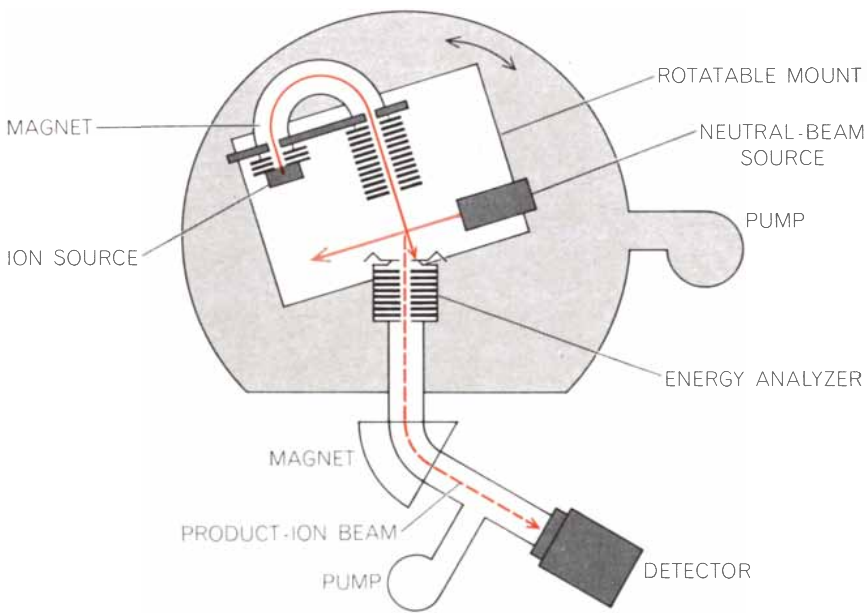
What we found was that at most energies the ArH^+ was produced at an angle smaller and a velocity greater than predicted by either of these mechanisms. Clearly little, if any, long-lived intermediate ArH_2^+ was formed. This is significant, since chemists have often assumed that, at least at low energies, reactions between such strongly attracting chemicals always involved such a complex.

The actual mechanism, as we deduce it from the data, appears to be as follows [*see illustration on page 49*]: As the particles approach each other, the positive charge of the Ar^+ pulls electrons to the nearer end of the H_2 molecule, thus polarizing its electric charge. Electrostatic attraction between the ion and the polarized hydrogen molecule deflects and accelerates each toward the other. On "contact" a hydrogen atom jumps to the Ar^+ to form ArH^+. Both the freshly formed ArH^+ and the leftover hydrogen atom retain their increased momentum, although their direction has been changed by the impact. The ArH^+ ion now induces only weak polarization in the hydrogen atom, and so the resulting mutual deceleration is slight and the final products are left with more velocity than the initial ion and molecule had. The actual trajectories of the system will of course depend on the initial energy and also on the exact geometry of the three atoms on contact. As a result there is a distribution of product angles and velocities, and these distributions change with energy. This kind of mechanism seems to be generally applicable to direct reactions. Many other reactions, however, do go through an intermediate-complex stage, and future studies should reveal just how and when such a complex is formed and the manner in which it breaks up.

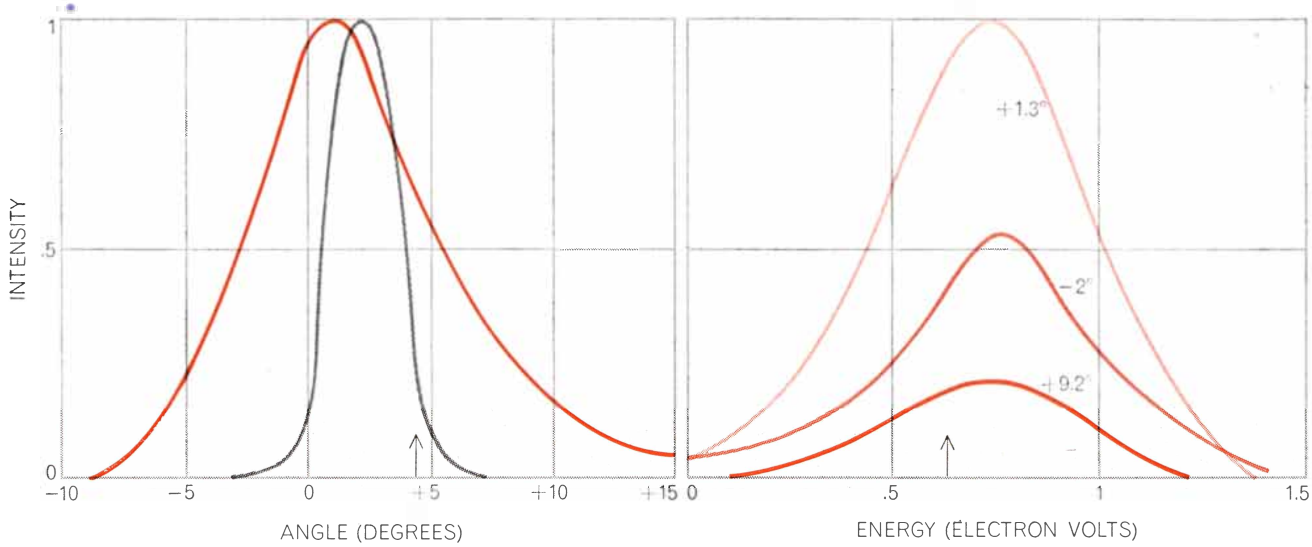
EVA was designed to get into the low-energy range near one electron volt, but it required a trick to get still lower and make contact with the thermal-energy range at .1 electron volt. If the accelerated ion is much heavier than the target molecule, at collision most of the energy continues to be in the form of forward motion; from the point of view of the collision partners, only a small fraction is available to effect the reaction. This trick can only be used, of course, if the two reactants have dissimilar masses. A more general way to gain access to the low-energy region is by the "merging beam" technique, in which reactants are formed into beams that are made to merge while moving in the same direction. The colli-



ION BEAM is produced by boiling electrons (*black*) out of a glowing negative filament and accelerating them into a gas-filled chamber. They collide with gas molecules (*color*), knocking electrons out of them to leave positive ions, which are accelerated by a negatively charged plate and focused into a beam by plates and tubes at various potentials.



EVA, a crossed-beam accelerator, forms an ion beam that is accelerated by charged plates, bent through 180 degrees to select ions of a specified mass, further focused and brought to the desired energy. It meets a target beam of neutral molecules (*light color*). Products are detected by a mass spectrometer. Angular distribution is measured by rotating both beams, energy distribution by varying the charge on a grid at the entrance to the spectrometer.



DATA OBTAINED WITH EVA give angular distribution (*left*) and energy distribution (*right*) of a reaction product. The angular-distribution peak is at a smaller angle than expected for the intermediate-complex (*arrow*) or spectator-stripping (*gray curve*) mechanisms. Energy-distribution peaks, shown for products at three angles, are higher than expected with an intermediate (*arrow*).

sions then occur at a relative velocity corresponding to the difference in velocities of the two particles, so that even if the two beams have quite high energies, the energy of collision can readily be made as small as desired [*see top illustration on page 50*]. This technique is directly suitable for studies of reactions between two ions. By neutralizing one of the beams by charge exchange, a method I shall describe below, Stephen M. Trujillo, Roy H. Neynaber and Erhard W. Rothe in the U.S. and V. A. Belyayev, B. G. Brezhnev and E. M. Erastov in the U.S.S.R. have also used it to study electron-transfer processes between molecules and ions.

As for the much more difficult problem of accelerating neutral, or un-ionized, molecules and atoms, several quite different approaches are being developed. Some are mechanical, as the original Bull and Moon device was, but depend on a gas instead of a steel rotor to push the reactant. This concept is being developed by, among others, John B. Fenn, James B. Anderson and R. P. Andres of Princeton University, J. Deckers of the University of Toronto and Alva T. Stair of the Air Force Cambridge Research Laboratories. Consider a dense gas being released through a nozzle into a vacuum [*see middle illustration on page 50*]. At first the molecules move at many different speeds and in all directions, but as they are formed into a stream this random motion is converted into forward motion; the dense gas in the reservoir inhibits backward motion and the sides of the nozzle prevent sidewise motion. After the jet leaves the nozzle, particles that still tend to move sideways are simply lost. At the same time the forward-moving molecules undergo collisions with one another that tend to equalize their velocities, so that at a certain distance from the nozzle there is a stream of particles moving ahead at fairly similar energies. It is now a supersonic flow, since its forward velocity considerably exceeds the remaining random motion of the particles within it, and the velocity of sound is determined by this random motion.

By this simple means random thermal motion is largely converted into the organized kinetic energy of a beam. A gas at room temperature yields a beam energy in the neighborhood of .1 electron volt. This energy is rather too low to be useful for chemical accelerators, but if the gas is initially at a temperature of several thousand degrees, beam energies of about one electron volt can be achieved. The heat can be provided by a shock wave or by an electric discharge called a plasma arc. Eldon L. Knuth and his co-workers at the University of California at Los Angeles have used the plasma-arc method to produce beams with energies of up to three electron volts.

Now, at any given temperature a molecule of a light gas such as helium or hydrogen will have the same average kinetic energy as a molecule of a heavy gas, but because of its smaller mass it will move at a higher velocity, both thermally before expansion and afterward as a beam. Suppose that a light gas is "seeded" with a small percentage of heavy molecules. The velocity in the jet will still be high, being determined by the more abundant light molecules, and the heavier molecules will tend to be swept along at the same high velocity. As a result they will acquire an energy greater than that of the light "driver" molecules in the ratio of their masses. By this means Fenn and his co-workers at Princeton have achieved energies of up to five electron volts for fairly heavy molecules.

Although supersonic flows have been used to make neutral beams in the low-electron-volt range, few if any chemical reactions have yet been detected by this means. This points up the second great problem in the use of chemical accelerators: Whereas ions can be detected by measuring an electric current, no such simple and sensitive method is available for neutral atoms and molecules. The obvious solution is to convert the neutrals to ions, and that is what Bull and Moon did in their early experiments. The surface-ionization technique they used will only work, however, with atoms and molecules that have an electron so loosely bound that it can be lost by contact with a hot metal. A more general way of converting molecules to ions is by the electron-bombardment method (as in forming an ion beam) but that method has low efficiency.

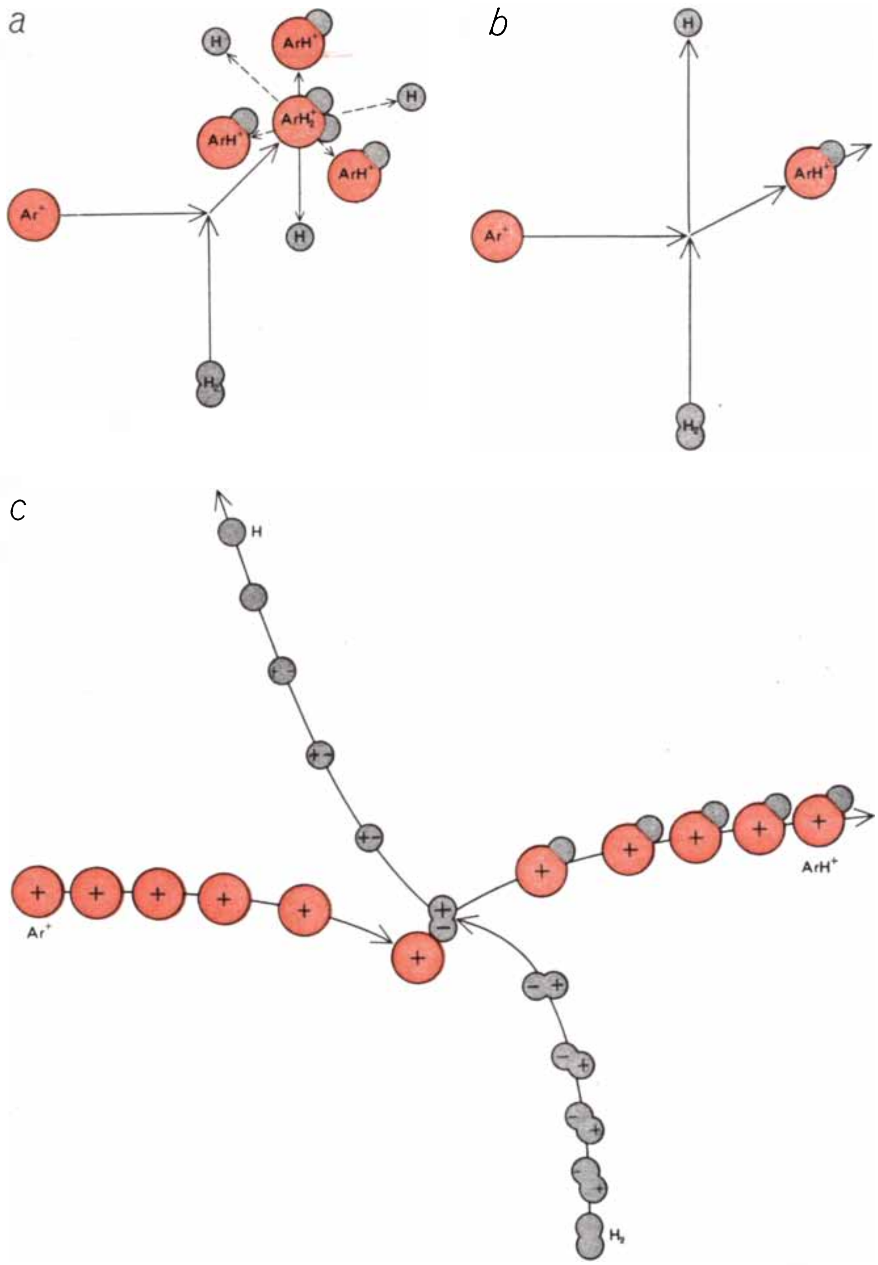
A different approach to detection is not to measure the product molecules directly but rather to look for the radiation they may give off. In most reactions the new molecules that are formed contain excess energy in the form of vibration, and eventually this energy is emitted as infrared radiation. J. C. Polanyi of the University of Toronto has pioneered in detecting such radiation when it is emitted from reacting gases. The technique has much promise for chemical accelerators, but again there is a difficulty: the radiation process is slow, and since the products are moving rapidly the chance that they will emit within view of the radiation detector is quite small.

The problem of detecting neutral particles is, then, as critical as the problem of forming neutral beams. Actually, of course, the problems are complementary. Given an intense beam, inefficient detection will do; given an efficient detector, a weak beam is enough. Once again the never ending plaint of the physical scientist is heard: "It's all a question of intensity."

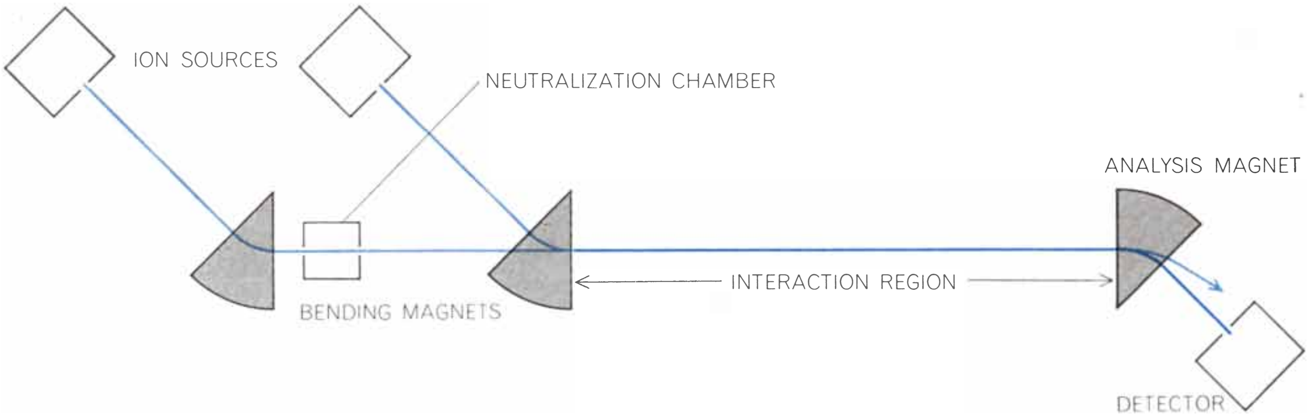
Another method of mechanical acceleration is "sputtering," a technique whereby a very fast beam of ions (for example argon at 40,000 electron volts) is allowed to hit a solid target of the reactant and dislodge from its surface a spray of neutral atoms at a broad range of electron-volt energies. As the "hot" atoms travel, spreading out according to their velocity, they encounter a rapidly spinning disk with one or more slots cut into it, and this stops most of them; only those atoms pass that have just the right velocity to arrive at the rotating wheel in time to go through a slit. By adjusting the speed of rotation and timing the initial burst of ions with respect to the position of the slit, one can create a beam with the desired energy [*see bottom illustration on next page*]. This technique is being developed by J. M. Los and his co-workers in Amsterdam and by C. Schlier and his collaborators at the University of Freiburg, and Los has recently studied simple electron-transfer reactions between neutrals.

If mechanical acceleration of molecules by simply shoving or hitting them seems crude, a more subtle method is to put them in a vacuum where there is some kind of force field. Gravity is such a force, although too weak to be useful: a hydrogen atom dropped to earth will acquire only one ten-thousandth of an electron volt per kilometer. An electric field can be much more effective, and will accelerate even a neutral molecule if the molecule has a dipole (if one end is positive and the other negative) and if the field is inhomogeneous. The molecule can lower its potential energy if its positive end is as near as possible to the negative pole of the field while its negative end is near the positive pole, and so the field draws the molecule between the poles just as a small magnet is drawn between the poles of a large magnet. In the process the molecule is accelerated, and if the field is switched off as the molecule reaches the position between the poles, it retains its velocity. As the field is switched on and off the molecule is further accelerated by a series of poles.

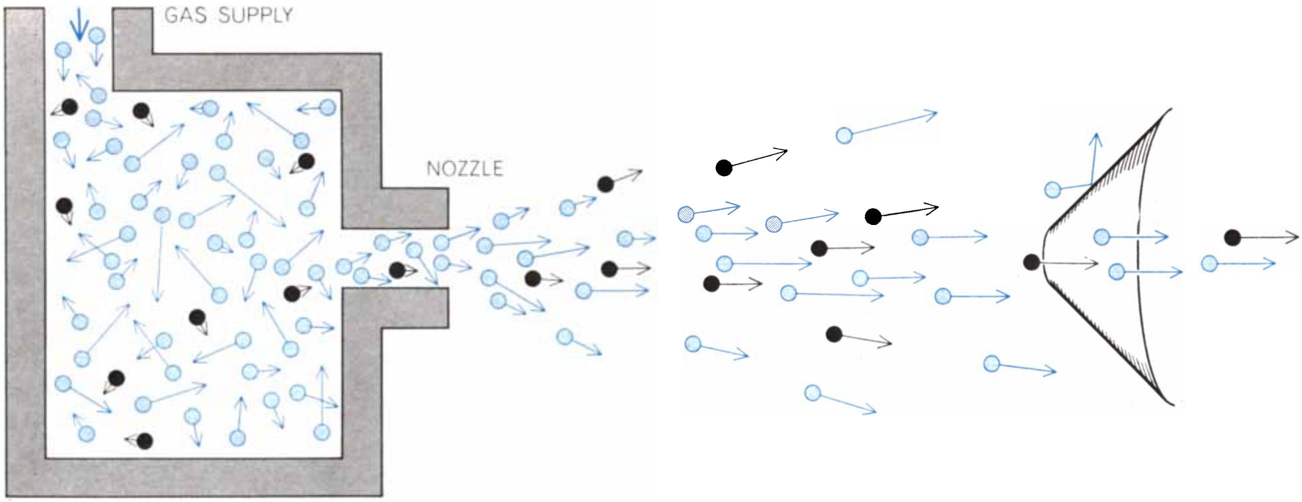
Lennard Wharton of the University of Chicago is now building a dipole accelerator with 700 stages to accelerate molecules, such as lithium fluoride, that have a high dipole moment. The energy gain per stage is modest—only about .003 electron volt—so that a 33-foot accelerator is required to yield molecules with only two electron volts of energy. In spite of this low final energy and relatively high expense, the apparatus should be quite useful. It will cover an energy range difficult to reach by ion-



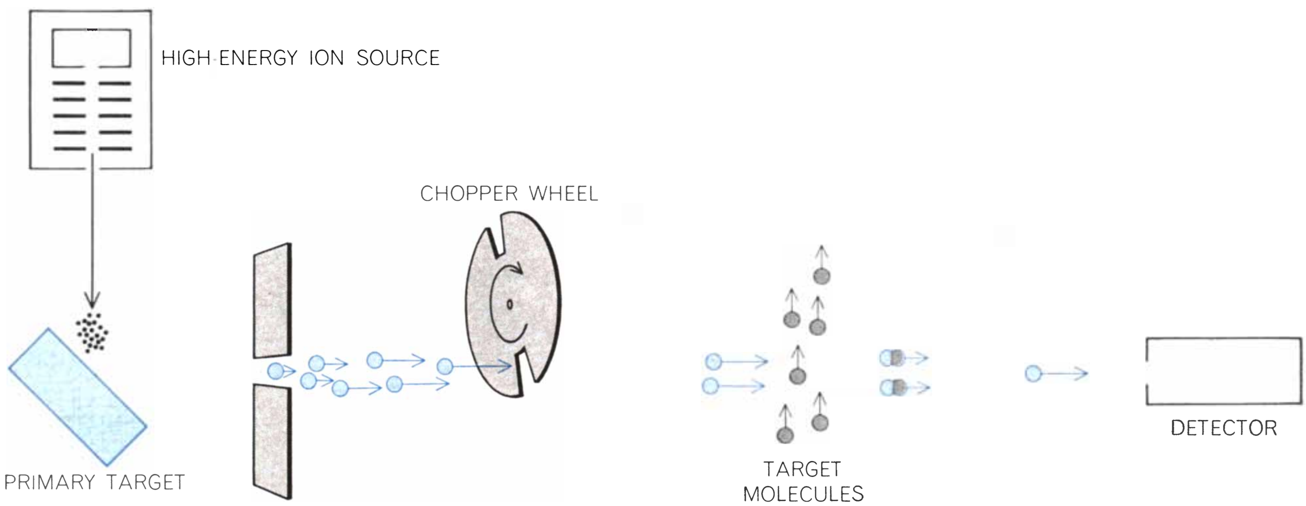
TRAJECTORIES corresponding to the intermediate-complex (*a*) and spectator-stripping (*b*) mechanisms are compared with the trajectories indicated by the experimental data for the reaction Ar$^+$ + H_2 → ArH$^+$ + H (*c*). In complexing, the products are distributed widely about a relatively large angle (*a*). The product appears at a smaller angle in spectator-stripping (*b*). The angle is still smaller in the actual process (*c*), in which the Ar$^+$ induces an increasingly strong polarization of the H_2, accelerating and deflecting both species. A weak dipole induced after reaction by the ArH$^+$ decelerates products only slightly. Final average velocity is larger and angle smaller than for originally proposed mechanisms.



MERGING-BEAM ACCELERATOR produces lower-energy collisions. Ion sources produce beams of two reactants at high but similar energies. Bending magnets merge the beams, one of which may first be neutralized. Reaction occurs at an energy proportional to the difference in the velocities of the two reactants. Finally an analysis magnet separates reactants and products for detection.



SUPERSONIC FLOW is attained by allowing gas molecules to expand into a vacuum. As molecules go through the nozzle their random velocities become forward-directed. Collisions among molecules tend to equalize velocities and molecules moving sideways are lost, leaving a uniform-velocity beam. The gas is "seeded" with a small number of heavier molecules (*black*), which begin with the same kinetic energy but lower velocity. In the beam the heavy molecules are speeded up by collisions, acquiring substantial energy.



SPUTTERING produces a beam of neutral atoms by knocking them off a solid target. A pulse of very-high-energy ions (*black*) strikes a target of the substance to be accelerated, dislodging atoms that spread out according to their velocity. The chopper wheel is timed to select those traveling at the desired velocity, forming a pulse of atoms that meet and combine with the second reactant.

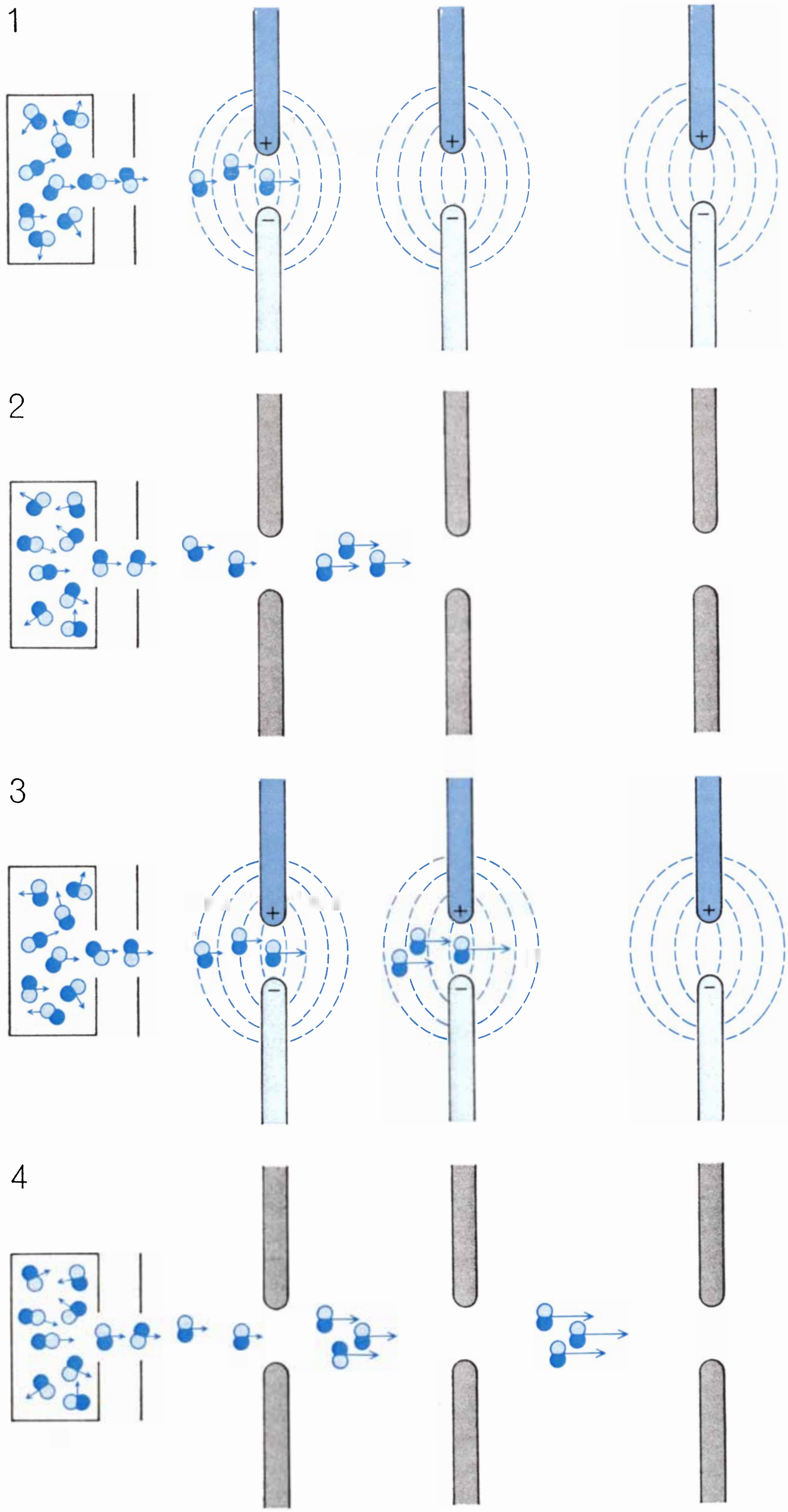
neutralization methods, it is applicable to a wide range of molecules and, perhaps most important, it should produce molecules of precisely defined velocity and orientation.

The fact that it is much more difficult to accelerate neutral atoms and molecules than it is ions leads naturally to a simple idea: Why not make a neutral species into an ion, accelerate it as such and then neutralize it again? The reneutralization must be efficient and must not change the velocity or direction of the beam. This is quite possible if the neutralization can be accomplished by the simple addition or subtraction of an electron, since the electron is so light that it carries little momentum to disturb the motion of a particle.

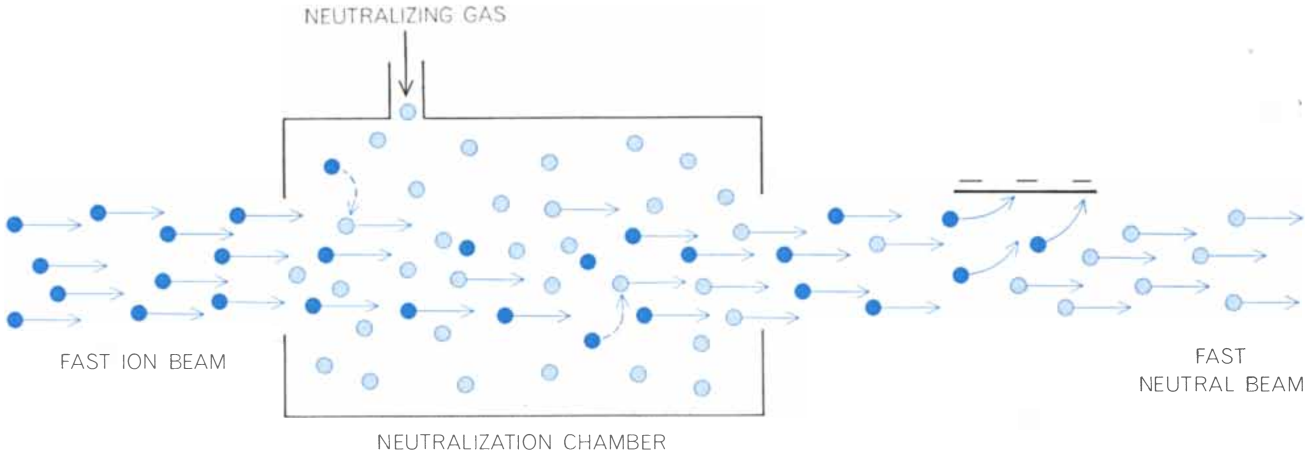
One possibility is to remove an electron from a negative ion by shining light on it. This process, first suggested by the Yale astrophysicist Rupert Wildt, is now being thoroughly investigated at the Joint Institute for Laboratory Astrophysics of the University of Colorado. Its full effectiveness probably awaits the development of suitable sources of intense laser light as well as high-intensity negative-ion beams. When these are achieved, the method will be particularly useful because, like most photochemical methods, it leaves the resulting neutral atom or molecule in a precisely known state of internal excitation.

Meanwhile the simple process of electron exchange, or electron transfer, has already proved to be a highly successful source of fast neutral beams. For example, a beam of accelerated positive ions passes through a gas that donates electrons to neutralize it [*see illustration on next page*]. The transfer process is very efficient if the electron is attracted about as strongly to the ion as it was to the particle from which it was removed. Under these circumstances there is also little excess energy to dispose of and the new neutral species is formed in a state of low excitation. Most important, the electron transfer can occur at such a distance that the ion and the neutral do not collide in the usual sense. As a result little momentum is transferred, and the fast species goes on its way neutralized but having suffered no other change.

This technique has been used for some years by I. Amdur of the Massachusetts Institute of Technology and others to make neutral beams with very high energies. It was adapted for making beams in the chemical-energy range by Nyle Utterback and Robert C. Amme and their associates at the University of



DIPOLE ACCELERATOR is shown schematically at successive times. Dipolar molecules with a positive (*solid color*) and negative (*light color*) end drift into a field produced by a pair of rods and are accelerated into the gap between the rods (*1*). Then the field is turned off and the dipoles drift toward the next pair of rods (*2*). The field is switched on again, further accelerating the molecules (*3*), and then off, allowing them to drift again (*4*). As the cycle is repeated many times, the molecules gain more energy at each stage.



NEUTRALIZATION of a fast ion beam produces a beam of fast neutrals. Positive ions (*dark color*) enter a chamber containing a low pressure of the same species, un-ionized (*light color*). Electrons transferred from neutrals to ions (*broken arrows*) produce fast neutrals and leave thermal ions. The mixed beam leaves the chamber and passes a charged plate that removes remaining ions.

Denver and the General Motors Corporation. In their first studies they sidestepped the bothersome problem of detecting neutrals by examining a reaction that yields ionic products: $N_2 + CO \rightarrow CN^- + NO^+$. Reactions between neutrals do not usually yield ions, however, and efficient means of detecting uncharged products must be found to make full use of this relatively well-developed method of making fast neutral beams.

The difficulty of detecting the neutral products of most reactions by converting them to ions has led some workers to combine the chemical-accelerator concept with the radioactive-isotope methods used in nuclear-recoil studies of hot reactions. The idea is simple: The accelerated beam consists of radioactive atoms (or molecules containing radioactive atoms), so that its reaction products will also be radioactive and can be assayed by radiochemical means. The method's extreme sensitivity is illustrated, in the case of tritium (the radioactive isotope of hydrogen), by the fact that a beam consisting of a total of only 10 billion atoms (less than one ten-trillionth of a gram) can yield detectable products.

Accelerators in which tritium atoms in the chemical-energy range are produced by electron transfer of tritium-ion beams are currently being built or operated by J. P. Adloff and J. M. Paulus at the University of Strasbourg, by Solomon Wexler at the Argonne National Laboratory and by M. Menzinger and myself at the University of Colorado. We call our apparatus ADAM (to accompany EVA), and we have used it to make the first measurements of the minimum energies at which hot-atom reactions can occur.

Radiochemical detection is of course limited by the availability of appropriate radioactive isotopes. In addition to tritium, radioactive carbon is promising. High-velocity carbon-14-ion beams have already been produced by Richard M. Lemmon of the University of California at Berkeley, David Blaxell and Alfred Maddock of the University of Cambridge and F. Cacace of the University of Rome, but the energy of these devices is still too great for them to be considered true chemical accelerators. In time, however, the availability of these two isotopes should open up a new world of high-energy organic chemistry, since almost any organic molecule can be labeled with either carbon 14 or tritium. Nor is the method limited to stable molecules. With beams it should be easy to investigate reactions of species that are difficult to make by ordinary methods—such as methyne (CH) or the carbon molecule (C_2).

I have taken up only a sampling of possible chemical-accelerator concepts. Others include such diverse ideas as acceleration by a rifle bullet or shock waves and the vaporization of fast dust particles by laser light. The range of techniques and the vigor with which they are being developed indicates the importance of this new field. Ion accelerators are already providing an intimate view of the nature of reactions between ions and molecules. To most chemists, however, reactions of medium and high-energy neutral species are of even greater interest. For information on these we must still rely almost exclusively on the nuclear-recoil technology that revealed the richness and order of hot-atom chemistry and stimulated the surge of interest in chemical accelerators. This situation is about to change. Although simple mass-spectrometric, nuclear-recoil and photochemical methods will retain their importance in mapping out the broad outlines of hot chemistry, chemical accelerators will add more depth and breadth to our understanding.

For the next few years the emphasis will probably be on studying what happens in chemical change as a function of the kinetic energy—of how fast the reactants are moving when they collide. The course of chemical change is determined not only by kinetic energy, however, but also by the internal energy of the reactants: the energy levels of the electrons and the extent to which the atoms vibrate and rotate around one another. Chemical accelerators built in the future will undoubtedly offer means of varying the internal as well as the kinetic energy of the reactants. A promising way to do that is by shining light on molecules to excite them internally before accelerating them. A forerunner of such a device, designed to examine the effects of internal—but not yet kinetic—energy, has already been built by William A. Chupka and Joseph Berkowitz of the Argonne National Laboratory. A marriage of such a technique of internal energy-state selection to the chemical accelerator should provide all possible information on the process of chemical reaction.

Finally, the chemical accelerator can uncover a new chemistry of species so hard to produce, so reactive or so unstable that they are beyond the methods of classical kinetics. In spite of their exotic nature, such chemicals can be formed into beams almost as readily as more prosaic species. Their study should advance our understanding of what happens in flames, at the boundaries of space and in the atmospheres of stars.

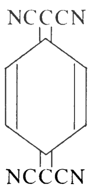
In hope of doing each other some good

Kodak

Free consultation

If encountering difficulties achieving desired color balance in photomicrography, please describe them to L. C. Wall, Department 942, Eastman Kodak Company, Rochester, N.Y. 14650.

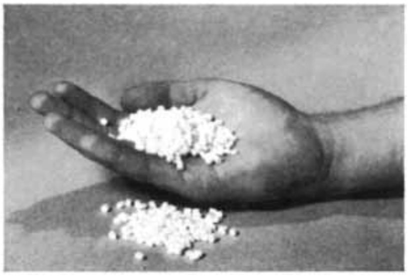
Along the road to conductive resins



Molecules like this are enveloped in π-clouds of electrons. Even some high school chemistry students (but not all) know that much. Confidence in concepts like π-electrons grows from such work as was done by a chap who acquired a bunch of our benzene derivatives and watched them under the microscope to see which would or wouldn't form brightly colored addition compounds from a fusion mixture with 2,4,7-trinitro-9-fluorenone (available as EASTMAN 7135).

The structure shown above is known for brevity as TCNQ, known for convenience as EASTMAN 9771, but known indeed where a connection is perceived between π-clouds and electrically conductive resins that might be sprayed or molded. The possibility of an eventual descent from the π-clouds to the factory floor affects the picture. A patent owner who asserts some rights on this compound but who does not want to constrict unduly the free flow of science has licensed us to sell modest quantities for further study. Takers have appeared in rising numbers.

B&A, Curtin, Fisher, Howe & French, North-Strong, Sargent-Welch, Van Waters & Rogers, Walker, or Will will know TCNQ as 7,7,8,8,-Tetracyanoquinodimethan. *Any of them can supply any* EASTMAN *Organic Chemical.*



Heat and stick

EASTMAN High Performance Adhesives —something new—enter the customer's factory looking like this. The customer is a pretty up-to-date organization if it assembles its products by sticking components together. Nuts and bolts, rivets, and spot welders are encountering a new competitor at the product designer's board, now that much more is known about adhesives. We may have launched the trend a few years ago with a picture of a convertible. The vehicle, a conventionally assembled one loaded with beautiful girls, was being lifted by a crane through a joint between flat ends of 2-inch steel rods established 30 minutes earlier by a drop of EASTMAN 910 Adhesive.

The new EASTMAN High Performance Adhesives don't have to perform that high. They are cheaper and more tractable in application, suggested where 200-260C can be tolerated in bonding operations and where good bond strength up to 200C is needed. Bond strengths, as measured in tensile shear, develop to the point that metal failure of 7-mil-thick coated steel strips occurs before the bond fails. These adhesives are linear polyesters of high molecular weight, not the usual polyolefins. Formulations of differing resistance to chlorinated or phenolic solvents are offered, and all bonds, once formed, resist oils and greases such as might be encountered in metal-to-metal applications.

Correspondence on EASTMAN *High Performance Adhesives is conducted by Eastman Chemical Products, Inc., Kingsport, Tenn. 37662 (Subsidiary of Eastman Kodak Company).*

Getting in

Ralph Brown's case sounds a bit pat:

Family migrated from Plymouth, Fla., to Rochester, where father became moulder in foundry. Inner-city grade school raises visions of scientific career. Visions busted in resounding flunk of high school chemistry. Quits school. Goes slack. Hangs around street corners late at night jeering at fate. Wakes up in Air Force blues one day on isle of Crete. Decides to try for job in foundry alongside dad. When hitch is up, dad disagrees. Suggests applying to Kodak.

Policy has long demanded good high school grades for lab assistants. Policy must face up to the facts of the day. Hired as laboratory trainee. Does much better than in high school. Raised to regular employee of department that tests ingredients of photographic paper and checks production steps. Undertakes evening course at community college. Makes passing grade. Marries.

Switches on September 9, 1968 to manning x-ray fluorescence spectrometer. Two-man night team receives paper samples by pneumatic tube from various stages of production and checks amount of Ag, Si, Ti, Cr, Mo, and Ba present. College by day. One of these nights may find self in position where our profit on many acres of photographic paper will hang on his judgment and alertness. Confident. Getting the insider's view. Unashamed of that. Hopes to move into management some day. Wouldn't surprise us in the least. Might surprise the high school chemistry teacher, though.

More typical laboratory trainee is José D-----. "Disadvantaged" more applicable here. Hesitate to put him under more pressure by displaying his picture. Schooling ended with 6th grade in Puerto Rico. English weak. Joins Job Corps. One of crew of compatriots sent to Medina, N.Y., fruit-belt town west of Rochester. Assigned as orderly in Veterans' Hospital. Peeks into a laboratory. Seems like nice place. Kodak personnel man visits camp. Told that José wants to work in lab. OK, hired into lab trainee program. Goes on payroll. Put through intensive educational upgrading. 3 R's for adults not the same as for kids. Afternoons devoted to atomic weights, spectrophotometers, densitometers, melting points, distillations, extractions, making soap, making oil of wintergreen. Incredible what the advanced educators we engage are trying these days. José hangs on! Soon should reach point where his work needn't be checked at every step. Due for raise then.

José not the real problem either. Real problem those who just can't get interested. Haven't been able to solve that yet.

EASTMAN KODAK COMPANY

An equal-opportunity employer

Electronic troubleshooter takes pulse of giant plane • Ultra-fast memory system speeds handling of huge data quantities • Statistical approach reduces Lunar Orbiter photo information • Compression techniques now can reduce telemetry data by 80%

Ways to cope with exploding masses of data—by storing it, speeding it, reducing it, converting it, analyzing it—together with new methods for gathering still more vitally needed facts, are becoming prime concerns among scientists, businessmen and administrators alike. Lockheed's involvement in this great numbers game is producing new kinds of hardware and fresh approaches to growing problems. Below are some samples of current Lockheed information projects.

Madar. In 1968, the maiden flight of the largest airplane ever built also will mark a first in airborne information systems. MADAR (malfunction detection analysis and recording), a maintenance management tool, was chosen by the U.S. Air Force to monitor the giant C-5A.

Lockheed's MADAR system is a combination of sensing, computing and recording components. It automatically provides information on dozens of a plane's critical subsystems through hundreds of test points. It monitors and records conditions, making comparisons between actual and expected data. It classifies performance usually as either "go" or "no go."

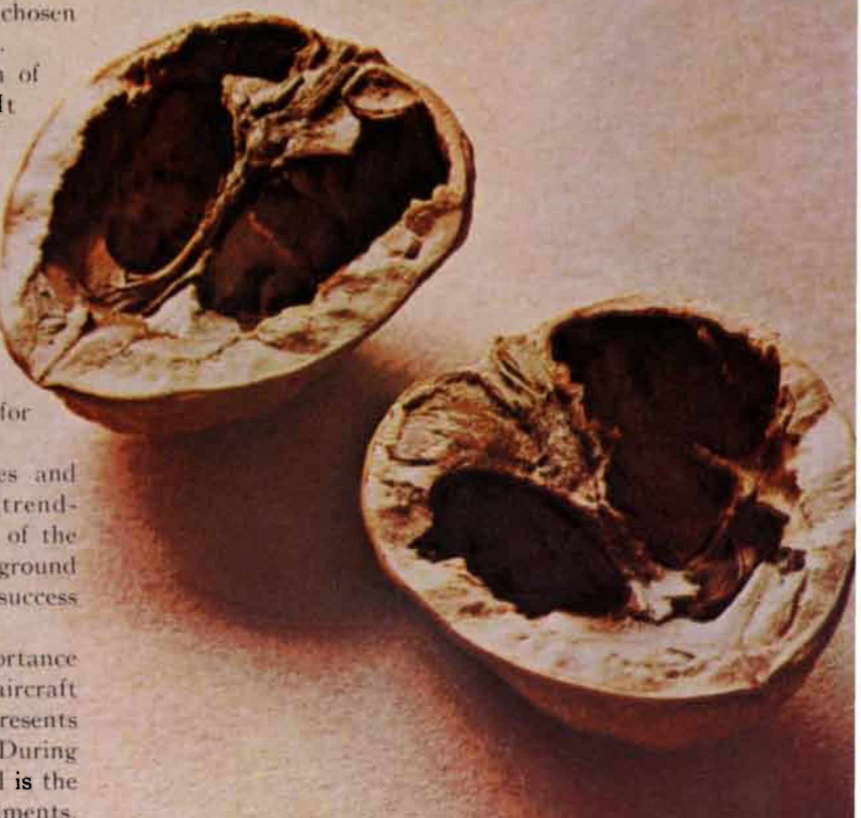
When a "no go" condition is found, MADAR records the LRU (line-replaceable unit) number, time and date. It alerts the flight engineers and pinpoints the problem, printing out instructions for immediate repair.

At programmed intervals, MADAR measures and records all instrumented functions to obtain trend-significant data. This information becomes part of the ship's statistical history. After processing by ground equipment, these data are used to predict mission success and improve maintenance cyclic rates.

The value of MADAR, besides the obvious importance of in-flight repairs, is considerably increased aircraft utility. The total picture of capability MADAR presents adds to the accuracy of readiness evaluations. During flight, the system confirms success prediction and is the basis for determining mission extensions or curtailments. It also lowers operating costs by reducing needed maintenance man-hours for troubleshooting and pinpoints the skill level of maintenance men required.

500 nanosecond memory system. The world's fastest ferrite core memory system now has been developed and put into production by Lockheed. Complete memory

Putting information in its place



LOCKHEED

LOCKHEED AIRCRAFT CORPORATION

cycle time is 500 nanoseconds (2 million storage and retrieval functions per second) and storage capacity is in excess of 1 million bits.

Section showing 18 mil ferrite memory cores wired in 2½D organization. Magnified 12 X.

At the heart of the system are Lockheed-produced 18-thousandth-inch-diameter lithium ferrite memory cores. Through each of these toroid-shaped cores pass 3 wires—X drive, Y drive and sense—utilizing a 2½D organization for storage and retrieval of binary digital data.

The 2½D organization provides inherently greater operating margins by eliminating the inhibit current required in 3D organization. This is because absolute current tolerance, dictated by the knee of the memory core, is divided between only X and Y currents, rather than X, Y and inhibit currents.

Another advantage of 2½D organization is that the Y lines essentially are driven on a bit by bit basis. Because both the number of cores linked is small and the length of each Y line is short, resultant circuit requirements are considerably less stringent, permitting simpler, more economical circuit designs.

The most important advantage gained from the new system—higher speeds—stems from eliminating the inhibit current. Without this current, associated transient current on the sense line disappears, thereby removing a major obstacle to faster operation.

Now available, large-scale, ultra-fast 2½D memory systems offer definite economies for applications where capacity is 16,000 words and above. In total, the 2½D organization's advantages add up to the most significant innovation in high-speed memory technology during the past decade.

Lunar orbiter data conversion. To define a single high-resolution photograph (covering 20 square miles of the moon's surface) beamed back by the Lunar Orbiter takes approximately 30 million computer words of 36 bits each. That is unless the computer can use statistical analysis on selected portions of the photograph, thereby greatly reducing the number of words needed.

Achieving this end, Lockheed designers have created the Lunar Orbiter Data Conversion System. Incorporated in the system is electronic equipment carefully integrated to provide the accuracy and intricate timing required by the statistical approach. Besides equipment to transfer data from magnetic tape into the computer, the LODCS features a display system used to visually evaluate and photograph both raw data and computer-reconstituted data.

The immediate application for the LODCS is to help find the best landing site for Apollo astronauts. In the future, the system holds promise for use in other fields.

Data compression. With every successful space shot, mountains of new technical data pour in for processing. So much that stored masses of information are overflowing archives. Ground networks are reaching the saturation point; their ability to handle vital real-time data is becoming overtaxed. Among the consequences are increasing preflight checkout times...and costs.

Well aware of this growing dilemma, Lockheed researchers have been pursuing techniques to compress amounts of data since 1960. An idea once used only by human analysts and for processing data off-line, data compression now has been made workable for on-line service—including space vehicle telemetry data.

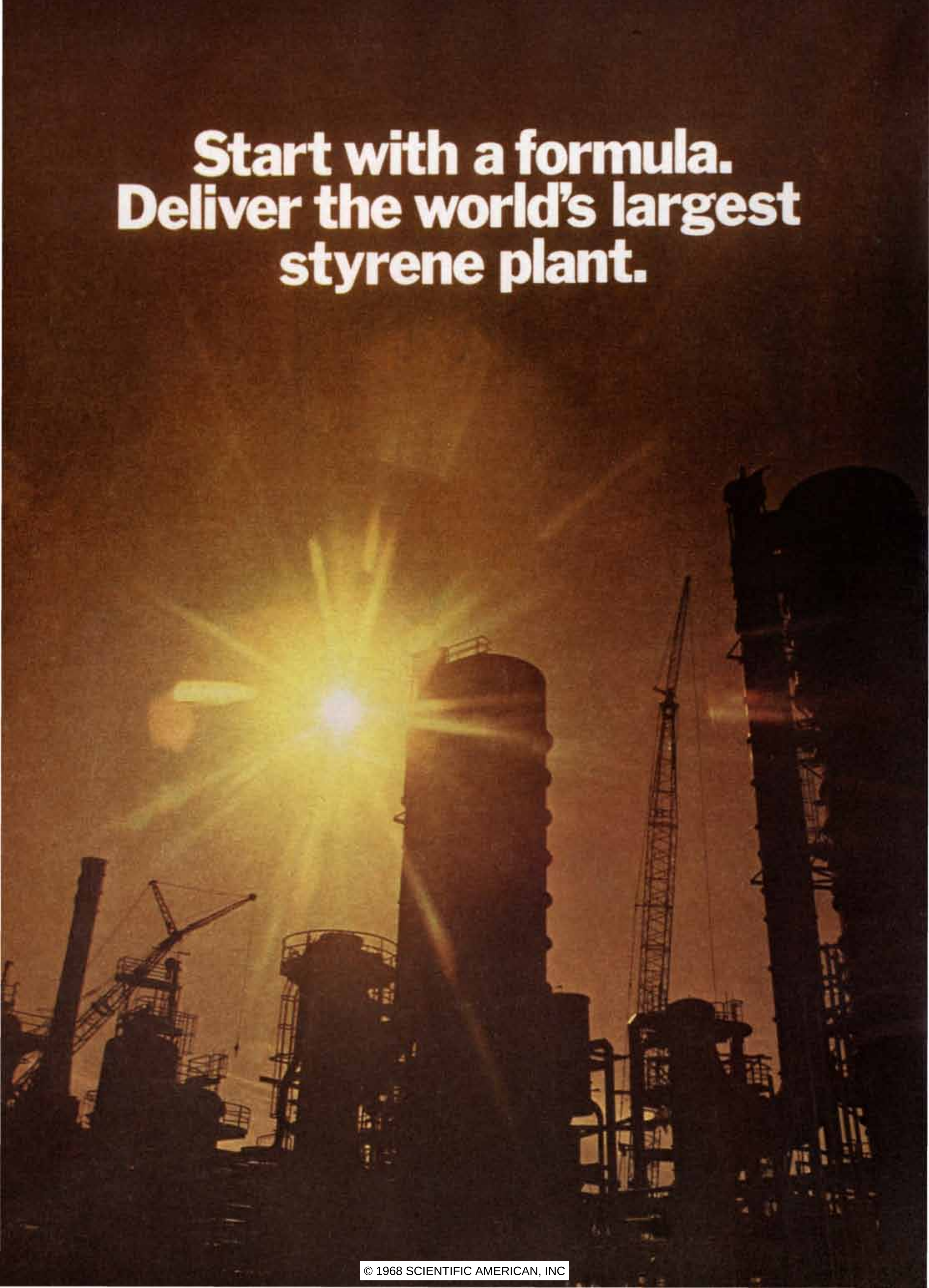
Basically, compression minimizes data by eliminating redundant samples. The number of total data samples to the actual number used is the compression ratio.

Lockheed's studies, both theoretical and computer-simulated, produced a telemetry data compressor that can handle up to 1,024 separate data channels. It will accept inputs either directly from a telemetry multiplexer-encoder or from a telemetry decommutation station...and at more than 50,000 words per second.

Besides telemetry data, a wide variety of inputs can be compressed effectively—such as facsimile and video information, biomedical data and industrial process data. Currently, compression ratios of 4:1 to 6:1 are being achieved. And with new improvements in techniques, ratios of 50:1 or more can be reached without significantly degrading data.

Television picture taken during GEMINI mission. Left: as originally taken. Right: reconstructed from 6:1 compressed data.

The activities mentioned here are only a few of Lockheed's current R&D projects in data handling. If you are an engineer or scientist interested in this field of work, Lockheed invites your inquiry. Write: K. R. Kiddoo, Lockheed Aircraft Corporation, Burbank, California. An equal opportunity employer.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Deliver the world's largest
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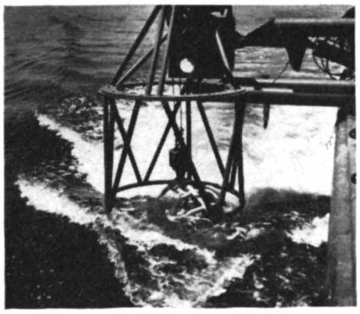
You live in a world of plastics. Your fountain pen, telephone, picnic dishes — maybe even your automobile body — had their beginnings in a complex chemical processing plant like this, built by The Badger Company, Raytheon's newest subsidiary.

But Badger is more than just a builder. Badger's service starts with process design and ends with delivery of a complete facility. More than 300 petroleum and chemical plants around the world are evidence of Badger's special skills.

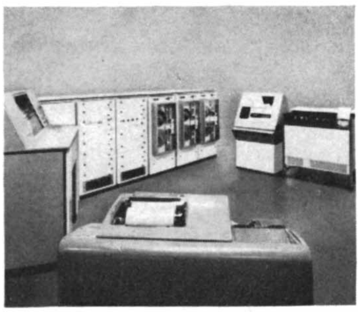
This is an example of Raytheon's growing role in natural resources exploration and development.

Exploration crews from Seismograph Service Corporation, another Raytheon subsidiary, are at work throughout the world helping customers locate oil and gas reserves. Capitalizing on Raytheon's long experience in sonar technology, SSC is using a new, non-explosive, acoustic energy source — developed at Raytheon — to search for offshore oil.

Raytheon makes many things happen. By mixing and matching a broad range of technologies and bringing them to bear on complex problems, we are helping satisfy the needs of people and industry all over the world. Raytheon Company, Lexington, Massachusetts 02173.



Acoustic energy probes beneath the ocean floor in search for oil.



703 computer speeds seismic, radar or other scientific data handling.

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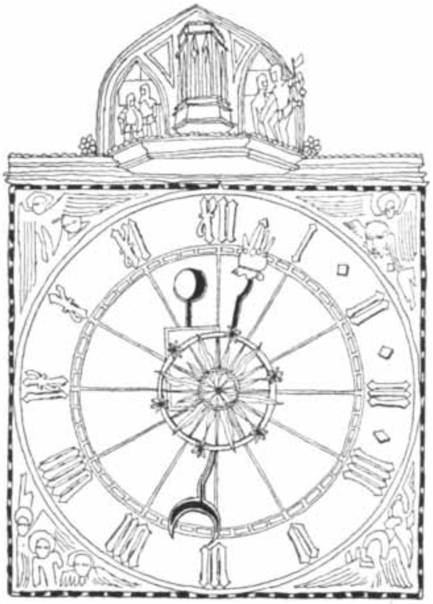

Behavioral Science and Government

The Government should get more out of behavioral science, a committee of the National Research Council has urged—and also put more into it. Complex decisions in foreign affairs, defense, urban reconstruction and many other areas call for valid social and economic information and judgments about human behavior, according to the council's advisory committee on Government programs in the behavioral sciences; the knowledge and methods of disciplines that deal with group and individual behavior and social institutions should be brought to bear more effectively in making those decisions. Conversely, the behavioral sciences (like the physical and biological sciences) require further financial support from the Federal Government in order to develop more knowledge and better methods.

The committee, of which Donald R. Young of Rockefeller University was chairman and Gene M. Lyons of Dartmouth College executive secretary, recommends increased use of behavioral science and scientists in a wide range of Federal programs and agencies. Giving the Bureau of the Census and the Council of Economic Advisers as instances of behavioral-science expertise in government, it asks for similar developments in other fields, "especially in sociology, social psychology, political science and anthropology, that are relevant to new social programs." Apparently with the Project Camelot affair (an Army-sponsored study of internal conflict in Latin America) in mind, the committee urges that Government research in foreign affairs be coordinated by the Department of State and emphasize international cooperation.

Within the Executive Branch, the report states, the behavioral sciences have been slighted by both the Office of Science and Technology and the President's Science Advisory Committee. The Office of Science and Technology should be broadened to coordinate Government programs in the behavioral sciences and the advisory committee should include behavioral scientists so as to deal more effectively with such matters as the social and economic effects of scientific and technological change. Moreover, the National Science Foundation should give increased emphasis to grants in the behavioral sciences.

Finally, the committee recommends the founding of a new National Institute for Advanced Research and Public Policy. The institute would undertake long-range analyses of national problems, provide for continuing interchange between Government policy makers and scientists and promote the application of knowledge from all the sciences to the major issues of society. The report concludes by suggesting that such an institute, adequately financed and with sufficient prestige and independence, "would be a sign of dedication to the place of knowledge in democratic government."

Lumpy Moon

Whereas green cheese has been out of favor as a model of the moon, a description of the latest picture of the moon's composition is provided by raisin bread. Analysis of slight variations in the orbital speed of *Lunar Orbiter V*, which was placed in orbit around the moon last year, indicates that the main body of the moon is interspersed with lumps of comparatively dense material. Selecting a 10-day period in August, 1967, Paul M. Muller and William L. Sjogren of the Jet Propulsion Laboratory of the California Institute of Technology compared differences in frequency between signals transmitted by *Lunar Orbiter V* and signals received at the Jet Propulsion Laboratory tracking station. Analyzing 80 consecutive polar orbits, they were able to plot some 9,000 points along *Lunar Orbiter V*'s flight path. Variations in velocity from point to point permitted construction of a gravity contour map. When the contours were superposed on a topographic map of the moon, the investigators found that five points of greater than average gravitational attraction coincided with five of the six large "ringed seas" visible on the moon's earth-side face. The moon's more irregularly shaped "seas," in contrast, showed no variation in gravitational attraction.

Writing in *Science,* Muller and Sjogren note that the findings agree with the suggestion of Harold C. Urey and others that the moon's ringed seas are impact scars caused by colliding asteroids and that the heat of impact would have caused local high-density concentrations to form. They estimate that the mass concentration centered in the Sea of Showers is equivalent to a nickel-iron sphere some 100 kilometers in diameter.

Ultimate Fossils?

The earth's oldest known fossil organisms now appear to be tiny alga-like spheroids found in sedimentary rocks of the Onverwacht formation of South Africa that may be as much as 3.5 billion years old. Until recently the record was held by other alga-like fossils from the three-billion-year-old Fig Tree formation, which overlies the Onverwacht formation, and before that by similar fossils from the two-billion-year-old Gunflint cherts of Ontario.

The discovery of the microfossils was described in *Science* by Albert E. J. Engel, a geologist at the University of California at San Diego, in a report written jointly with five colleagues. Noting that the Onverwacht sediments, located in the Komati River valley of eastern Transvaal, are probably the oldest well-preserved fossil-bearing rocks in Africa and perhaps in the world, Engel suggests that their discovery may mark the end of the search for the origins of unicellular life. Any evidence of life that may once have been contained in still older sediments, he points out, would almost certainly have been destroyed by subsequent geological activity.

Enriched Rainwater

Rainwater is apparently a significant source of the vitamin B-12 required by more than 70 percent of all the species of freshwater and marine algae, according to experiments conducted by Bruce C. Parker of Washington University. "This discovery," he writes in *Nature,* "stemmed from the observation that a species of *Chlamydomonas* repeatedly dominated the phytoplankton of a small experimental pond after the spring rains and that a significant increase in soluble B-12 in this pond correlated consistently with these specific rains." Parker found appreciable amounts of the vitamin in seven of nine collections of rainwater that he made during a recent period of 13 months.

To test the possibility that the vitamin arose from microbial activity during the several hours between the beginning of collection and the sterilization of a sample, Parker collected one sample in alcohol, which kills microorganisms. The sample contained B-12. "One hypothesis now being tested," according to Parker, "is that soil borne into the atmosphere by the wind is the chief source of vitamin B-12 in rainfall." Parker points out that the presence of the vitamin in rainfall may be of considerable ecological significance: If the vitamin gives certain species of algae an advantage over other ones that do not benefit from the presence of the vitamin, "then rains containing this vitamin may directly affect the biology of lakes and seas."

Psychological Autopsy

What causes death? Even a postmortem examination cannot truly establish the answer, according to Avery D. Weisman of the Harvard Medical School and Robert Kastenbaum of Clark University. "What prompts a person to become ill . . . and die at a particular time and in a particular way cannot always be ascribed entirely to a disease process," they suggest. "The final illness is a psychosocial as well as a medical event." This being so, Weisman and Kastenbaum advocate the "psychological autopsy" as a means of correlating medical, social and psychiatric information about a patient after his death. In a *Community Mental Health Journal* monograph they report on their method and on the first 80 such autopsies they conducted in Cushing Hospital, a state geriatric institution in Framingham, Mass.

The core of the authors' method is a multidisciplinary conference at which nurses, therapists, social workers, the chaplain and other hospital workers join the psychologist and psychiatrist in an effort to evaluate the patient's life, especially the "preterminal" phase before his final illness, and determine the psychosocial factors in his death. The investigation deals with the patient's life before hospitalization, his course in the hospital, the preterminal period and the final illness. The study has shown that death may be heralded by some distinct emotional or social crisis. There may be a phase of resignation or acceptance; a few patients have a clear intimation that death is imminent. The authors maintain that most patients do not "lose contact" completely until the very end; by assuming that very sick elderly people cannot respond, hospital personnel may contribute to their alienation and thus to their death. Another finding is that fear of dying was observed only in patients so helpless that their apprehension may have been the result of inability to communicate.

Such preliminary results suggest that psychological autopsies can have direct benefits: improving the care of older people and meeting the pressing needs of dying patients within an institution. Beyond that, the psychological autopsy should contribute to basic understanding of old age and of the process of dying.

Messenger for Mold and Man

The substance secreted by certain social amoebae, the amoeboid slime molds, that causes them to gather by the hundreds into a single sluglike mass in order to reproduce has proved to be identical with the chemical messenger that acts inside human cells that are stimulated by hormones. It is a cyclic, or ring-shaped, form of the compound adenosine monophosphate (AMP). Its chemical identity, recently established by Theo M. Konijn, John Tyler Bonner and their co-workers at Princeton University, comes some 20 years after Bonner, in pioneering experiments with the amoeboid slime molds, first demonstrated the existence of the substance, which he named "acrasin."

In the peculiar life cycle of the amoeboid slime molds a single amoeba will suddenly increase its secretion of cyclic AMP. Other amoebae, attracted by the substance, move toward the source and also begin to secrete more of the compound, attracting still other amoebae until a multicellular aggregate is formed that behaves as a single organism. The cylindrical slug moves a few inches and raises a vertical stalk, stiffened by the secretion of cellulose fibers and topped by a spherical mass of spores that will become the individual amoebae of the next generation. The slime molds also secrete the enzyme phosphodiesterase, which destroys the attractant and thus makes the aggregation process self-regulating.

Writing in *The American Naturalist,* Konijn, Bonner and their colleagues note that studies by Earl W. Sutherland, Jr., of Vanderbilt University and others have shown that when hormones reach the surface of animal cells on which they are to act, they enter into a chemical reaction that releases cyclic AMP inside the cell wall. Thus a great variety of hormones act as "primary messengers," but the "secondary messenger," which triggers further chemical activity within the cell, is always the same substance. "For the biologist," Bonner concludes, "the problem is to discover the relation of these specialized, complex hormone effects to the chemical's profound effect in the cellular slime molds."

Fertilizer by Pipeline

The trend toward transportation of an increasing number of products by pipeline is about to add fertilizer. Two pipelines that will transport anhydrous ammonia in liquid form from producing areas on the Gulf Coast to corn-growing areas in the Middle West are in advanced stages of development. A 1,200-mile line from Texas to Iowa is under construction by the Mid-America Pipeline System of MAPCO, Inc., and is scheduled to begin operating by the end of this year. The Gulf Central Pipeline Company has announced plans for an 1,800-mile pipeline system between Louisiana and Nebraska, with branch lines into other Middle Western states. At full capacity the Gulf Central system, which is due to start operating next summer, will carry about three million tons of ammonia a year.

Farmers in the corn belt annually use about 1.5 million tons of anhydrous ammonia applied directly to the soil as a nitrogenous fertilizer. Most of the ammonia is now transported by river barges. Transportation by pipeline is foreseen as a low-cost and automatic process.

Early Man in the Northwest

A cave in central Oregon has yielded charcoal from a prehistoric hunter's hearth that has been shown to be some 13,600 years old by carbon-14 analysis. The site of the fire is Fort Rock Cave, where anthropologists from the University of Oregon have worked for several seasons. The presence of man in Oregon at so early a date is added evidence that the American Northwest had already been populated before glacial ice blocked the route from Asia to the New World for some 15,000 years between

25,000 and 10,000 B.C. Other recent evidence to this effect includes discovery of the 11,000-to-13,000-year-old remains of "Marmes man" in eastern Washington in 1965 and of 15,000-year-old artifacts at Wilson Butte Cave in southern Idaho in 1960.

Luther S. Cressman, professor emeritus of anthropology at the University of Oregon, first explored the Fort Rock Cave site 30 years ago, discovering a number of ancient sandals that proved to be some 9,000 years old. Since his retirement in 1963 Cressman has continued work at the site with the assistance of university undergraduate and graduate students. One graduate student, Stephen Bedwell, shares the discovery of the charcoal with Cressman.

Bioholography

The latest example of a technological innovation turning out to be anticipated by a natural process may be in the field of holography, or photography by wave-front reconstruction. The holographic principle is involved in a startling conjecture put forward by a Hungarian investigator to account for the extraordinary sensitivity of the ultrasonic echo-location systems used by bats, whales, dolphins and porpoises to "see" in the dark. This capability has been known for many years to resemble modern sonar, but no satisfactory explanation has yet been offered for the fact that these animals can apparently distinguish between targets of different shapes and can discriminate between their own signal and those emitted by their companions, even though the frequency of the pulses is the same.

Writing in *Nature,* Paul Greguss of the RSRI Ultrasonic Laboratory in Budapest maintains that the characteristics of the animal systems suggest that the animals perceive not only the amplitude but also the phase of the ultrasonic waves, which they can discriminate by using a coherent "background" level of ultrasound as a reference. In other words, the animals are using a version of the holographic technique.

According to Greguss' conjecture, when a bat emits an ultrasonic pulse of a certain frequency, the part of the brain that orders the pulse to be emitted simultaneously sends information concerning the pulse to a second part of the brain, where the ultrasonic information is received and processed. The information sent from the first part of the brain to the second is the coherent reference background.

Greguss points out that the receiving and associating parts of the bat's brain have a structure that looks like an assembly of minute dipoles, which suggests to him binary digital processing. He concludes that bats use the holographic principle to interpret the data supplied by the dipole-shaped receptors. This would enable a bat to distinguish shapes and to orient itself in three dimensions. The bat would not be disturbed by the pulses emitted by its companions, because it would employ only its own signal for reference.

To test his idea, Greguss has made a model of the bat's brain, which operates in water at a frequency of about one megacycle, which is approximately the frequency used by hunting bats. The resulting ultrasonic holograms were recorded on sound-sensitive photographic plates and were scanned with a microdensitometer. From these records he has succeeded in reconstructing images of objects.

Superfine Machining

A machine tool of remarkable precision, which can make cuts so fine that the removed metal floats in the air, has been developed at E. I. du Pont de Nemours & Co. In some applications the tool, which is called "ultraprecision positioner and shaper," uses a knife made from a cleaved and sharpened diamond of gem quality. The machine maintains straight-line accuracy of 20 millionths of an inch over a 30-inch length and a precision of cut within two millionths of an inch. Angular deviation can be held to one second of arc. In many applications the tool achieves higher accuracy and smoother finish than can be obtained with grinding.

The ultraprecision tool achieves positioning control on three axes by means of interferometer fringes arising from a point of white light. Temperature control presents no major problem; because of air-film lubrication and low cutting forces, relatively little power is required, and thus little heat is generated within the machine. The heavy construction of the machine acts as a sizable heat sump, thus making the tool insensitive to brief variations in temperature. With nonferrous metals and alloys such as aluminum and bronze a mirror-like finish of optical quality can be obtained by direct machining. The machine has been used to make precision dies, extrusion equipment, optical components such as front-surface mirrors, and complex processing equipment for polymeric materials.

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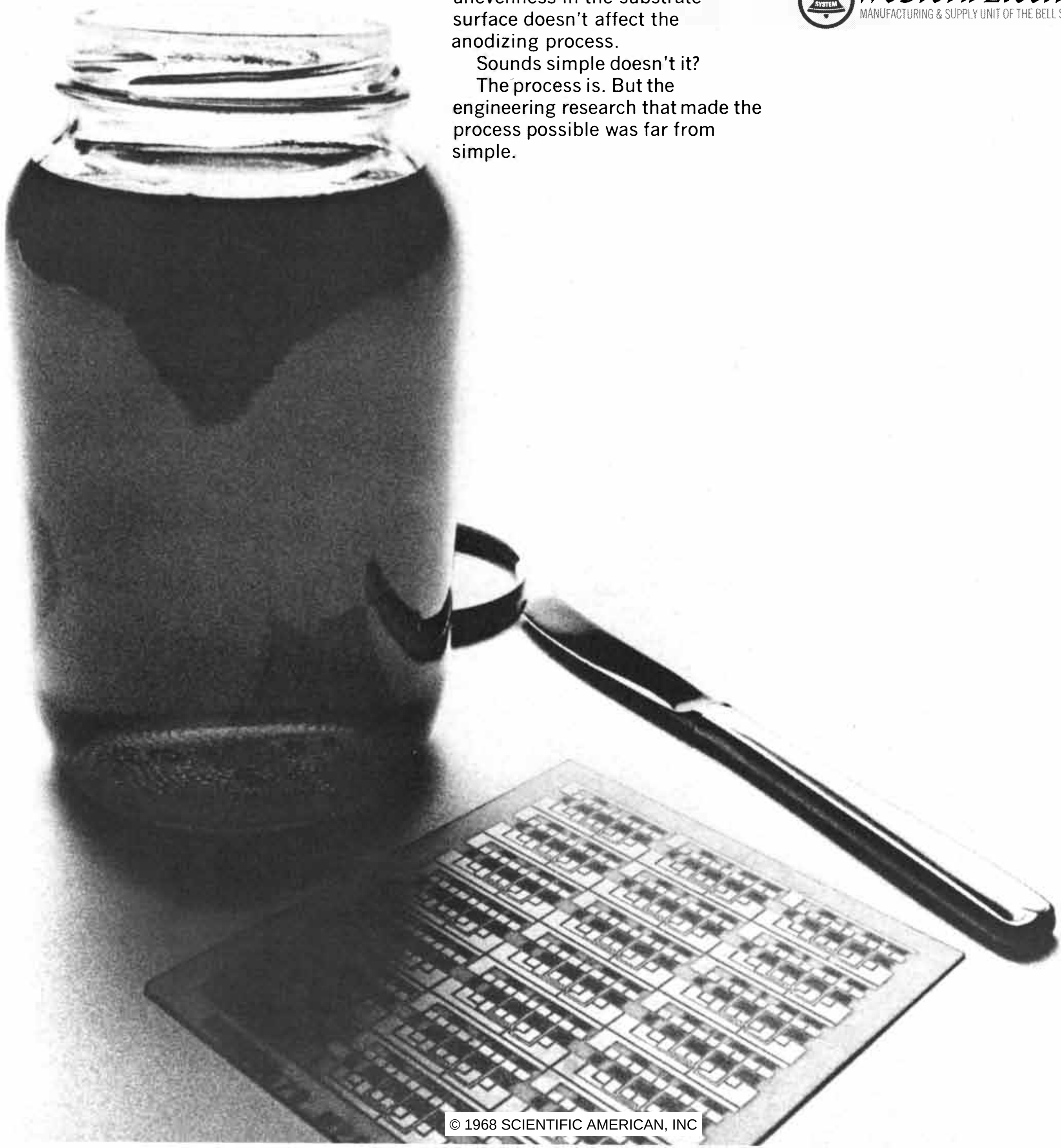


THE SYNTHESIS OF DNA

Test-tube synthesis of the double helix that controls heredity climaxes a half-century of effort by biochemists to re-create biologically active giant molecules outside the living cell

by Arthur Kornberg

My colleagues and I first undertook to synthesize nucleic acids outside the living cell, with the help of cellular enzymes, in 1954. A year earlier James Watson and Francis Crick had proposed their double-helix model of DNA, the nucleic acid that conveys genetic information from generation to generation in all organisms except certain viruses. We attained our goal within a year, but not until some months ago—14 years later—were we able to report a completely synthetic DNA, made with natural DNA as a template, that has the full biological activity of the native material.

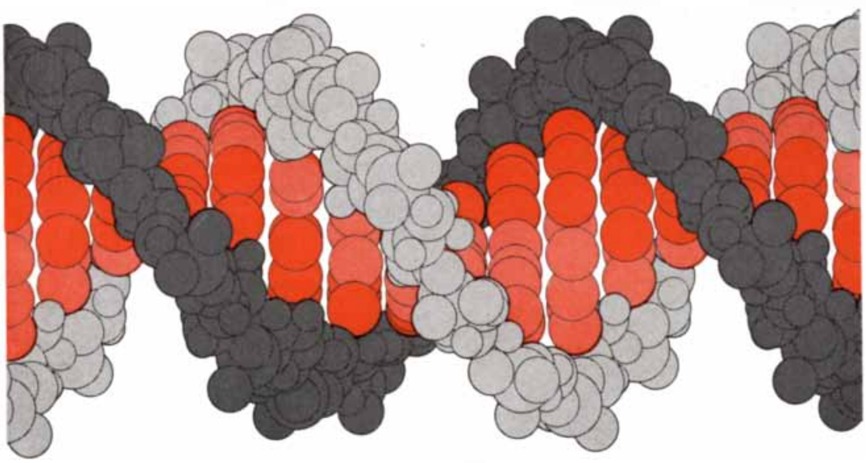
Our starting point was an unusual single-strand form of DNA found in the bacterial virus designated ϕX174. The single strand is in the form of a closed loop. When ϕX174 infects cells of the bacterium *Escherichia coli,* the single-strand loop of DNA serves as the template that directs enzymes in the synthesis of a second loop of DNA. The two loops form a ring-shaped double helix similar to the DNA helixes found in bacterial cells and higher organisms. In our laboratory at the Stanford University School of Medicine we succeeded in reconstructing the synthesis of the single-strand DNA copies of viral DNA and finally in making a completely synthetic double helix. The way now seems open for the synthesis of DNA from other sources: viruses associated with human disease, bacteria, multicellular organisms and ultimately the DNA of vertebrates such as mammals.

An Earlier Beginning

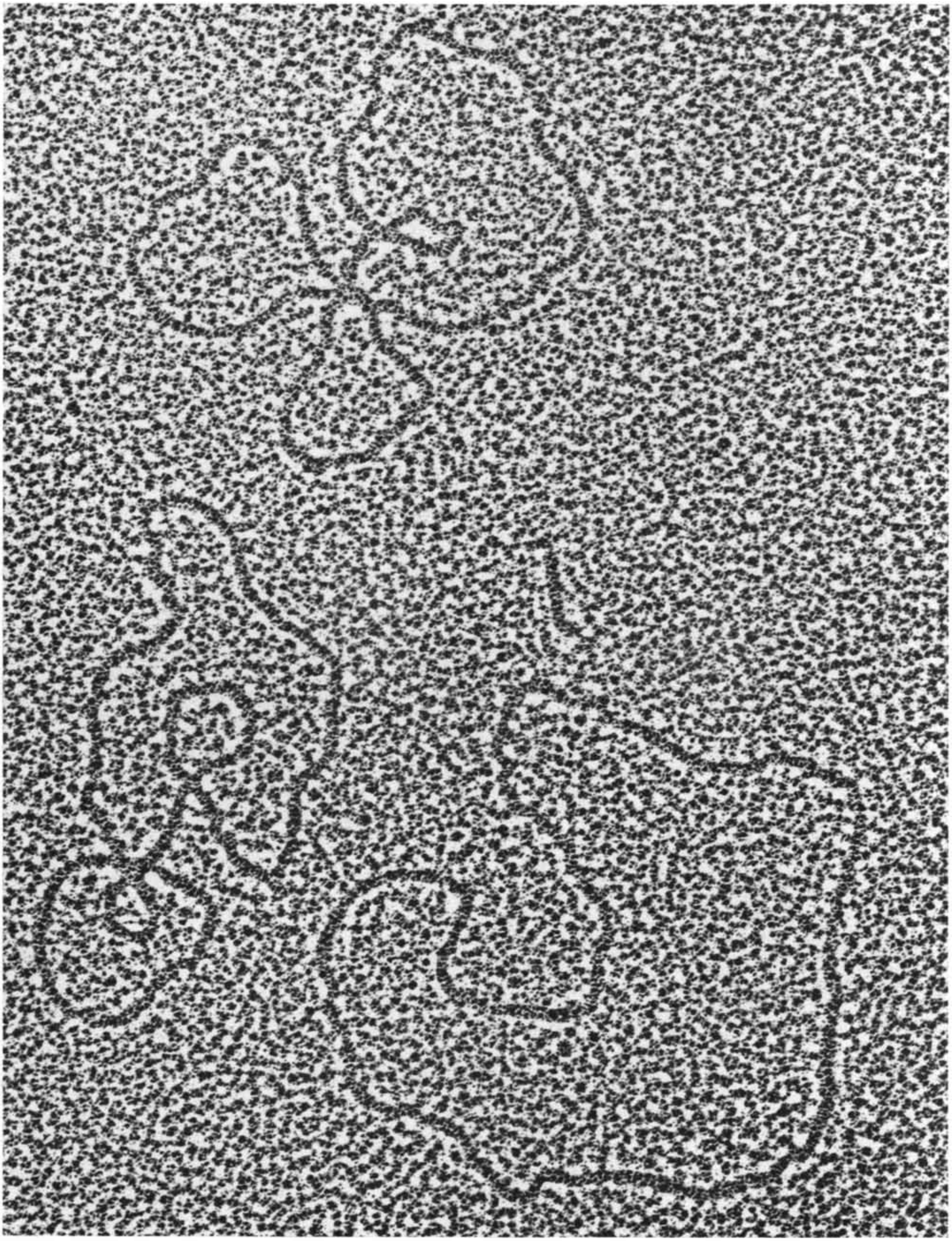
The story of the cell-free synthesis of DNA does not start with the revelation of the structure of DNA in 1953. It begins around 1900 with the biochemical understanding of how the fermentation of fruit juices yields alcohol. Some 40 years earlier Louis Pasteur had convinced his contemporaries that the living yeast cell played an essential role in the fermentation process. Then Eduard Buchner observed in 1897 that a cell-free juice obtained from yeast was just as effective as intact cells for converting sugar to alcohol. This observation opened the era of modern biochemistry.

During the first half of this century biochemists resolved the overall conversion of sucrose to alcohol into a sequence of 14 reactions, each catalyzed by a specific enzyme. When this fermentation proceeds in the absence of air, each molecule of sucrose consumed gives rise to four molecules of adenosine triphosphate (ATP), the universal currency of energy exchange in living cells. The energy represented by the fourfold output of ATP per molecule of sucrose is sufficient to maintain the growth and multiplication of yeast cells. When the fermentation takes place in air, the oxidation of sucrose goes to completion, yielding carbon dioxide and water along with 18 times as much energy as the anaerobic process does. This understanding of how the combustion of sugar provides energy for cell metabolism was succeeded by similar explanations of how enzymes catalyze the oxidation of fatty acids, amino acids and the subunits of nucleic acids for the energy needs of the cell.

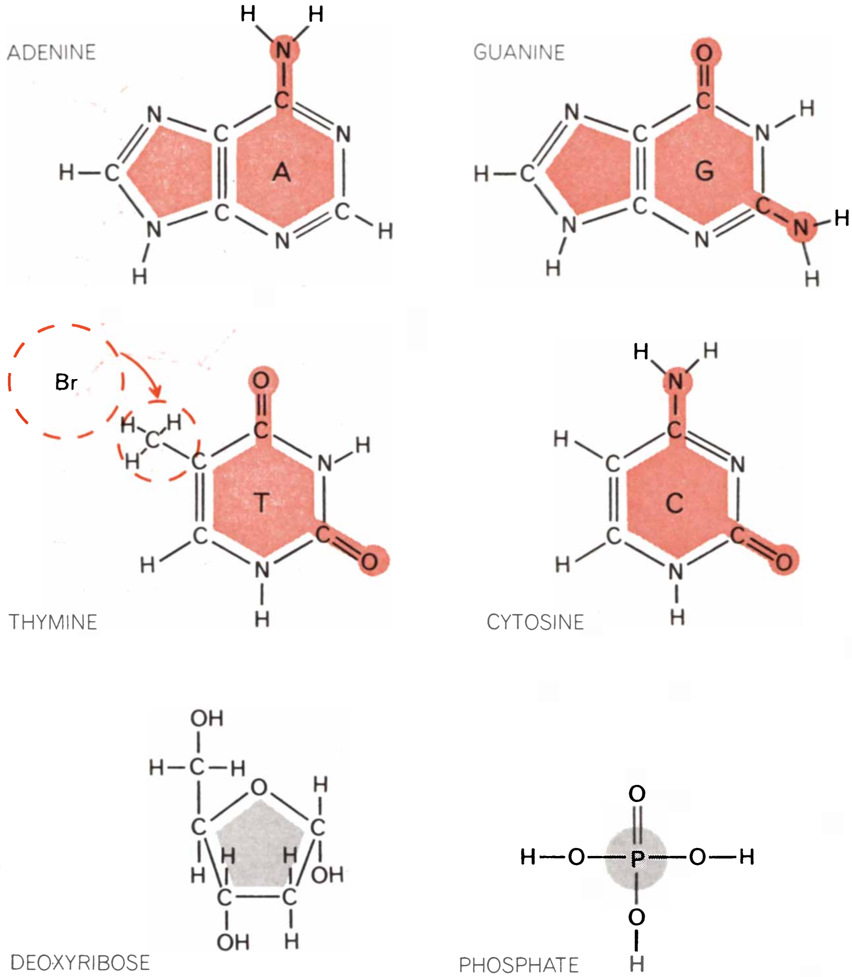
By 1950 the enzymatic dismantling of large molecules was well understood. Little thought or effort had yet been invested, however, in exploring how the cell makes large molecules out of small ones. In fact, many biochemists doubted that biosynthetic pathways could be suc-



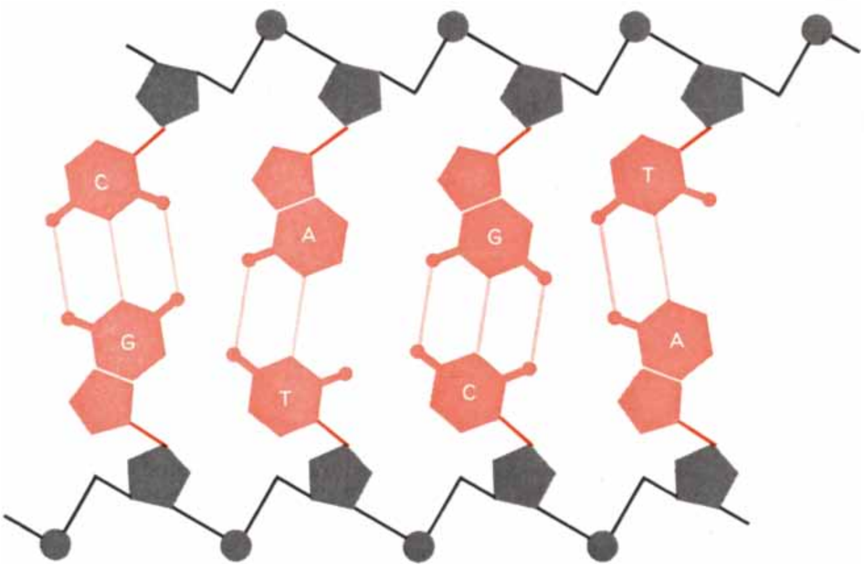
DOUBLE HELIX, the celebrated model of deoxyribonucleic acid (DNA) proposed in 1953 by James D. Watson and F. H. C. Crick, consists of two strands held together by crossties (*color*) that spell out a genetic message, unique for each organism. The Watson-Crick model explained for the first time how each crosstie consists of two subunits, called bases, that form obligatory pairs (*see illustrations on page 66*). Thus each strand of the double helix and its associated sequence of bases is complementary to the other strand and its bases. Consequently each strand can serve as a template for the reconstruction of the other strand.



THREE CLOSED LOOPS OF DNA, each a complete double helix, are shown in this electron micrograph made in the author's laboratory at the Stanford University School of Medicine. One strand of each loop is the natural single-strand DNA of the bacterial virus ϕX174, which served as a template for the test-tube synthesis, carried out by enzymes, of a synthetic complementary strand. The hybrid molecules are biologically active. The enlargement is about 200,000 diameters. Each loop contains some 5,500 pairs of bases. If enlarged to the scale of the model on the opposite page, each loop of DNA would form a circle roughly 150 feet in circumference.



DNA CONSTITUENTS are bases of four kinds, deoxyribose (a sugar) and a simple phosphate. The bases are adenine (*A*) and thymine (*T*), which form one obligatory pair, and guanine (*G*) and cytosine (*C*), which form another. Deoxyribose and phosphate form the backbone of each strand of the DNA molecule. The bases provide the code letters of the genetic message. For purposes of tagging synthetic DNA, thymine can be replaced by 5′-bromouracil, which contains a bromine atom where thymine contains a lighter CH_3 group.



DNA STRUCTURE resembles a ladder in which the side pieces consist of alternating units of deoxyribose and phosphate. The rungs are formed by the bases paired in a special way, A with T and G with C, and held together respectively by two and three hydrogen bonds.

cessfully reconstructed in cell-free systems. Since then nearly two decades of intensive study have been devoted to the cell-free biosynthesis of large molecules. Two things above all have been made clear.

The first is that large molecules can be assembled in cell-free systems with the aid of purified enzymes and coenzymes. The second is that the routes of biosynthesis are different from those of degradation. Some biochemists had speculated that the routes of breakdown were really two-way streets whose flow might somehow be reversed. Now we know that the molecular traffic in cells flows on distinctive and divided highways. All cells have the enzymatic machinery to manufacture most of the subunits of large molecules from simple nutrients such as glucose, ammonia and carbon dioxide. Cells also have the capacity to salvage preformed subunits when they are available. On the basis of what has been learned the prospects are that in this century biochemists will assemble in the test tube complex viruses and major components of the cell. Perhaps the next century will bring the synthesis of a complete cell.

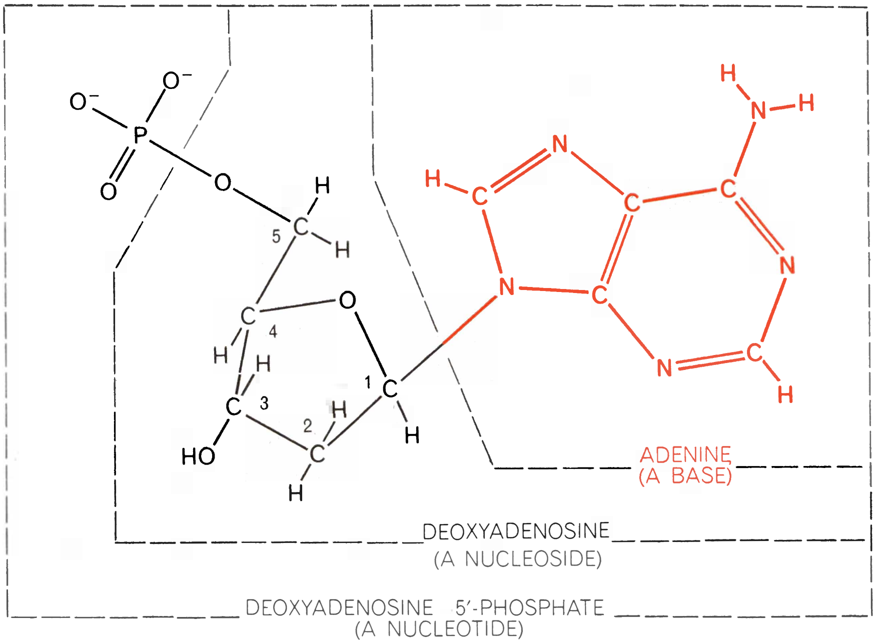
The Nucleotides

My co-workers and I were at Washington University in St. Louis when we made our first attempts to synthesize a nucleic acid in the test tube. By that time the constituents of nucleic acid were well known [*see illustrations at left*]. If one regards DNA as a chain made up of repeating links, the basic link is a structure known as a nucleotide [*see illustration on opposite page*]. It consists of a phosphate group attached to the five-carbon sugar deoxyribose, which is linked in turn to one of four different nitrogen-containing bases. The four bases are adenine (A), thymine (T), guanine (G) and cytosine (C). In the double helix of DNA the phosphate and deoxyribose units alternate to form the two sides of a twisted ladder. The rungs joining the sides consist of two bases: A is invariably linked to T and G is invariably linked to C. This particular pairing arrangement was the key insight of the Watson-Crick model. It means that if the two strands of the helix are separated, uncoupling the paired bases, each half can serve as a template for re-creating the missing half. Thus if the bases projecting from a single strand follow the sequence A, G, G, C, A, T . . . , one immediately knows that the complementary bases on the missing strand are T, C, C, G, T, A. . . . This base-pairing mechanism enables the cell to make accurate copies of the DNA molecule however many times the cell may divide.

When a strand of DNA is taken apart link by link (by treatment with acid or certain enzymes), the phosphate group of the nucleotide may be found attached to carbon No. 3 of the five-carbon deoxyribose sugar. Such a structure is called a 3′-nucleoside monophosphate. We judged, however, that better subunits for purposes of synthesis would be the 5′-nucleoside monophosphates, in which the phosphate linkage is to carbon No. 5 of deoxyribose.

This judgment was based on two lines of evidence. The first had just emerged from an understanding of how the cell itself made nucleotides from glucose, ammonia, carbon dioxide and amino acids. John M. Buchanan of the Massachusetts Institute of Technology had shown that nucleotides containing the bases A and G were naturally synthesized with a 5′ linkage. Our own work had shown the same thing for nucleotides containing T and C. The second line of evidence came from earlier studies my group had conducted at the National Institutes of Health. We had found that certain coenzymes, the simplest molecules formed from two nucleotides, were elaborated from 5′ nucleotide units. For the enzymatic linkage to take place the phosphate of the nucleotide had to be activated by an additional phosphate group [*see illustration on next page*]. Thus it seemed reasonable that activated 5′ nucleotides (nucleoside 5′ triphosphates) might combine with each other, under the proper enzymatic guidance, to form long chains of nucleic acid.

Our initial attempts at nucleic acid synthesis relied principally on two techniques. The first involved the use of radioactive atoms to label the nucleotide so that we could detect the incorporation of even minute amounts of it into nucleic acid. We sought the enzymatic machinery for synthesizing nucleic acids in the juices of the thymus gland, bone marrow and bacterial cells. Unfortunately such extracts also have a potent capacity for degrading nucleic acids. We added our labeled nucleotides to a pool of nucleic acids and hoped that a few synthesized molecules containing a labeled nucleotide would survive by being mixed into the pool. Even if there were net destruction of the pool of nucleic acids, the synthesis of a few molecules trapped in this pool might still be detected. The second technique exploited the fact that the nucleic acid could be precipitated by making the medium strongly acidic, whereas the nucleotide precursors remained behind in solution.



DNA BUILDING BLOCK, the monomer from which DNA polymers are constructed, is termed a nucleotide. There are four nucleotides, one for each of the four bases A, T, G and C. Deoxyadenosine 5′-phosphate, the nucleotide incorporating adenine, is shown here. If the phosphate group is replaced by a hydrogen atom, the structure is called a nucleoside.

Our first experiments with animal-cell extracts were uniformly negative. Therefore we turned to *E. coli*, which has the virtue of reproducing once every 20 minutes. Here we saw a glimmer. In samples to which we had added a quantity of labeled nucleotides whose radioactive atoms disintegrated at the rate of a million per minute we detected about 50 radioactive disintegrations per minute in the nucleic acid fraction that was precipitated by acid. Although the amount of nucleotide incorporated into nucleic acid was minuscule, it was nonetheless significantly above the level of background "noise." Through this tiny crack we tried to drive a wedge. The hammer was enzyme purification, a technique that had matured during the elucidation of alcoholic fermentation.

DNA Polymerase

In these experiments Uriel Littauer, a Fellow of the Weizmann Institute in Israel, and I observed the incorporation of adenylate (a nucleotide) from ATP into ribonucleic acid (RNA), in which the five-carbon sugar in the backbone of the chain is ribose rather than deoxyribose. Actually the first definitive demonstration of synthesis of an RNA-like molecule in a cell-free system had been achieved in the laboratory of Severo Ochoa in 1955. Working at the New York University School of Medicine, he and Marianne Grunberg-Manago were investigating an aspect of energy metabolism and made the unexpected observation that one of the reactants, adenosine diphosphate (ADP), had been polymerized by cell juices into a chain of adenylates resembling RNA.

In our first attempts to achieve DNA synthesis in a cell-free system we used the deoxyribonucleoside called deoxythymidine. To Morris E. Friedkin, who was then at Washington University, we are grateful not only for supplying the radioactively labeled compound but also for the knowledge that the compound was readily incorporated into DNA by bone marrow cells and other animal cells. We were hopeful that extracts of *E. coli* would be able to incoporate deoxythymidine into nucleic acid by converting it first into the 5′ deoxynucleotide and then activating the deoxynucleotide to the triphosphate form. I found this to be the case. In subsequent months Ernest Simms and I were able to prepare separately deoxythymidine 5′-triphosphate and the other deoxynucleoside triphosphates, using enzymes or chemical synthetic routes. (In what follows the various deoxynucleosides in their 5′ triphosphate form will be designated simply by the initial of the base followed by an asterisk. Thus deoxythymidine 5′-triphosphate will be T*.)

In November, 1955, I. Robert Lehman, who is now at Stanford, started on the purification of the enzyme system in *E. coli* extracts that is responsible for converting T^* into DNA. We were joined by Maurice J. Bessman some weeks later. Those were eventful days in which the enzyme, now given the name DNA polymerase, was progressively separated from other large molecules. With each step in purification the character of this DNA synthetic reaction became clearer. By June, 1956, when we participated at a conference on the chemical basis of heredity held at Johns Hopkins University, we could report two important facts about DNA synthesis in vitro, although we still lacked the answers to many important questions.

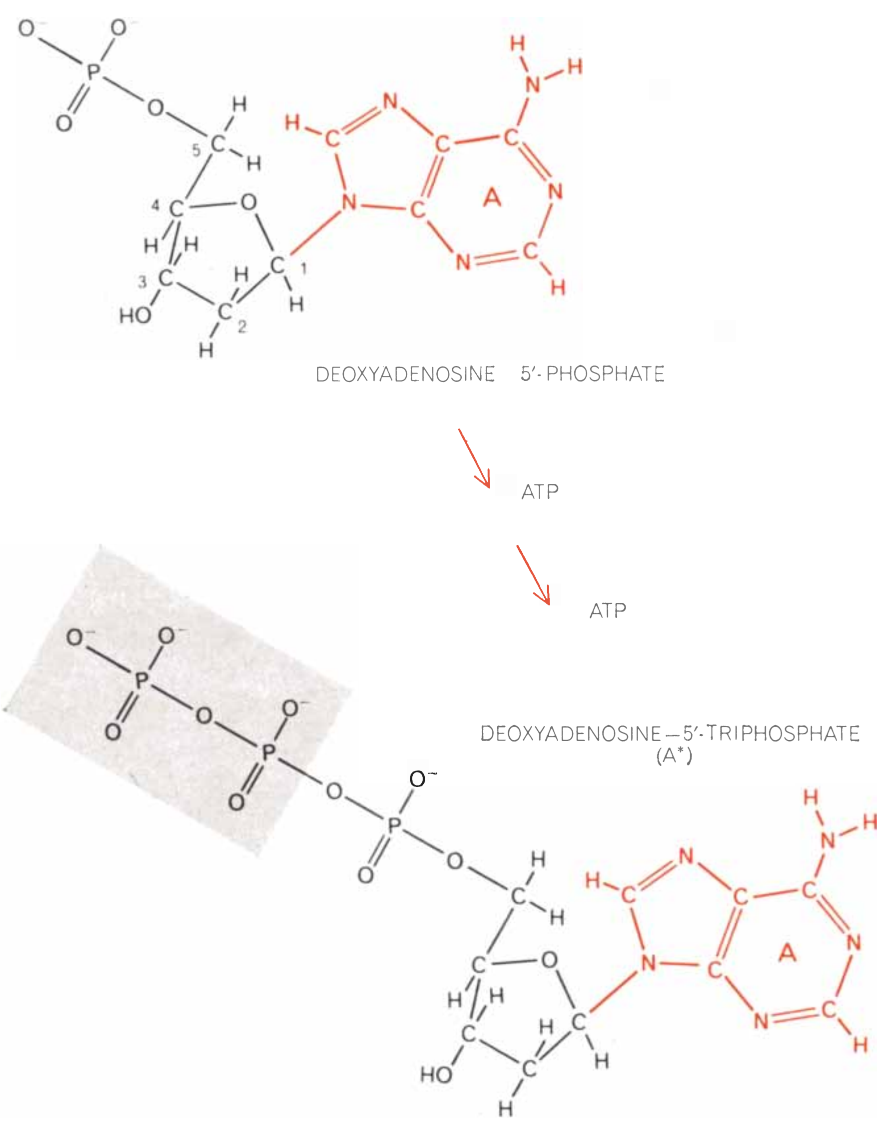
We reported first that preformed DNA had to be present along with DNA polymerase, and that all four of the deoxynucleotides that occur in DNA (A, G, T and C) had to be furnished in the activated triphosphate form. We also reported that DNA from virtually any source—virus, bacterium or animal—could serve with the *E. coli* enzyme. What we still did not know was whether the synthetic DNA was a new molecule or an extension of a preexisting one. There were other questions. Did the synthetic DNA have the same chemical backbone and physical structure as natural DNA? Did it have a chemical composition typical of DNA, in which A equals T and G equals C, and in which, therefore, A plus G equals T plus C? Finally, and crucially: Did the chemical composition of the synthetic DNA reflect the composition of the particular natural DNA used to direct the reaction.

During the next three years these questions and related ones were resolved by the efforts of Julius Adler, Sylvy Kornberg and Steven B. Zimmerman. The synthetic DNA was shown to be a molecule with the chemical structure typical of DNA and the same ratio of A-T pairs to G-C pairs as the particular DNA used to prime, or direct, the reaction [*see illustration on page 70*]. The relative starting amounts of the four deoxynucleoside triphosphates had no influence whatever on the composition of the new DNA. The composition of the synthetic DNA was determined solely by the composition of the DNA that served as a template. An interesting illustration of this last fact justifies a slight digression.

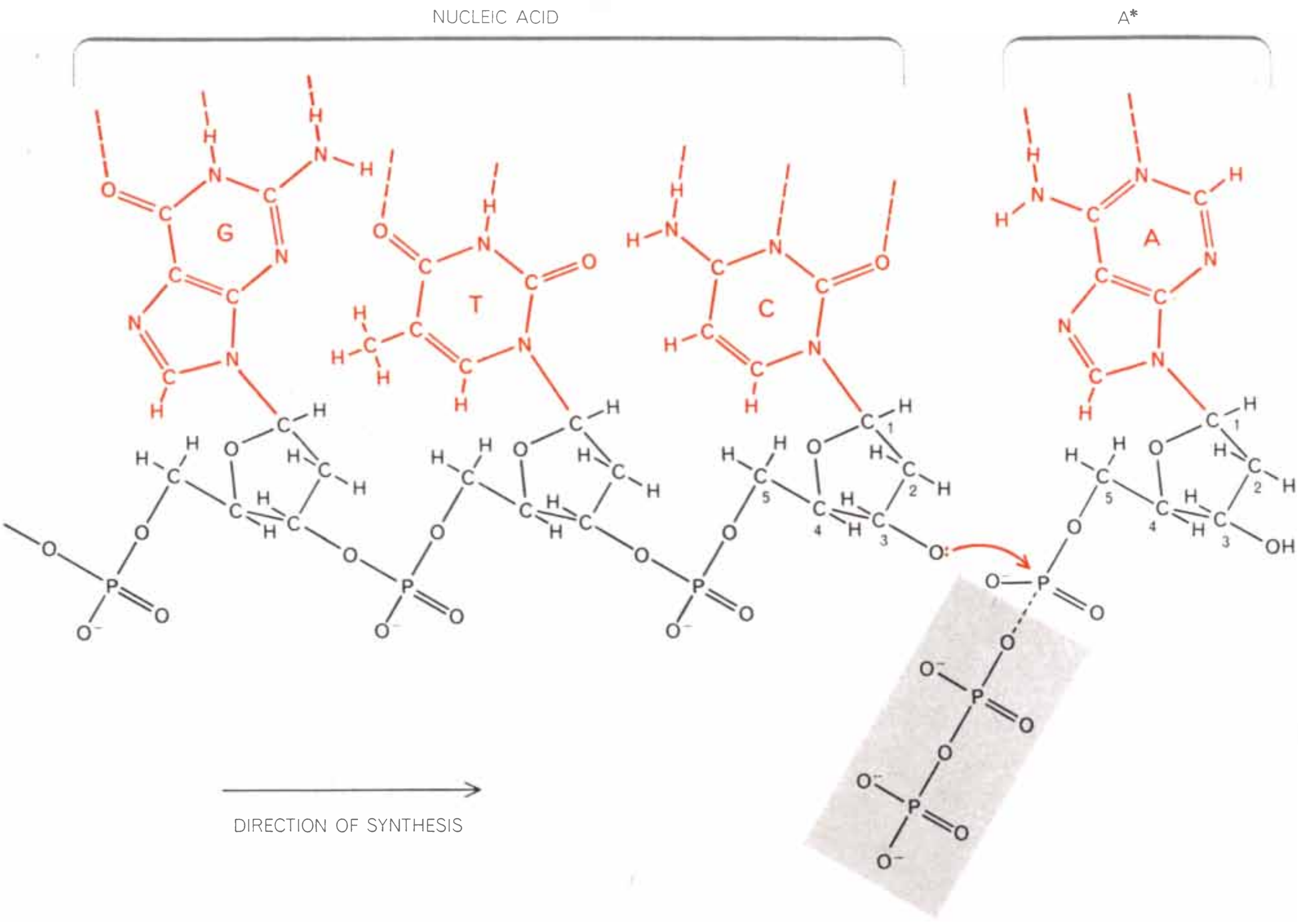
Howard K. Schachman of the University of California at Berkeley spent his sabbatical year of 1957–1958 with us at Washington University examining the physical properties of the synthetic DNA. It had the high viscosity, the comparatively slow rate of sedimentation and other physical properties typical of natural DNA. The new DNA, like the natural one, was therefore a long, fibrous polymer molecule. Moreover, the longer the mixture of active ingredients was allowed to incubate, the greater the viscosity of the product was; this was direct evidence that the synthetic DNA was continuing to grow in length and in amount. However, we were startled to find one day that viscosity developed in a control test tube that lacked one of the essential triphosphates, G^*. To be sure, no reaction was observed during the standard incubation period of one or two hours. On prolonging the incubation for several more hours, however, a viscous substance materialized!

Analysis proved this substance to be a DNA that contained only A and T nucleotides. They were arranged in a perfect alternating sequence. The isolated polymer, named dAT, behaved like any other DNA in directing DNA synthesis: it led to the immediate synthesis of more dAT polymer. Would any G^* and C^* be polymerized if these nucleotides were present in equal or even far greater amounts than A^* and T^* in a synthesis directed by dAT polymer? We found no detectable incorporation of G or C under conditions that would have measured the inclusion of even one G for every 100,000 A or T nucleotides polymerized. Thus DNA polymerase rarely, if ever, made the mistake of matching G or C with A or T.

The DNA of a chromosome is a linear array of many genes. Each gene, in turn,



ACTIVATED BUILDING BLOCK is required when synthesizing DNA on a template of natural DNA with the aid of enzymes. The activated form of the nucleotide containing adenine is deoxyadenosine 5′-triphosphate, symbolized in this article by "A*." It is made from deoxyadenosine 5′-monophosphate by two different enzymes in two steps. Each step involves the donation of a terminal phosphate group from adenosine triphosphate (ATP).



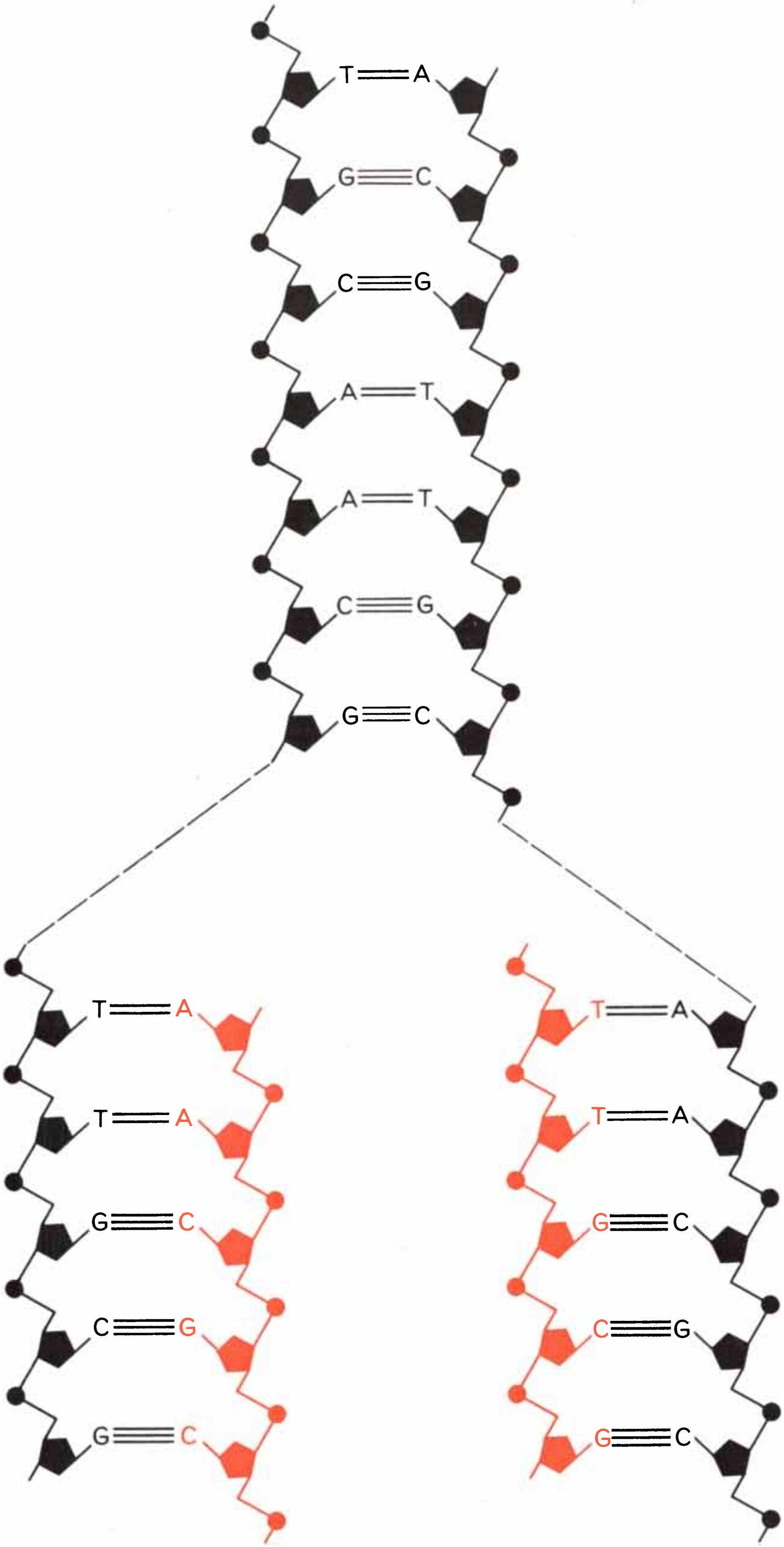
SYNTHESIS OF DNA involves the stepwise addition of activated nucleotides to the growing polymer chain. In this illustration deoxyadenosine 5′-triphosphate (A*) is being coupled through a phosphodiester bond that links the 3′ carbon in the deoxyribose portion of the last nucleotide in the growing chain to the 5′ carbon in the deoxyribose portion of the newest member of the chain.

is a chain of about 1,000 nucleotides in a precisely defined sequence, which when translated into amino acids spells out a particular protein or enzyme. Does DNA polymerase in its test-tube synthesis of DNA accurately copy the sequential arrangement of nucleotides by base-pairing (A = T, G = C) without errors of mismatching, omission, commission or transposition? Unfortunately techniques are not available for determining the precise sequence of nucleotides of even short DNA chains. Because it is impossible to spell out the base sequence of natural DNA or any copy of it, we have resorted to two other techniques to test the fidelity with which DNA polymerase copies the template DNA. One is "nearest neighbor" analysis. The other is the duplication of genes with demonstrable biological activity.

Nearest-Neighbor Analysis

The nearest-neighbor analysis devised by John Josse, A. Dale Kaiser and myself in 1959 determines the relative frequency with which two nucleotides can end up side by side in a molecule of synthetic DNA. There are 16 possible combinations in all. There are four possible nearest-neighbor sequences of A (AA, AG, AT and AC), four for G (GA, GG, GT and GC) and similarly four for T and four for C. How can the frequency of these dinucleotide sequences be determined in a synthetic DNA chain? The procedure is to use a triphosphate labeled with a radioactive phosphorus atom in conducting the synthesis and to treat the synthesized DNA with a specific enzyme that cleaves the DNA and leaves the radioactive phosphorus atom attached to its nearest neighbor. For example, DNA synthesis is carried out with A* labeled in the innermost phosphate group, the group that will be included in the DNA product. This labeled phosphate group now forms a normal linkage (10^{16} times in a typical experiment!) with the nucleotide next to it in the chain—its nearest neighbor [*see illustration on page 76*]. After the synthetic DNA is isolated it is subjected to degradation by an enzyme that cleaves every bond between the 5′ carbon of deoxyribose and the phosphate, leaving the radioactive phosphorus atom attached to the neighboring nucleotide rather than to the one (A) to which it had originally been attached. The nucleotides of the degraded DNA are readily separated by electrophoresis or paper chromatography into the four types of which DNA is composed: A, G, T and C. Radioactive assay establishes the radioactive phosphorus content in each of these nucleotides and at once indicates the frequency with which A is next to A, to G, to T and to C.

The entire experiment is repeated, this time with the radioactive label in G* instead of A*. The second experiment yields the frequency of GA, GG, GT and GC dinucleotides. Two more experiments with radioactive T* and C* complete the analysis and establish the 16 possible nearest-neighbor frequencies.



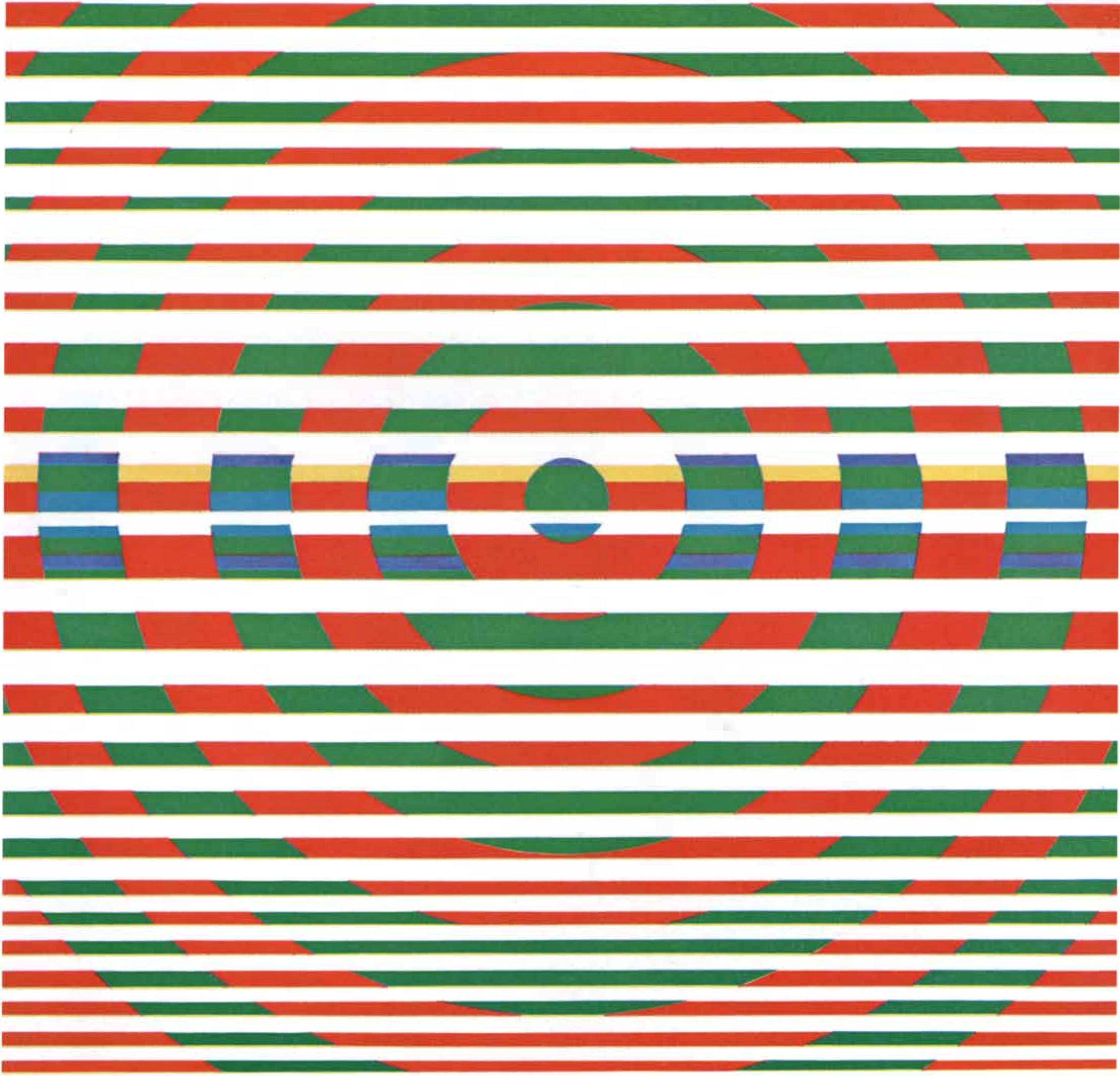
SYNTHESIS OF DUPLEX CHAIN OF DNA yields two hybrid molecules, consisting of a parental strand and a daughter strand, that are identical with each other and with the original duplex molecule. During the replicating process the parental duplex (*black*) separates into two strands, each of which then serves as the template for assembly of a daughter strand (*color*). The pairing of A with T and G with C guarantees faithful reproduction.

Many such experiments were performed with DNA templates obtained from viruses, bacteria, plants and animals. The DNA of each species guided the synthesis of DNA with what proved to be a distinctive assortment of nearest-neighbor frequencies. What is more, when a synthetic DNA was used as a template for a new round of replication, it gave rise to DNA with a nearest-neighbor frequency distribution identical with itself. Among the other insights obtained from these analyses was the recognition of a basic fact about the structure of the double helix. In replication the direction of the DNA chain being synthesized was found to run opposite to that of its template. By inference we can conclude that the chains of the double helix in natural DNA, as surmised by Watson and Crick, must also run in opposite directions.

Even with considerable care the accuracy of nearest-neighbor frequency analysis cannot be better than about 98 percent. Consequently we were still left with major uncertainties as to the precision of copying chains that contain 1,000 nucleotides or more, corresponding to the length of genes. An important question thus remained unanswered: Does DNA that is synthesized on a genetically or biologically active template duplicate the activity of that template?

One way to recognize the biological activity of bacterial DNA is to see if it can carry out "transformation," a process in which DNA from one species of bacteria alters the genetic endowment of a second species. For example, DNA from a strain of *Bacillus subtilis* resistant to streptomycin can be assimilated by a strain susceptible to the antibiotic, whereupon the recipient bacterium and all its descendants carry the trait of resistance to streptomycin. In other words, DNA molecules carrying the genes for a particular characteristic can be identified by their capacity for assimilation into the chromosome of a cell that previously lacked that trait. Yet when DNA was synthesized on a template of DNA that had transforming ability, the synthetic product invariably lacked that ability.

Part of the difficulty in synthesizing biologically active DNA lay in the persistence of trace quantities of nuclease enzymes in our DNA polymerase preparations. Nucleases are enzymes that degrade DNA. The introduction by a nuclease of one break in a long chain of DNA is enough to destroy its genetic activity. Further purification of DNA polymerase was indicated. Efforts over



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several years by Charles C. Richardson, Thomas Jovin, Paul T. Englund and LeRoy L. Bertsch resulted in a new procedure that was both simple and efficient. Finally, in April, 1967, with the assistance of the personnel and large-scale equipment of the New England Enzyme Center (sponsored by the National Institutes of Health at the Tufts University School of Medicine), we processed 100 kilograms of *E. coli* bacterial paste and obtained about half a gram of pure enzyme, free of the nuclease that puts random breaks in a DNA chain.

Unfortunately even this highly purified DNA polymerase has proved incapable of producing a biologically active DNA from a template of bacterial DNA. The difficulty, we believe, is that the DNA we extract from a bacterium such as *B. subtilis* provides the enzyme with a poor template. A proper template would be the natural chromosome, which is a double-strand loop about one millimeter in circumference. During its isolation from the bacterium the chromosome is broken, probably at random, into 100 or more fragments. The manner in which DNA polymerase and its related enzymes go about the replication of a DNA molecule as large and complex as the *B. subtilis* chromosome is the subject of current study in many laboratories.

The Virus ϕX174

It occurred to us in 1964 that the problem of synthesizing biologically active DNA might be solved by dealing with a simpler form of DNA that also has genetic activity. This is represented in viruses, such as ϕX174, whose DNA core is a single-strand loop. This "chromosome" not only is simpler in structure but also it is so small (about two microns in circumference) that it is fairly easy to extract without breakage. We also knew from the work of Robert L. Sinsheimer at the California Institute of Technology that when the DNA of ϕX174 invades *E. coli,* the first stage of infection involves the "subversion" of one of the host's enzymes to convert the single-strand loop into a double-strand helical loop. Sinsheimer called this first-stage product a "replicative form." Could the host enzyme that copies the viral DNA be the same DNA polymerase we had isolated from *E. coli?*

In undertaking the problem of copying a closed-loop DNA we could foresee some serious obstacles. Would it be possible for DNA polymerase to orient itself and start replication on a DNA template if the template had no ends? Shashanka Mitra and later Peter Reichard succeeded in finding conditions under which the enzyme, as judged by electron microscope pictures, appeared to copy the single-strand loop. We then wondered if in spite of appearances in the electron micrographs, the DNA of ϕX174 was really just a simple loop. Perhaps, as had been suggested by other workers, it was really more like a necklace with a clasp, the clasp consisting of substances unrelated to the nucleotides we were supplying. Finally, we were aware from Sinsheimer's work that the DNA of ϕX174 had to be a completely closed loop in order to be infectious. We knew that our polymerase could only catalyze the synthesis of linear DNA molecules. How could we synthesize a genuinely closed loop? We were still missing either the clasplike component to insert into our product or, if the clasp was a mistaken hypothesis, a new kind of enzyme to close the loop.

Fortunately the missing factor was provided for us by work carried on independently in five different laboratories. The discovery in 1966 of a polynucleotide-joining enzyme was made almost simultaneously by Martin F. Gellert and his co-workers at the National Institutes of Health, by Richardson and Bernard Weiss at the Harvard Medical School, by Jerard Hurwitz and his colleagues at the Albert Einstein College of Medicine in New York, by Lehman and Baldomero M. Olivera at Stanford and by Nicholas R. Cozzarelli in my own group. It was the Lehman-Olivera preparation that we now employed in our experiments.

The polynucleotide-joining enzyme has the ability to repair "nicks" in the DNA strand. The nicks occur where there is a break in the sugar-phosphate backbone of one strand of the DNA molecule. The enzyme can repair a break only if all the nucleotides are intact and if what is missing is the covalent bond in the DNA backbone between a sugar and the neighboring phosphate. Provided with the joining enzyme, we were now in a position to find out whether it could work in conjunction with DNA polymerase to synthesize a completely circular and biologically active virus DNA.

By using the DNA of ϕX174 as a template we gained an important advantage over experiments based on transforming ability. Even if we were successful in synthesizing a DNA with transforming activity, this would still be of relatively limited significance. We could then say only that a restricted section of the

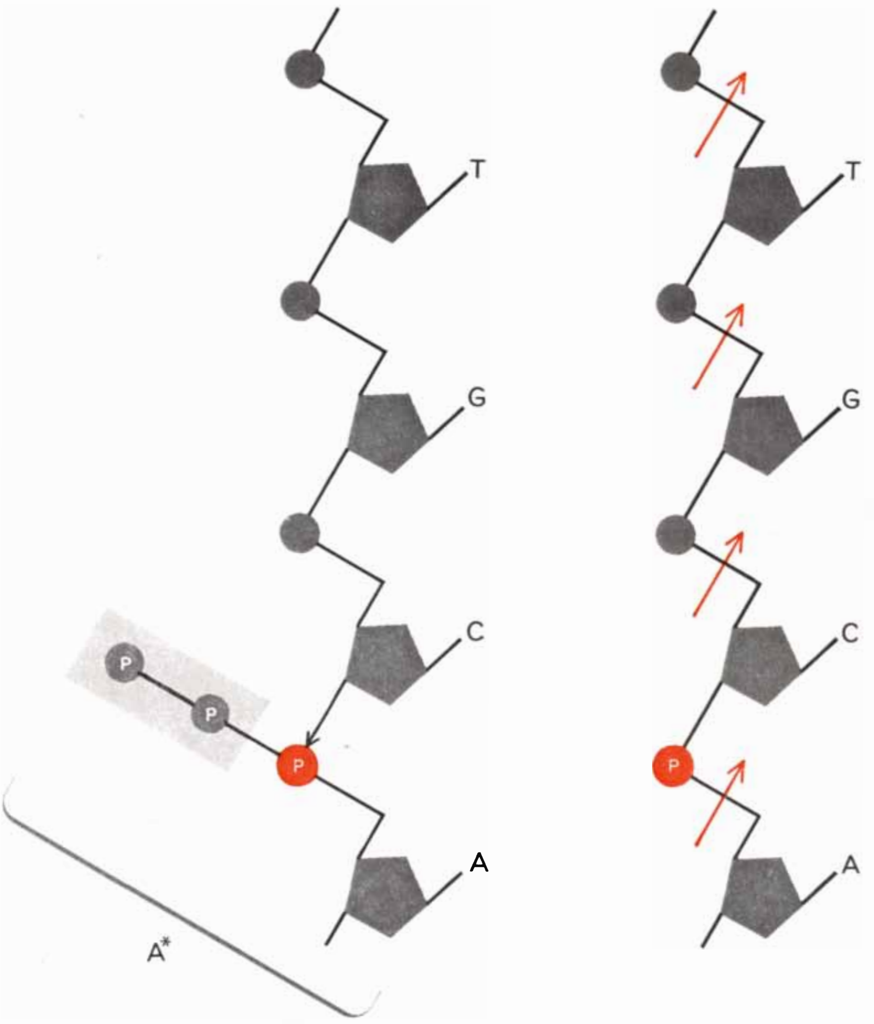
DNA—a section as small as a part of a gene—had been assimilated by the recipient cell to replace a comparable section of its chromosome, substituting a proper sequence for a defective or incorrect one. However, Sinsheimer had demonstrated with the DNA of φX174 that a change in even one of its 5,500 nucleotides is sufficient to make the virus noninfective. Therefore the demonstration of infectivity in a completely synthetic virus DNA would conclusively prove that we had carried out virtually error-free synthesis of this large number of nucleotides, comprising the five or six genes that carry out the virus's biological function.

In less than a year the test-tube synthesis of φX174 DNA was achieved. The steps can be summarized as follows. Template DNA was obtained from φX174 and labeled with tritium, the radioactive isotope of hydrogen. Tritium would thereafter provide a continuing label identifying the template. To the template were added DNA polymerase, purified joining enzyme and a cofactor (diphosphopyridine nucleotide), together with A*, T*, G* and C*. One of the nucleoside triphosphates was labeled with radioactive phosphorus. The radioactive phosphorus would thus provide a label for synthetic material analogous to the tritium label for the template. The interaction of the reagents then proceeded until the number of nucleotide units polymerized was exactly equal to the number of nucleotides in the template DNA. This equality was readily determined by comparing the radioactivity from the tritium in the template with the radioactivity from the phosphorus in the nucleotides provided for synthesis.

Such comparison showed that the experiments had progressed to an extent adequate for the formation of complementary loops of synthetic DNA. Complementary loops were designated (−) to distinguish them from the template loop (+). We had to demonstrate that the synthetic (−) loops were really loops. Had the polymerase made a full turn around the template and had the two ends of the chain been united by the joining enzyme? Several physical measurements, including electron microscopy, assured us that our product was a closed loop coiled tightly around the virus-DNA template and that it was identical in size and other details with the replicative form of DNA that appears in the infected cells. We could now exclude the possibility that some clasp material different from the nucleotide-containing compounds we had employed was involved in closing the virus-DNA loop.

The critical questions remaining were whether the synthetic (−) loops had biological activity—that is, infectivity—and whether the synthetic loops could in turn act as templates for the formation of a completely synthetic "duplex" DNA analogous to the replicative forms that were produced naturally inside infected cells. In order to answer the first of these questions we had to isolate the synthetic DNA strands from the partially synthetic duplexes. For reasons that will be apparent below, we substituted bromouracil, a synthetic but biologically active analogue of thymine, for thymine [*see top illustration on page 66*]. We then introduced just enough nuclease to produce a single nick in one strand of about half the population of molecules. The duplex loops that had been nicked would release a single linear strand of DNA; these single strands could be separated from their circular companions and from unnicked duplex loops by heating. Thus we were left with a mixture that contained (+) template loops, (−) synthetic loops, (+) template linear forms, (−) synthetic linear forms—all in about equal quantities—and full duplex loops.

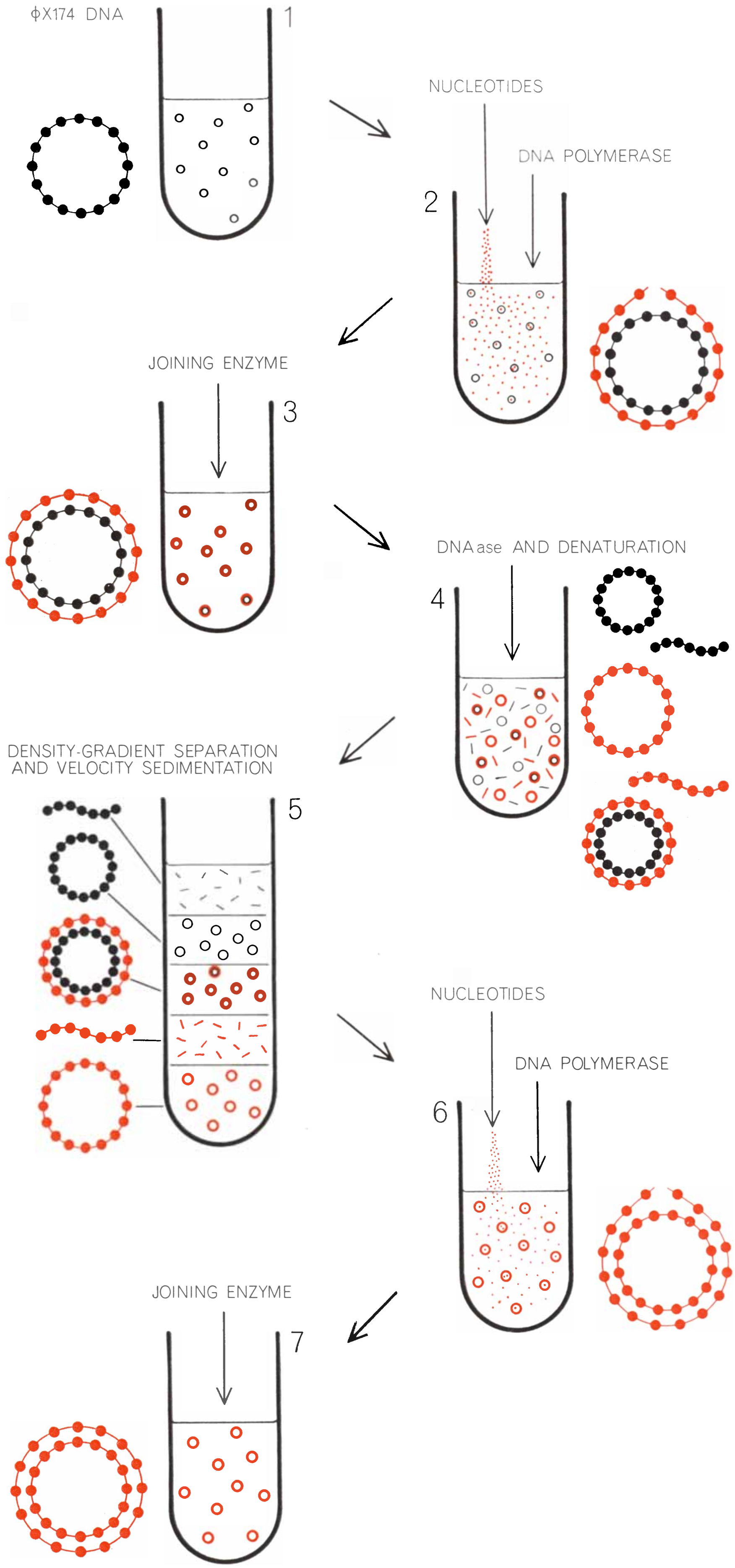
It was at this point that the substitution of bromouracil for thymine became



"NEAREST NEIGHBOR" ANALYSIS can reveal how often any of the four bases is located next to any other base in a single strand of synthetic DNA. Thus one can learn how often A is next to A, T, G or C, and so on. A radioactive phosphorus atom (*color*) is placed in the innermost position of one of the activated nucleotides, for example A*. The finished DNA molecule is then treated with an enzyme (*right*) that cleaves the chain between every phosphate and the 5′ carbon of the adjacent deoxyribose. Thus the phosphate is separated from the nucleotide on which it entered the chain and ends up attached to the nearest neighbor instead, C in the above example. The four kinds of nucleotide are separated by paper chromatography and the radioactivity associated with each is measured. The experiment is repeated with radioactive phosphorus linked to the other activated nucleotides.

useful. Because bromouracil contains a bromine atom in place of the methyl group of thymine, it is heavier than the thymine. Therefore a molecule containing bromouracil can be separated from one containing thymine by high-speed centrifugation in a heavy salt solution (the density-gradient technique perfected by Jerome R. Vinograd of Cal Tech). In this system the denser a substance is, the lower in the centrifuge tube it will settle. Thus from top to bottom of the centrifuge tube we obtained fractions containing the light single strands of thymine-containing (+) template DNA, the duplex hybrids of intermediate weight and finally the single-strand synthetic (−) DNA "weighted down" with bromouracil. The reliability of this fractionation was confirmed by three separate peaks of radioactivity corresponding to each of the fractions. We were further reassured by observations that the mean density of each fraction corresponded almost exactly to the mean density of standard samples of virus DNA containing bromouracil or thymine.

Still another physical technique involving density-gradient sedimentation was employed to separate the synthetic linear forms from the synthetic circular forms. The circular forms could then be used in tests of infectivity, by methods previously developed by Sinsheimer to demonstrate the infectivity of circular ϕX174 DNA. We tested our (−) loops by incubating them with *E. coli* cells whose walls had been removed by the action of the enzyme lysozyme. Infectivity is assayed by the ability of the virus to lyse, or dissolve, these cells when they are "plated" on a nutrient me-



SYNTHESIS OF ϕX174 DNA was accomplished by the following steps. Circular single-strand ϕX174 DNA, tagged with tritium, served as a template (*1*). Activated nucleotides containing A, G, C and 5′-bromouracil instead of T were added to the template, together with DNA polymerase. One of the activated nucleotides was tagged with radioactive phosphorus. The DNA synthesized on the template was complete but not yet joined in a loop (*2*). The loop was closed by the joining enzyme (*3*). Enough nuclease was now added to cut one strand in about half of all the duplex loops (*4*). This left a mixture of complete duplex loops, template loops, synthetic loops, linear template strands and linear synthetic strands. Since the synthetic strands contained 5′-bromouracil, they were heavier than the template strands and could be separated by centrifugation (*5*). The synthetic loops were then isolated and used as templates for making wholly synthetic duplex loops (*6 and 7*).

dium. Our synthetic loops showed almost exactly the same patterns of infectivity as their natural counterparts had. Their biological activity was now demonstrated.

One further set of experiments remained in which the (−) synthetic loops were employed as the template to determine if we could produce completely synthetic duplex circular forms analogous to the replicative forms found in cells infected with natural ϕX174 virus. Because the synthetic (−) loops were labeled with radioactive phosphorus, this time we added tritium to one of the nucleotide-containing subunits (C*). The remaining procedures were essentially the same as the ones described above, and we did produce fully synthetic duplex loops of ϕX174. The (+) loops were then separated and were found to be identical in all respects with the (+) loops of natural ϕX174 virus. Their infectivity could also be demonstrated. Sinsheimer had previously shown that, under these assay conditions, a change in a single nucleotide of the virus gave rise to a mutant of markedly decreased infectivity. Therefore the correspondence between the infectivity of our synthetic forms and their natural counterparts attested to the precision of the enzymatic operation.

Future Directions

The total synthesis of infective virus DNA by DNA polymerase with the four deoxynucleoside triphosphates not only demonstrates the capacity of this enzyme to copy a small chromosome (of five or six genes) without error but also shows that this chromosome, at least, is as simple and straightforward as a linear sequence of the standard four deoxynucleotide units. It is a long step to the human chromosome, some 10,000 times larger, yet we are encouraged to extrapolate our current conceptions of nucleotide composition and nucleotide linkage from the tiny ϕX174 chromosome to larger ones.

What are the major directions this research will take? I see at least three immediate and productive paths. One is the exploration of the physical and chemical nature of DNA polymerase in order to understand exactly how it performs its error-free replication of DNA. Without this knowledge of the structure of the enzyme and how it operates under defined conditions in the test tube, our understanding of the intracellular behavior of the enzyme will be incomplete.

A second direction is to clarify the control of DNA replication in the cell and in the animal. Why is DNA synthesis arrested in a mature liver cell and what sets it in motion 24 hours after part of the liver is removed surgically? What determines the slow rate of DNA replication in adult cells compared with the rate in embryonic or cancer cells? The time is ripe for exploration of the factors that govern the initiation and rate of DNA synthesis in the intact cell and animal. Finally, there are now prospects of applying our knowledge of DNA structure and synthesis directly to human welfare. This is the realm of genetic engineering, and it is our collective responsibility to see that we exploit our great opportunities to improve the quality of human life.

An obvious area for investigation would be the synthesis of the polyoma virus, a virus known to induce a variety of malignant tumors in several species of rodents. Polyoma virus in its infective form is made up of duplex circular DNA and presumably replicates in this form on entering the cell. On the basis of our experience it would appear quite feasible to synthesize polyoma virus DNA. If this synthesis is accomplished, there would seem to be many opportunities for modifying the virus DNA and thus determining where in the chromosome its tumor-producing capacity lies. With this knowledge it might prove possible to modify the virus in order to control its tumor-producing potential.

Our speculations can extend even to large DNA molecules. For example, if a failure in the production of insulin were to be traced to a genetic deficit, then administration of the appropriate synthetic DNA might conceivably provide a cure for diabetes. Of course, a system for delivering the corrective DNA to the cells must be devised. Even this does not seem inconceivable. The extremely interesting work of Stanfield Rogers at the Oak Ridge National Laboratory suggests a possibility. Rogers has shown that the Shope papilloma virus, which is not pathogenic in man, is capable of inducing production of the enzyme arginase in rabbits at the same time that it induces tumors. Rogers found that in the blood of laboratory investigators working with the virus there is a significant reduction of the amino acid arginine, which is destroyed by arginase. This is apparently an expression of enhanced arginase activity. Might it not be possible, then, to use similar nonpathogenic viruses to carry into man pieces of DNA capable of replacing or repairing defective genes?

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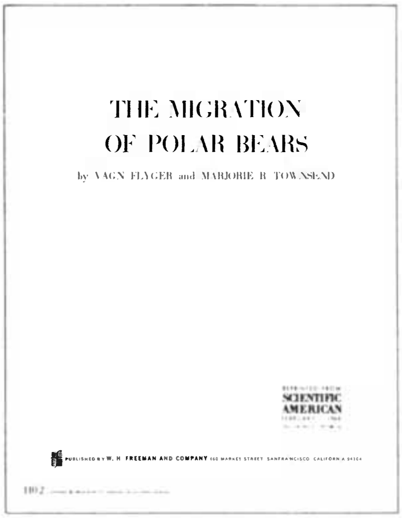
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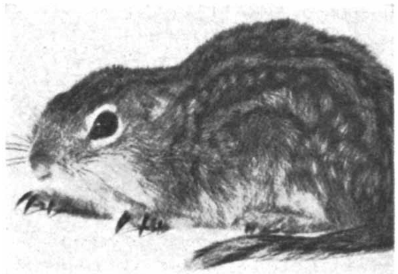

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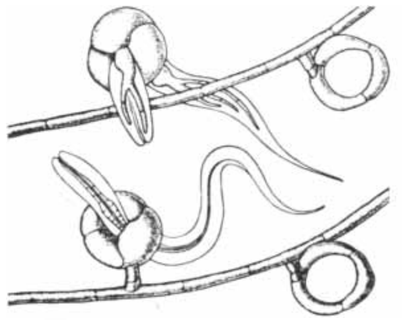

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CARGO-HANDLING

Mechanization and containerization, with emphasis on facilitating the transfer of cargo between land vehicles, ships and airplanes, have become strong trends in both national and international trade

by Roger H. Gilman

Within the past few years the international transportation of cargo has undergone the most significant technological change since steam replaced sail a little more than a century ago. A term that sums up the change is "containerization." Much general cargo, which has traditionally been shipped in separately packaged lots requiring a considerable amount of manual labor at each loading and unloading, is now shipped in large vanlike containers that can be transferred easily to and from trains, trucks, ships and planes by highly mechanized routines.

The change can be described in terms of two ships. The new technique is represented by the *Trenton,* a 16,000-ton container ship. The traditional technique is represented by a hypothetical vessel, typical of many freighters still in service, that I shall call the *Breakbulk*. The two ships are comparable in carrying capacity and cruising speed. Let us suppose we are watching each of these freighters as it enters the Port of New York to discharge and take on cargo.

The *Trenton* carries, on its decks and in its holds, 609 metal containers, each 35 feet long, eight feet wide and 8½ feet high. They were loaded aboard the ship five days earlier in San Juan and contain a typical assortment of the products of Puerto Rico. The ship's destination is the Elizabeth–Port Authority Marine Terminal, a container-ship terminal the Port of New York Authority has built at Elizabeth, N.J. The terminal's berths are quays—in effect parallel extensions of the shoreline—rather than the finger-like piers that are common elsewhere in the Port of New York.

As the *Trenton* is warped alongside a quay, large cranes that move along the quay on tracks are put into position to work the ship. Eleven minutes after the last line from the *Trenton* has been secured to the wharf the first of the containers is lifted gently off the ship by one of the cranes and put on a trailer dolly. Special grips controlled by the operator of the crane make it possible to lift the container by its four upper corners.

As a tractor pulls the trailer to the storage area that is an integral part of the terminal another trailer is moved into place for the next container. It takes about three minutes to pick up a container from the ship and deposit it on a trailer. In 20 hours all the *Trenton*'s containers (each holding up to 20 tons of cargo) have been taken off the ship, 609 other containers with outbound cargo have been put aboard and the ship is on its way back to San Juan.

The *Breakbulk* must be handled in a much different way. It is a breakbulk freighter: its cargo consists of thousands of comparatively small units fitted into its large holds. When the *Breakbulk* is tied up at its berth, its hatches are opened and gangs of longshoremen go aboard to unload its cargo. The ship's booms are positioned to lift rope slings that carry loads of cargo from the hold and put them on the pier. Winches, powered by electricity generated by the ship's steam, are manned by longshoremen experienced in working together so that one winch is used to lift and lower a cargo sling while a second winch moves it over the horizontal distance between the hold and the pier.

The longshoremen assigned to work in the ship's hold quickly begin to load packages of cargo into the slings. When a sling is filled, the deck man signals the winchman. The winches lift the sling out of the hold and swing it over to the pier. There more longshoremen detach the sling and fasten an empty sling to the tackle. The time elapsed from loading the sling to detaching it on the dock is about four minutes. The amount of cargo handled in that time is about one ton, perhaps as much as two.

The *Breakbulk* takes three days to discharge cargo consigned to the Port of

CONTAINER-SHIP TERMINAL at Elizabeth, N.J., was built by the Port of New York Authority to facilitate the movement

New York. It then goes to other ports along the Atlantic Coast, unloads the remainder of its inbound cargo and picks up cargo for its outbound voyage. After moving for a week from port to port it returns to New York to "top off," or take on last-minute cargo, before proceeding on its transocean voyage. The topping off takes three more days, including several hours of overtime for the five work gangs and the large dock force required to handle the cargo. Finally the ship's hatches are secured and it is able to get under way—two weeks after it arrived in New York from overseas.

One of the basic economic facts of transportation is that a vehicle, whether it is a ship, an airplane, a truck, a barge or a train, earns revenue only when it is carrying cargo. While the vehicle is being loaded or unloaded it earns nothing. On the basis of time spent in port it is clear that the container ship *Trenton,* which unloaded and loaded the same amount of cargo as the *Breakbulk,* is by far the more efficient, economical and productive carrier.

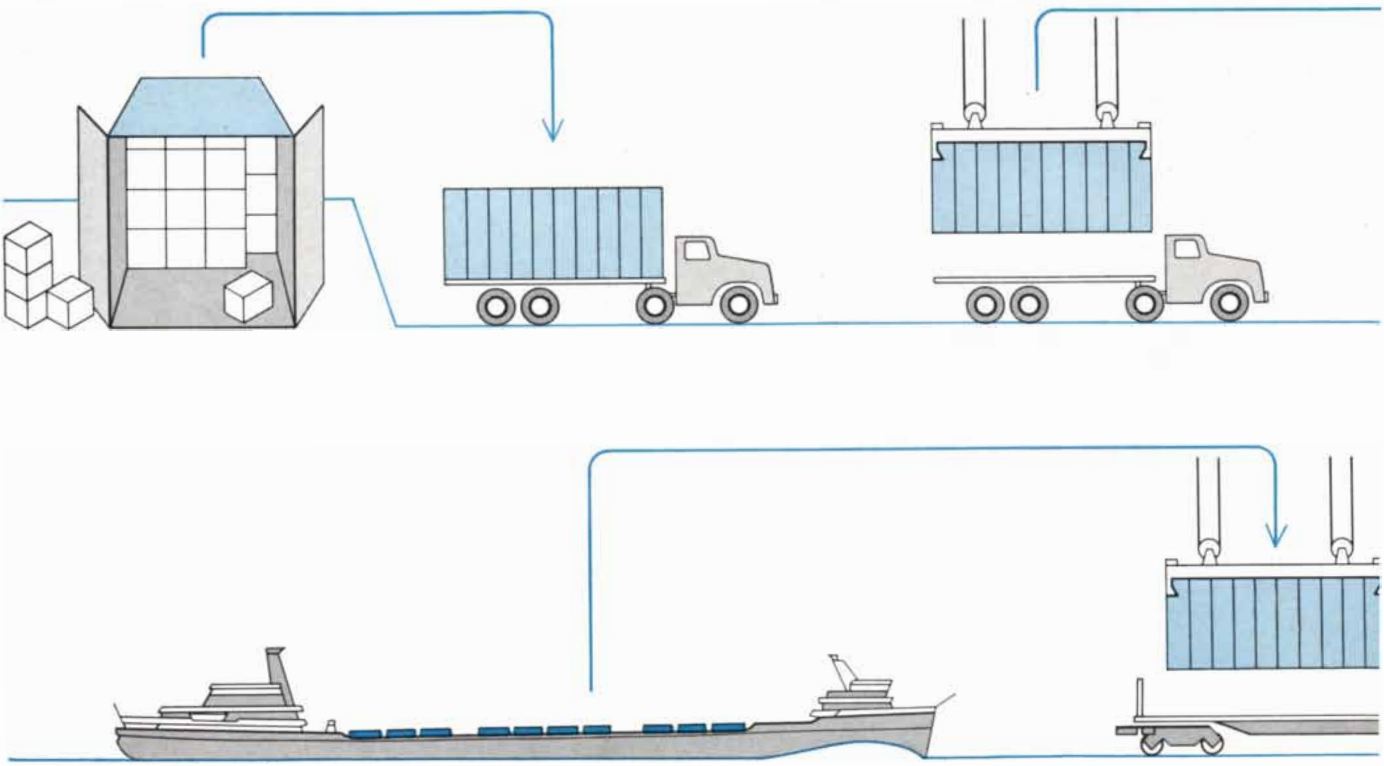
The trend exemplified by the *Trenton* is toward eliminating the handling in cargo-handling, that is, toward mechanizing the operation and incorporating automatic control. It is not too strong a statement to say that the trend is rapidly revolutionizing the transportation of cargo on land, across the oceans and in the air. The tremendous improvements that have taken place in the vehicles of commerce (from horse-drawn wagon to jet airplane and from sailing vessel to turbine-driven container ship) are at last being matched by advances in the methods of transferring goods from storage places to carriers and from one type of carrier to another.

The amount of handling that is required in traditional methods of moving cargo can be described in terms of a box of nails being sent from a factory in Ohio to a ranch in South America. It takes manpower to (1) put the box at the factory into a larger package with other boxes of nails, (2) move the larger package onto a truck that carries it to a railroad depot, (3) unload the package from the truck to the depot platform, (4) load it onto a freight car, (5) take it from the freight car at the port of embarkation and put it on a truck or a lighter, (6) move it from there to a storage place on the pier, (7) put it in a sling at the pier, (8) take it out of the sling and stow it in the ship's hold, (9) get it out of the hold and into a sling for unloading at the South American port, (10) move it from the sling to the pier, (11) put it on a freight car or a truck, (12) remove it from the vehicle and (13) separate the box of nails from the larger package for delivery to the ranch.

Each of the 13 handlings adds to the cost of moving the box of nails from the factory to the ranch. The costs are incurred mainly for manpower and for preparing the documents that must be presented at each transfer point. Traditional methods of cargo-handling also involve the risks of damage and of loss

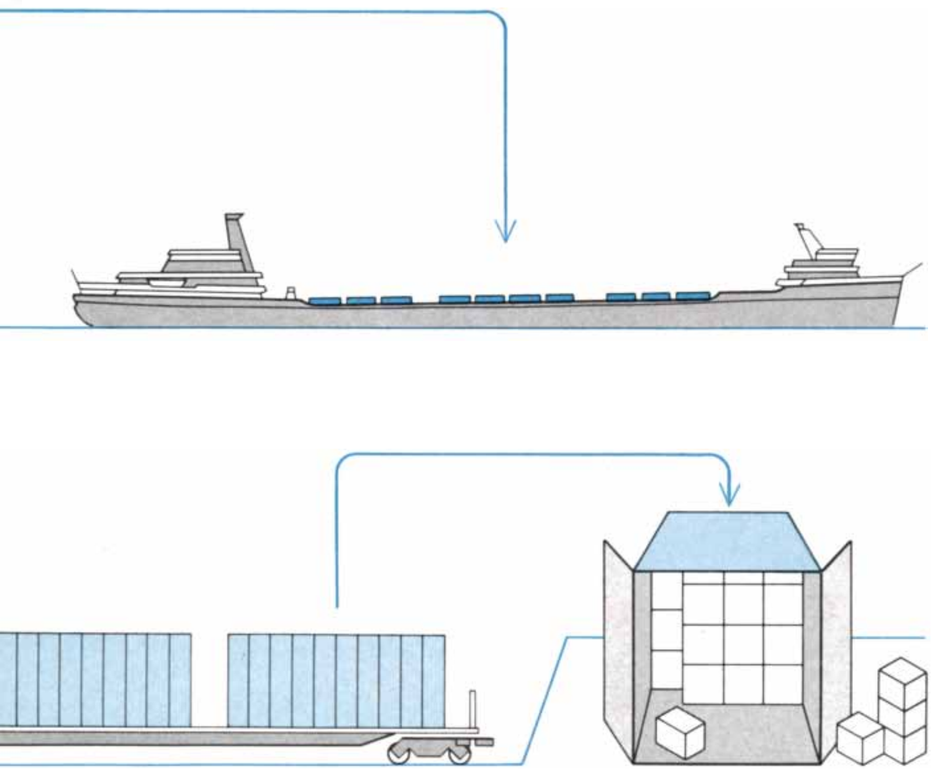
of cargo in large vanlike containers, many of which appear in the storage area adjacent to the quay. The ship at right is a modern container vessel, with no gear of its own for loading and unloading vans. That work is done by the shoreside cranes, which move on tracks along the quay. The wide apron adjacent to the ships provides ready access for trucks bringing or carrying away containers.

LOADING OPERATION is carried out by one of the cranes at the Elizabeth–Port Authority Marine Terminal. The container is lifted by grips that are controlled by the operator of the crane. A container such as the one being moved can hold up to 20 tons of cargo.



FLOW OF CARGO in a containerized shipment begins (*top left*) with the loading of individual packages in a vanlike container, which can be either wheeled, and thus pulled as a trailer, or wheelless and thus moved on a trailer dolly. By truck or rail the con-

CONTAINER-SHIP STOWAGE is achieved by fitting containers into slots or grips that hold them firmly. A container ship such as this one can hold some 600 containers of this size.



tainer is taken to a port and put aboard a ship. After the sea voyage the container is put on a train or a truck and taken to a terminal where the packages are unloaded and delivered.

through theft or misdirection of the shipment.

The stowage of general cargo (which is defined as goods shipped in fairly small lots and mixed with other goods in the same vehicle) in containers makes it possible to move the entire contents of the container as a unit. The container lends itself to mechanical handling and thereby lowers the costs. Moreover, the container provides protection against theft and is not readily misdirected.

In many respects modern container shipping evolved from technological advances in transporting bulk cargo such as grain, ore and petroleum. At one time bulk products were transported as general cargo. Grain was (and to some extent still is) carried in bags on break-bulk ships; petroleum products were shipped in barrels and five-gallon tins; coal was carried in cars that were mixed in with boxcars on trains.

As requirements for bulk products increased, more efficient methods were developed to reduce the amount of handling required to move them. Special ships were designed to carry ore, petroleum and grain. The emphasis in these ships was on mechanical devices for loading and unloading. Ore is scooped onto conveyors that carry it to and from the ship. Grain is blown into elevators or the holds of ships. Petroleum is pumped. All this work is done with little manual labor, although many skilled workers are employed in the manufacture and operation of the mechanical devices.

The use of machinery for loading and unloading made possible the construction of larger bulk-cargo ships. Tankers with a capacity of 250,000 deadweight tons are now in operation, and 500,000-ton tankers are in the design stage. Ore carriers with a capacity of 50,000 deadweight tons are hauling ore from South America to steel mills in the U.S. Shipments of 60,000 tons of grain in converted tankers are becoming common. The trend is to ship more and more products in bulk. The list includes cement, sugar, wood pulp, orange juice, wine, molasses and chemicals.

It was logical that transportation men should seek some means of applying bulk-transportation principles to general cargo. Plainly the solution was to transform such cargo so that it would have a uniform size and shape. This objective could be achieved by stowing items of different shapes in containers. If shippers would accept such a method, the designing of machinery to move containers by ships, trains, planes or other modes of transportation would be comparatively simple.

The concept was not accepted quickly by the transportation industry, which has traditionally resisted capital investment in new techniques. Containerization as it is known today finally found a foothold in the highly competitive field of trucking. Truckers had learned early to use detachable trailers that could be loaded and unloaded at terminals while the tractor was hauling other trailers. The logical step forward from this procedure was to have the vans of trucks serve as containers.

Imaginative trucking and railroad men saw the possibilities of having railcars carry loaded trucks as long ago as World War I. Legal difficulties prevented the full development of this simple concept until 1954, when a decision of the United States Supreme Court allowed railroads to haul containers as units of freight without regard to the nature of the commodities in the containers. As a result moving truck trailers "piggyback" by train advanced rapidly. In 1955 the service was offered by 32 railroads; by 1965 it was available on 59 railroads. Indeed, the hauling of truck trailers has been one of the few bright spots in railroad economics. Although freight-car loadings decreased 22 percent between 1955 and 1967, piggyback operations increased 700 percent.

The piggyback procedure originally emphasized the hauling of truck trailers because it is fairly easy to rig sloping platforms for pulling trailers on and off flatcars. Recently the trend has been toward containers that have no wheels to take up revenue-earning space. It seems likely that railroads will someday be hauling stacked containers on specially designed flatcars. Containers already account for about 10 percent of the piggyback loads on railroads.

The principal advantage of container shipping is its adaptability to efficient transfer between different modes of transportation. Containers can be hauled by truck to railroad freight terminals or airports, where they can be transferred readily to flatcars or airplanes. The transfer of containers between a railroad freight terminal and a marine terminal can be accomplished with equal facility. No matter where the container is transferred, machinery performs the work with a minimum of manual labor.

The container's adaptability to transfer between the different modes of transportation has had a major impact on the designing of carriers. Container ships such as the *Trenton* are representative of the change; larger and faster container ships, some of which will handle as many as 1,000 containers, are now being designed. Airplane designers have plans for huge container planes. Railroads, which have been applying the principles of bulk-cargo hauling by operating unit

CONTAINER TRAIN of the type now being operated by a number of railroads to move only containers is loaded by a movable crane designed for the purpose. An advantage of containers is that they can be transferred readily among trains, trucks, ships and planes.

trains for coal, grain and a number of other bulk commodities, are making up container trains.

Containerization has made possible the operation of larger and faster general-cargo vessels just as mechanization of loading and unloading set the stage for the huge vessels that carry bulk products. Because containerization greatly reduces the amount of time a ship must spend in port, it has become economically feasible to make the heavy capital investment necessary for specialized container ships. In contrast, heavy capital investment in large break-bulk ships, which must spend approximately half of their time in port, would be most unattractive.

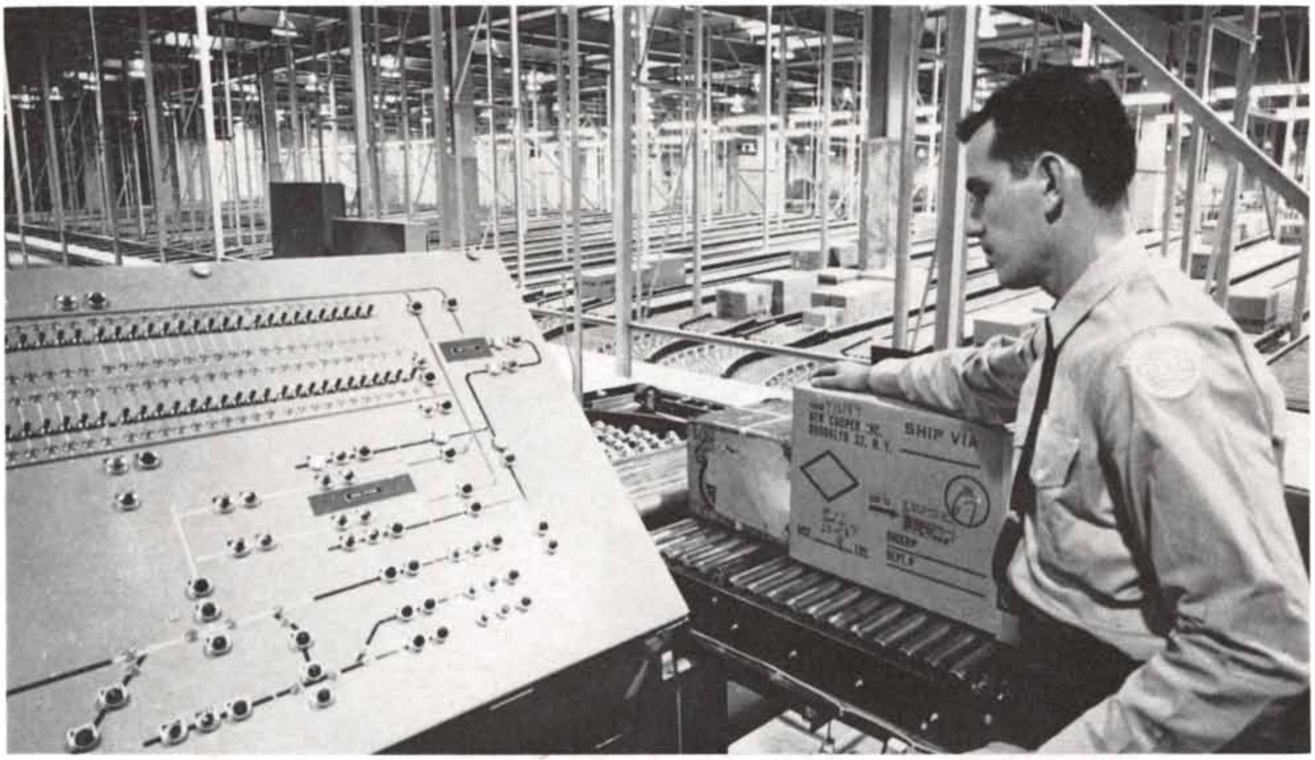
The economic trend is clear in figures assembled by the U.S. Maritime Administration showing that 122 container ships were under construction or on order at the end of 1967. American shipyards led with 38; these vessels will be large ones, averaging 17,400 deadweight tons, compared with conventional break-bulk freighters that average about 10,000 tons and seldom have a capacity of more than 14,000 tons. West German yards were in second place with 22 container ships averaging 12,400 tons, and yards in Japan and the United Kingdom were not far behind.

Container-ship terminals, if they are to operate at maximum efficiency, must be designed differently from the conventional roofed piers used by break-bulk ships. The quay wharf with powerful shoreside cranes is the best kind of facility for handling container ships. Wide aprons are needed to provide easy access to the side of a ship for tractors moving containers. Moreover, a container-ship terminal needs ample room for assembling containers coming from overseas for delivery inland and vice versa. Studies have shown that 12 to 15 acres of assembly area is the minimum requirement for each ship berth. Such an area can hold about 1,000 containers, half of which are inbound and half outbound. Finally, it goes almost without saying that a container-ship terminal should be close to major highways and convenient to trunk-line railroads.

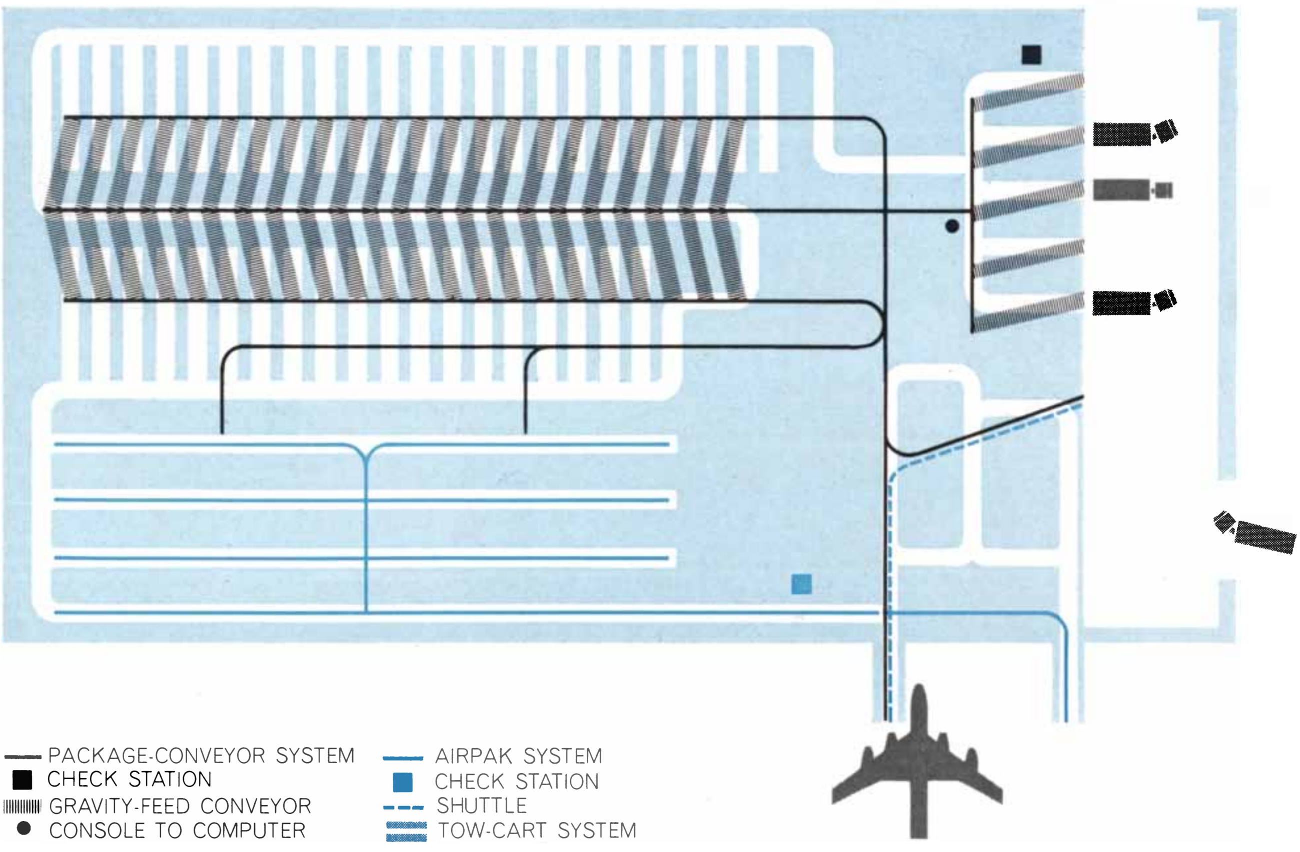
More than a decade ago the Port of New York Authority (the joint public agency of New York and New Jersey responsible for developing transportation and terminal facilities in the New York–New Jersey port district) recognized the trend toward containerization in ocean trade and acquired the land on which the Elizabeth–Port Authority Marine

CARGO AIRPLANE awaits loading of freight at the highly mechanized cargo terminal recently opened by Pan American World Airways at John F. Kennedy International Airport in New York, where a mechanized terminal has also been opened by Seaboard World Airlines.

MECHANIZED PLATFORMS load cargo onto an airplane at the Pan American freight terminal. The cargo has been put on the pallet in such a way as to fit the shape of the plane.



CONVEYOR SYSTEM in the air freight terminal is operated by a console that directs packages to particular storage areas reserved for certain flights or destinations. From the storage areas the packages can be moved by gravity to the part of the terminal where they are put on pallets for loading aboard airplanes. A computer keeps track of all shipments that pass through the freight terminal.



CARGO FLOW in the Pan American terminal is on two levels. Heavy packages are moved by the automatic tow-cart system on the ground level. At the check station they are logged on the computer and then moved to storage areas until flight time, when they are moved to the flight makeup area, loaded on pallets and lifted by elevators to the rollers that put cargo on the plane. Packages weighing up to 75 pounds move on the conveyor system and are stored on gravity-flow racks on the second level until makeup time.

Terminal has been built. At the time the land was a swamp. In 1962 the facility began operation as the world's first container-ship terminal. So far the Port Authority has completed 11 container-ship berths at Elizabeth and at adjacent Port Newark and is constructing another 20 berths, which are scheduled to go into operation by 1975. The need for these facilities is indicated by a recent Port Authority study estimating that by 1975 some 8.8 million tons of ocean-borne general cargo—half of the port's entire foreign commerce—will be containerized.

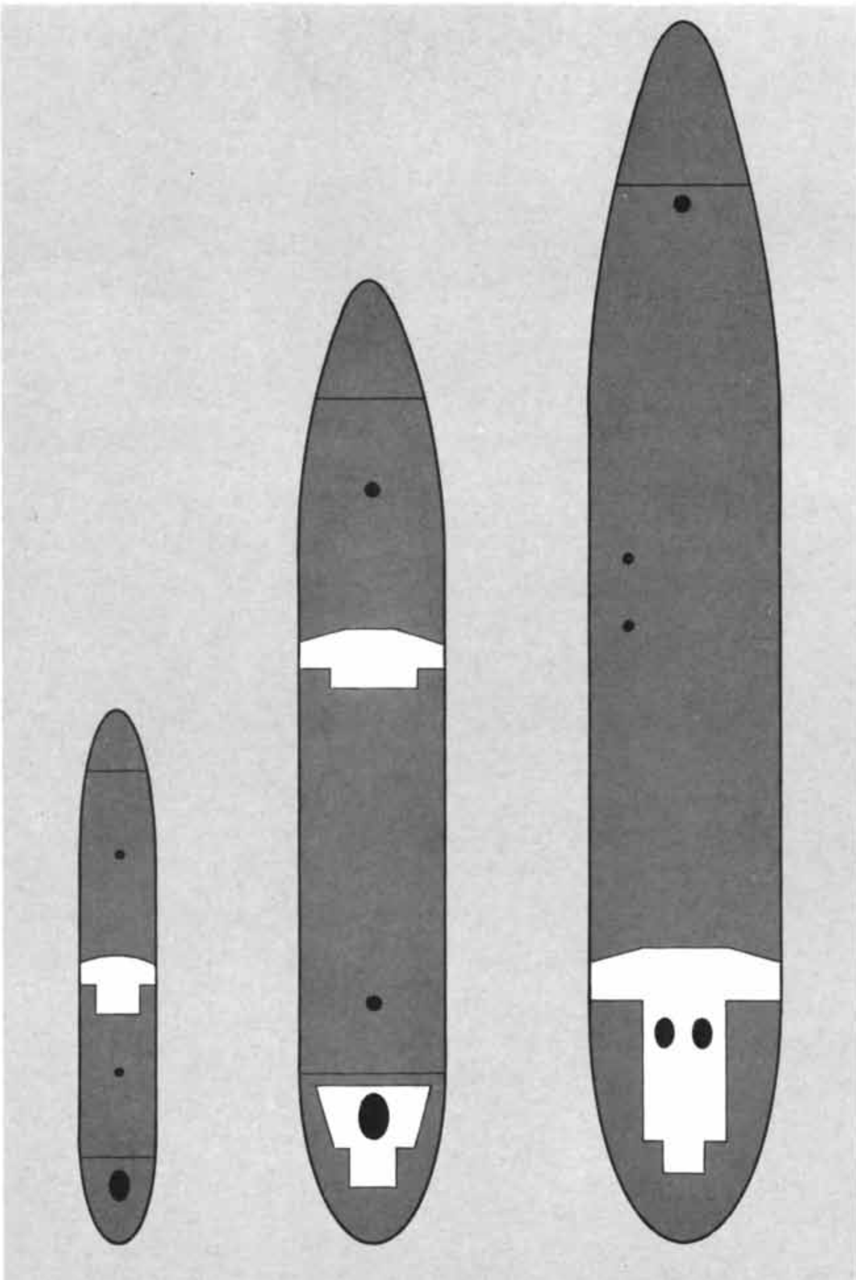
Containerization is rapidly becoming a major factor in the movement of cargo by air. Indeed, the economic feasibility of the huge air freighters scheduled to go into operation within the next five years is predicated on the prospect that containerized cargo will be loaded and unloaded by highly automatic mechanical devices. Underlying these recent and prospective developments is a change in attitude toward air freight. Until recently most air freight was of a priority nature; the plane's speed was more important to the shipper than the freight charge. Now other reasons prevail. Air transportation enables many wholesalers to reduce inventories of stock on hand, because they can get more stock quickly by air freight. New markets have been opened or extended by air freight. For example, fresh strawberries, melons, avocados and other out-of-season foods are now available during much of the year because they can be shipped quickly by air. Flowers are regular items of air cargo.

The scope for air freight was increased considerably by the advent of jet planes as commercial vehicles in 1958. Since then the domestic movement of cargo on scheduled airlines has more than doubled to upward of 1.6 billion ton-miles. International movement has almost quadrupled to 1.8 billion ton-miles. Those figures, compiled as of 1965 by the International Air Transport Association, represent a total movement of nearly 3.5 billion ton-miles. The forecast is that the total on scheduled carriers alone will be 10.6 billion ton-miles by 1970 and 52.7 billion by 1980.

The largest share of air freight is still uncontainerized. The use of containers is advancing rapidly, however, as is the development of mechanical handling techniques for air freight. Two major airlines have opened highly mechanized cargo buildings at John F. Kennedy International Airport in New York. Within the next four years more than 60 automatic cargo facilities are scheduled to be built throughout the world.

The loads now carried by jet freighters range up to 50 tons. The Boeing 747's and Lockheed 500's due to begin operation in a few years will be able to carry more than 100 tons. The costs of operating these large jets fully loaded will be as much as 30 percent lower per ton-mile than current costs, offering the possibility of reduced rates for air freight if enough traffic can be generated to keep the planes full. Indeed, Lockheed believes its L-500 could reduce the cost of door-to-door shipment to about 10 cents per ton-mile, making it quite competitive with surface transportation for types of cargo not now sent by air because of the cost.

The trend to containerization is not without its problems. Stowage is one of the more serious ones, particularly on ships. Inexpert stowage of articles in seagoing vans has caused a number of consignees to receive their shipments in a highly scrambled condition.



GROWTH OF TANKERS since 1945 is depicted schematically. The "supertanker" immediately following World War II (*left*) was 617.5 feet long, 68.2 feet wide and 43.9 feet deep; its capacity was 30,000 long tons. By 1959 (*center*) the capacity was up to 114,000 tons. Latest vessel (*right*) is 1,135 feet long, 105 feet deep and has 312,000-ton capacity.

Another problem is backhaul, the transportation man's word for what a freight-carrying vehicle carries on its return trip. If more cargo moves in one direction than moves on the return route, it becomes necessary to deal with empty containers. Several ship companies have met this problem by carrying a full load of containers on every voyage. When all the loaded containers have been put aboard, the remaining space is filled with empty ones. In this way the possibility of a shortage of empty containers at one end of a run (at a time when there may be a surplus of empty containers at the other end) is reduced.

Paper work continues to be a problem. In parts of the world separate bills of lading are still demanded for each item in a container. Frequently individual bills of lading are required to move a container by truck to a rail terminal, by rail to a port, by ship to a foreign port and by train or truck for the inland trip abroad. Alan S. Boyd, secretary of the new U.S. Department of Transportation, took note of the situation last year. "When it takes a sheet of paper 12 feet long and 11 inches wide to describe the processing steps involved in documenting international shipments," he said, "it is easy to see why some transactions produce so little profit." Industrial groups involved in cargo-handling have formed a National Committee on International Trade Documentation to attack the paper-work problem.

The U.S. Bureau of Customs, under its mandate to enforce laws requiring the inspection of all imports, could establish regulatory procedures that would impede the movement of containerized cargo. The bureau, however, has cooperated closely with the air and sea transportation industries as containerization has developed. The cooperation has included assigning customs inspectors to inland points to inspect cargo when the consignee opens the container. Regulatory barriers in foreign countries are expected to fall as pressure from shippers overcomes the reluctance of governments to change traditional practices.

The full advantages of this revolutionary method of moving cargo will be realized only when containers themselves—rather than trucks, trains or ships—are regarded as the vehicles of cargo movement. In other words, one would think in terms of a container transportation system rather than of railroading, trucking, shipping or air freight. This intermodal concept, or total transportation system, is gaining increasing recognition in the transportation industry.

An altimeter is just one of hundreds of components on every U.S. Air Force plane. Each is a potential trouble spot. The Air Force has skilled mechanics to detect faulty parts on the ground, and it has given them access to a UNIVAC® real-time computer system to locate replacement parts from inventory in a matter of seconds. And, the parts can be delivered to the flight line in about twelve minutes.

The warehouse location, quantity on hand and cost of 65,000 parts is in the memory of a Univac real-time computer system.

When the mechanic orders a replacement altimeter, the computer notifies issue clerks and indicates where it's stored. The computer checks its memory again. This time to see how many altimeters should be on hand. If inventory is now too low to meet expected demand, it initiates a re-order and updates accounting records for Base Level Supply Command.

Multiply that altimeter order by a few hundred an hour and you have a rough idea how much work the Air Force gets out of this Univac inventory system. A total system with forecasting, control and cost-cutting functions built in.

There's a Univac system at virtually every Air Force base. 166 systems to be more precise. All equipment and procedures are the same. Personnel have to be trained only once to use any of them.

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

SPERRY RAND

According to the instruments this plane is at 32,000 feet.

Air Force mechanics can ask a computer system for a new altimeter. They can get it delivered in about twelve minutes.

The enchanted

This may seem an unlikely photograph. But Esso's Fawley refinery on England's south coast is an unlikely place.

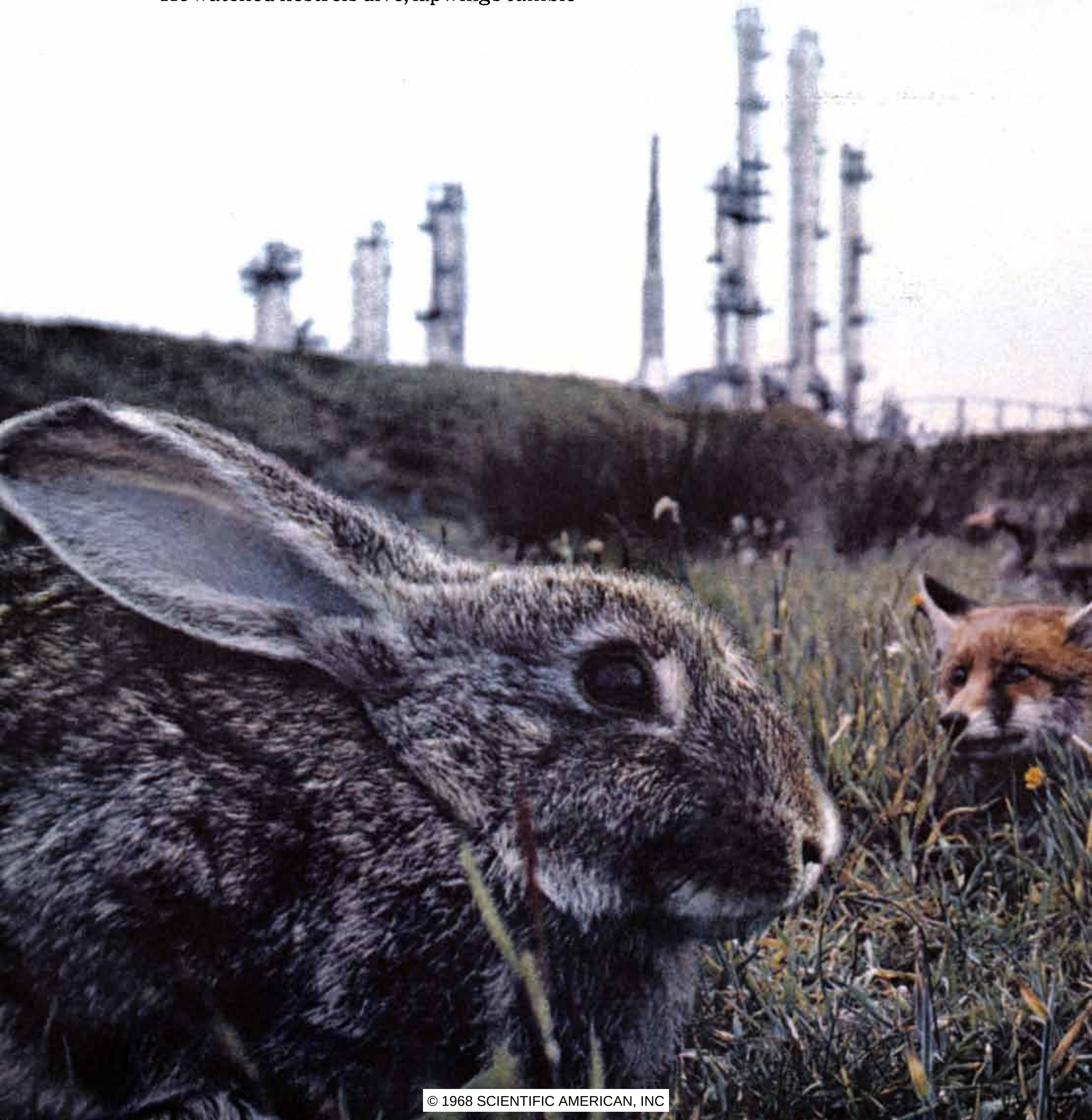
Major Oliver Kite, a prominent British naturalist, said it was one of the most remarkable examples of wildlife conservation he had ever seen. And, shortly before his untimely death last June, he finished making a film about it.

In a single year, Major Kite identified eighty-eight species of bird and twelve species of butterfly within the refinery fence.

He watched kestrels dive, lapwings tumble and kingfishers eye their royal dinners. And, in May, "the nightingales sang throughout the day." Some refinery.

He also fly-fished.

He hooked a two-pound trout from the refinery's cooling lake. And, even at the jetties, where tankers unload sixteen million tons of oil a year, he found nature just as ebullient. "This is where flounders provide food for the resident



oil refinery.

cormorants and charms of goldfinches feed on the seeding thistleheads."

Fawley's foliage impressed him too. When Jersey's Esso affiliate built the refinery, they planted twenty-six thousand trees and shrubs to screen it from the road. This tree belt now provides woodland runs for squirrels, moles and foxes.

And, sometimes, even a wild pony wanders in. Perhaps to admire the rhododendrons.

What does all this prove? Simply that an oil refinery can be a good neighbor. It needn't be ugly. It needn't disturb the peace. It needn't soil the air, the land or the water. And it needn't upset the balance of nature.

Fawley isn't exactly a vacation spot. But it's nice to think that so many living things find it a good place to raise a family.

Standard Oil Company (New Jersey)

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And to make her more alluring to you, another UOP group creates fragrance formulations—for perfumes, cosmetics, toiletries.

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How Fast Can Computers Add?

Computers today add at a rate of 10 million calculations per second and will soon add even faster. Mathematical analysis can now predict the best performance attainable by any computer, present or future

by Shmuel Winograd

The first large digital computers of the late 1930's could add two numbers at the rate of about three pairs of digits per second. This performance has been improved by more than six orders of magnitude: today's computers can carry out 10 million additions in a second. Multiplication by computers has advanced even further. Its speed has increased from one calculation every three seconds to more than three million per second. It is these phenomenal gains in the rate of computation that have transformed the role of the computer, for example making possible the processing of data in "real time," that is, as events are actually taking place.

An increase in the speed of computation by an additional order of magnitude is forecast for the next few years. Looking to the future, the designers of computers and mathematicians concerned with computer theory are confronted by fundamental questions. How fast can computers be expected to operate? Is there any limit to their speed and, if so, what is it? These questions involve two different considerations. One has to do with the performance of tomorrow's computer components, the "hardware" of the future. Whatever ultimate limits there may be to the operating speed of components, they will be determined by the laws of physics and lie beyond the scope of this article. Here I shall take up a second consideration. What improvements are possible in the ways computer components are organized to do their work?

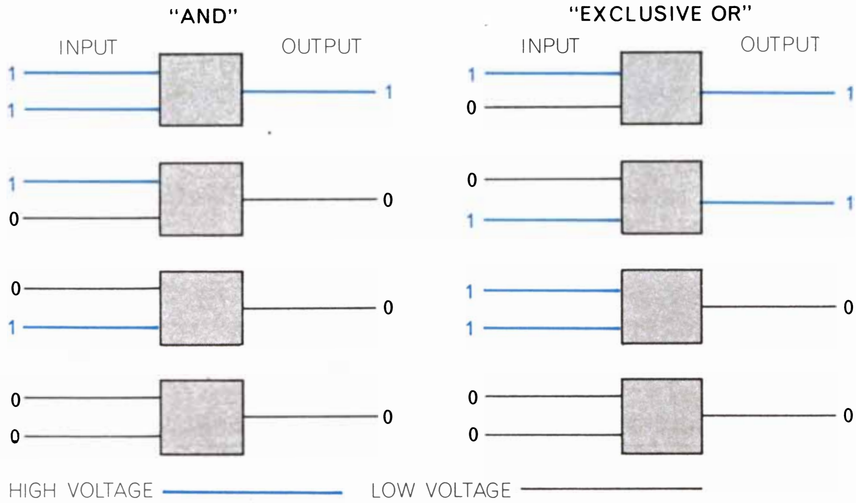
For some years I have been interested in finding out what limitations there may be on the speed of computers in terms of their organization. The number of possible computer designs is of course limitless. It is only by mathematical reasoning, and not by experimentation, that one can determine the least possible time it would take the computer to add or multiply two numbers. At this point it will be useful to briefly review computer circuitry and computer arithmetic and to give some examples of how unorthodox computer organization can achieve gains in speed.

The basic elements in the arithmetic section of a computer are its switching circuits. A switching circuit has one or more input leads, through which incoming signals are received, and an output lead to carry away whatever output signal is predetermined by the design of the switch. Usually input and output leads carry only one of two possible signals: either a high voltage or a low voltage, a large amount of current or a small amount. It is this "either-or" characteristic of switching circuits that is responsible for the fact that the notation of computer arithmetic is customarily binary notation. The two binary digits, 0 and 1, can represent any number, and they are admirably suited to a high-voltage, low-voltage switching system. A high-voltage signal is read as a 1 and a low-voltage signal as a 0.

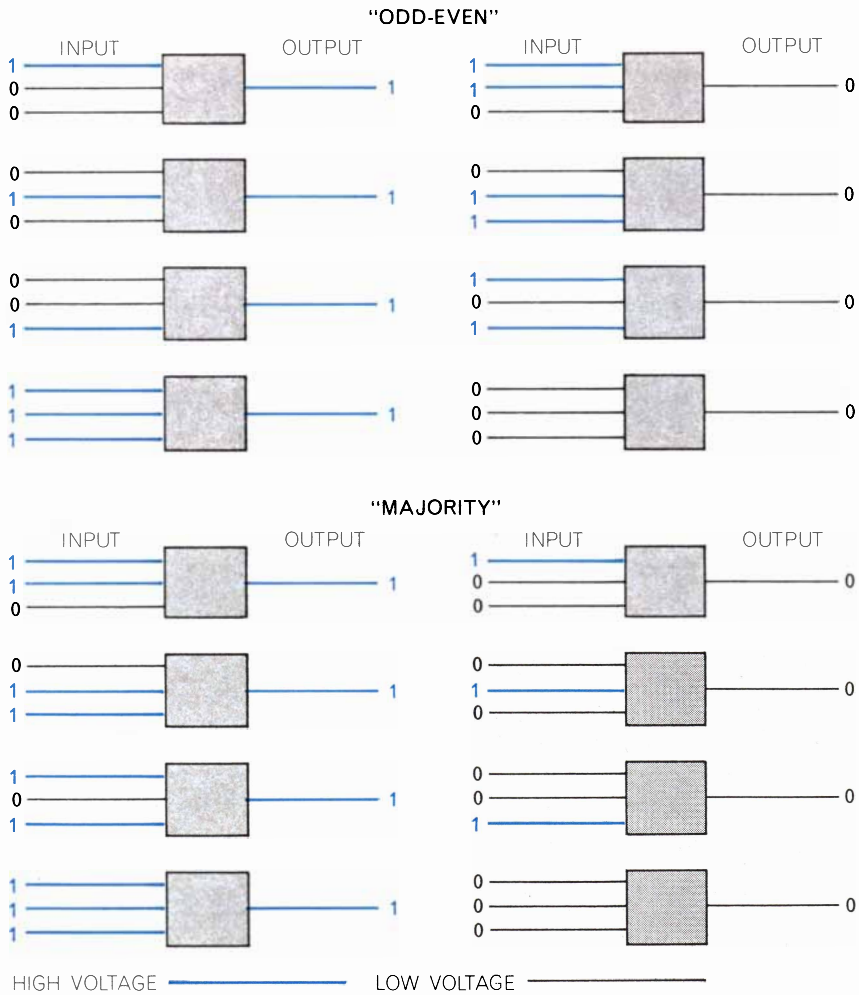
The signal on the output lead of a switching circuit depends on the input signals. Let us consider four switching circuits that can be combined to form a standard adder. The first is a two-input circuit called an "and" switch: a high-voltage 1 appears on its output lead only when the signals on both its input leads are high-voltage 1's. A second two-input circuit is called an "exclusive or" switch; here the outgoing signal is a 1 only if one or the other, but not both, of the incoming signals is a 1 [*see top illustration on next page*].

BASE 10	BASE 2	BASE 10	BASE 2	BASE 10	BASE 2	BASE 10	BASE 2
0	0						
1	1	9	1001	17	10001	25	11001
2	10	10	1010	18	10010	26	11010
3	11	11	1011	19	10011	27	11011
4	100	12	1100	20	10100	28	11100
5	101	13	1101	21	10101	29	11101
6	110	14	1110	22	10110	30	11110
7	111	15	1111	23	10111	31	11111
8	1000	16	10000	24	11000	32	100000

BINARY NOTATION needs only a sequence of two digits, 0 and 1, to represent numbers of any size (the numbers from 0 to 32 are shown in base-10 and base-2 representation). Such an "either-or" system is ideally suited to computers with switching circuits that respond either to high-voltage signals (which can be read as 1's) or to low-voltage signals (which can be read as 0's). Binary notation can be used for many representations other than base-2.



TWO COMPUTER SWITCHES, each with two input leads and one output lead, are designed to respond in different ways. The "and" switch (*left*) has a high-voltage output (readable as the binary digit 1) when both input signals are high-voltage, but not otherwise. The "exclusive or" switch (*right*) has a high-voltage output (readable as 1) when either input signal is high-voltage but not when both are high-voltage or low-voltage.



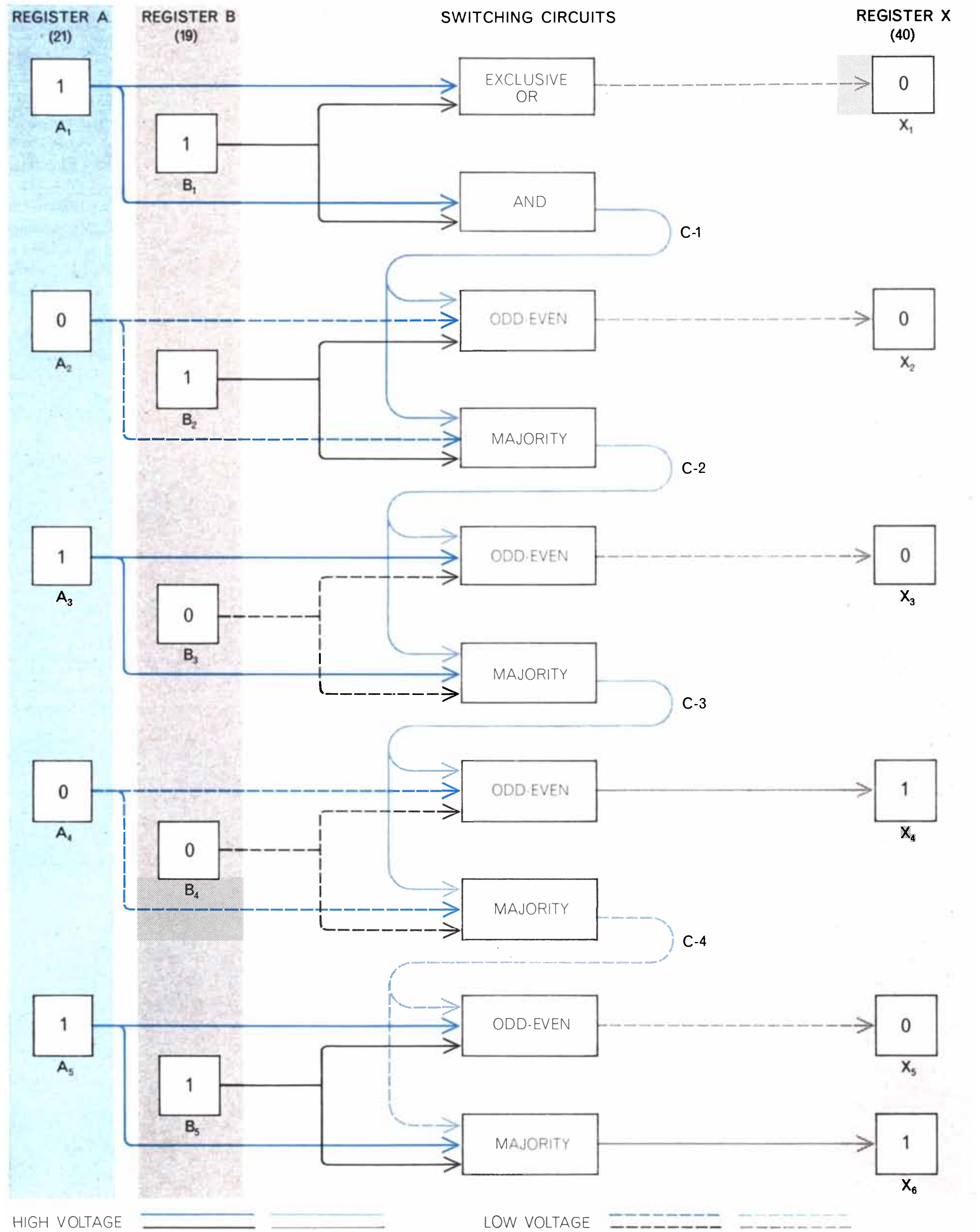
SWITCHES WITH THREE INPUTS are more complex; they can receive eight possible signals compared with only four possible with two-input switches. The "odd-even" switch (*top*) has a high-voltage output, readable as 1, in the four instances when the number of high-voltage input signals is odd. The "majority" switch (*bottom*) has a high-voltage output when two or more input signals are high-voltage. These two switches and the two in the top illustration, combined, form an adding circuit (*see illustration on opposite page*).

The other two switching circuits have three input leads. The output signal of one, the "odd-even" switching circuit, is a 1 only when the number of 1 signals on the input side is odd. Thus when any one, but only one, of the three odd-even input leads carries a high-voltage signal, the output signal will be high-voltage, and the same is true when all three of its input leads carry a high-voltage signal. The second three-input switching circuit, the "majority" circuit, has an output signal of 1 when, and only when, at least two of the input signals are 1's. Therefore in one instance the odd-even and majority switches have the same output: when all three of their input leads carry high-voltage signals [*see bottom illustration at left*].

No switching circuit acts instantaneously; there is a brief delay between the instant incoming signals appear on the input leads and the instant an outgoing signal appears on the output lead. In the days of vacuum-tube circuitry the delay was about 10 microseconds (millionths of a second). Some of today's solid-state circuits have a switching delay no greater than one nanosecond (a billionth of a second). This represents a gain in speed of four orders of magnitude in about a decade. Large or small, switching delay is a factor that affects the speed of computation. Called delay time, it is represented by the expression Δt.

Another factor that must be considered in relation to computation speed is the physical limit on the number of input leads a switching circuit can have. Typically the number of input leads varies from three to five. If a circuit could have many more than five input leads, it could process more information simultaneously, and its increased capacity would greatly increase computation speeds. Regardless of whether the circuit has two input leads or 20, however, the number of leads is a factor that sets a limit on its performance. The number of input leads is called the "fan-in," and it is represented by the letter r. In any formula that expresses the least possible time it takes a computer to add or multiply, both Δt and r must appear. The numbers they stand for will depend on the characteristics of the particular components involved.

Let us take the switching circuits described above and make an adder that can combine any two numbers between 0 and 31. I set this limit for the sake of simplicity; in the "base-2" representation only five digits are needed to write numbers of this magnitude. Base-2 means that the value of each digit from



FIVE-DIGIT ADDER contains 10 switches grouped in five pairs (*vertical row, center*): an "exclusive or" and "and" pair to start, followed by four sets of paired odd-even and majority switches. The registers *A* and *B* (*left*) contain the numbers to be added, 21 and 19, in base-2 representation. The input leads of each pair of switches receive signals from matching sections of the registers. All 1's in the registers are received as high-voltage signals (*solid lines*) and all 0's as low-voltage signals (*broken lines*). The consequent output signal is a 1 or a 0, depending on switch design (*see illustrations on opposite page*). The output of the first switch in each pair appears as a 1 or a 0 in register *X* (*right*), which stores the result of each addition. Simultaneously the second switch of the pair sends a "carry" of 1 or 0 to the next pair of switches. Because five consecutive steps are involved in the process, five delays are required.

right to left is twice the preceding power of two. Thus the digit at right represents 2^0, or one; the next to the left, 2^1, or two; the next, 2^2, or four; the next, 2^3, or eight, and the last, 2^4, or 16.

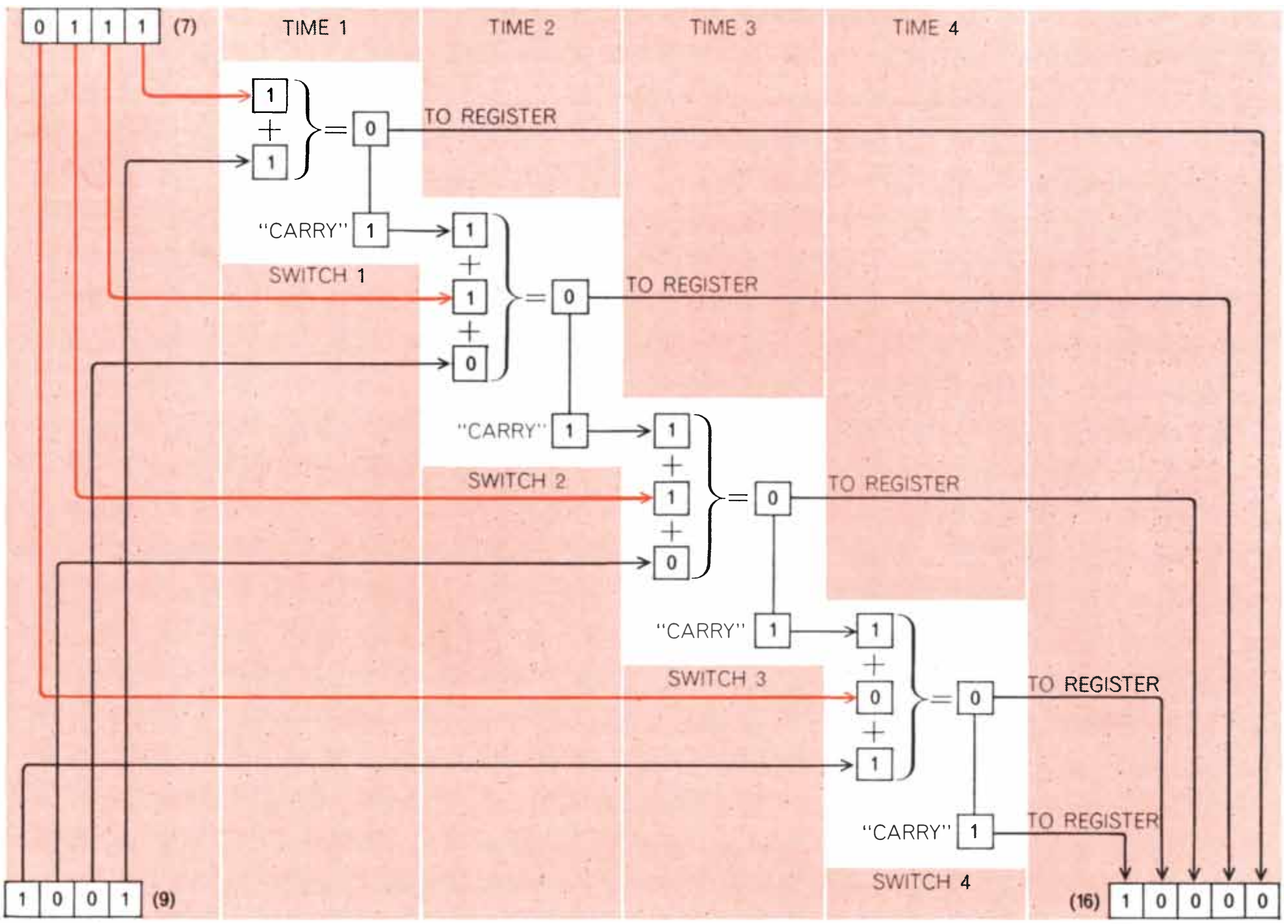
The task we shall set our adder is to combine the number 21 (10101 in base-2 representation, 21 equaling one 16 plus no 8 plus one 4 plus no 2 plus one 1) and the number 19 (10011, 19 equaling one 16 plus no 8 plus no 4 plus one 2 plus one 1). Because each of the two numbers is smaller than 31, the largest number that can be written in five binary digits, each of the input registers of the adder, in which the numbers are stored, will have only five positions. The sum of 21 plus 19, however, is greater than 31; for this reason the output register, in which the product of the addition appears, will need to have six positions (the number needed to display binary numbers from 32 to 63).

The way our adder works is similar to the way binary addition is taught in school. Starting at the right side of the two numbers, as if one were working with pencil and paper, the first addition is 1 plus 1. This, of course, is 2, written as 10 in base-2 representation, so one puts down 0 and carries 1 to the next place to the left. Here one adds the 1 plus the 0 plus the "carry" of 1; again the total is 2. Again one puts down 0 and carries the 1 to the next place to the left. When the two digits plus the carry add up to less than 2 (which happens, for example, in the fourth position from the right), the adder—human or mechanical—sets down the number 1; otherwise 0 is set down and the 1 is carried to the next place to the left. Our final result is 101000, the base-2 representation of the number 40.

Substituting switching circuits for pencil and paper, we find that after five consecutive switching operations have taken place the same six-digit representation of the product, 40, appears in the output register. (It is possible to obtain a six-digit number in only five steps because the final carry, which produces the sixth digit in the output register, takes place at the same time as the switching action that combines the fifth digits of the input registers.) Assuming that each switching circuit has a delay time of 10 nanoseconds, our adder needs 50 nanoseconds to complete the operation.

The length of time taken by the adder to complete its task was dictated by three implicit decisions we had made at the start. First, we decided that the adder would handle only the numbers from 0 to 31. Second, we decided that we would use base-2 representation. The fact that our switching circuits are binary does *not* dictate this choice; for example, in Morse code all numbers are written in binary symbols (a dot and a dash), but the number representation in Morse code is not base-2. Third, we decided on a way to carry out the addition process, choosing a method much like the schoolroom one. If we change any one of these three decisions, we find that the addition time also changes.

In the world of real computers the de-



DELAY TIME involved in conventional computer addition is shown schematically; the numbers 7 and 9 are being added. Because 9 is represented by four binary digits, four switching circuits must be activated consecutively, producing four delays. Unorthodox arithmetic procedures and methods of representing numbers can reduce the number of steps required, thus minimizing delay.

signer is faced with the same choices. His first choice is to pick a size for his output register, that is, to establish the largest number that can be represented without "overflow." In our five-position adder, for example, the largest number that can be represented is 31, because the binary representation of 32 (2^5) will overflow into a sixth position. Real adder circuits, of course, handle numbers many thousands of times larger than 2^5. One common adder handles numbers with magnitudes on the order of 2^{36}, which is roughly 100 billion. Another goes up to 2^{48}, which means that numbers in excess of 100 trillion can be added without overflowing the output register. Our five-position adder could easily be extended to handle such enormous numbers, and could accomplish the addition of any two numbers between 0 and $2^n - 1$ in n times the delay time ($n \times \Delta t$).

Having set his maximum number, the designer has two more choices to make. First he must decide how to represent the numbers of the real world. His customary choice is the base-2 representation, but he can elect any other method he wishes. His second choice is the means by which his arithmetic operation will be carried out. He is certainly not required to use the orthodox arithmetic organization used in our model five-position adder. Increases in the speed of computation can be achieved both by performing arithmetic in unorthodox ways and by choosing novel means of number representation. Because these two tactics are unfamiliar to most people outside the computer field I shall give an example of each.

The first example is a method known as conditional-sum addition. This method uses the base-2 representation of numbers but handles the numbers in an unusual manner. To allow comparison with the orthodox arithmetic of our model adder I shall again combine the numbers 21 and 19. This time, however, we shall break up the five binary digits representing each number into groups. First we set aside the three lower digits of each number (a grouping I shall call "addition problem *A*"). We then write down the two higher digits of each number twice (groupings I shall call "addition problems *B* and *C*"). We add a carry of 1 to the digit at the right in addition problem *B* but leave addition problem *C* as it is. We now add *A*, *B* and *C* simultaneously. If *A* propagates a carry when it is added, then *B* will be the correct sum of the higher numbers; if it does not, then *C* will be correct. Since all three adding operations go on at the same time, they are all completed in the time required by the longest one. This is the addition of the three lower digits, *A*, which requires three delay times. (*B* and *C* are completed in only two delay times.) When the addition of *A* is completed, it is evident that a carry has been propagated. This means that *B* is the correct sum to be recombined with *A*. The recombination costs us a fourth delay time and we arrive at the final number: 101000. Assuming that a machine working with conditional-sum addition contains switching circuits like those of our orthodox model adder, our use of the unorthodox arithmetic method will save us 10 nanoseconds per addition. The reason for the saving is that we are doing several operations simultaneously rather than consecutively.

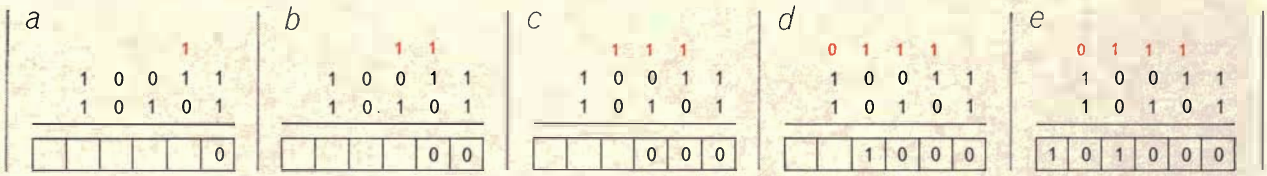
My example of unorthodox number representation is the "modulus" technique, which is used in the arithmetic method called remainder addition. Daily experience has made us all familiar with remainder addition, indeed so familiar that we are seldom conscious of using it. When a train leaves on a four-hour trip at 10:00 A.M., we know that we should reach our destination at 2:00 P.M. because we have done a sum in modulo-12 addition. Ten plus 4, modulo-12, equals 2 because 14 (the sum of 10 plus 4) divided by 12 yields a quotient of 1 (which is ignored) and a remainder of 2. We deal with the days of the week in modulo-7, with the months of the year in modulo-12 and, three years out of four, with the days of the year in modulo-365. Indeed, when the computer designer selects the largest number his machine is to handle, he is preparing for addition modulo-*N*, the value of *N* being the maximum number he chooses.

To see how remainder addition can save computation time, let us try adding modulo-15. I choose modulo-15 because of its simplicity. The number 15 is equal to 5 times 3; this property allows us to obtain an unorthodox, two-digit representation of every number from 0 through 14 in the following manner. The digit at the left in each two-digit pair will be the remainder after dividing the chosen number by 5; in the case of 0, for example, the digit at the left will be 0. The digit at the right will be the remainder after dividing the number by 3; in the case of 0, again 0. Thus the representation of 0, modulo-15, is 0,0. In the same manner the number 7 is represented by 2,1 because 7 divided by 5 yields a quotient of 1 (which is ignored) and a remainder of 2, whereas 7 divided by 3 yields a quotient of 2 (also ignored) and a remainder of 1. Following this method number by number, we find that every number from 0 to 14 is represented by a unique pair of digits, modulo-15 [*see table in illustration above*]. In writing the table I have used familiar decimal notation; only five digits, 0 through 4, are needed to write all 15 numbers. In actual practice, of course, the digit pairs would have to be translated into binary notation before they could be handled by a computer's switching circuits.

To do modulo-15 addition we set down the digit pairs representative of the numbers to be added and proceed by adding the two right-hand digits modulo-3 and the two left-hand digits modulo-5. As an example we shall add 4 and 12. The digit pair, modulo-15, for

NUMBER	REPRESENTATION	NUMBER	REPRESENTATION
0	0,0	8	3,2
1	1,1	9	4,0
2	2,2	10	0,1
3	3,0	11	1,2
4	4,1	12	2,0
5	0,2	13	3,1
6	1,0	14	4,2
7	2,1		

UNORTHODOX NUMBER REPRESENTATION uses the modulus method to obtain unique two-digit representations of the numbers from 0 to 14. Representations of this kind can be used for "remainder addition," the familiar method by which, for example, time is told. The table is in modulo-15, 15 being 5 times 3. The left digit in each digit-pair is the remainder after the number it represents is divided by 5; the right, after its division by 3.



CONVENTIONAL ADDITION requires as many sequential steps as there are digits in the numbers. Adding 19 (10011 in base-2 representation) and 21 (10101 in base-2) requires the five steps illustrated (numerals in color are "carries"). The addition problem is the same as the one handled by the adder illustrated on page 95, where a pair of switches was activated for each step shown here.

4 is 4,1; the pair for 12 is 2,0. Starting at the right and adding 1 and 0, we obtain 1 (which, since it does not overflow modulo-3, stands as 1 in the sum). Adding 4 and 2, we obtain 6. This sum overflows modulo-5 by 1, so that we set down 1. Thus our final result is 1,1. Reference to the table of modulo-15 representations shows that 1,1 is the representation for the number 1. This is the correct answer: 4 plus 12 is 16 and 16 overflows modulo-15 by 1.

Done with pencil and paper, remainder addition is tedious and seems a very hard way to achieve a simple result. As with conditional-sum addition, however, the method has great potential advantages for computers because the two digits in each pair can be added simultaneously rather than consecutively, thereby accelerating the computation. Furthermore, remainder numbers are obviously not peculiar to modulo-15. If any number N is a product of two numbers N_1 and N_2 such that no number except 1 divides both N_1 and N_2, then we can represent every number between 0 and $N - 1$ by a unique pair of numbers. The first number will represent the remainder after dividing by N_1 and the second the remainder after dividing by N_2. Modulo-N addition is then performed exactly as modulo-15 addition was; the first numbers are added modulo-N_1 and the second modulo-N_2. The only numbers, N, that are not the product of two such numbers, N_1 and N_2, are those that are the powers of a single prime number. This means that remainder addition cannot be used to add modulo-2^n, because 2 is a prime number, divisible only by itself and 1.

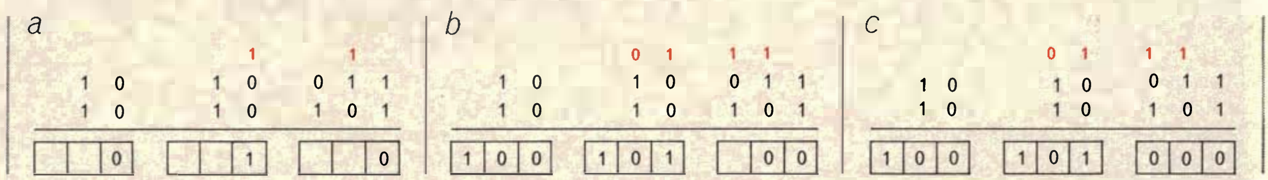
The two examples I have given are representative of the two principal tactics available to the computer designer: a free choice of representation and operation methods. From a theoretical point of view the dilemma is that no imaginable system of number representation or way of performing arithmetic can be declared advantageous or worthless without a trial, yet to try each and every one of an essentially unlimited number of tactics would be impossible.

Four years ago M. O. Rabin of the Hebrew University of Jerusalem visited us at the IBM Watson Research Center, and he and I were discussing such matters. Among other things we wondered how base-2 representation had become such a *sine qua non* in computer arithmetic. Why not some other base? For that matter, why any base representation at all? The result of our discussion was that I set out to seek the minimum time for addition that would hold true regardless of the hardware involved, of the way the numbers were represented (except that each must comprise a unique combination of 0's and 1's) or of the method of doing the addition. Unless a sound theoretical basis for calculating the least possible time of computation was available, the designers of computers could never be certain if their intuitive schemes were the most efficient ones possible.

As a starting point, let us compute the time required for addition with both conditional-sum adding and remainder arithmetic. One first breaks down N, the number selected as the modulus, into its constituent powers of prime numbers. The largest of these constituents is our bottleneck; its size is a key factor in determining the length of the computation process. We denote this number, the largest power of a single prime that divides N, as the alpha of N, $\alpha(N)$.

To suit the computer's switching circuits the various parts of the remainder-arithmetic representation have to be translated into binary notation. Because we want to use the conditional-sum method of addition, we choose a base-2 representation. The number of binary digits necessary to represent the integers 0 through $\alpha(N) - 1$ is $\lceil \log_2 \alpha(N) \rceil$. I use $\lceil \log_a b \rceil$ to denote the smallest integer, x, such that $a^x \geq b$. The reader can easily verify for himself that, by repeated application of conditional-sum addition, it takes $\lceil \log_2 2n \rceil \Delta t$ to add two n-digit numbers. Conditional-sum addition can, however, be generalized by breaking the numbers into r parts, rather than just the two parts shown in our example. Under these circumstances $\lceil \log_r 2n \rceil \Delta t$ is required to add two n-digit numbers. Combining the two formulas, we find that the delay time for performing addition with remainder arithmetic and conditional-sum addition is expressed by the formula $\lceil \log_r 2 \lceil \log_2 \alpha(N) \rceil \rceil \Delta t$.

I was surprised to discover that no way exists to improve this method of performing addition. This is to say that



UNORTHODOX ADDITION, using the conditional-sum method, sets apart the three lower digits of the same two binary numbers and then enters their two higher digits twice, once with a carry (*color*) and once without it. Next, all three groups are added simultaneously. The largest group comprises three digits; all addition is therefore complete after three delays. If addition of the lower digits propagates a carry (as in this example), the product of the higher digits that included the conditional carry is the correct one. A no matter what representation is used or what method of operation is selected, the process of addition has to take *at least* the delay time shown by the formula.

Let us now use the formula to find the least time for modulo-2^{48} addition. We start by assuming a computer component technology in which r, the input-lead fan-in, is equal to three, and Δt, the delay time, is a hundred-millionth of a second (10^{-8} second). To find the least time we must first determine the alpha of 2^{48}, the largest number that is a power of a prime number and by which 2^{48} is divisible. Since 2^{48} is a power of a prime number, the alpha of N proves to be 2^{48} itself. We next find the logarithm to the base-2 of 2^{48}; it is 48. Entering all these values in the formula, we learn that the least time is $\lceil \log_3 2 \times 48 \rceil 10^{-8}$, or five hundred-millionths of a second (5×10^{-8} second).

How close to the absolute maximum speed of addition are contemporary computers getting? By using the formula we can move for the first time from an area of intuition to the realm of hard fact. For example, one high-performance computer has an input-lead fan-in of four, a delay time of one nanosecond (10^{-9} second) and an N of 2^{32} (equal to 4,294,967,296). Using these values, we learn that the computer cannot possibly add two numbers faster than $\lceil \log_4 64 \rceil 10^{-9}$, or three nanoseconds ($3 \times 10^{-9}$ second). In point of fact, the machine takes five nanoseconds to add. The formula enables us to show that five-nanosecond addition is within 40 percent of the maximum speed possible. The establishment of absolute maximums gives designers a much clearer measure of the amount of room for improvement that may exist in any computer.

Let us give N an even larger value—13,762,686,640—and find the speed with which addition at that modulus value is possible. The number is more than three times the size of 2^{32}; intuition would suggest that addition with so much larger a modulus would be more time-consuming. The number I have selected, however, is a special one: it is the product of nine numbers—$5 \times 7 \times 9 \times 11 \times 13 \times 16 \times 17 \times 19 \times 23$—that are mutually divisible only by 1. The largest of the numbers, the alpha of this N, is 23 and $\lceil \log_2 23 \rceil$ is 5. With a fan-in of four and a delay time of one nanosecond, the time of addition using this modulus proves to be only two nanoseconds. Thus even though N is substantially larger, adding with this modulus is faster than modulo-2^{32} addition.

Why have computer designers left such phenomena unexploited and continued to use moduli that are powers of 2? Because modulo-N addition involves a companion process that cannot be speeded up. Modulo-N addition and conventional addition give the same answers only as long as the product does not overflow the modulus. In every modulo-N addition it is necessary to know if an overflow occurs (in which case some correction is necessary) or if it does not (in which case the final result is correct). This companion process, called "overflow indication," cannot be speeded up using remainder arithmetic. I have proved that no representation of numbers can increase the speed of overflow indication beyond what can be achieved by base-2 representation. As long as both the addition operation and the overflow indication must be completed in order to accomplish the entire operation of addition there can be no speed gained by substituting remainder addition for base-2 representation.

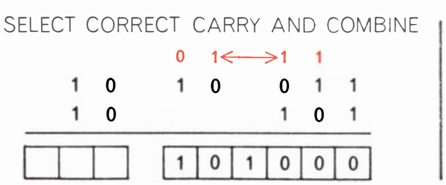
A surprisingly different picture emerges with regard to multiplication. Primary school pencil-and-paper multiplication, which is the method used in most computers, is simply consecutive addition in which one of the two numbers is added to itself over and over again. Since the operation is consecutive it has been assumed that multiplication has to be more time-consuming than addition. Surprisingly this is not the case. Consider the most common computer situation, in which binary representation is used and N is therefore a power of 2. Denoting N as 2^n, we discover that in multiplication modulo-2^n the formula is $t \geq \lceil \log_r 2(n-2) \rceil \Delta t$.

Comparing this with the result for addition modulo-2^n, one finds that the multiplication process is not necessarily slower than addition and may even be faster. Once again the key to this apparent contradiction of intuition lies in how the numbers are represented. The familiar "base" method of representation, including base-2 and base-10, is quite efficient insofar as addition is concerned. For fast multiplication, however, another unorthodox representation is necessary. I shall describe it with another example: modulo-64 multiplication.

As in modulo-15 addition, in modulo-64 multiplication each number from 0 upward is represented by a special combination of digits. Each combination in our example is a triplet; the digit at the right ranges from 0 to 6, the center digit is either 0 or 1, and the number at the left ranges from 0 to 15 [*see illustration on next page*]. As in modulo-15 addition, each modulo-64 triplet is a unique representation of one of a series of numbers, in this instance the series running from 0 to 63.

An instance of modulo-64 multiplication, performed according to its own special rules, is the following: Let us multiply 23 (represented by the triplet 14,1,0) by 43 (the triplet 13,1,0). We begin by adding the pair of digits at the right, both of which are 0; this yields a total of 0 to set down. (According to the rules, if the total of the digits at the right is more than 6—as would be the case if we multiplied 48 by 8—the total is set back to 6.) Next the center digits are added, modulo-2. In this case 1 plus 1 equals 2, and 2, modulo-2, is 0. Therefore we set a second 0 to the left of the first one. We now add the pair of digits at the left, 14 plus 13, for a total of 27. The rule governing the addition of this pair of numbers says it is to be done modulo-2^{4-k}, where k is the result of the addition of the pair of digits at the right. Here k equals 0, and the modulus for the addition of the digits at the left is therefore 16. The result is 11 (the remainder when 27 is divided by 16) and the final triplet, showing our result, is 11,0,0. Reference to the table shows that 11,0,0 is the representation for 29. This checks: 23 times 43 is 989; 989, modulo-64, is 29 because 989 divided by 64 yields a quotient of 15, which is ignored, and a remainder of 29.

The rules for modulo-64 multiplication are exacting and seem even more complicated than those for modulo-15 addition insofar as paper-and-pencil computation is concerned. The reader will note, however, that the modulo-64 system consists of three groups of digits that the computer can process simultaneously. Indeed, the most time-consuming part of the operation is the addition of the digits at the left, which, as the example shows, is done according to a



fourth switching delay combines that product with the three lower digits. With only four delays, conditional-sum addition proves 20 percent faster than conventional addition.

0	0,0,6	16	0,0,4	32	0,0,5	48	0,1,4
1	0,0,0	17	12,0,0	33	8,0,0	49	4,0,0
2	0,0,1	18	6,0,1	34	4,0,1	50	2,0,1
3	3,1,0	19	7,1,0	35	11,1,0	51	15,1,0
4	0,0,2	20	1,0,2	36	2,0,2	52	3,0,2
5	1,0,0	21	13,0,0	37	9,0,0	53	5,0,0
6	3,1,1	22	5,1,1	38	7,1,1	54	1,1,1
7	10,1,0	23	14,1,0	39	2,1,0	55	6,1,0
8	0,0,3	24	1,1,3	40	1,0,3	56	0,1,3
9	6,0,0	25	2,0,0	41	14,0,0	57	10,0,0
10	1,0,1	26	7,0,1	42	5,0,1	58	3,0,1
11	5,1,0	27	9,1,0	43	13,1,0	59	1,1,0
12	3,1,2	28	2,1,2	44	1,1,2	60	0,1,2
13	15,0,0	29	11,0,0	45	7,0,0	61	3,0,0
14	10,1,1	30	4,1,1	46	6,1,1	62	0,1,1
15	4,1,0	31	8,1,0	47	12,1,0	63	0,1,0

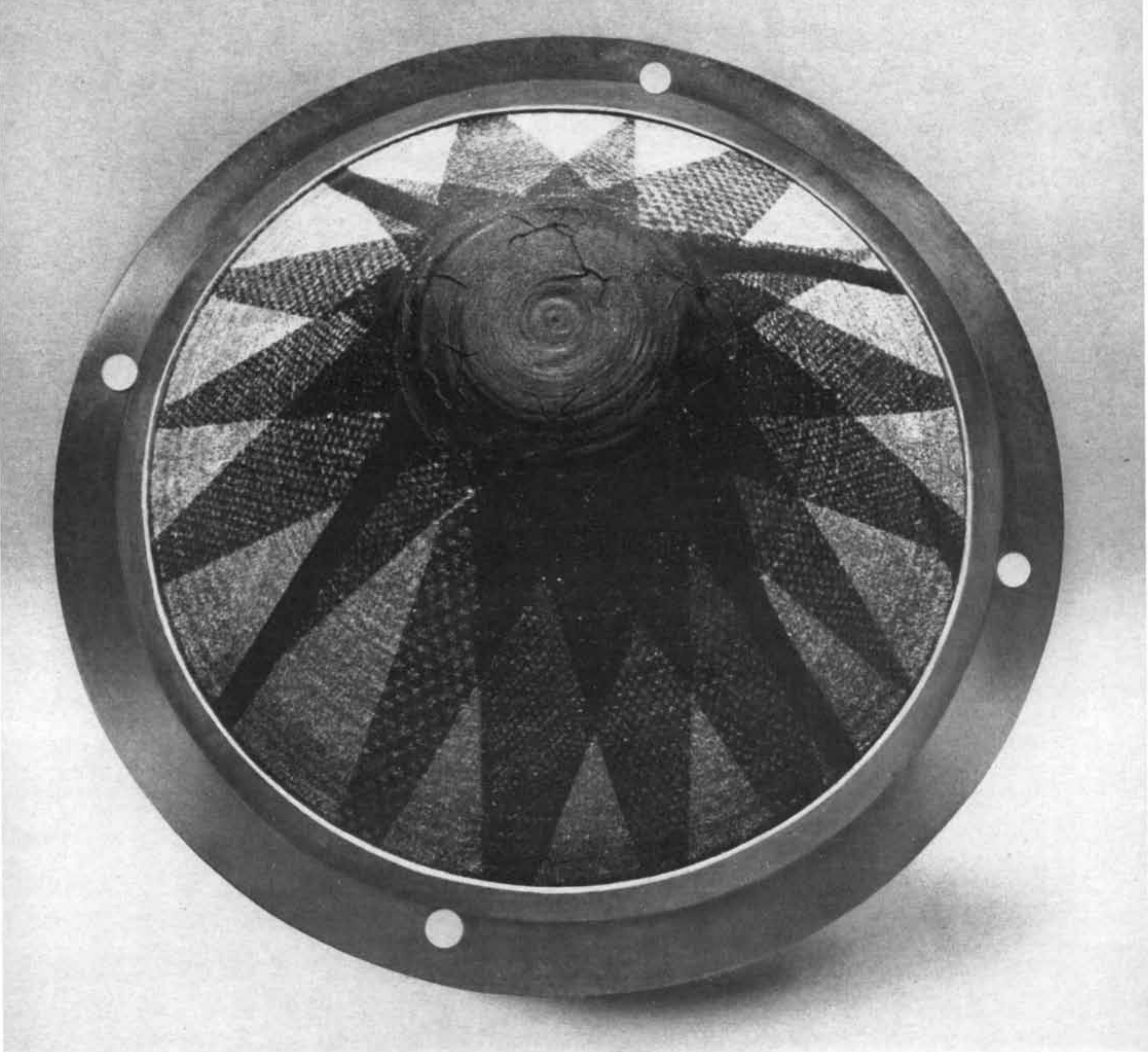
MODULUS MULTIPLICATION offers advantages similar to those of remainder addition because the system of number representation allows the computer to process several groups of digits simultaneously. The table shows the unique triplets representing the numbers from 0 to 63 that are used in multiplication modulo-64. The method is as fast as adding modulo-16.

variety of moduli depending on the value of k. The "worst case," that is, the most complex possible modulus for this pair, is modulo-16; thus modulo-64 multiplication is essentially no more time-consuming than modulo-16 addition.

The method of multiplication described here is about as fast as any possible method. I should mention that the same qualitative comparison between addition and multiplication holds not just for powers of 2 but for any number N. Accordingly it is clear that the intuitive feeling that multiplication is a more time-consuming operation than addition arises mainly from the nature of the base representation that is usually adopted. It is not an inherent property of these operations.

The logical deductions I have outlined provide the computer designer with a means of evaluating various designs. Knowing the capabilities of the available hardware, he can determine how fast his computer will compare with an ideally fast one. Let us assume that the designer's objective is to add modulo-2^{48} in 20 nanoseconds. As long as his components' input fan-in is three and their delay time is 10 nanoseconds, the shortest time the operation could take proves to be 50 nanoseconds. Thus in order to attain his goal the designer will need either components with an input fan-in that has been raised to 10 or components with a delay time that has been shaved to four nanoseconds. The formula does not and cannot decide which approach the designer should take; what it does provide is a quantitative measure of the effect on the speed of arithmetic operations that any imaginable change in hardware can produce.

Finding the absolute speed limits for addition and multiplication has been only one in a series of continuing investigations of the effort required to compute functions. For example, we should like to know what is the minimum number of arithmetic operations necessary to compute an nth-degree polynomial and the minimum number of operations necessary for matrix multiplication. Just as the widespread use of the steam engine in the 19th century greatly increased theoretical interest in thermodynamics, the increasing use of computers today is a driving force behind the study of computational complexity. It is safe to assume that as work on these questions continues mathematicians will gain a better insight into the whole realm of computation.



Air-breathing Fishes

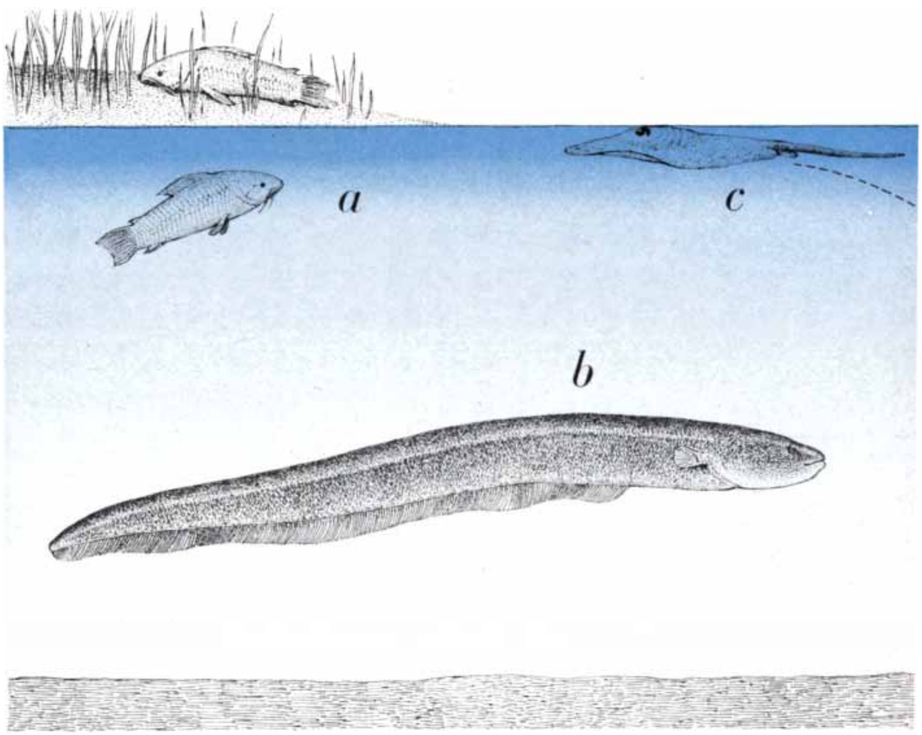
Lack of oxygen in water forced certain Devonian fishes to develop air-breathing organs. Some left the water and colonized the land; descendants of others are today's remarkable air-breathing species

by Kjell Johansen

The transition from breathing water to breathing air was perhaps the most significant single event in the evolution of vertebrate life. How did it come about? The change in respiration is commonly identified with the emergence of animals from the water to dry land. Actually the fossil and living evidence shows that air-breathing by vertebrates began long before that development. Well before the evolution of amphibians some fishes had begun to use air instead of water for respiration. The crucial steps toward the development of lungs came about not as an adaptation to living out of the water but in response to changes in the aquatic environment itself.

During the Devonian period of some 350 million years ago a respiration crisis developed for much of the vertebrate life inhabiting the freshwater basins of the earth. The oxygen content of the waters gradually declined, as a result of high temperatures and the oxygen-consuming decay of dead organic material in shallow lakes, rivers and swamps. Throughout a vast portion of the aquatic environment the oxygen supply dropped to a marginal level. For the fishes, equipped only with gills for obtaining oxygen from water, life became quite precarious. Yet they were mere inches away from the limitless reservoir of oxygen in the atmosphere above the surface of the water. This saving circumstance led to the evolution of a variety of organs that enabled fishes to obtain oxygen from the air.

We can see the adjustments that were made to the oxygen problem in many fishes today, among both modern and archaic species. Certain species living in stagnant tropical pools, for instance, spend their entire existence close to the surface, within ready reach of the thin top layer of water that contains more oxygen than the waters below. Some of these species come to the surface layer to replenish their oxygen at frequent intervals; others visit the layer less frequently but stay in it longer each time. During a recent expedition to the Amazon River area I witnessed a dramatic demonstration of the latter performance. We had placed a freshwater stingray in a tank containing only a small amount of water. We noted that as the oxygen content of the water declined the fish pumped water over its gills more and more rapidly. Suddenly, when the oxygen pressure dropped below 20 millimeters of mercury, the fish swam straight to the surface, began to draw the surface film of water into the intake openings on its upper side and continued this performance at the surface for more than 15 minutes. The whole act was beautiful, and we were excited to discover this illuminating behavior—which the Amazon stingray probably has been performing routinely for millions of years. All the close relatives of this stingray are marine or brackish-water fishes with the flattened shape of bottom-dwellers and with water-intake openings on their upper surface, where the openings cannot be clogged by debris from the bottom. In the amazing freshwater stingray the



OXYGEN-DEFICIENT TROPICAL SWAMP is the habitat of air-breathing fishes and some that breathe near the surface where the oxygen supply is best. The relative oxygenation is shown by the color intensity. *Hoplosternum littorale* (*a*) is an intestinal breather that gets

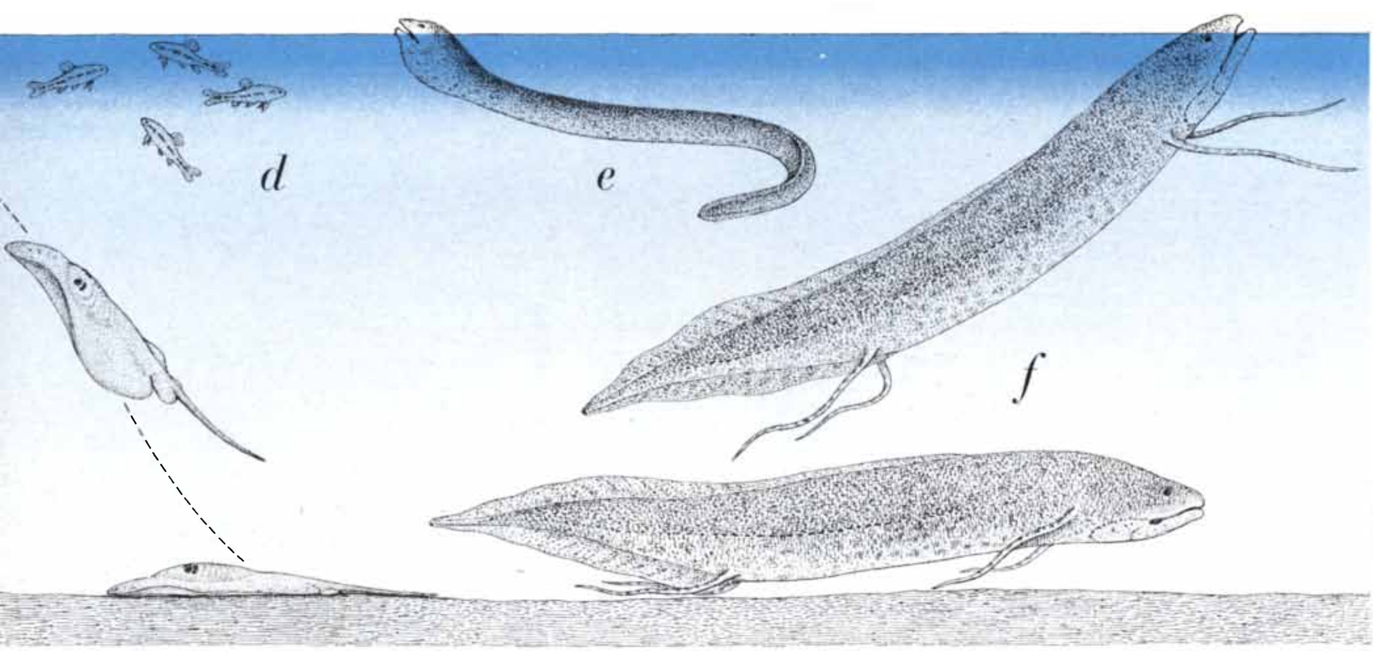
same morphology exploits the opposite side of the hydrosphere: the interface with the air! It is also significant that the gills of the stingray (and of other fishes with similar habits) are large and well developed, maximizing gas exchange so that the fish can make efficient use of the limited supply of oxygen in the surface water.

The step from tapping surface water for oxygen to obtaining oxygen from the air above the surface was of course a drastic one for fishes, requiring radical modification of their respiratory structures. The typical gills of a fish, although well suited for gas exchange in the water, are totally unsuited to performance of that function in the air. The thin lamellae of the gills, with their fine blood vessels, collapse under gravity in the air. In order to breathe air fishes had to develop air-holding chambers of one kind or another. Some species became air-breathers by adapting the stomach or a segment of the intestine to this purpose; they swallowed air and expelled it again at the mouth or the cloaca. Others developed elaborate air-holding structures in the mouth or throat. The most common adaptation for breathing air was the development of the special organ now recognized in many fishes as the swim bladder. This chamber serves other purposes in water-breathing fishes: it maintains the fish's buoyancy by adjusting to the hydrostatic pressure, and it may also act as an organ for detecting and producing sounds. The fossil evidence indicates, however, that the swim bladder of fishes originally came into being as an organ for respiration, and in some species it eventually evolved into a true lung.

A surprisingly large number of modern species of teleosts (bony fishes) are capable of breathing air. Evidently conditions like those that existed in Devonian times—swampy, oxygen-deficient waters—have given rise again and again to air-breathing fishes. Apart from these latter-day examples, we have considerable direct information on the respiratory revolution that led to the liberation of vertebrates from the aquatic environment during the Devonian. The information is provided not only by fossils from that time but also by living representatives of several archaic groups of air-breathing fishes that still exist today. These include two African genera in the primitive order Chondrostei, two American genera in the order Holostei and three genera of lungfishes (Dipnoi) in Africa, Australia and South America. These descendants from Devonian times inhabit oxygen-deficient waters and are so remarkably little changed from their ancestors that we can consider them representative of the early vertebrate forms that made the first crucial step toward air-breathing. The amphibians are believed to have arisen from the archaic ancestors of the lungfishes.

The lungfishes have an air bladder that developed originally as a diverticulum, or pouch, from the gut. The acquisition of this incipient lung was of course only a first step toward effective air-breathing. It had to be accompanied by changes in the fishes' system of blood circulation that would provide efficient transportation to the body tissues of blood oxygenated in the lung. In the lungfishes we see the circulation transformed in that way. In short, the lungfishes are truly lung breathers, with a respiratory and circulatory system that forecasts the system later developed by the higher vertebrates—the birds and the mammals. Fortunately the three living genera of lungfishes depict three stages in the transition from water-breathing to air-breathing, so that we are able to trace the anatomical changes that effected this transition.

Curiously, although the lungfishes offer an inviting opportunity to investigate the evolution of air-breathing by experimental studies, it is only within the past decade that such studies have been undertaken. With the collaboration of Claude Lenfant and other colleagues I have been pursuing this inquiry with lungfishes and certain other

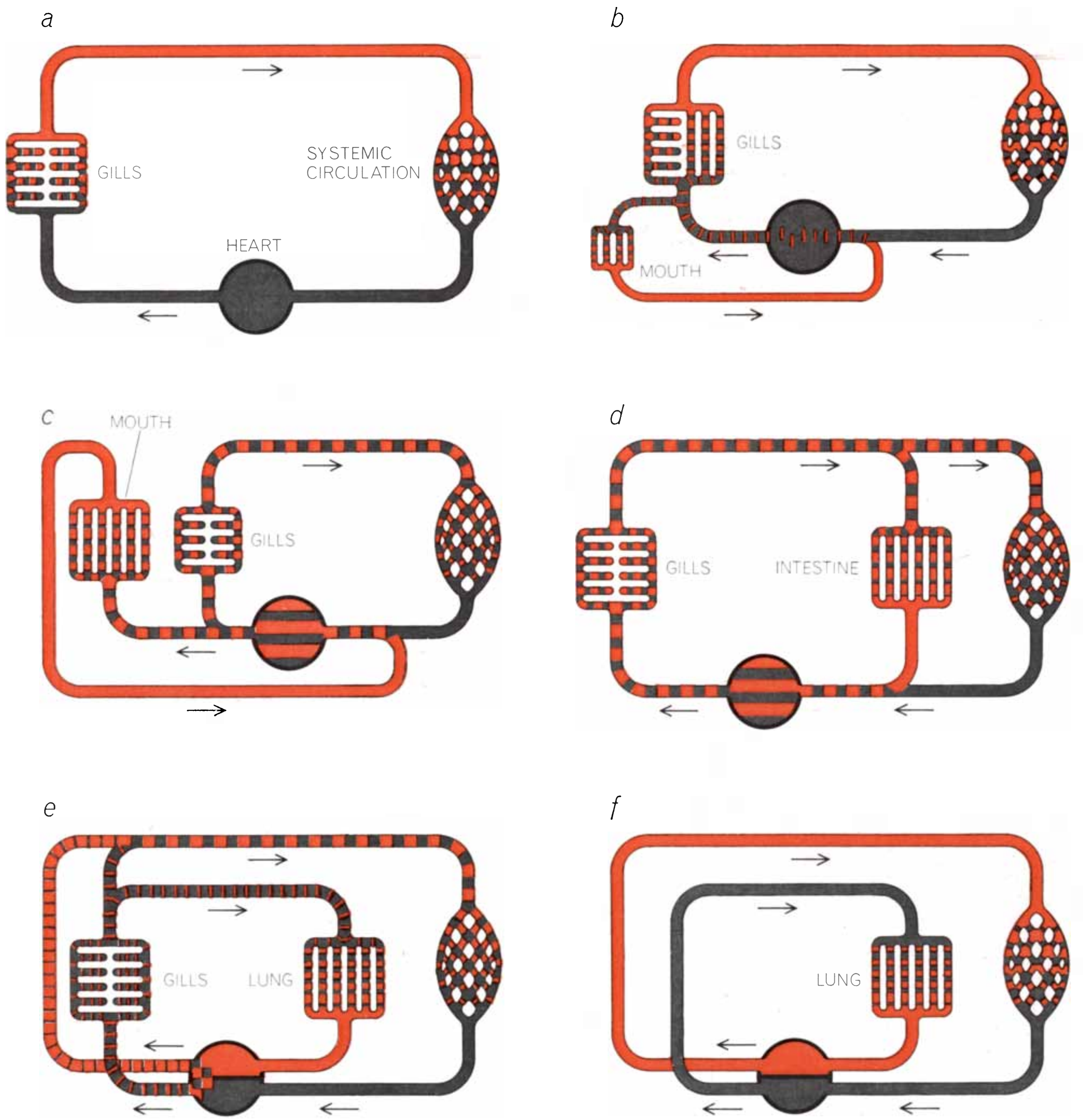


oxygen from air it swallows. *Electrophorus*, the electric eel (*b*), gulps air and obtains oxygen through the walls of the mouth. The freshwater stingray (*c*) visits the surface to breathe oxygenated water, as does *Characidium* (*d*). The gills of *Symbranchus marmoratus* (*e*) function in air as well as water. In lungfishes such as *Protopterus* (*f*) the swim bladder has become a well-developed lung.

air-breathing fishes in Africa, Australia, South America, Norway and in my laboratory at the University of Washington. The following is an account of our findings.

The lungfishes have long been known to man; they have been an important source of food for primitive peoples, in part because many of the species go into estivation (a dormant state) during dry seasons and therefore are easy to catch. Some of the lungfishes grow to considerable size; one African specimen displayed in a Nairobi museum measures seven feet in length. It was only about 130 years ago that lungfishes began to attract the attention of scientists. The discovery at that time of their remarkable ability to breathe air evoked considerable excitement and confusion in zoological societies. Reluctant to accept an air-breather as a fish, the zoologists at first classified the lungfishes as amphibians, and the surprise occasioned by the discovery is still preserved in the species name of a South American lungfish: *paradoxa*.

In the three lungfish genera we can observe a sequence of development from very little dependence on air-breathing to a stage where air-breathing became the principal means of respiration. The

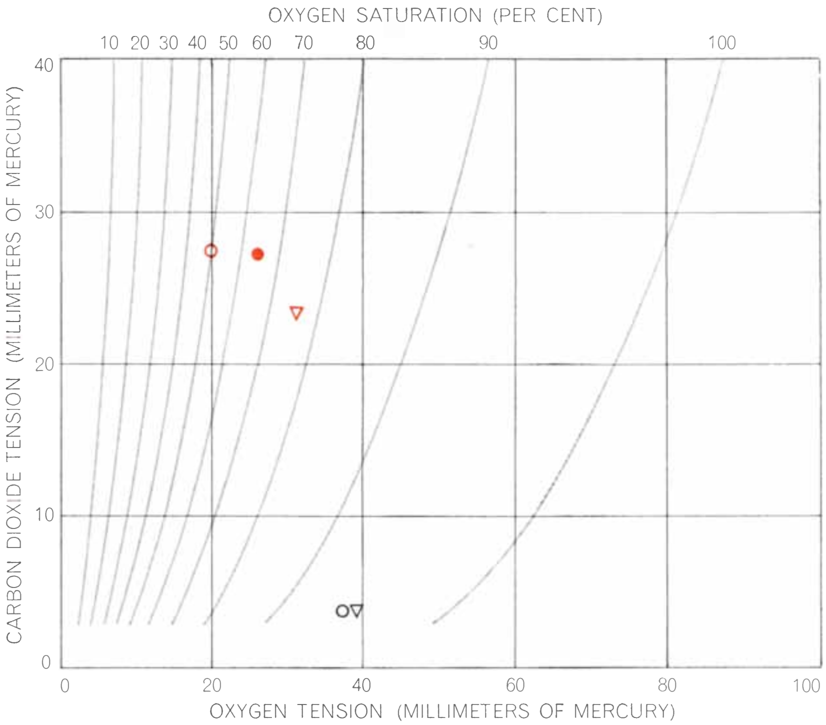


VASCULAR SYSTEM is diagrammed in relation to air- and water-breathing organs in typical fishes (*a*), birds and mammals (*f*) and various "in-between" air-breathing fishes: *Symbranchus* (*b*), *Electrophorus* (*c*), *Hoplosternum* (*d*) and the lungfishes (*e*). Water-breathing fishes have a single circulation with no mixing between oxygenated (*red*) and deoxygenated (*gray*) blood (*a*). Birds and mammals have a double circulation with no mixing (*f*). In the others there is more or less mixing of blood. The lungfish arrangement (*e*) was conducive to development toward the vertebrate condition: two circuits are arranged in parallel, with variable mixing.

Australian lungfishes (genus *Neoceratodus*), living today in rivers that are never severely deficient in oxygen, are primarily water-breathers, with well-developed and functioning gills. They do, however, possess lungs and can raise their heads out of the water to breathe air when necessary. The South American lungfishes (*Lepidosiren*) and the African (*Protopterus*) live in swamps whose waters are severely deoxygenated and periodically dried up by droughts. In dry periods these fishes entomb themselves in burrows or cocoons in the mud and go into a profound state of suspended animation; one might say their metabolic furnace is turned down all the way to the pilot light. Within minutes or hours after the swamp is flooded again by rainfall they revert to active life. Although water is their natural habitat, they depend mainly on their lungs and air-breathing for the absorption of oxygen. In the adult South American and African lungfishes large portions of the gills have degenerated to the point where they are little more than vestiges.

For examination of the functioning of the lungfishes' respiratory apparatus we have used catheters and transducers that enable us to determine blood flow and blood pressure in the vessels supplying the respiratory organs. We implant the instrumentation in the important blood vessels and in the lung itself, and after the fishes' recovery from the surgery we are able to obtain a continuous record of blood flow and pressure as the animals swim about in an aquarium, and to measure the oxygen tension in the blood and lung by analyzing samples from those organs. With this technique we have studied the lungfishes' respiratory behavior under normal conditions and under experimental variations of their environment.

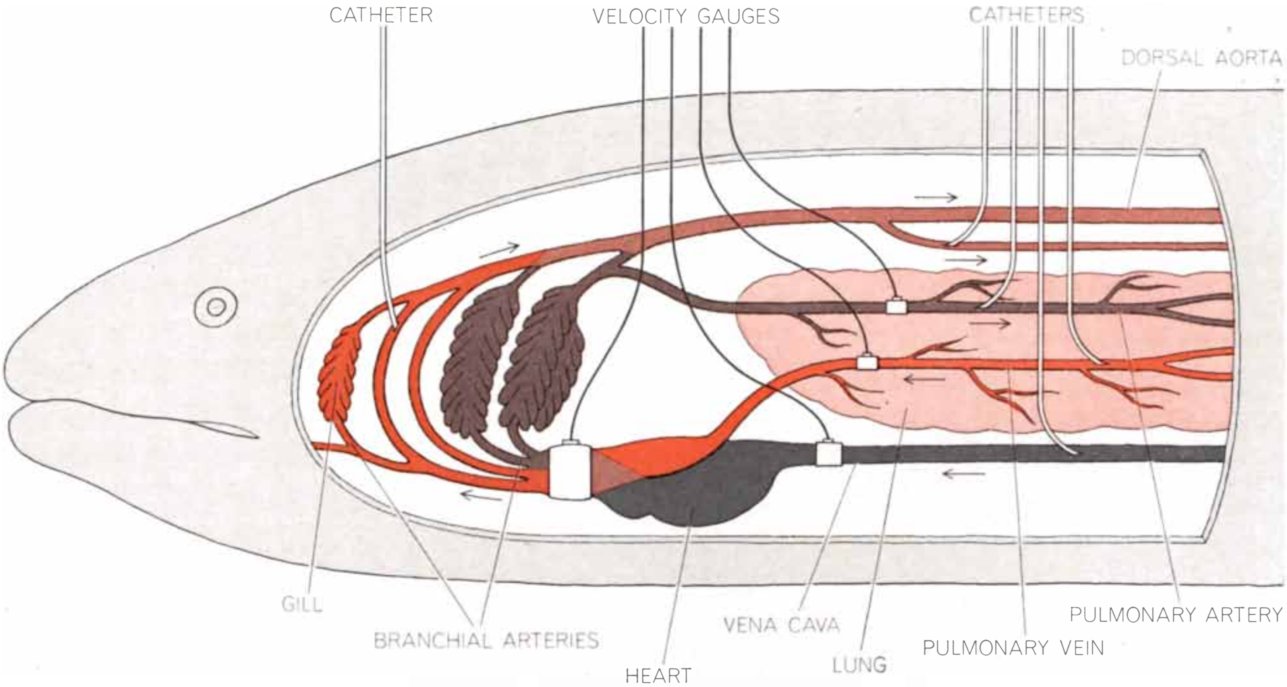
The observations that are thus made possible show clearly the extent of the difference between the Australian lungfish and, say, the African lungfish with regard to breathing behavior [*see illustration on this page*]. With the fish swimming in well-oxygenated water, the blood coming from the gills of the Australian lungfish is almost fully saturated with oxygen. The lung then has little or no importance; there is no need to add to the oxygen supply by means of air in the lung. Furthermore, the carbon dioxide in the blood is kept at a very low level, because carbon dioxide has a relatively high solubility in water and the gills are remarkably efficient in exchanging this gas. In the African lungfish, on the other hand, the situation is somewhat reversed. The blood delivered to the lung from this fish's vestigial gills is not nearly as rich in oxygen, and the lung makes a large additional contribution to the oxygen tension, raising the oxygen saturation of the blood to about 80 percent. The lung also serves to eliminate some carbon dioxide. It is less efficient in this function than gills are, however, and the carbon dioxide tension in the blood is therefore considerably higher in the African lungfish than it is in the Australian lungfish.



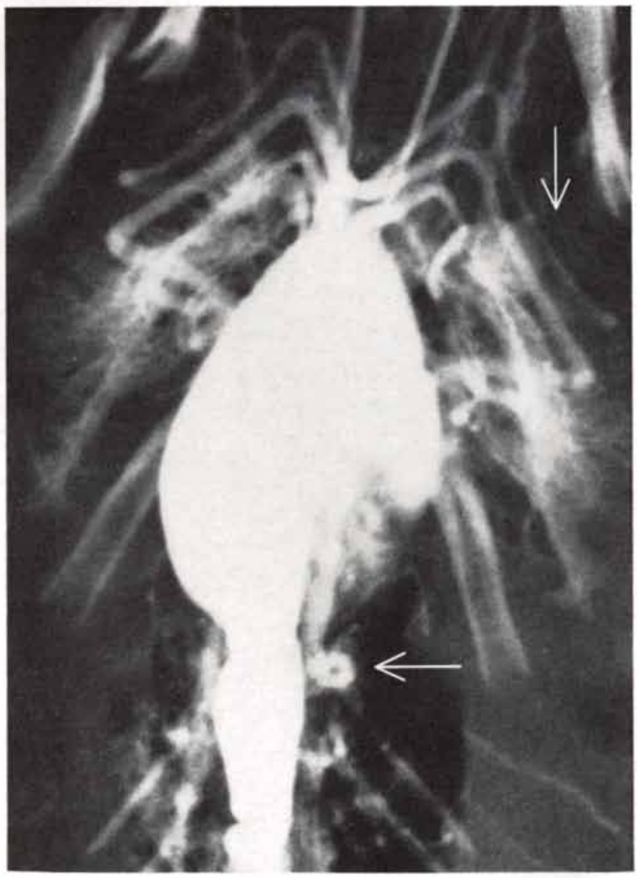
MEASUREMENTS of the oxygen and carbon dioxide content of the blood in the Australian lungfish *Neoceratodus* (*black*) and the African lungfish *Protopterus* (*color*) show that the latter depends more on its lung even in the water. In *Neoceratodus*, blood going to the lung in the pulmonary artery (*circle*) is about as well saturated with oxygen (*gray curves*) as blood coming from the lung in the pulmonary vein (*triangle*). In *Protopterus*, however, oxygen saturation is higher and carbon dioxide tension lower in blood coming from the lung (*triangle*) than in blood going to it (*open circle*); the oxygenated blood is channeled preferentially to the systemic arteries (*dot*) rather than to the lung. The lower carbon dioxide tensions in *Neoceratodus* reflect the dominance of water-breathing with efficient gills.

Now let us drain the water from the tank and leave both types of fish exposed to air. The Australian lungfish frantically searches for a return to water and at the same time begins to gulp air into its lung at a rapid rate. This effort succeeds in saturating the blood flowing through the lung with oxygen, but the rate of blood flow is not sufficient to maintain the oxygen level in the arterial system. The oxygen tension in the arteries of the fish's body rapidly declines. Moreover, the lung does not eliminate carbon dioxide at the requisite rate, and in less than 30 minutes the carbon dioxide tension in this fish's arterial blood rises more than fivefold. In contrast, the African lungfish fares much better when it is left completely exposed to air. The intensification of this fish's air-breathing succeeds in keeping the oxygen tension in the arteries at a high level. The carbon dioxide concentration in the blood does rise for a time, but the elimination of that gas through the lung is such that the carbon dioxide tension soon levels off [*see top illustration on page 107*]. Thus the African lungfish clearly shows that its air-breathing system is sufficiently developed to enable it to survive out of water, as it must do during periods of drought, whereas the Australian lungfish normally never leaves the water.

Obviously the African lungfish's superior performance in air-breathing must depend on a circulatory advantage that enables it to make more effective use of the oxygen taken up through the lung. The possession of a lung, even one well supplied with blood vessels, cannot efficiently provide oxygen to an animal for its metabolic needs unless it is accom-



LUNGFISH was the major subject of the author's investigations. The schematic diagram shows how blood-velocity gauges and catheters for the measurement of blood pressure and blood-gas tensions were attached; animals swam freely after the instruments were implanted. In the lungfish blood is shunted either to the gills and lung for gas exchange or to the dorsal aorta for systemic circulation.



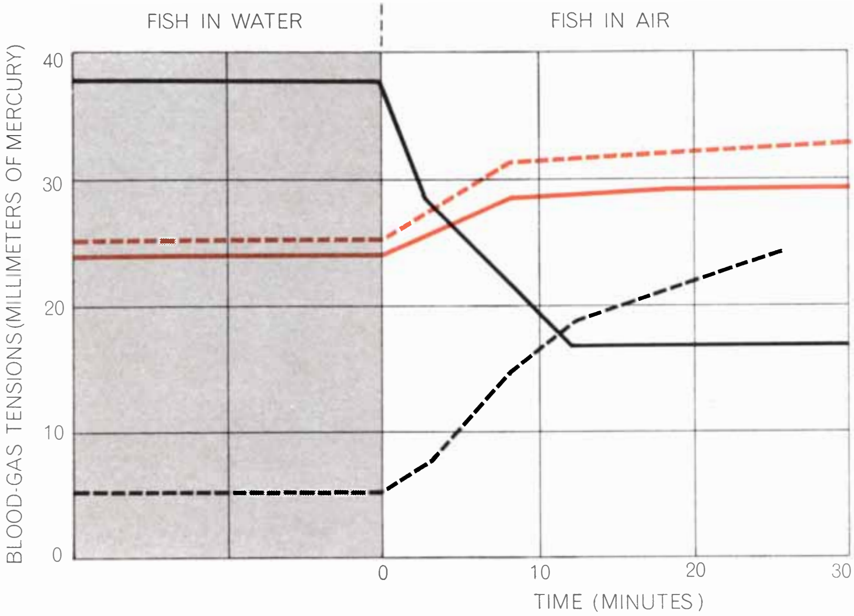
X-RAY ANGIOGRAPHY of *Protopterus* shows that blood returning to the heart from the lung is preferentially sent to the systemic circulation, with slight recirculation to the lung. When contrast medium is injected in the pulmonary vein (*left*), it appears mainly in two gill-less branchial arteries (*arrow*) and does not enter the pulmonary artery. Injected in the vena cava, however (*right*), it appears in all the branchial arteries and fine gill capillaries (*vertical arrow*) and also enters the pulmonary artery (*horizontal arrow*).

panied by an appropriate circulation for effective direct delivery of the oxygen to the metabolizing tissues. The circulatory requirement for an air-breather is fundamentally different from that for a water-breather. Hence a principal key to the transition from water-breathing to air-breathing lies in the evolution of the cardiovascular apparatus. The circulatory systems of the air-breathing fishes, differing one from another, show the steps in this evolution.

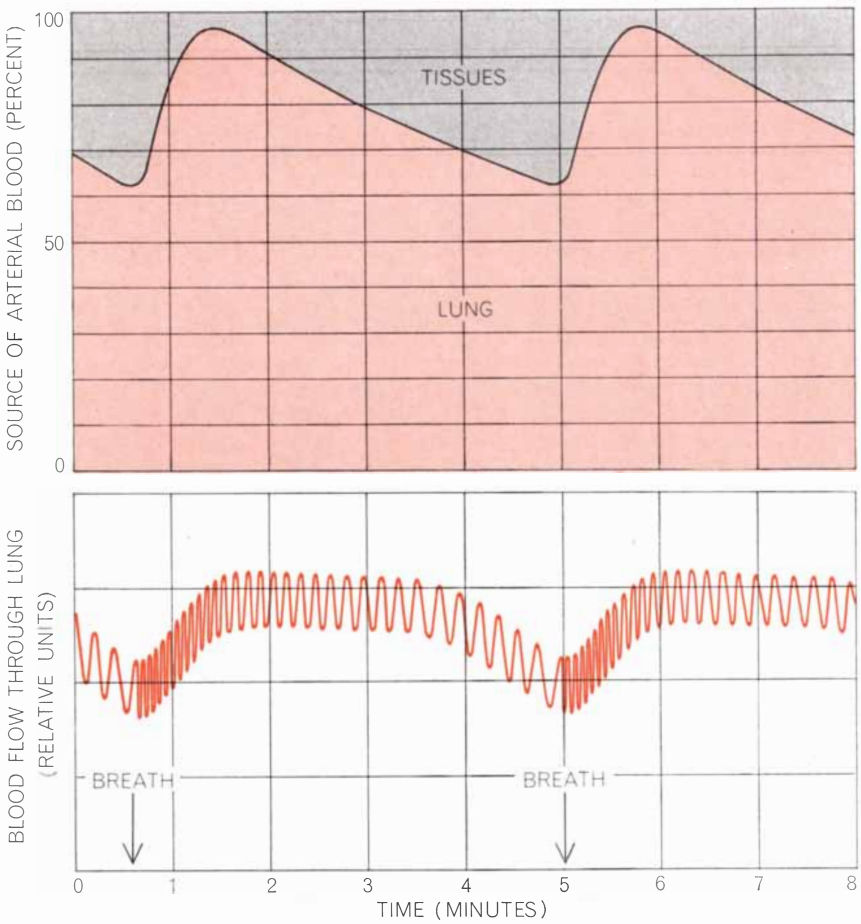
In ordinary water-breathing fishes the blood issuing from the pumping heart is not oxygenated. It flows to the gills, picks up oxygen there, emerges into a dorsal aorta and then flows through arteries to the various parts of the body, returning to the heart by way of the venous system. In short, the water-breathing fish has a single circulation, in contrast to the double circulation of a mammal, which first sends the venous blood from the right ventricle of the heart to the lungs and then, on return of the oxygenated blood to the left ventricle, pumps it out into the systemic circulation. For the fish the single circulation is perfectly adequate; the gills are highly efficient gas exchangers, and the blood flowing freely through them needs no extra input of energy in order to travel on through the arterial system.

When a fish acquires a lung and breathes air, complications begin to arise. The fish tends to retain its gills, at least at first, as an escape hatch for carbon dioxide, which is eliminated much more readily through gills than through a lung. Now, with gas exchange taking place both in the lung and in the gills, and with new avenues of blood circulation developing, the oxygenated blood from the lung becomes mixed with deoxygenated blood from the veins [*see illustration on page 104*]. Many of the air-breathing fishes still retain a single-circulation system in spite of this disadvantage. In the lungfishes, however, we see the beginnings of development of a double circulation. The two circulations are parallel, one passing through the lung, the other through the gills. They are not distinctly separated, and consequently there is some mixing of blood between them.

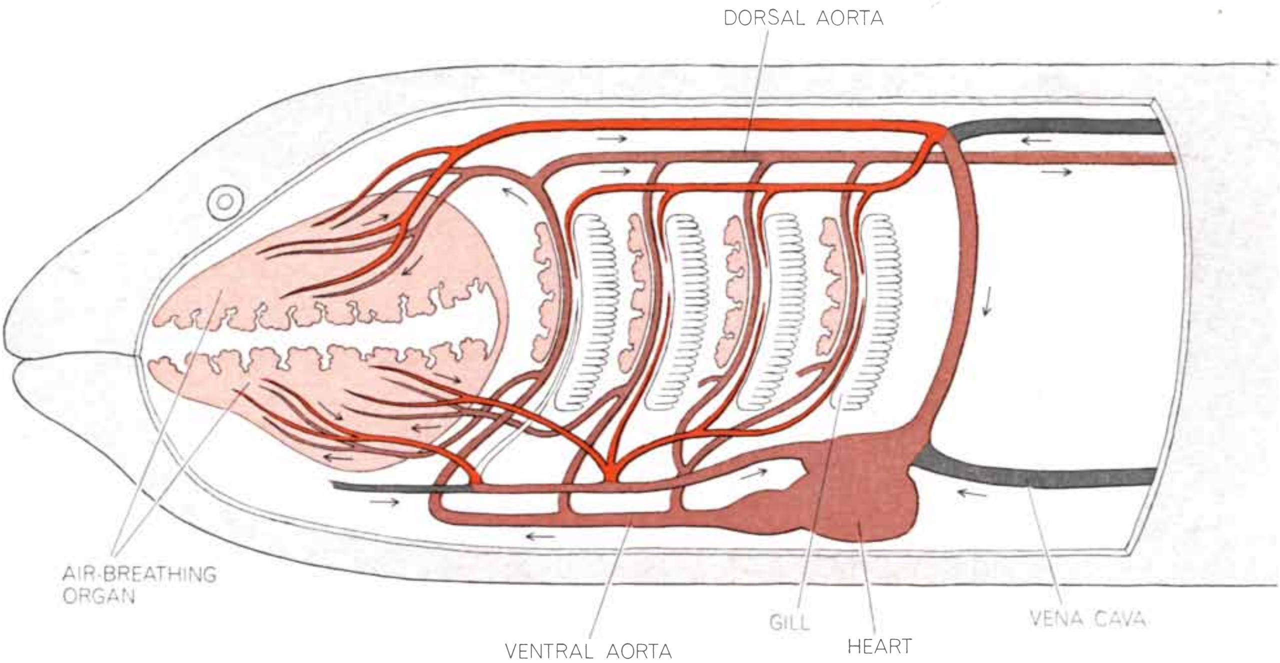
The Australian lungfish, as we have noted, is principally a water-breather and still has well-developed gills. It resorts to air-breathing only when the oxygen content of the water falls below normal. This fish could not survive long in severely deoxygenated water because the oxygen it gained by breathing air would be lost to the water as its oxy-



ADAPTABILITY TO AIR exposure varies in *Protopterus* (*color*) and *Neoceratodus* (*black*). When the tank is drained, both fish intensify air-breathing. *Protopterus* increases arterial oxygen tension (*solid curve*) and controls carbon dioxide (*broken curve*). *Neoceratodus* cannot get enough oxygen into its circulation or eliminate carbon dioxide efficiently.



SHUNTING of oxygenated blood changes with the breathing cycle in *Protopterus*. Right after each breath almost all blood entering the systemic arteries is oxygenated blood from the lung; later in the cycle the proportion is lower. Blood flow through the lung also tends to be highest just after a breath and then to diminish until the next breath is taken.

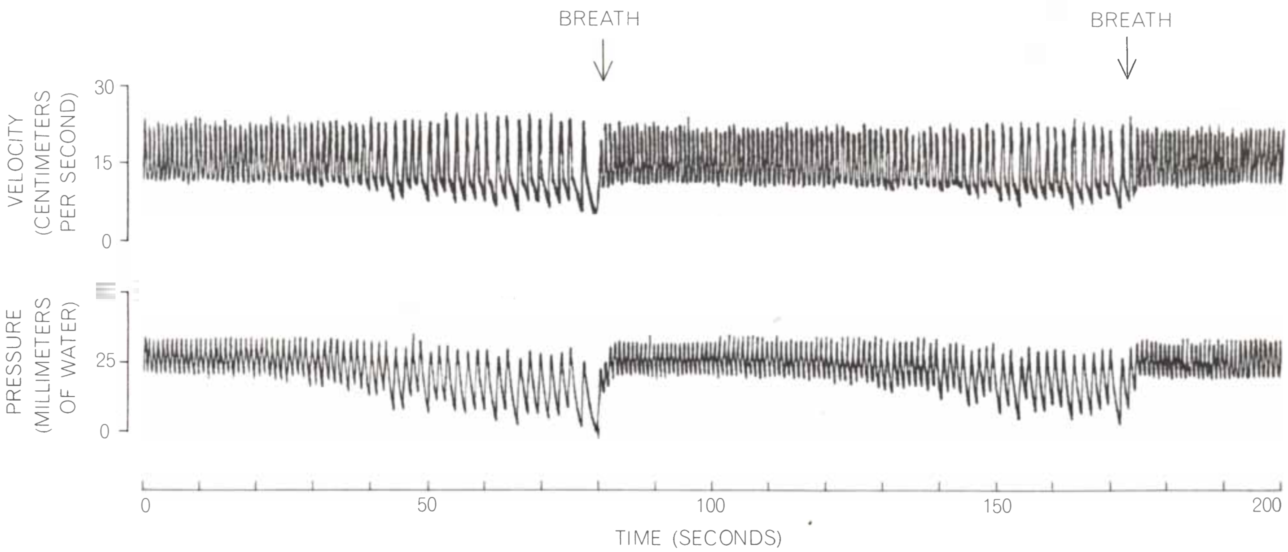


ELECTRIC EEL is a mouth breather. The mucous membrane lining its mouth is creased and wrinkled, providing a large surface richly supplied with blood vessels for gas exchange. Blood moves past the vestigial gills, which are unimportant in gas exchange.

genated blood circulated through the well-developed gills. The African lungfish, however, gets along without stress in oxygen-depleted waters partly because its gills are degenerated and even bypassed by the two largest arteries from the heart, which go directly to the dorsal aorta, and partly because its lung circulation is more fully developed.

By means of X-ray angiography, using special film changers capable of exposing several frames per second, we have examined the pattern of circulation in the African lungfish in considerable detail. We find that the channeling of venous and arterial blood is highly selective in this fish; the recirculation, or mixing, of blood is very slight in the pulmonary circuit and only moderate in the systemic circuit. The X-ray studies of blood flow and oxygen analysis of the blood also show that the blood flow through the lung is greatest immediately after the intake of an air breath (when the lung gas is richest in oxygen) and that the blood in the arteries issuing from the heart to the tissues reflects a similar cycle: it is richest in oxygen right after a breath and gives way to deoxygenated blood from the tissues in the interval before the next breath.

Evidently the African lungfish has a control system that coordinates the respiratory and circulatory mechanisms to achieve a maximal yield in gas exchange and gas transport. Interestingly enough, an interaction of the two mechanisms such as we observe in the African lungfish can also be seen in man. When part of the human lung is blocked from contact with air or is poorly ventilated for



BLOOD FLOW in the electric eel is coordinated with breathing. Right after each breath (*arrows*) the cardiac output is high; the heart rate (pulse) and the average blood velocity and pressure then decline until the next breath, when they return to the high level.

some other reason, the vascular system reduces the flow of blood to that part. That is to say, the blood flow is adjusted to the availability of oxygen at the lung interface, as it is in the lungfish.

An even more basic parallel between the lungfish and human respiratory systems can be noted. Human respiration is regulated by an elaborate process of negative feedback in which the respiratory activities are controlled by changes in the oxygen and carbon dioxide tensions and the acidity of the blood. A rise in the blood's carbon dioxide tension, for instance, stimulates more rapid breathing to reduce it to the normal level. In air the African lungfish displays a similar sensitivity to specific internal cues. If it is exposed to air deficient in oxygen, the lungfish responds by breathing more rapidly than it would on taking normal atmospheric air into its lungs. Evidently its internal receptors sense hypoxia (oxygen deficiency) within the blood, and this acts as negative feedback to stimulate increased respiratory activity. In water, however, the response is different. If an adult African lungfish is placed in even severely deoxygenated water, the rate of its air-breathing, the gas tensions in its arterial blood and the normally slow rate of water-pumping across its gills all remain unchanged. The fish has been relieved of the threat of internal deoxygenation from oxygen-poor water; the gills no longer offer effective communication between the blood and the external environment and the respiratory control system monitors predominantly the activity of what is now the principal organ for oxygen extraction: the lung.

(It is easy to see that a feedback response prompting increased water-breathing in severely oxygen-depleted water would be harmful rather than advantageous to a fish that depends primarily on water-breathing. For an inhabitant of a tropical swamp it would lead only to an energy-consuming effort to obtain oxygen that is simply not available. The few truly water-breathing fishes living in such waters depend on a high tolerance for lack of oxygen in their blood and an ability to stay away from water masses most deficient in oxygen.)

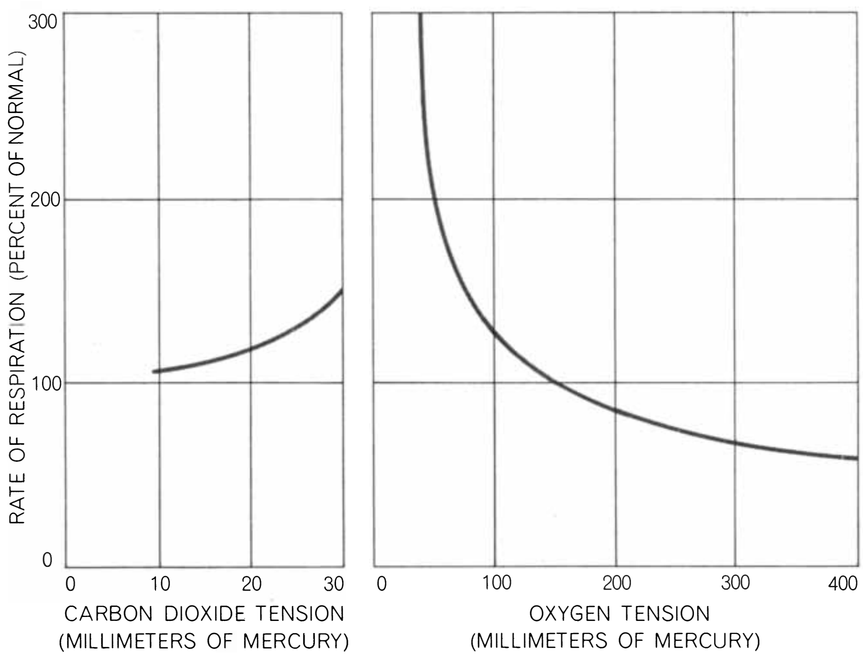
What causes a lungfish to intensify its breathing efforts when it is totally exposed to air? This response is so prompt that it seems unlikely it is initiated by the operation of some internal chemical mechanism. My own surmise is that the response is probably triggered by the sudden translation of the fish from its weightless condition in water to the exposure to net gravitational force in the air. This represents a massive physical stimulus that may well jolt the animal into a burst of rapid breathing. We may have here a phylogenetic parallel to mammalian ontogeny. The newborn baby's first breath after it emerges from the amniotic pool of its mother's womb seems to be triggered by the massive impingement of physical stimuli to which it is suddenly exposed in the air.

We come now to certain fishes in which the mouth serves as a lung. One example is the famous climbing perch of India (which, contrary to its mythology, does not actually climb trees). Probably the most remarkable of the mouth breathers is the electric eel (*Electrophorus electricus*) that lives in shallow, muddy pools along creeks and rivers in tropical South America. This fish is an obligate air-breather; it could not survive if it did not come up frequently for air. At regular intervals—every minute or two—the fish rises to the surface, gulps air into its mouth and then sinks back to the bottom. It expels the air through flap-covered opercular openings.

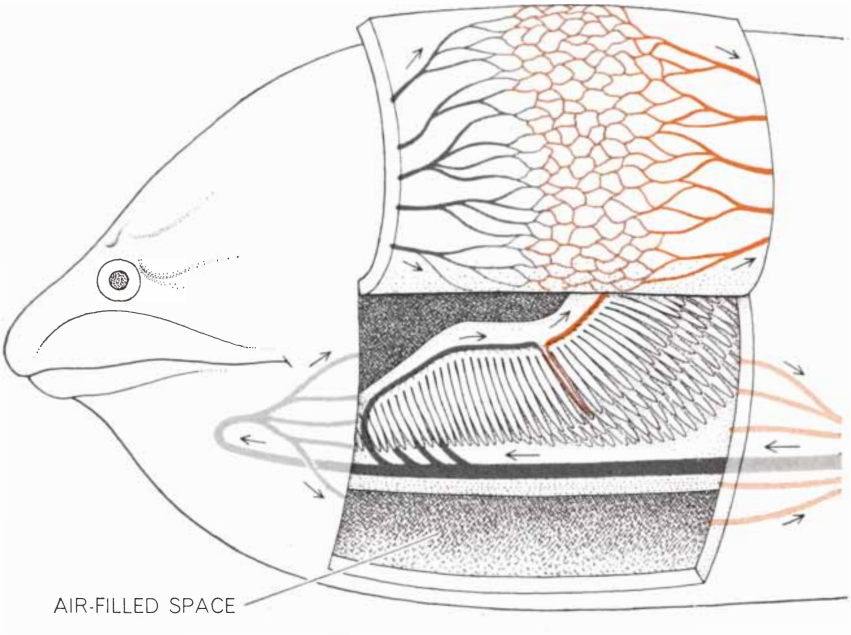
The electric eel has markedly degenerate gills that play no significant part in its respiration. The uptake of oxygen occurs in the mouth, which is almost entirely lined with papillae (protuberances) that provide a large total surface area for gas exchange. Comparatively little carbon dioxide is released through the mouth; most of it is discharged into the water by way of the skin and the vestigial gills.

A rich network of blood vessels is embedded in the lining of the mouth for the absorption of oxygen. For the carnivorous electric eel the presence of these fragile vessels would be a serious drawback if it had to kill and chew its prey with its mouth, but it avoids that problem by stunning its victim with a powerful electric charge (up to 500 volts) and swallowing the food whole. The electric eel's respiration is handicapped, however, by a relatively inefficient circulatory system. The blood, after its oxygenation in the mouth, is not dispatched directly to the body tissues by way of the arteries but goes into veins that carry it to the heart [*see illustration on page 104*]. Consequently the oxygenated blood is mixed with the deoxygenated blood. As a result of the circulatory pattern, in which the blood is shunted through the respiratory organ between the arterial side and the venous side of the circulation, the arteries receive only part of the cardiac output, and the blood delivered to the tissues is a mixture of oxygenated and deoxygenated blood.

Our studies of blood flow in the electric eel showed that it pulses in a cyclic pattern like the pattern in the lungfish. Immediately after the eel has taken a breath the heart steps up its output; the

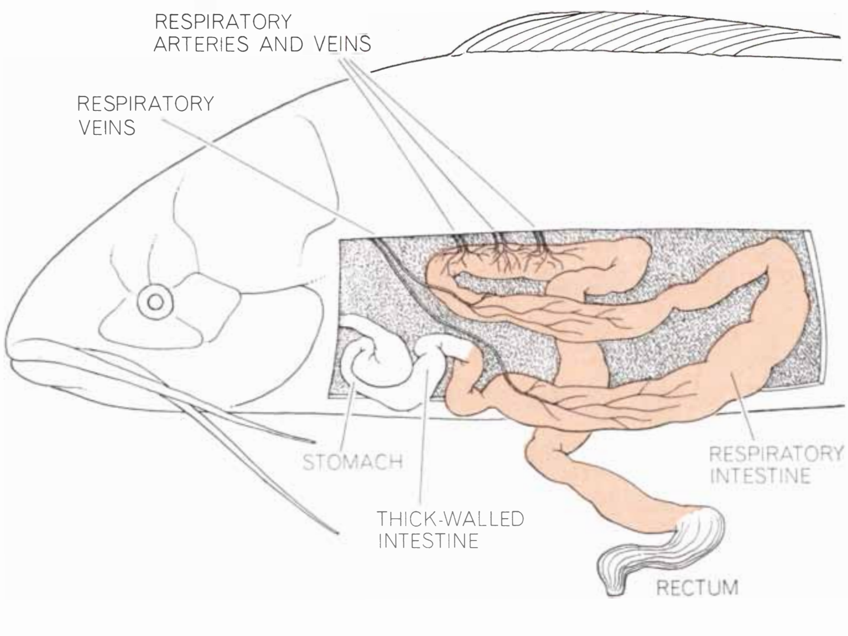


RESPONSE of electric eel to changes in the ambient atmosphere is clear and prompt. If it surfaces in an atmosphere low in oxygen (or high in carbon dioxide), its breathing rate is accelerated. If there is more oxygen present than in normal air, the breathing rate declines.



SYMBRANCHUS **is unusual in that it can use the same organ, its gills, for air- and water-breathing, and can do both quite successfully. In addition to gills modified for air-breathing, it has a richly vascularized mouth lining (*flap*) that participates in gas exchange.**

heart rate, output and blood pressure then decline until the next air breath. During the accelerated phase of the cardiac output a high proportion of the blood flow goes to the mouth, where it can be oxygenated; then, as the oxygen in the mouth is used up, the proportion of the cardiac output delivered there declines. Thus the operation of the circulatory system partly compensates for the inefficiency of its structure by delivering more blood to the respiratory organ when the availability of oxygen in the organ rises to a peak. The increase in cardiac output evidently stems from stimulation of mechanical receptors in the mouth by the act of inhalation; we have found that it can be elicited by inflating the eel's mouth with pure oxygen or with nitrogen. Our experiments have also shown that the electric eel, like the African lungfish, is responsive to the oxygen content of the air it breathes. When it is subjected to air that is low in oxygen, the eel speeds up its breathing efforts; when the air is abnormally high in oxygen, the fish's breathing slows down.



HOPLOSTERNUM **is one of several kinds of intestinal-tract breathers. It swallows air, which fills a long, coiled portion of the intestine that is thin-walled and richly supplied with blood vessels. Only a short segment of the intestine remains to function in digestion.**

A few remarkable fishes are able to use their gills for breathing air. An outstanding example is an eellike freshwater fish of South America named *Symbranchus marmoratus*. The gills of this fish are so organized that their fine blood vessels do not collapse under the force of gravity in the air; hence the blood flow through the gills remains normal. In *Symbranchus* the gills serve as an effective breathing organ both in the water and in the air. In air they are assisted by the lining of the mouth cavity, which also is well vascularized and provides gas exchange between the air and the blood. As long as the water contains an adequate oxygen content the fish spends all its time underwater. When the oxygen content drops, however, as commonly happens in tropical waters during the heat of the day, the fish rises to the surface, inflates its mouth and throat with air, closes its mouth and uses the trapped air for respiration. The inflation of the head makes the fish buoyant, and it may float on the surface for a considerable time, sometimes for hours, opening its mouth at intervals to expel the spent air and take a fresh breath. *Symbranchus*' air-breathing ability is so well developed that during a dry season it can survive for several months out of the water in the dormant state.

According to our measurements of the gases in this fish's blood, the oxygen tension of the arterial blood rises to higher levels when the fish is breathing air than when it breathes water. The carbon dioxide tension of the blood, however, also rises during air-breathing, both because the gills are less efficient in eliminating carbon dioxide in air than in water and because, as the fish rebreathes the air trapped in its closed mouth, waste carbon dioxide accumulates there. We found that when we removed *Symbranchus* from the water, it changed its breathing behavior so that the mouth was ventilated more or less continually, which allowed more carbon dioxide to escape. The fish kept its mouth open and made intermittent inhaling movements with its lower jaw. This change in breathing behavior on dry land may also be related to the fact that the fish no longer needs to maintain positive buoyancy.

Several species of tropical freshwater fishes use rhythmically ventilated air pockets in the gastrointestinal tract for air respiration. Air is swallowed and oxygen is delivered to the blood at the specialized, thin-walled and richly vascular portions of the gut. The circulatory system in these cases is generally inefficient for delivery of the oxygen to the body tissues because the arrangement is such that the oxygenated and deoxygenated blood is completely mixed and the arteries carry this mixture to the tissues [*see illustration on page 104*].

For the gastrointestinal-breathing species air-breathing by way of the gut is accessory to water-breathing with the gills. Nonetheless, the intestinal breathers are vitally dependent on air; most of them cannot survive if they are denied occasional access to the air, and for some species air-breathing has become the dominant method of respiration. A case in point is *Hoplosternum littorale*, a common fish of tropical South America that cannot live by water-breathing alone even if the water is saturated with oxygen, but that on the other hand is able to survive indefinitely in waters very severely deficient in oxygen by breathing air. Incidentally, this fish, like most other intestinal breathers, presents a puzzling question. Most of its intestine, a coiled tube that occupies nearly the entire body cavity, is modified for air-breathing. How can it carry out the usual intestinal functions, or, for that matter, how can it convey foodstuffs without disturbing the gas-exchange process of respiration? In our examinations we have always found the intestine full of gas and empty of solid food. It appears that the fish must feed only at long intervals and perform the digestive and absorptive functions with the short sections of the intestine that have not been modified for breathing.

The air-breathing fishes give a striking exhibition of the combination of exploratory and conservative forces that shaped the course of animal evolution. Changes in the oxygen tension of their aquatic environment forced the fishes to develop an apparatus for breathing air, yet they clung to the advantages that living primarily in water had to offer. At the same time, the crucial acquisition of the ability to breathe air opened a new world that inexorably led some fishes to develop the structural modifications that enabled vertebrates to step out of the water and walk onto dry land.

REPRESENTATIVES OF MONSTROUS TRIBES were believed to inhabit actual lands, principally India. Among the foreign peoples described by Herodotus, Ktesias and Megasthenes are (*from left to right, top to bottom*) the one-eyed people; the Blemmyae, or headless ones; the long-eared Phanesians; the big-lipped people; the Sciapodes (who used their single foot as an umbrella) and the goat-footed people, later called satyrs. The woodcuts are from the *Liber Chronicarum*, by Hartmann Schedel, published in 1493.

HOMO MONSTROSUS

For 2,000 years most educated men believed that remote areas were inhabited by monstrous races. It was only with the 19th century that it became clear that there was only one species of living men

by Annemarie de Waal Malefijt

When Carl von Linné (Linnaeus) worked out his monumental classification of natural things in the 18th century, he included the species *Homo monstrosus*. By *Homo monstrosus* he meant a species related to *Homo sapiens* but markedly different in physical appearance. To do Linnaeus full justice, he was quite aware that there were men on all continents who belonged to the species *Homo sapiens*. He nonetheless believed, as many of his contemporaries and predecessors did, that in remote areas there were manlike creatures with weird characteristics.

The belief in the existence of monstrous races had endured in the Western world for at least 2,000 years. During that time a rich assortment of semihuman creatures were described by explorers and travelers, whose accounts were probably based largely on malformed individuals and the desire to enhance their own fame at home. No part of the human body was neglected; each was conceived as having elaborate variations. There were, for example, peoples with tiny heads, with gigantic heads, with pointed heads, with no heads, with detachable heads, with dog heads, with horse heads, with pig snouts and with bird beaks. In the absence of knowledge about faraway places (and about the limits of human variation) men populated them with creatures of their imagination.

At the same time there were efforts to explain how such strange beings could have originated and what was responsible for their extraordinary characteristics. Thus in the rise and decline of *Homo monstrosus* one encounters ideas and attitudes that hold much interest for the modern anthropologist. The credulousness of those who accepted the reality of monstrous peoples is not so very different from the unfounded prejudices that human groups often harbor toward one another today, and one of the major tasks of anthropology is to clear away misinformation that may lead to such misunderstanding.

Among the earlier writers on fabulous peoples was the Greek historian Herodotus. In the fifth century B.C. he traveled widely in the world that was known to him. He was fairly objective in his accounts of the nearby Egyptians and Persians, and he certainly did not believe everything he was told. In lands far from home, however, people and their habits often appear more unusual; as Herodotus wrote, "The ends of the earth produce the things that we think most fair and rare." Thus he reports that in Ethiopia near the Egyptian border a tribe called the Troglodytes live underground. They eat snakes and lizards, and their language resembles the screeching of bats. Near the Atlas Mountains live the Atlantes, who are unable to dream. The Indian Padaei consume their fellow men as soon as they show the slightest sign of illness; the Lybian Adyrmachidae, after catching a flea on their person, give it bite for bite before throwing it away.

If human habits could be so strange, it was perhaps not surprising that physical differences also existed. Herodotus reports that the Agrippaei across the River Don are totally bald. In the mountains of the same region, so the bald men told him, are a goat-footed race of men and another group that sleeps six months of the year, hibernating like bears.

"I don't believe it," Herodotus comments, yet he continues. He describes the Arimaspi, who have only one eye situated in the middle of their forehead, and the griffins (half-lion, half-eagle) that guard hoards of gold. He writes that, according to the Libyans, their region has dog-headed men, headless people with eyes in their chest, wild men and wild women and many other monstrous races.

It may be that Herodotus actually heard such stories in his travels, but it should be noted that other Greeks of his time were acquainted with similar fabulous tales. Several centuries before Herodotus the poet Hesiod had mentioned one-eyed, dog-headed and breast-eyed tribes. Homer wrote about the one-eyed Cyclops and about giants and pygmies; the epic poet Aristeas spoke of the one-eyed Arimaspi. Herodotus thus did not invent the monsters; he was rather the first to locate them in actual geographic areas.

The Greeks knew that surrounding them were peoples with cultures quite different from their own. This may have made it easier for them to accept the monstrous races as a reality. There was at least one Greek theory of evolution that could account for the existence of hybrid creatures. Empedocles, a contemporary of Herodotus, held that parts of men and animals arose separately and independently. Hands wandered without arms, feet without legs and heads without trunks. These isolated parts combined at random, so that there could be animals with human heads or manlike creatures with the features of animals. Although in time only favorable combinations survived, peculiar ones could still be found.

Soon after the death of Herodotus reports about India added to the credibility of monstrous races. At the beginning of the fourth century B.C. Ktesias, who had once been a physician at the Persian court, wrote that India was populated by many wondrous tribes. He described the Sciapodes, who had a single large foot on which they could hop faster than any biped. They made further use of this appendage by employing it as a kind of umbrella, holding it over their head for protection against the rain or the heat of the sun. The Cynocephali, or dog-headed ones, were said to bark rather than to use words; the Blemmyae were headless, with their face between their shoulders. There were people with ears so long they covered their arms as far as the elbow; others had long and very hairy tails; still others had eight fingers on each hand and eight toes on each foot.

Similar reports about India came from Megasthenes, the learned ambassador of the Babylonian king Seleucus I. Having served at the Indian court of Chandragupta, he added some new examples to the older ones and was the first to give currency to the tale of certain Indian nomads who had no nose but only small holes for nostrils. He also spoke of Sciapodes whose feet pointed backward, and of the happy Hyborians, whose lifespan was 1,000 years. The Phanesians, he said, had ears so long they slept in them, with one ear serving as a mattress and the other as a blanket. There were also Indian tribes that had dog ears or had an upper lip extending below their chin or had no mouth. The last, being unable to eat (or to speak), subsisted on the odor of roast meat and fruit and the perfume of flowers.

The invasion of India by Alexander the Great in 326 B.C. probably gave rise to similar reports. With Alexander's army were scholars charged with describing the countries through which they passed. Most of these writings have been lost, but the *Romance of Alexander* (which some scholars date back to 200 B.C.) was translated into many languages in the early Middle Ages. Together with the works of Megasthenes it was for centuries an important source of knowledge about the real and imaginary inhabitants of India.

A number of learned Greeks challenged the stories about monsters. The geographer Strabo, who lived at about the time of the birth of Christ, did not hesitate to call such tales mere superstition. Nonetheless, the tradition remained vigorously alive.

In the first century A.D. the Roman naturalist Pliny the Elder devoted several volumes of his encyclopedic *Historia Naturalis* (*Natural History*) to descriptions of the physical nature and manners of mankind. Asserting that he had read more than 2,000 books, Pliny repeated in a systematic manner all that had been said about monsters; he also added a few embellishments of his own. Some later commentators remarked that a more appropriate title for these writings would have been "Unnatural History." Pliny's contributions included the cannibal Scythians, who used skulls for drinking vessels; the Thibii, who had a double pupil in one eye and the image of a horse in the other, and the solitary Essenes, who lived without women and yet propagated. Other Roman writers, such as Pomponius Mela (first century A.D.) and Caius Julius Solinus (third century), elaborated on Pliny. The ears of the Phanesians and the feet of the Sciapodes grew larger and larger; in the land of the Neuers the men were transformed into wolves in summer and regained human form in winter. These writers were important sources for the medieval acquaintance with monsters. Belief in their reliability was bolstered by

ANIMAL-HEADED PEOPLE were popular during the Middle Ages. At left is shown one of the Cynocephali, or dog-headed ones, also believed to inhabit India. They were often assigned allegorical roles, at one time signifying harshness of temper, at another meekness. The goose-headed man shown at right and others like him were depicted on printed pamphlets that sold well at 17th-century country fairs. The woodcuts are reproduced from *Monstrorum Historia*, by Ulisse Aldrovandi, which was published in 1642.

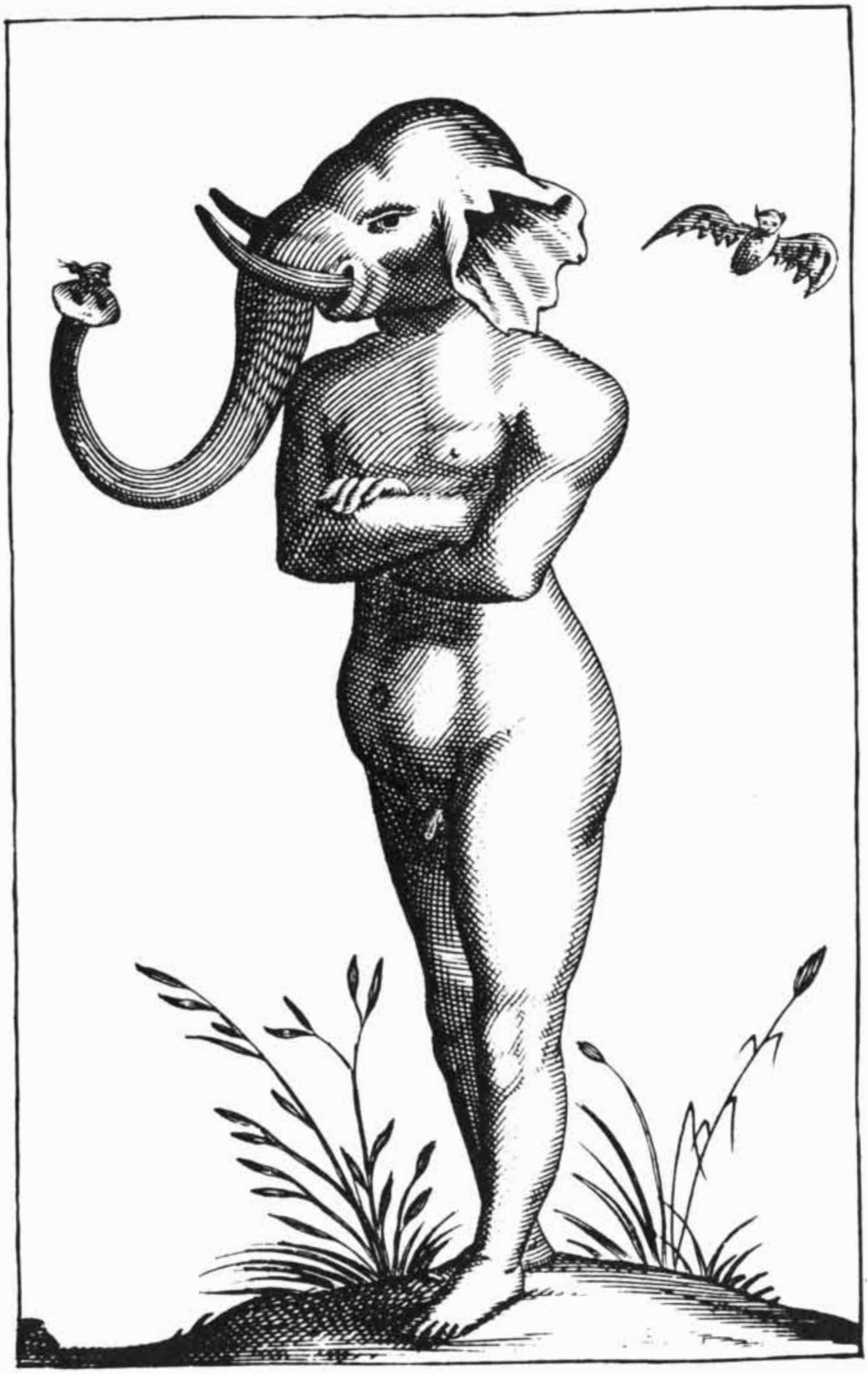
reports of travelers and missionaries that were written with apparent sincerity and conviction.

Monstrous races presented a problem for the early church fathers. It was difficult to deny the reality of such creatures, not only because of the missionaries' reports but also because of the Bible. The Book of Genesis refers to races of giants. A passage in St. Jerome's translation of Isaiah reads: "And the hairy ones shall dance there." St. Jerome's own commentary explained that "the hairy ones" might be wild men.

In *The City of God* St. Augustine dealt with the question of the reality of such beings. If, he wrote, the stories about monsters are not plain lies, such beings either are not men at all or, if they are men, they are, like other men, descendants of Adam. St. Augustine tended to favor the last possibility. He argued that individual monstrous births do occur and are clearly descended from Adam. Monstrous races might therefore exist and be human.

Later medieval scholars asked themselves how such transformations could have taken place. A common answer was that the devil had so perverted the souls of some pagans that their appearance had also degenerated. Scripture could be invoked to prove that such changes were possible. The evil king Nebuchadnezzar had been transformed from a man into a beastlike creature: his hair grew like an eagle's feathers, his nails were like a bird's claws and he ate grass.

Other commentators who were less strict about the concept that man—monstrous or otherwise—had a single origin advanced the idea that monsters might have been separately created by the devil in an effort to confound God's creation, man. It was also deemed possible that monsters were creatures of the Antipodes who had managed to climb up over the edges of the (flat) world.



LATTER-DAY MONSTER was a subject of "scientific" study. Fortunio Liceti, who introduced the elephant-headed man, was one of those who considered fabulous monsters together with cases of abnormal birth. The etching is from Liceti's *De Monstris*, published in 1665.

Meanwhile medieval travelers steadily made the monsters more monstrous. There were peoples with one eye, three eyes or five eyes, with eyes in the back of their head, with four or more arms and legs or with enormously long teeth. There were others without nostrils, without eyes, without a mouth or with a mouth so small they could only drink through a straw. Some had ears so long they hindered walking and had to be knotted together behind the back or wound around the arms; some had ears shaped like large fans. Some walked on all fours or had legs that were mere leather strips so that they could only crawl; some had spider legs or goat feet or bird claws. Some were entirely bald or exceedingly hairy; some had tails or had the neck as well as the head of horses or mice. There was also a tribe of creatures that had only a head; the rest of the body was lacking.

It was understood that monsters had monstrous habits: they were naked, lascivious, promiscuous and filthy; they had a bad smell and no religion. They ate snakes, lizards, dogs, mice, fleas and flies; they ate their parents or (after fattening them for years) their children.

The celebrated myth of Prester John lent further credence to fabulous creatures. In the 12th century there appeared the Latin text of a letter addressed to the Byzantine emperor Manuel Comnenus and purportedly written by Prester John, ruler of a realm in the East. Prester John professed to be a devout Christian whose land was enormously wealthy, harboring not only rich mineral resources but also the fountain of perpetual youth. The inhabitants of the region included, in addition to a normal human population, nearly all the marvelous and monstrous creatures ever described: wild men, men with horns, one-eyed men, pygmies, giants 40 ells (about 90 feet) tall, centaurs, fauns and so on.

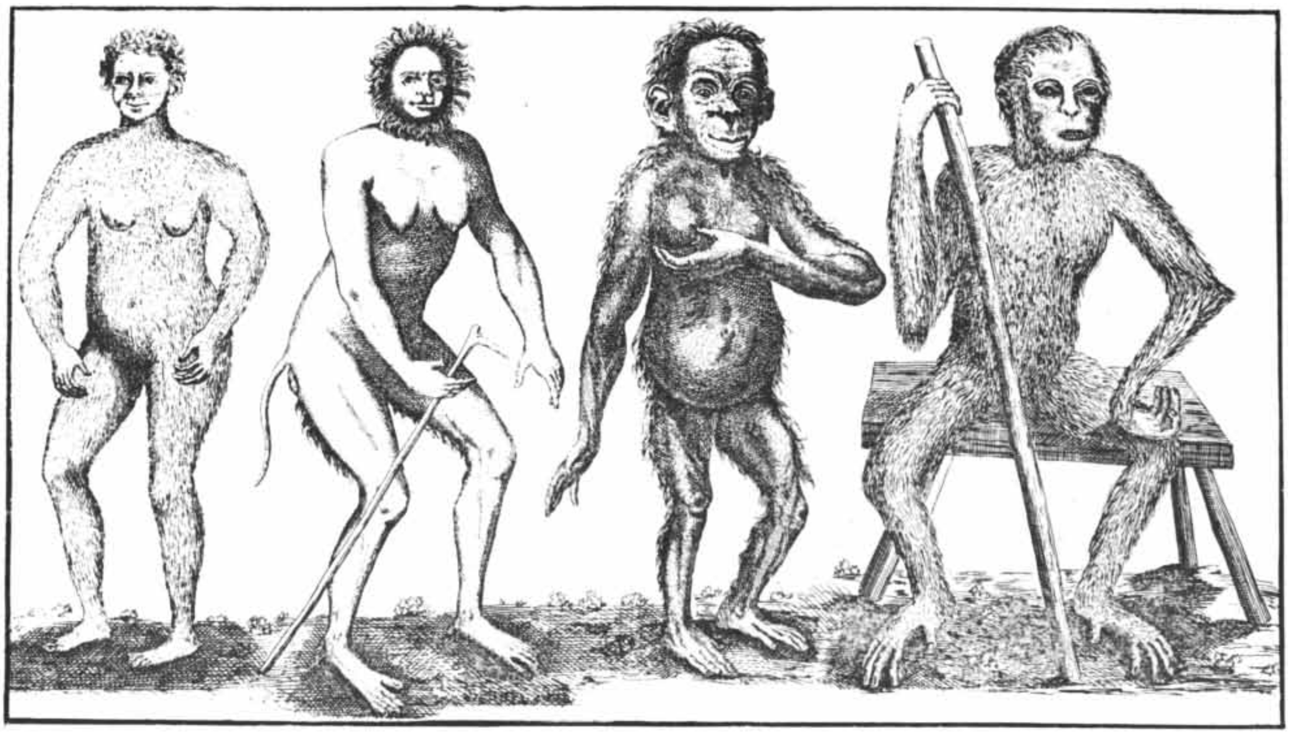
The letter was widely accepted as being genuine. European monarchs were eager to discover Prester John's realm, if only to enlist a powerful ally in their struggle with Islam. Pope Alexander III wrote a letter to Prester John and entrusted it to his physician for personal delivery. The physician never returned. Many travelers who later set out to discover this earthly paradise did return, and they gave "eyewitness" accounts. As late as 1590 an English traveler by the name of Edward Webbe reported that he had visited Prester John's court and had seen a monster there. It was kept chained to prevent it from devouring human beings, but after executions it was fed human flesh. The geographic location of Prester John's country was variously conceived. At first it was usually in or near India; later it was in Abyssinia. The discovery of the Cape of Good Hope was due in part to the efforts of the Portuguese to find Prester John's country. Columbus believed he had passed near it.

Apart from the Prester John myth and the fictitious accounts of travelers, there were many literary sources dealing with monsters. One of the earliest encyclopedic works was *Etymologies,* written by Isidore of Seville in the seventh century A.D. Isidore attempted single-handedly to summarize all knowledge; he devoted a volume to "men and monsters," and he placed the monsters in definite geographic areas. This immensely popular work was translated into several languages and was often imitated. In the 13th century a similar work explicitly directed to unlearned people (*On the Properties of Things,* by Bartholomaeus Anglicus) was translated into six European languages; with the invention of the printing press it reached 46 editions. The popularity of monsters is further attested by the fact that printed pictures of them were often sold at country fairs.

Monstrous men are also depicted on the medieval *mappa mundi,* maps of the world. In earlier editions the fabulous races were drawn on the maps themselves, indicating their supposed geographic distribution. On a late-13th-century map in Hereford Cathedral the Sciapodes, pygmies and giants are found in India, horse-hoofed and long-eared tribes in Scythia, and tailed satyrs and the Blemmyae in Abyssinia. On later maps the creatures often appear as border decorations, suggesting the direction in which they might be found.

In the Middle Ages monsters were cited to teach moral lessons. According to one 13th-century source, pygmies denoted humility, giants pride and Cynocephali harshness of temper. The long-lipped races were gossips and mischief-makers. In the widely translated *Gesta Romanorum,* a late-medieval collection of moral tales, the symbolism had changed. Long-lipped people now signified justice; long-eared ones were devout. (They were listening to the word of God.) The dog-headed people were humble. (They were said to be a model for priests.) The headless Blemmyae also represented humility.

The question St. Augustine had raised—Are the monstrous races human? —became a matter of practical concern with the discovery of the New World and its inhabitants. Columbus (convinced to the day of his death that he had found the sea route to India) wrote quite objectively about the Indians of Hispaniola (today Haiti and the Dominican Republic). They were, he said, well-made men who were so generous with their possessions that they never refused anything that was requested. He described the Carib Indians as being handsome of face and figure and intelligent. Nonetheless, Columbus also men-



APELIKE MEN, thought to be human species, were the result of the enduring belief in monstrous peoples and confused observations of apes in the wild. Reading from left to right, the species are *Homo troglodytus, Homo luciferus, Homo satyrus* and *Homo pygmaeus*. The etching is reproduced from an article titled "Anthropomorpha," by C. E. Hoppius, which was published in 1760.

tioned the existence of races that were hairless, tailed or dog-headed.

Later explorers less restrained than Columbus maintained that they had personally met Indians who were monstrous both in appearance and habits. It was necessary for Pope Paul II to declare explicitly (in his Papal Bull of 1537) that American Indians were fully human and in possession of an immortal soul.

Many Europeans had the opportunity to examine human representatives of the New World. Captured "specimens" were shipped to Europe and placed on public display; some of them, dressed in tiger skins and fed raw meat, were exhibited in cages. Even so, it must have been a disappointment to many onlookers that they had no tail, were not very hirsute and had only two eyes, two arms and normal-sized ears.

The character Caliban in *The Tempest* no doubt reflects attitudes toward the peoples of the New World in Shakespeare's time. Caliban is "as disproportion'd in his manners as in his shape," "a thing most brutish," a member of a "vile race," a "monster of the isle with four legs." He is filthy and smells like a fish, and one of the European sailors shipwrecked on his island at first mistakes him for a devil. Another sailor calls him a puppy-headed monster. Caliban is said to use the language taught him by his master, but only to curse. He has no capacity for abstraction and understands neither music nor love. "A devil, a born devil, on whose nature nurture can never stick. . . ."

The name Caliban is an anagram of *canibal* and this Spanish word is itself a corruption of *Caribal,* an inhabitant of the Caribbean islands. *Canibal* in turn suggests *canino,* Spanish for "dog." The Cynocephali come readily to mind, the more so because of the term "puppy-headed monster." Shakespeare thus equated the monstrous Caliban with inhabitants of the New World. A further indication that he was thinking of the New World in *The Tempest* is his mention of "vex'd Bermoothes" (Bermuda).

With the development of modern science in the 17th century, emphasis was placed on systematic study by direct observation; this method was also applied to the study of monsters. The only monsters available for examination, however, were those resulting from abnormal births. In the absence of detailed knowledge of embryology, endocrine glands and hormones the causes of such births were little understood. Most of the scholarly works dealing with them were a mixture of science and credulousness; congenital abnormalities were discussed on the same level as the fictitious monstrous races. In his book *De Monstris* (1665) Fortunio Liceti added an elephant-headed creature to the lengthy catalogue of composite beings. Other students of teratology (the study of monstrous living forms) occupied themselves with classification; they grouped fabulous tribes according to the part of the body that was abnormal. Moral lessons were not lacking: monstrous births were seen as punishment for deviation from accepted customs, most particularly for incest or promiscuity but also for a variety of other transgressions.

In the 17th century, as increasing numbers of animal and plant species were being discovered, efforts were made to arrange the species in an orderly array. In some of the earlier systems of classification the monsters presented no problem: they were simply left out (together with man himself). Linnaeus, however, proposed to classify everything in nature. In the first edition of his *System of Nature,* which appeared in 1735, he boldly classified man as a quadruped, placing him in the same order as the sloth and the ape. At that time Linnaeus had not yet introduced his binomial system of nomenclature (genus and species); he simply noted that satyrs (described as being tailed, hairy and bearded and having a human body) and tailed men were ape species.

In the 10th edition of Linnaeus (1758) man was given the name *Homo sapiens,* and the separate species *Homo monstrosus* was also listed. Linnaeus considered the satyrs and the pygmies to be closer to the apes, as is indicated by their names: *Simia satyrus* and *Simia sylvanus.* He described a somewhat more human species believed to live in Abyssinia and on Java. They are, he said, nocturnal, they walk erect, they have frizzled white hair, they speak in a hiss, they are able to think and they believe the world was made for them.

HIRSUTE ABORIGINE exemplifies the "hairy nations" described by Pliny the Elder and believed to exist by New World explorers. This woodcut is from *Anthropometamorphosis: Man Transformed: or The Artificial Changling,* by John Bulwer, which was published in 1653.

Linnaeus granted that it was extremely difficult to distinguish such creatures from man. He was of course severely handicapped; not only were there no specimens of monsters but also he had not seen many apes. The only ape he mentioned as being accessible to him for examination was an immature chimpanzee.

At least two followers of Linnaeus continued to classify fabulous tribes in a scientific manner. C. E. Hoppius, a pupil of Linnaeus', ranked *Homo troglodytus* closest to man. Next came *Homo luciferus,* as Hoppius named human creatures with tails; he was followed by *Homo satyrus* and *Homo pygmaeus.* A German physician named Martinus contended that there were two races of *Homo sylvestris,* the members of one race being smaller than those of the other.

Nonetheless, the end of *Homo monstrosus* and his like was approaching. With increased knowledge of anatomy, in particular the anatomy of the great apes, it was realized that the stories about satyrs and men with tails, if they were not fantasies, came from faulty observations of apes and monkeys. Although many a 19th-century traveler wrote about tailed men, such reports eventually became rare.

The puzzling similarities and differences between men and apes were clarified by Darwin's theory of evolution, but the theory did not solve the problem of man's specific ancestry. The erroneous idea that the lineage of man could be traced to known ape species spurred the search for a "missing link," a creature half-ape, half-man. Eugène Dubois believed that (in the fossil remains of *Pithecanthropus erectus,* or Java man) he had found such a link, a belief many people shared until the discovery of other human fossils changed the picture. With the knowledge that the ancestors of man are not represented among contemporary ape species, the search for links between men and apes ended.

Curiously, however, *Homo monstrosus* is not quite dead. Reports of an "abominable snowman" living in hidden fastnesses of the Himalayas are still in circulation. Speculation about life on other planets gives rise to new monsters with pointed heads and strange appendages. These fanciful beings are mostly invented in a spirit of fun, but the lesson is the same: When men can conceive of some remote place where other men or manlike creatures might exist, he is profoundly motivated to populate the unknown with creatures of his imagination.

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MATHEMATICAL GAMES

MacMahon's color triangles and the joys of fitting them together

by Martin Gardner

Last year Franz O. Armbruster, a California computer programmer, redesigned a tantalizing little puzzle that has been marketed in dozens of different forms for more than half a century. He packaged it cleverly and inexpensively with brief, amusing instructions and called it "Instant Insanity." It was an instant success. Parker Brothers took it over and this year its sales have been astonishing. The puzzle consists of nothing more than four plastic cubes, all the same size, each face bearing one of four colors. The problem is simply to arrange the cubes in a straight row so that all four colors appear on each of the row's four sides. I had mentioned this puzzle in a chapter on "The 24 Color Squares and the 30 Color Cubes" in *New Mathematical Diversions from Scientific American* (1966), but the puzzle's most complete analysis is to be found in Chapter 7 of *Puzzles and Paradoxes* (1965) by the Glasgow mathematician Thomas H. O'Beirne. O'Beirne calculated the probability of solving the puzzle by chance as one in 41,472 random tries! He wrote that the most tantalizing feature of the "Tantalizer," as it was called in one of its most recent incarnations, is that it "can be brought out again and again, with trivial variations, while many other good puzzles appear once and vanish, or circulate only privately, if at all!"

"Instant Insanity" can be considered one of a huge general class of combinatorial problems in which regular polygons or polyhedrons with their edges or faces colored or distinguished by numbers or other symbols are to be fitted together under certain restraints to achieve specified results. One of the pioneering authorities on combinatorial mathematics, Major Percy Alexander MacMahon, who died in 1929, devoted a great deal of thought to such puzzles. MacMahon, a professor of physics and a mathematician, was the author of the classic two-volume *Combinatory Analysis* (1915, 1916) and an excellent introductory article on the same topic for the 11th edition of *The Encyclopedia Britannica*. He also wrote a little-known and long-out-of-print book called *New Mathematical Pastimes* (1921), in which he explored a large variety of puzzles of the general type characterized here.

In my chapter on the 30 color cubes (a remarkable set of cubes discussed by MacMahon in *New Mathematical Pastimes*) I also dealt with MacMahon's analogous two-dimensional set of 24 color squares. This month I should like to introduce MacMahon's companion set of 24 color triangles. If the three edges of an equilateral triangle are each colored with one of two colors, and if rotations of triangles are not considered different, a set of four triangles results. Three colors produce a set of 11 distinct triangles and four colors the set of 24 triangles shown in the top illustration on the opposite page. To work with such a set, cut from cardboard, it is convenient to divide each triangle into three identical triangular parts as shown and then color each part, using four contrasting colors for the four differently labeled regions. The triangles are not to be turned over, because the set includes mirror-image pairs, and so only one side of the cardboard should be colored.

The formula for the number of different equilateral triangles that can be produced in this way, given n colors, is

$$\frac{n^3 + 2n}{3}.$$

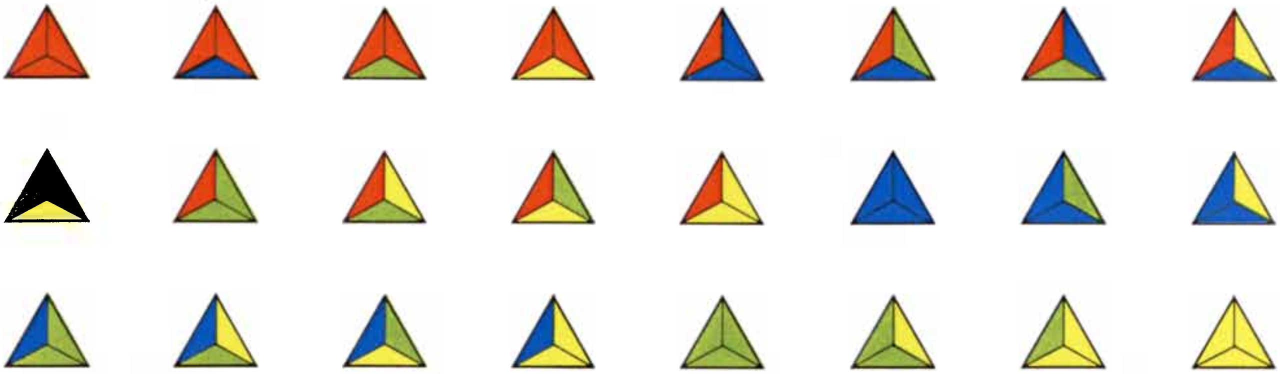
When n is 3, the resulting set of 11 triangles is small and will not form any interesting shapes. When n is 5, the set of 45 triangles is a little too large for recreational purposes. The set of 24, using four colors, is just about right; moreover, its pieces will form a regular hexagon as well as an unusually large number of different symmetrical shapes. MacMahon gives many combinatorial problems connected with this set. The simplest problems treat the pieces as triangular "dominoes" to be fitted together with adjacent edges matching in color to form symmetrical polygons. To this he adds a second restriction: the entire border of the polygon must be the same color. (Henceforth these will be referred to as MacMahon's two provisos.) Since each color appears in the set on 18 edges (an even number) and since the contact proviso requires that the color appear within a polygon on an even number of edges, it follows that the perimeter of any shape solvable under the two provisos must have a border composed of an even number of edges.

Wade E. Philpott, a retired engineer who lives in Lima, Ohio, has done more work on this set of MacMahon color triangles than anyone else I know of. What follows is taken from my correspondence with him and is presented here, with his kind permission, for the first time.

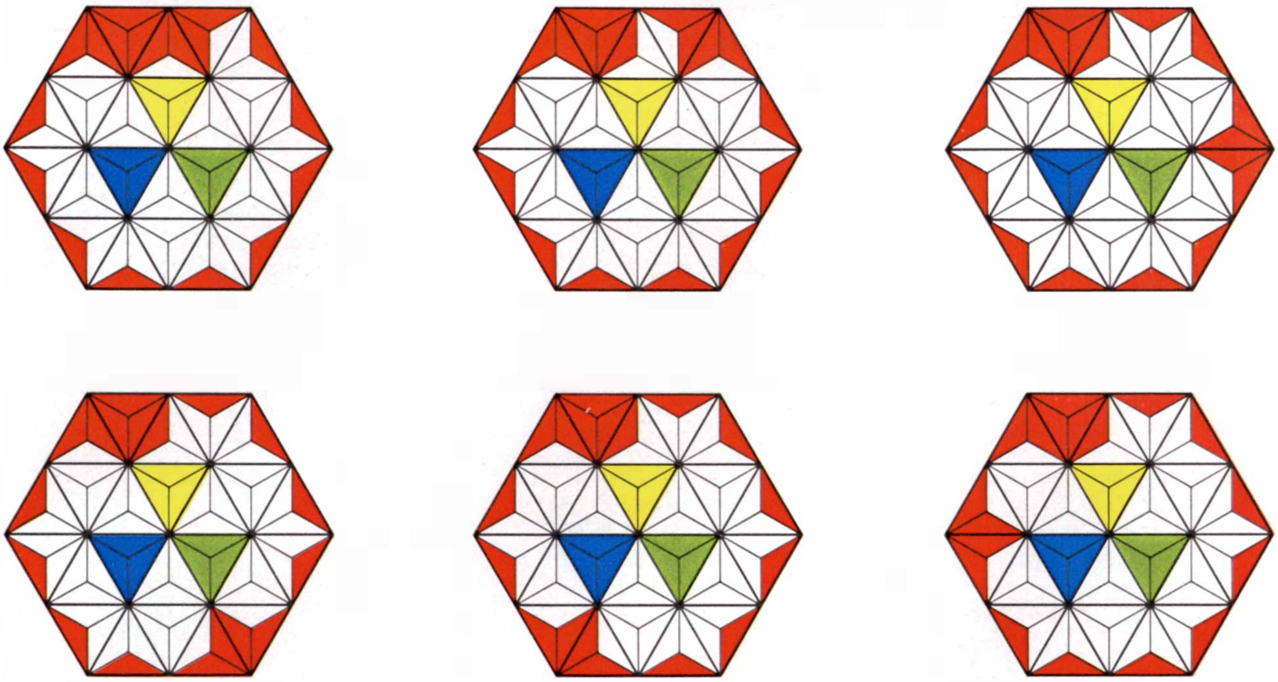
It is not hard to prove that all polygons formed by the 24 color triangles under MacMahon's two provisos must have perimeters of 12, 14 or 16 unit edges. The perimeter, as we have seen, must have an even number of edges. The minimum-length perimeter of a polygon formed by putting together 24 unit triangles is 12. A perimeter of 18 is impossible because there are only 18 edges of a given color in the set and the solid-color triangle cannot contribute all three of its edges to a polygon. Therefore 16 is the maximum length of the perimeter of a solvable polygon.

Only one polygon, the regular hexagon, has the minimum perimeter of 12. Its one-color border can be formed in six different ways, each with an unknown number of different solutions. Philpott estimates the total number of solutions as several thousand. (This does not include rotations and reflections as different, or new solutions obtained simply by interchanging colors.) Philpott has discovered that for each type of border the hexagon can be solved with the three triangles of solid color (necessarily differing in color from the border) placed symmetrically around the center of the hexagon. Since each solid-color triangle must be surrounded by triangular segments of the same color, the result is three smaller regular hexagons of solid color situated symmetrically within the larger hexagon. The middle illustration on the opposite page shows the general schemata for the six different ways of making the one-color border, with the solid-color triangles symmetrically placed at the hexagon's center in one of two possible ways. Next month I shall give six solutions (none unique) supplied by Philpott, one for each of the schematic patterns.

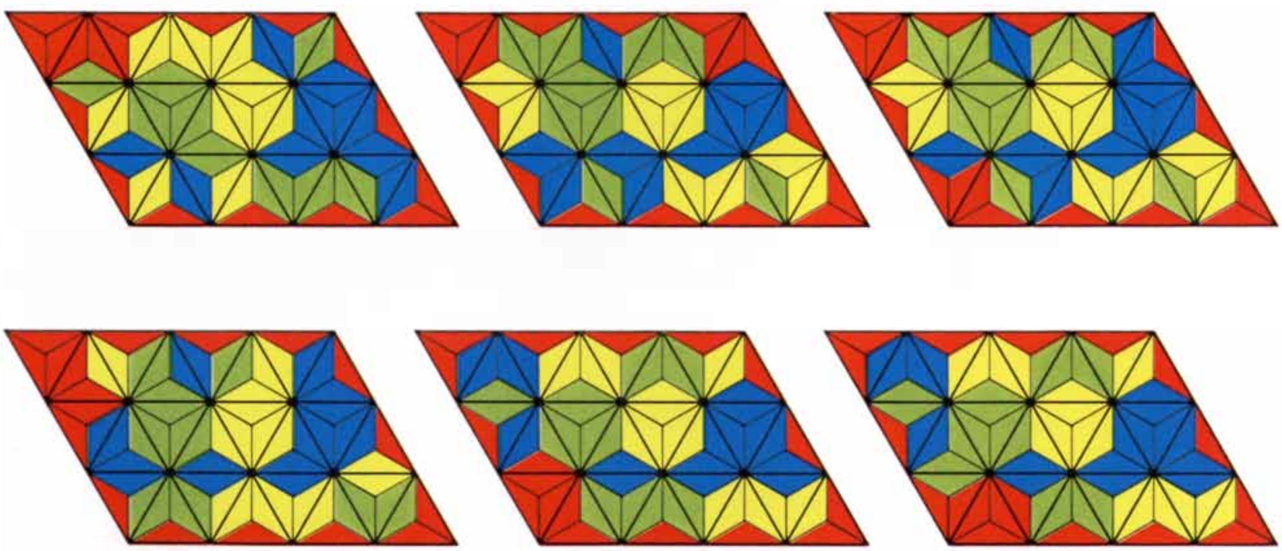
The 24 triangles will form two kinds



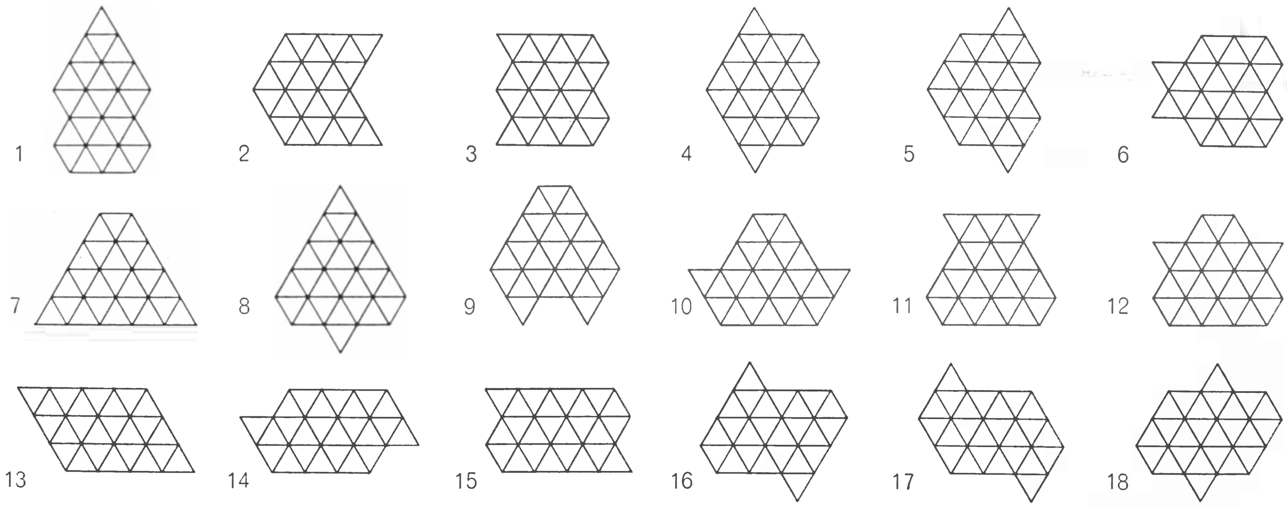
The 24 color triangles



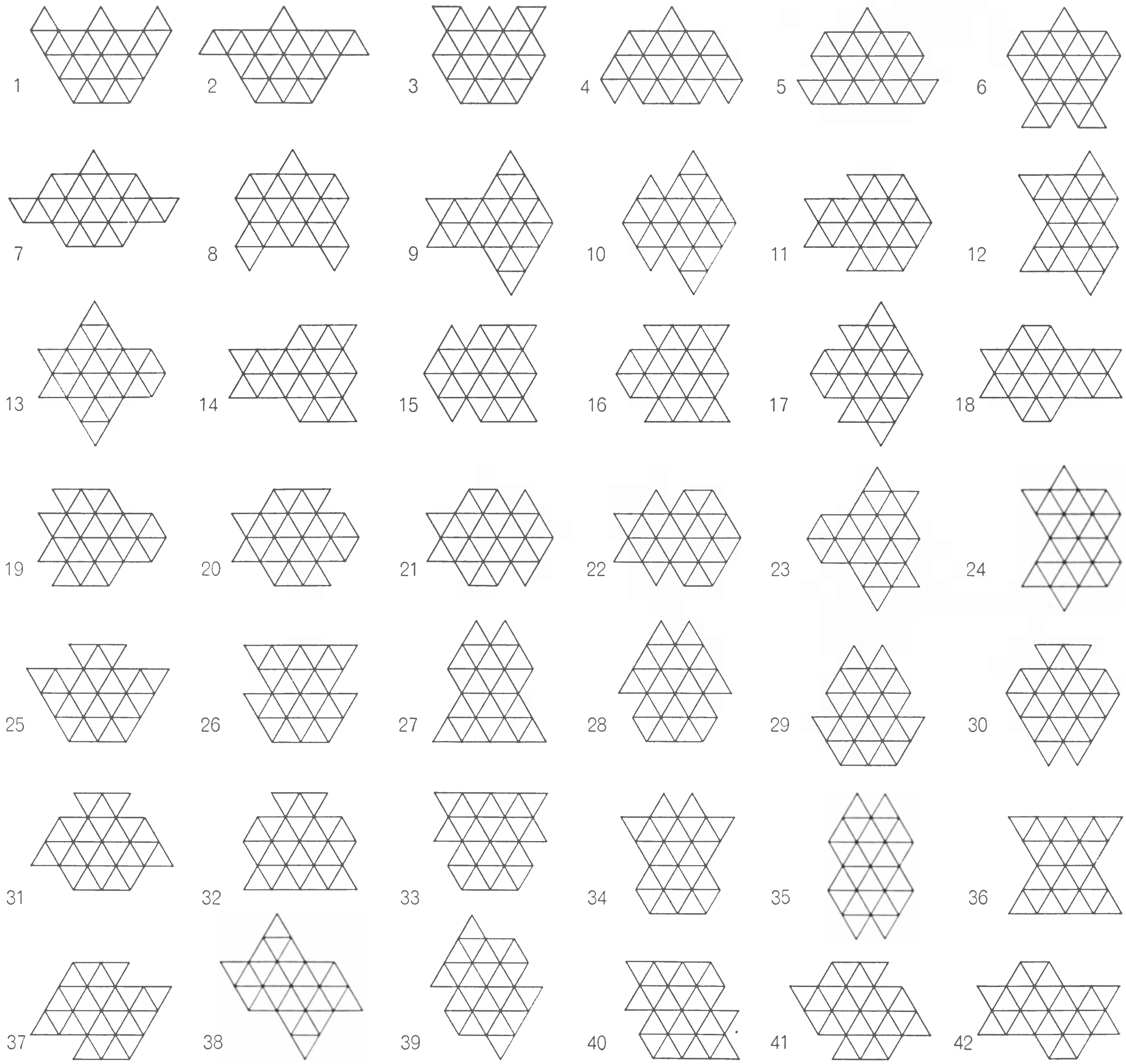
The six types of border for a regular hexagon



A solution for each type of border for the 3 × 4 parallelogram



The 18 solvable symmetrical polygons with 14-edge perimeters



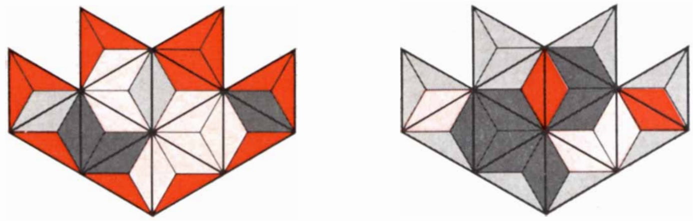
The 42 solvable symmetrical polygons with 16-edge perimeters of parallelogram: 2 × 6 and 3 × 4. It is easy to prove that the 2 × 6 cannot meet MacMahon's two provisos: the parallelogram has 14 triangles that contribute an edge to its perimeter, but only 13 triangles bear the same color. The 3 × 4 parallelogram *is* solvable. Again, the total number of solutions is not known, although Philpott guesses it is less than for the regular hexagon. Like the hexagon, it has six different types of border. The bottom illustration on page 121 shows a solution by Philpott for each type, each with the three solid-color triangles (necessarily differing from the border color) arranged in a row.

The 3 × 4 parallelogram is an example of a symmetrical shape with a perimeter of 14 unit edges. Philpott has found 18 polygons with 14-edge perimeters that possess symmetry, either reflectional or rotational, or both, and that are solvable under MacMahon's two provisos. The 18 are reproduced in the top illustration on the opposite page. All have more than one solution. It is easy to see that to be solvable a 14-edge polygon must have at least one "point" (a 60-degree corner) because at least one triangle with adjacent edges of the same color must contribute both of those edges to the perimeter. The solid-color triangle cannot be used for a point. Note that only one of the 18 figures (the first one) has a single point. This is also one of 11 symmetrical shapes of 14 or 16 edges for which there is only one type of one-color perimeter. Shape No. 5 is also of special interest. According to Philpott, it is the only symmetrical pattern that has 11 kinds of one-color border (the maximum possible). Solutions are known for each of these 11 forms.

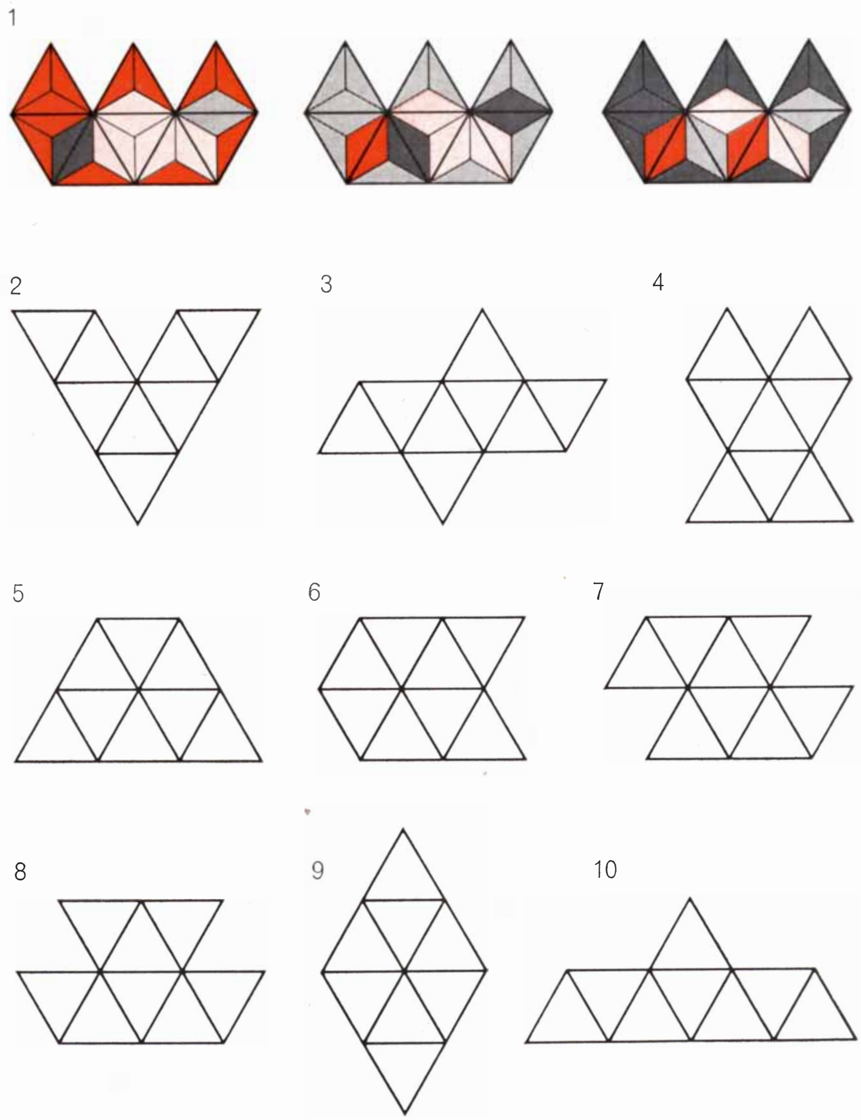
Philpott found 42 solvable symmetrical shapes with 16-edge perimeters [*see bottom illustration on opposite page*], making a total of 61 solvable symmetrical polygons in all. He reports that all solvable 16-edge polygons must have at least three points and not more than four. Not all three-point symmetrical shapes are solvable, but all four-point shapes are.

The "duplication problem," proposed by Philpott, is to form two identical symmetrical shapes, of 12 triangles each, that meet MacMahon's two provisos and have borders of different colors. He has found 22 such solvable shapes, one of which is shown in the illustration at the top of this page, and estimates the number of different solutions for each shape to be in the hundreds, not thousands. Philpott's "triplication problem" is to use the 24 triangles to form three identical symmetrical shapes, of eight triangles each, with perimeters of three different colors. There are, he reports, 10 such shapes, which are reproduced in the illustration below along with a solution for one of them. Philpott estimates the number of different solutions for each to be less than 100. The search for solvable triplication shapes was made easy to check, he writes, because each shape is an "octiamond," of which the 66 varieties had previously been enumerated ["Mathematical Games," December, 1964].

A tile set of the 45 MacMahon color triangles that have edges labeled with symbols (of which the 24 four-color triangles are a subset) recently went on sale in West Germany under the name "Trimino." The boxed set includes a booklet by Heinz Haber that pictures a number of symmetrical shapes to be made with the pieces and gives instruc-



Solution to a duplication problem



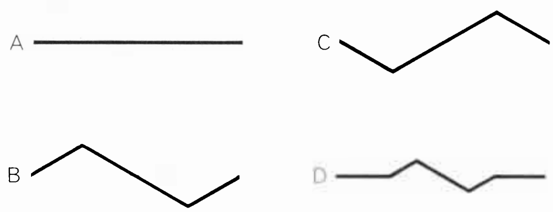
The 10 symmetrical polygons that can be triplicated, one of them solved tions for using the triangles to play a competitive game. A similar set is currently being imported into the U.S. from Hong Kong as a game called "Three Dimensional Dominoes." Other forms of MacMahon color triangles had earlier been marketed in this country as the basis for various domino-type games, such as "Contack" (Parker Brothers, 1939) and "Al-lo-co," put out by a Cleveland firm in 1964.

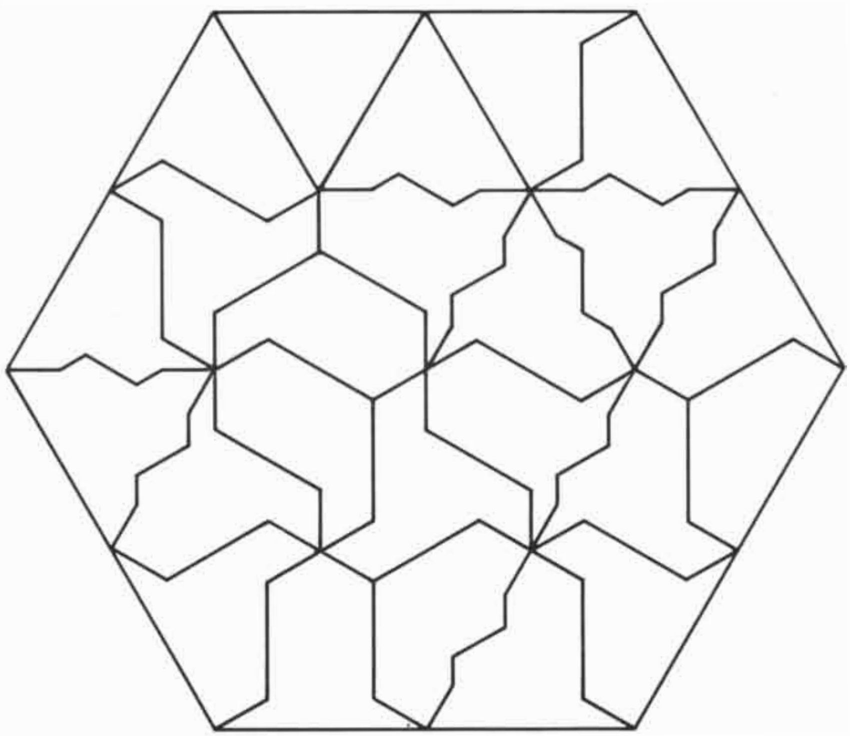
Instead of coloring the triangles with four colors, each colored edge can be replaced by one of four types of symmetrical edge. This was proposed by MacMahon as a way of transforming his color triangles into equivalent jigsaw puzzles [*see illustration below*].

In three dimensions the cube is the only regular solid replicas of which will fit together to fill space. This surely is one reason for its being used in so many different combinatorial puzzles of the "Instant Insanity" type. If the reader will obtain 27 identical cubes (alphabet blocks will do) and paint nine one color (on all sides), nine another color and nine a third color, he will have the material for working on two unusual three-dimensional combinatorial problems.

It is obviously impossible to form the 27 cubes into a single $3 \times 3 \times 3$ cube so that each of its 27 orthogonal rows (rows parallel to an edge of the large cube) consists of three cubes of the same color. Can they form a cube in which all three colors appear on each of the 27 orthogonal rows? They can; a unique solution (not counting rotations, reflections or permutations of colors as different) was discovered by Charles W. Trigg, a retired California mathematician. I shall give his solution next month.

The second problem, much more difficult, was recently discovered by John Horton Conway, a mathematician at Sidney Sussex College of the University of Cambridge and an inventor of the topological game of "sprouts" discussed here in July, 1967. Conway set himself

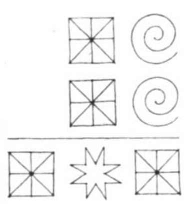




Jigsaw puzzle using triangles made with four different edges the task of forming the 3 × 3 × 3 cube so that *every* row of three (the cube's 27 orthogonal rows, its 18 diagonal rows on the nine square cross sections, and its four space diagonals that join opposite corners) contains *neither* three cubes of like color nor three of three different colors. In other words, each of the 49 straight rows of three cubes will consist of two cubes of one color and one of another. Conway found two distinct but closely related solutions (again not counting rotations, reflections or permutations of colors). The solutions will be published here next month for the first time.

One can, of course, work on both problems by drawing three ticktacktoe boards to represent the three levels of the large cube and labeling the 27 cells properly with nine *A*'s, nine *B*'s and nine *C*'s. It is easier and more fun to work with actual cubes, however, and well worth the trouble of acquiring and coloring a set, even if it is only a set of crayoned sugar cubes.

Last month's first problem was to determine the number of fingers on a Venusian's hand, assuming that this number is the base of the Venusian number system used in the following addition problem, in which each symbol is a Venusian digit:



The only solution is 12 + 12 = 101 in a ternary (base-3) system (equivalent to 5 + 5 = 10 in our decimal system), and so a Venusian presumably has three fingers on each hand.

The second question assumed that the 10 extended fingers of both hands represented the 10 1's of a binary number equivalent to the decimal $2^{10} - 1$, or 1,023, and asked for a simple method of using the fingers to subtract from such a number a given smaller number *n*. The answer, supplied by Frederik Pohl in his article cited last month, is simply to express *n* as a binary number, using the fingers in the manner explained. Now bend down every extended finger and extend every bent-down finger—the equivalent of changing every 1 to 0 and every 0 to 1. The new number is the desired binary answer.

THE AMATEUR SCIENTIST

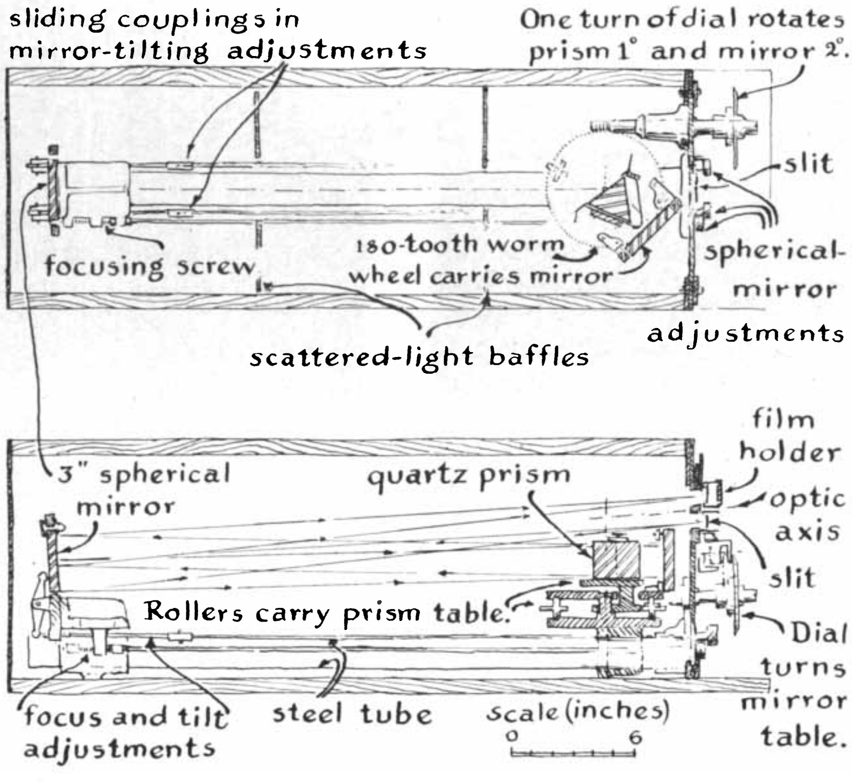
An ultraviolet spectrograph designed by the illustrator of this department

Conducted by C. L. Stong

Beginning where the blue of the rainbow fades into invisibility is a broad but normally unseen band of radiation that carries much of the story of the sun. The band is the ultraviolet region of the solar spectrum. To explore it and comparable spectra emitted by all luminous gases and vapors one needs an ultraviolet spectrograph, an instrument that separates relatively short electromagnetic waves according to length and records them on photographic film as a series of parallel lines that vary in spacing and intensity.

The pattern of the recorded lines is determined both by the kind of atoms in luminous gas that emit and absorb radiant energy and by the atoms' energy levels and velocities. A unique spectrographic pattern is associated with each kind of atom. The pattern is influenced in minor but significant ways by the atom's environment.

In terms of the frequency at which electromagnetic waves vibrate, the solar spectrum spans more than 30 octaves, including the single octave of visible light. Spectroscopists have measured, identified and tabulated some three million spectral lines. With this information and an instrument for recording ultraviolet spectra amateurs can identify the metals in ores, learn the relative velocities of particles in glowing gases and vapors, measure colors precisely and perform many related experiments. An inexpensive ultraviolet spectroscope has been built at home by Roger Hayward, the retired architect and optical designer who illustrates this department. Hayward writes:



Plan (top) *and section* (bottom) *views of Roger Hayward's ultraviolet spectrograph*

"Figuratively, at least, I have spent some of my most delightful hobby hours chasing rainbows. It all grew out of a pre-high-school desire to build an instrument that was good enough to show separately the two closely spaced yellow lines that appear in a spectroscope when a sheet of asbestos paper soaked in salt brine is held in the flame of a Bunsen burner. The instrument I planned was to consist of a slit through which light from the Bunsen burner would be admitted to a lens. The lens would make the diverging rays parallel and direct them into a glass prism that, like a drop of rain, would split the light into its constituent colors. The emerging colors would enter a second lens, through which I hoped to see a band of colored lines, each an image of the slit. In particular I hoped that the yellow emission lines of sodium in the salt would appear.

"A glass prism that dangled from the chandelier in our dining room was liberated to do the splitting of colors. A lens from a magnifying glass was appropriated for making the light rays parallel. A lens from another magnifying glass was used as the telescope lens for examining the spectrum. The slit was made from a tin can.

"When these parts had been assembled in a wooden box, I fired up the burner and had a look. I could make out a single yellow line with fuzzy edges, but no amount of adjustment made it split into the sodium pair. Finally I gave up in disgust, partly at my own ineptness and partly because of the inadequacy of the illustrations in my father's old high school physics text.

"The memory of that frustrating experience goaded me for nearly 30 years. Eventually I decided to try again and also to practice the art of making informative illustrations. In the meantime my interest in spectroscopy had expanded. I learned that the spectroscopic information of most interest lies outside the visible spectrum, much of it in the ultraviolet region to which glass is relatively opaque.

"Two basic schemes have been devised for dispersing ultraviolet radiation with minimum loss. In one of them the rays are reflected from a polished metallic surface, such as aluminum, that has been ruled with closely spaced parallel lines. This forms a diffraction grating, which causes reflected waves to interfere with one another selectively so that the angle at which they emerge from the rulings increases in proportion to their length. At the time I made my spectrograph diffraction gratings were not available at a price I could afford.

"The second scheme is to use a prism cut from a substance that is transparent to ultraviolet radiation. Quartz is such a substance. Fused quartz would work, but at that time it could not be made in large blocks of the necessary optical quality. The resolution of a spectrograph—the ability of the instrument to separate closely spaced spectral lines—increases with the size of the prism. I wanted a prism with at least two inches on a face, which meant I had to cut the prism from a natural crystal of quartz.

"This requirement introduced another complication. Crystalline quartz is an optically active substance. It polarizes light, meaning that it rotates the plane in which the light waves vibrate. It is also birefringent: unless the light travels along a path that parallels the optic axis of the crystal an entering ray is split. It emerges from the other side of the crystal as two rays that produce a double image.

"The effect of birefringence can be minimized by cutting the prism from the quartz in a direction such that the rays travel parallel to the optic axis of the crystal. The effect of polarization can be minimized by placing behind the crystal a mirror that reflects the rays back through the quartz. Waves that are rotated in one direction during their forward transit through the prism are untwisted by the same amount during the return trip.

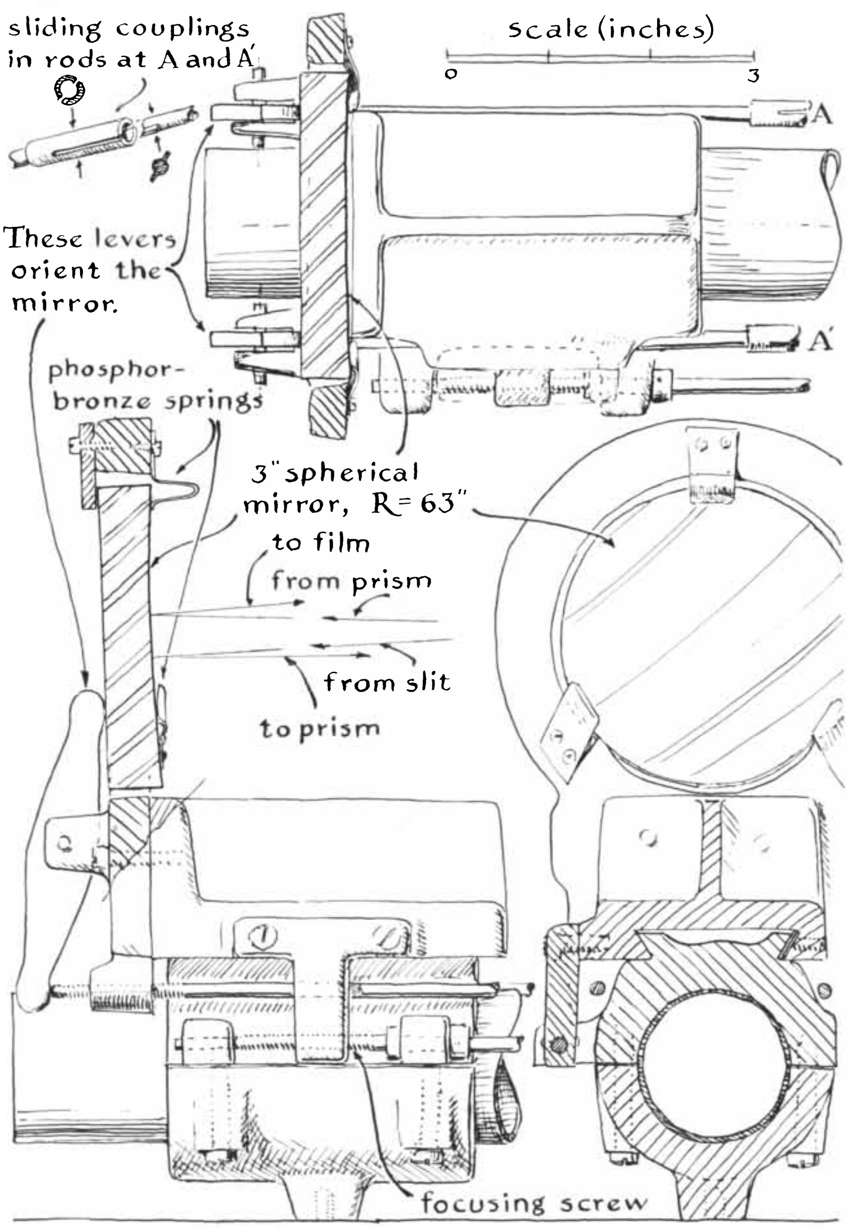
"In 1938 I bought a two-pound quartz crystal from the Brazilian Importing Company in New York for $5. (No doubt it would cost much more today.) The facets came to a point at one end, which indicated that the optic axis was parallel to the length of the piece.

"Quartz is difficult to cut, so I took the crystal to a shop that had a diamond saw. The technician simply held the crystal by hand and ran it against the blade, using kerosene as a coolant. After cutting out a block roughly in the form of an equilateral triangle we examined the piece critically. The corners were not filled out. It was clear that if we took thin slices off the sides, the prism would present a better appearance. So the technician took off the two slices by hand. As I recall I paid $10 for the job.

"We had just guessed at the angle of the apex. It turned out to be approximately 63 degrees. Prisms of commercial spectrographs are usually made with 60-degree angles, at which the loss of light by reflection from the faces is minimal. The extra loss at 63 degrees is trivial.

"The faces of the roughly cut blank were ground flat and smooth against a surface made of hexagonal ceramic tiles stuck to an eight-inch steel disk with hot pitch. For the grinding compound I used a slurry of Carborundum grains in water. The rough grinding was begun with No. 80 grit and continued with successively finer grits through No. 600, as explained in *Amateur Telescope Making: Book One*, by Albert G. Ingalls, which is published by SCIENTIFIC AMERICAN. I held the prism by hand and ground it back and forth across the ceramic surface, much as amateurs make telescope mirrors. To polish the faces I covered the ceramic blocks with pitch and used a slurry of rouge in water. The prism was supported by a wooden block during polishing.

"I cannot remember why I elected to



Details of the mounting of the spherical mirror of the spectrograph grind and polish the prism by this unorthodox procedure instead of mounting it conventionally in a plastic disk along with pieces of quartz to fill out the circular array. I suppose I was just impatient to see the finished product. Anyway, I knew that if the faces did not come out flat, I could always mount the piece conventionally and make the necessary corrections. One of the secrets of my success in handwork of this kind is that I have cold hands. The heat transmitted to the piece by my fingers did not distort the surfaces. People with warm, fleshy hands usually have difficulty getting good optical figures when they attempt handwork, but skinny hands like mine make out well.

"Having finished the prism, I made four mirrors. One had a flat surface for reflecting rays through the prism, one was spherical and two were cylindrical. The cylindrical mirrors collect light from the source and direct it through the slit of the instrument. The spherical mirror receives converging rays from the slit, transforms them into parallel rays, directs the parallel rays through the prism, receives the dispersed rays and reflects them to a focus on a strip of photographic film located immediately above the slit [*see illustration on page 126*].

"The glasses were ground, polished and figured by techniques somewhat similar to those used for making telescope mirrors. A commercial shop applied reflecting films of aluminum to the polished glasses. Incidentally, disks of cast iron that are used as weights on barbells can be made into handy flat surfaces on which to grind mirrors. They are generally available from dealers in sports accessories. The hole in the center is not much bother. I had the face of a disk ground flat on a Blanchard grinder by a local machine shop.

"The instrument is housed in a lightproof pine box with Masonite ends. A tube of 16-gauge steel 1½ inches in diameter forms the backbone of the mechanism for supporting and adjusting the position of the optical parts. One end of the tube slides into a bronze casting, locked by clamps, that forms a table for supporting the spherical mirror.

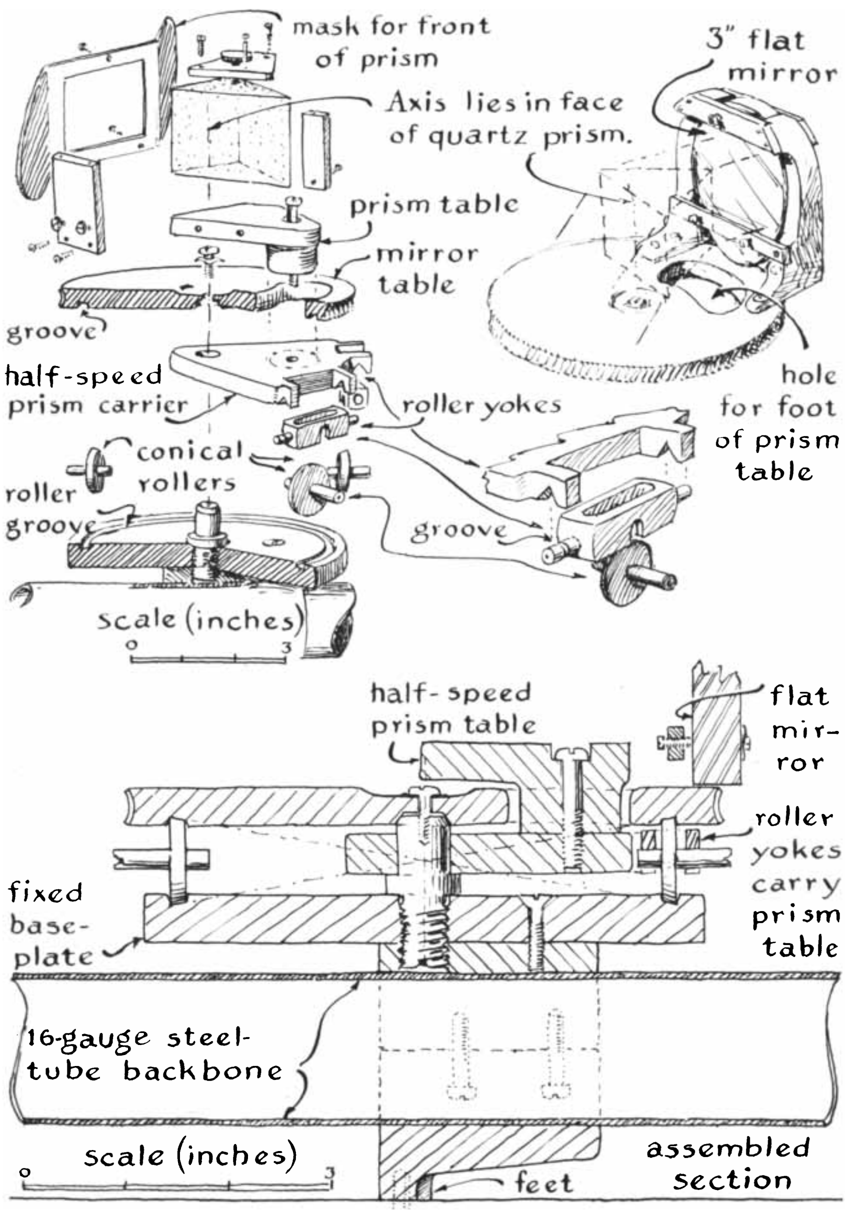
"The table has a sliding top for altering the distance between the mirror and the other optical elements of the instrument [*see illustration on preceding page*]. A threaded hole in a lug that extends downward on one side of the sliding tabletop engages a screw that can be turned by a knob on the front of the instrument. This control adjusts the focus of the spectral lines on the film.

"Two other knobs and similar screw mechanisms operate a pair of rocker arms that bear against the rear edges of the spherical mirror, which is supported in an annular cell by spring clips. By manipulating the screws I can adjust the angular position of the mirror. The bottom of the casting includes a foot that is fastened to the bottom of the box with a screw.

"The design of the mechanism for mounting and positioning the prism and the flat mirror is somewhat more elaborate. The prism must be rotated to bring the various regions of the spectrum into view and to center desired spectral lines on the photographic film. To accomplish the rotation certain optical properties of the prism must be taken into account in the design of the mounting fixture.

"A ray of light that traverses a prism is bent where it enters the prism and bent still more in the same direction when it emerges into the air. The magnitude of the total angle through which a ray is bent depends on the nature of the crystal and also on the angle between the ray and the face of the prism through which it enters. The ray is bent least when the angles between the ray and the front and rear faces of the prism are equal. Then the path of the ray is symmetrical with respect to the faces of the prism. When the prism is so positioned, it is said to operate at minimum deviation.

"Short waves are bent progressively more than long ones. The waves are dispersed according to their length. Some



Details of the mounting of the prism assembly transparent substances disperse waves of differing lengths more than other substances do. It turns out that the dispersion of quartz is relatively low. For this reason I decided to use a 60-degree prism instead of one of 30 degrees, as is customary in instruments of this type.

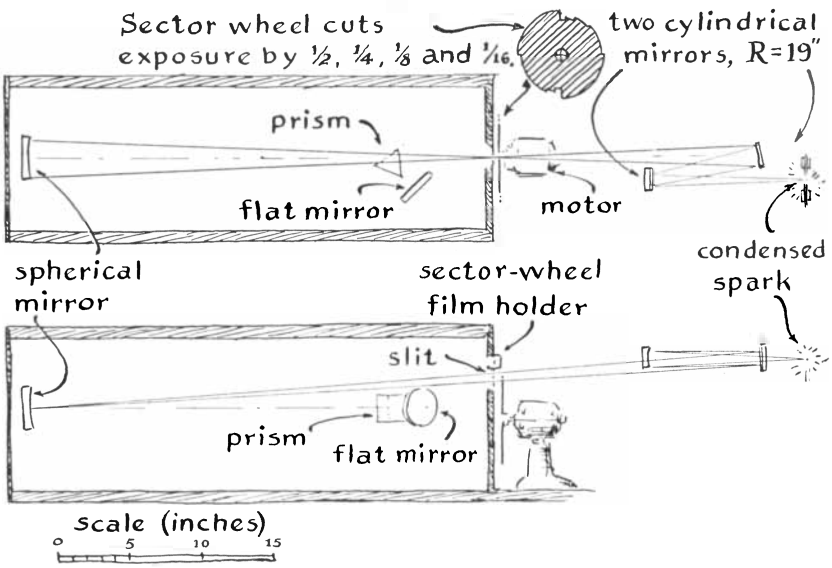
"This decision made it imperative that I operate the prism at minimum deviation because, as mentioned, quartz is birefringent. If a quartz prism is operated at other than minimum deviation, the oppositely polarized rays do not cancel completely, and two images appear in the focal plane. Of course, not all rays can be made to pass through the prism at minimum deviation because some waves are bent more than others, depending on their length. Even so, the prism can be placed so that the rays of most interest traverse it on a path that closely approaches minimum deviation.

"To achieve this condition it is essential when scanning the spectrum to rotate the flat mirror at exactly twice the rate of the prism. A system of differential gears would do the trick, but I was worried about the smoothness of gear motion. Gear teeth tend to introduce periodic accelerations.

"I decided to generate the desired motion by rotating a disk on a set of three conical rollers linked with yokes. One revolution of the disk would cause a half-revolution of the roller assembly [*see illustration on opposite page*]. The movement of the rollers is restrained by a pair of circular grooves. One groove is in the bottom of the disk and the other is in a circular baseplate.

"The disk, which is a flat worm gear, carries the mirror. A hole through the gear admits the foot of a prism table to the roller assembly, to which the table is attached by screws. The width of the hole restricts the rotation of the disk to 30 degrees, but in use the table turns only 26 degrees. Two of the rollers are yoked to the prism table. The third roller acts as an idler. A worm engages the teeth of the gear and is rotated by a shaft that terminates in a calibrated dial on the front of the instrument.

"Most of the metal parts are castings of red brass. They could have been made from strip, plate and rod stock of other metals. I undertook the project just after I had written a chapter on molding and casting for the book *Procedures in Experimental Physics,* by John Strong and others. It therefore seemed to me that I should design the apparatus to be built with castings made from my own patterns. There are 18 patterns all told, one for a wavelength drum that I later discarded. The bill from the foundry, as I recall, amounted to about $20. I sometimes wonder what the same job would cost today.



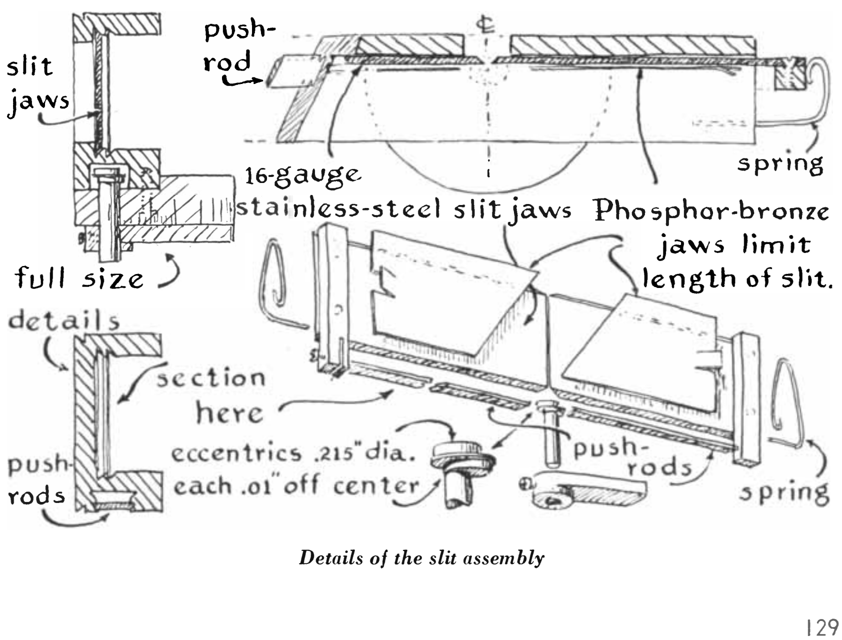
Optical path of the spectroscope

"The control panel consists of a brass plate that covers an opening in the front of the cabinet. It fits loosely in a groove in the edge of the Masonite front. In turn the plate supports the shaft bearings and control knobs, the slit assembly and the film carrier. When the spectrograph was completed, I learned that the spherical or autocollimating mirror could have been equipped with less fancy controls. The position of the mirror has not been altered since its initial adjustment more than 25 years ago!

"Ports for the slit assembly and the film carrier are identical. They are separated by a narrow dovetail strip. The optic axis of the system passes through the center of the strip. For this reason the slit and the film carrier can be interchanged.

"Access to the optic axis can be had by removing the dovetail strip, which is attached to the panel by four machine screws. By removing the strip and the prism it is possible to direct light along the optic axis by means of a half-silvered mirror. One can then look through the half-silvered mirror and adjust the positions of the flat and spherical mirrors so that light is returned along the optic axis. The mirrors are then in proper orientation.

"The dial that rotates the flat mirror is calibrated in minutes of angular arc. A setscrew locks it to its shaft in the zero position when the flat and spherical mir-



Details of the slit assembly

rors have been aligned. Each full turn of the minutes dial advances an associated degrees dial 1/30 of a turn.

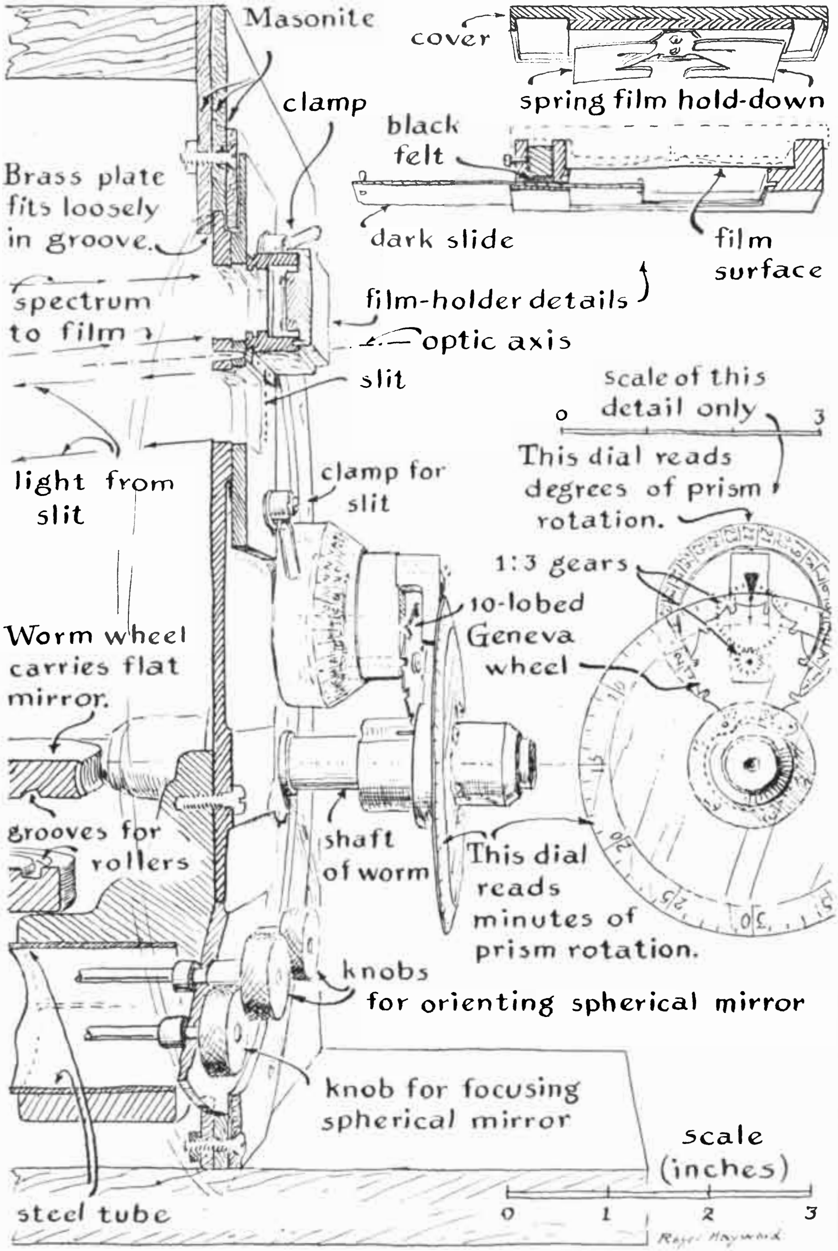
"The motion is transmitted from the minutes dial to the degrees dial through a Geneva movement and a pair of 1 : 3 reduction gears. This feature was an afterthought. I could have used a Veeder counter to record degrees, of course, but I had fun filing out the Geneva wheel by hand. I undertook the job mostly to see if I could do it. The cup-shaped degrees dial and the large flat minutes dial are made of Lucite.

"The film carrier was designed to take pieces of cut roll film, Type No. 120, 2¼ inches wide and 2½ inches long. Strips 3/4 inch wide can also be used. It is easier to make the film carrier lightproof if the dark slide that protects the emulsion when the carrier is removed from the instrument cannot be fully removed. I fastened a limiting stop to the inner end of the slide; it prevents the slide's removal. The slide was made from sheet brass 1/32 inch thick. The frame of the carrier is milled from stock brass strip one inch wide and 1/2 inch thick. The rim of the cover, which includes a flat spring for pressing the film in place, is also made of sheet brass and is silver-soldered to the top plate. It could be made of other metal.

"The body of the slit assembly was milled from the same stock used for the frame of the film carrier. The width of the slit should be adjustable so that the width of the spectral lines and the amount of light that enters the instrument can be controlled. The center of the slit should not be displaced when the width is altered, because the spectral lines would be similarly displaced.

"The slit of my instrument is formed by two strips of 16-gauge stainless steel that slide in *V* grooves of the body. Springs that bear against the outer ends of the strips move the strips together. A pair of eccentrics that bear against the inner ends of a pair of pushrods, which are coupled in turn to the ends of the strips, force the strips apart [*see bottom illustration on preceding page*]. A mechanism designed to force the strips together, instead of separating them, might damage the inner ends, which are honed to sharp edges.

"The frame of the slit assembly also supports a pair of strips made of phosphor bronze, the inner ends of which are cut at an angle of 45 degrees. These strips can be adjusted to admit rays through any part of the slit. In one position, for example, they may admit rays from an unknown source to the upper



Arrangement of the spectrograph's control panel

half of a piece of film. After the unknown spectrum has been recorded the position of the strips can be readjusted for recording a known spectrum on the lower half of the film as a comparison. The position of the diagonal strips can be similarly changed for registering a series of exposures of various time intervals.

"The most precise and convenient method of determining the wavelength of an unknown spectral line is to compare its position with that of a line of known wavelength. The spectrum of iron, which is particularly rich in lines that have been accurately measured and tabulated, is used routinely as the comparison spectrum. I generate emission from iron by means of a spark gap.

"The gap consists of a pair of cold-rolled steel electrodes 1/4 inch in diameter; they are sharpened to edges 1/32 inch wide and 1/4 inch long. The rods are supported in alignment by an electrically insulating fixture of plastic so that the inner edges are parallel and spaced 1/32 inch apart. Alternating current is applied to the electrodes by the smallest available neon-sign transformer. The one I use develops about 2,000 volts and perhaps 20 milliamperes.

"I connect a high-voltage capacitor across the gap. I made the capacitor by sandwiching sheets of aluminum foil between glass plates and connecting alternate sheets to the respective electrodes of the spark gap. Odd-numbered foils were connected to one electrode, even-numbered foils to the other.

"The glass plates are about one millimeter thick and of the quality used for supporting photographic emulsion. They are five inches long and 2¼ inches wide. The sheets of foil are 4¼ inches long and 1½ inches wide.

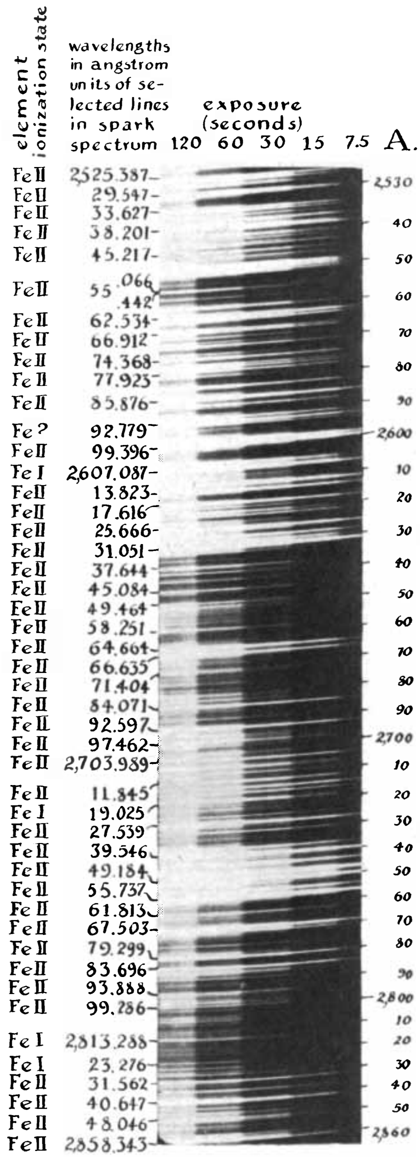
"A 350-micromicrofarad capacitor of the high-voltage type used in amateur radio transmitters would serve nicely. Without the capacitor in the circuit the spark is faint and bluish and radiates many spectral lines that arise from gases and chemical radicals in the atmosphere. With the capacitor it becomes a brilliant bluish white and the light is not contaminated by the atmosphere.

"For operation the instrument requires a final adjustment. The prism must be mounted on its table and oriented to the position of minimum deviation. Two accessories are needed: a source of monochromatic light and an eyepiece that includes a pair of cross hairs. For the source I use a mercury lamp; a sodium flame could be substituted. The eyepiece is trained on the center of the field normally occupied by the photographic film. The mechanism for adjusting the eyepiece is a mounting plate that slides into the grooves that hold the film carrier.

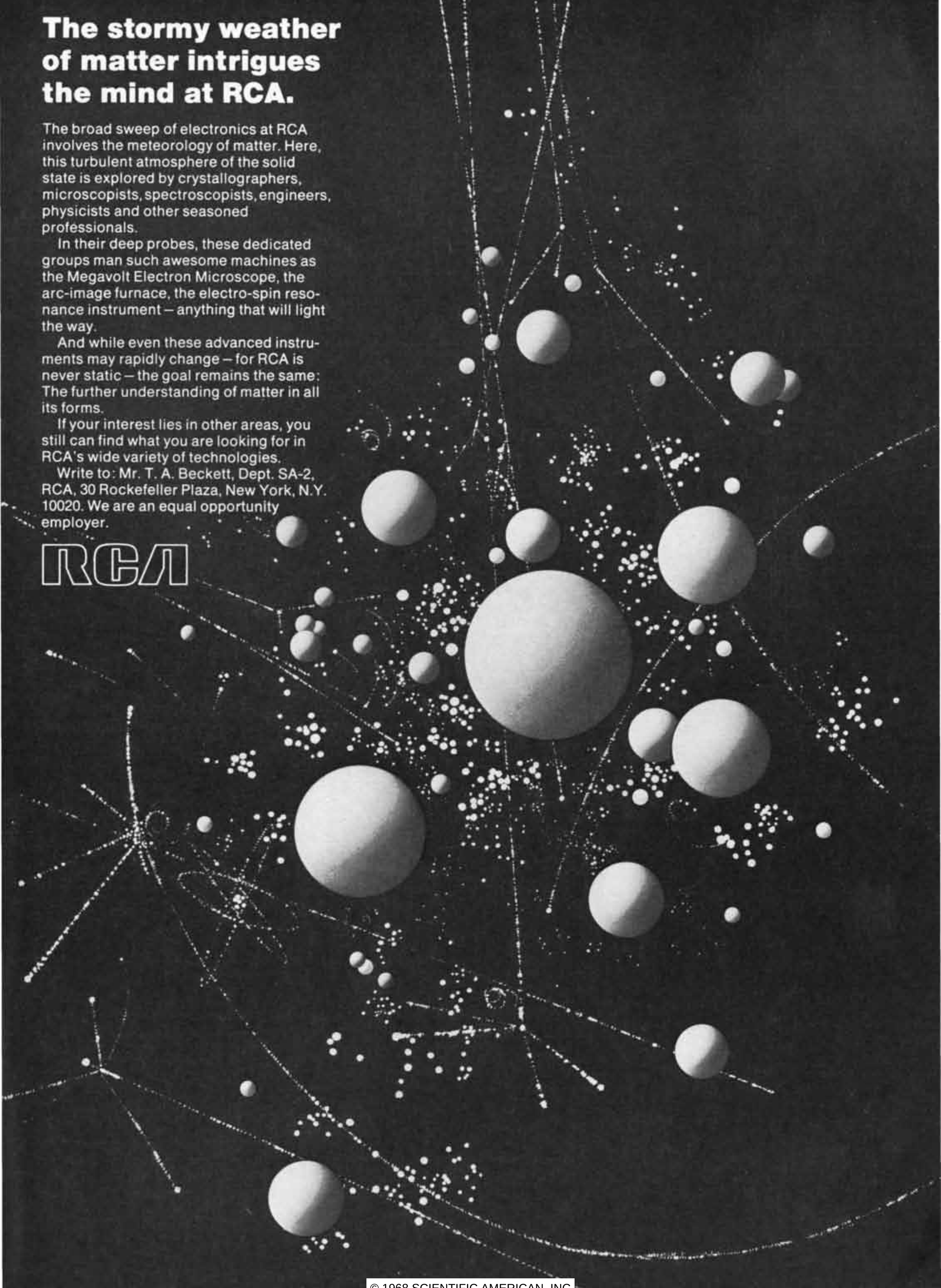
"Light from the mercury lamp is focused on the slit. With the prism table stationary I rotate the prism by hand, thereby moving the spectral line at a wavelength of 5,461 angstrom units (the most brilliant green line of mercury) into the field of view. As the prism is rotated still more in the same direction the green line advances at a constantly decreasing rate and finally comes to rest. At this point the prism is set for minimum deviation. If the prism is rotated still more in the same direction, the green line resumes its movement but in the reverse direction. The prism is lightly clamped to its table in the position of minimum deviation by means of a knurled screw.

"To record the iron spectrum I replace the eyepiece with the loaded film carrier, open the slit to about .004 inch and flood it with light from the spark gap. The time of exposure must be determined experimentally. Several exposure intervals can be tried by periodically advancing one of the two diagonal jaws to increase the length of the spectral lines by increments. A second spectrum, such as that of mercury, can then be recorded adjacent to the spectrum of iron. The brilliant green line, which is known to be located at 5,461 angstroms, is easily identified on the developed film and can serve as a starting point for identifying the iron lines by reference to published data.

"The spectral lines of iron are numerous and closely spaced. Their positions are most easily measured by means of a traveling microscope, which consists of a mechanical carriage with a calibrated micrometer screw for transporting a low-power microscope across the recorded spectrum at precisely measured intervals of length. A traveling microscope I made was described in this department in August, 1954. The accompanying photograph [*below*] shows a small length of the ultraviolet spectrum of iron that was made with my spectrograph and analyzed with the traveling microscope."



A small portion of the iron spectrum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BOOKS

T. H. Huxley and his clan

by Robert M. Adams

THE HUXLEYS, by Ronald W. Clark. McGraw-Hill Book Company ($8.95).

A book about the Huxleys is immediately attractive, since for more than 100 years the name has been a distinguished and influential one in British intellectual circles. Thomas Henry Huxley, Darwin's champion and popularizer, founded the dynasty, and there have been many scions. Indeed, there have been too many for biographical unity or completeness, as Ronald Clark must have realized with some dismay when he had the bushy family tree laid out in front of him. His solution was to concentrate on the three best-known Huxleys, Thomas Henry and his two grandsons Julian and Aldous, and to let the interwoven figures of the less public Huxleys form a tangled hedge, visible intermittently in the background.

However sensible this compromise, it exacted various prices, and the idea that seemed initially so promising has been flawed in the performance. It is tantalizing to find the work of the family's one winner of a Nobel prize, Andrew Huxley, dismissed in a paragraph. In order to cover the genealogical ground, the marriages and offspring of a great many respectable but undistinguished Huxleys are catalogued. Something in the family-chronicle approach, or in the values Clark brought to it, proved irresistibly reductive. There are moments when he sounds like the familiar parody of a Jewish mother reciting the varied accomplishments of her son the lawyer, her son the dentist and her son the taxicab driver. And by suggesting that the later Aldous Huxley (with his devotion to psychedelic drugs, dilute Buddhism and quack theories of vision) carried forward in a major way the intellectual traditions and methods of T. H. Huxley, Clark renders the real achievements of the family commonplace and even suspect.

To go back from this homogenized modern production to the writings of T. H. Huxley himself is to experience, even across the busiest of centuries, the stimulating rasp of a first-class mind. The man was a major prose stylist, whose command of the idiom was lucid, flexible and remarkably tough. He had a cruelly trenchant wit. Huxley laying out an errant bishop or scarifying the "host of pleasant, moneyed, well-bred young gentlemen who do a little learning and much boating by Cam and Isis" was a formidable figure, the more so because his own training and equipment as an intellectual gladiator were so impressively sound. His skeptical intellectual principles were grounded on a thorough acquaintance with the writings of Hume and Descartes, but he had read far beyond the range of his natural intellectual sympathies. He could launch against the bishop an apposite quotation from Joseph Butler's *Analogy of Religion,* quote Goethe or Dante to the young gentlemen in the original tongue, cite as a matter of course the great anatomists of ancient and modern times—in short, he could move with remarkable freedom and assurance through the cultural and scientific monuments of the Western world. The range of his acquaintance and the depth of his understanding would have been impressive in anyone; for a man whose formal education had been limited to a couple of elementary years in the Great Ealing School and a course of lectures in anatomy at the Charing Cross Hospital they were extraordinary. It was a mind quite without clutter, with a sharp cutting edge and plenty of energy behind it. One senses this aggressiveness, not only in his personal relationships—he was tough, and proud of it—but also in his attitude toward his work. Although he had been trained as a doctor, he disowned any humanitarian interest in curing people's ailments, and although he was famous as a naturalist, he never indulged in mere collecting or observation. He was no bird watcher. In retrospect, he thought he had "been all along a sort of mechanical engineer *in partibus infidelium.*" What fascinated him was the analysis of analogous structures, comparative morphology as the expression of functional adaptation. What he saw with delight in the multiple forms taken by a simple pattern of bones in fin, paw and hand was a kind of clean, adaptive economy that his own mind handsomely exemplified. It was a tool he turned to many purposes, and one for which he never lacked employment.

In social terms T. H. Huxley undertook a familiar, difficult job: widening a very solid and compact establishment to make room not only for himself but also for his kind. He could not have begun life more pronouncedly "out," as the seventh son of a provincial schoolmaster forced to turn bank manager; his career could not have owed less to favor, influence or family backing; he could scarcely (short of a bishopric or a seat in the House of Lords) have ended his life more pronouncedly "in." What he had joined and helped to create was that intricately woven thicket of conservative British intellectual aristocracy that has been so suggestively described by Noel Annan (*Studies in Social History: A Tribute to G. M. Trevelyan,* edited by J. H. Plumb, 1955). For this loosely defined yet limited group of families (among which it is inevitable to name the Wedgwoods, Darwins, Haldanes, Huxleys, Arnolds, Trevelyans, Macaulays, Stephens and Stracheys) the universities and the civil service were as landed estates, and the critical exercise of free intelligence was as a religion. Like the great Whig aristocracy of earlier days, they built up a cat's cradle of connections and influences, half-tribal, half-cultural, flexible, absorptive, tenacious and far-reaching. The descendants of T. H. Huxley are to be looked for not in the Great Ealing School or even in the Royal School of Mines but in Balliol College, Oxford; their problem is not to conquer the citadel of the establishment, which is theirs as a birthright, but to make some tolerable space for themselves within it or, failing that, to get out.

The fact is that although Clark pumps hard for marks of intellectual distinction and eminence among the descendants of T. H. Huxley, the record seems to show great energy, laudable curiosity and open-mindedness, immense verbal dexterity, some administrative versatility but no overwhelming amount of concentrated intellectual originality. Andrew Huxley and T. L. Eckersley (a grandson of T. H. Huxley through his daughter Rachel) evidently produced "hard" scientific work of great distinction, the former in cell physiology, the latter in short-wave radio. But they were exceptional, and the exceptional character of their work is obscured in the present account both by the author's reluctance to overtax his readers with hard words and complicated ideas, and by a plethora of miscellaneous relatives who did good work in propagandizing the general use of tea, achieved high diplomatic posts somewhere, became directors of large corporations or wrote amusing travel books. Until quite recently it was a largely unchallenged assumption that a man who had achieved a first at Oxford or Cambridge could be relied on to do a rather good job at practically anything, whether he knew the subject or not. It was on this assumption that Annan's intellectual aristocracy flourished, and flourish, after its own fashion, it certainly did. There is a curious passage in the biography where Clark speaks with relish of "the continuing Huxley facility (*sic*) for dropping the right word into the right ear at the right time," as if conniving and wire-pulling represented an order of talent like any other. There is no special moral attitude to be taken toward this particular fact of life, but one finds it irksome to see social privilege and entrée counted casually among the tokens of intellectual distinction. It certainly would have irked the soul of T. H. Huxley.

The two figures treated at length in the last two-thirds of Clark's book are instances of great talents incompletely and unsatisfactorily realized. Sir Julian Huxley, perhaps the more substantial of the two brothers, had at least five different careers: he was for a while a teacher; he became a popular lecturer, journalist and writer on science; he tried his hand at administration (the London zoo and UNESCO, not exactly parallel enterprises); he starred on a quiz program, and he crusaded on behalf of disappearing wildlife, on behalf of a semireligious creed loosely titled humanism, on behalf of population control and eugenics. He has been the author or coauthor of almost 30 volumes, many of them provocative, some of them weighty and, so far as one can tell at present, none of them permanently memorable. This in itself is no ultimate judgment. Sir Julian, like every other man who is quick with the pen, produced, and was bound to produce, a considerable amount of writing on occasional and ephemeral topics. Still, compared with his grandfather's command of the occasional essay, which he handled like a meat cleaver separating a joint, Julian Huxley's journalism is too often puffy and desultory. One feels that he never bent heart and soul to any one overwhelming task, as men less versatile or volatile are sometimes impelled to do. The record shows no one subject explored to a new limit, no fresh technique or hypothesis applied to new subject matter, no public campaign fought through to a distinct and perceptible conclusion. The account of Sir Julian could be written, and has been, without a single allusion to the biological revolutions of the recent past. Evidently a man born in 1887 could not be expected to take a very active part in these advances, but to present his life as a biologist exclusively in a 19th-century perspective should not have been as easy and natural as Clark evidently found it. Clark has a theory that it is the destiny of the Huxleys to work out the relation of mankind to the cosmos, and indeed most of the things they wrote turn out to bear, in one way or another, on this topic. But a concept so grandiose does not really provide a sense of an individual's intellectual unity and development, nor does it give one much insight into the different levels on which it is possible for a man to work—as a laboratory experimenter, observer of nature, summarizer of the literature, synthesizer of results or philosopher at large. Sir Julian has worn all these hats at different times, and it would have been helpful to know which one was on at what stage. *Problems of Relative Growth* (1932) presents fresh observations and draws them toward a coherent quantitative pattern; it is much closer to original research than *The Elements of Experimental Embryology* (1934), which is essentially a review of work in the field. Yet Clark simply calls it "an equally important volume," a judgment that is not so much wrong as blurred.

In the sphere of cultural statesmanship there are grounds for thinking that Sir Julian, if something less than an authoritative guide to the cosmos, has been a provocative and wide-ranging public spokesman. His brother Aldous provides a much more delicate and revelatory case—less of a success, perhaps, but a specimen of greater complexity and more poignant interest. Perhaps owing to a frail youth and poor eyesight, he was never as pronouncedly established as Julian in the establishment. Like his elder brothers, he passed from Eton to Balliol, getting his First there but pursuing his own development in almost perfect independence of the instructional program. Schoolteaching, tried briefly, proved temperamentally impossible, and the civil service was not even to be considered. Then, after the war, which had involved him in various uncongenial secretaryships, journalism and fiction claimed him, the two callings being intertwined, in his career, with particular intimacy.

The four novels Aldous Huxley wrote during the 1920's (*Crome Yellow*, 1921; *Antic Hay*, 1923; *Those Barren Leaves*, 1925, and *Point Counter Point*, 1928) were recognized at the time as not being novels in exactly the usual sense, but what to call them is still something of a problem. The people represented in them (the element of half-unconcealed autobiography was generous to a fault) could scarcely have been blamed for thinking them little better than yellow journalism; J. Middleton Murry, brutally caricatured in *Point Counter Point* under the name of Burlap, thought of challenging Huxley to a duel. In wider circles the novels were read as witty social satire, as light, brittle and amusing fables about absurdly mannered caricatures of the human species. Yet they also had a strong streak of the macabre. When Theodore Gumbril, Jr., and Myra Viveash concluded *Antic Hay* with a long, bored, meaningless taxi ride back and forth across nighttime London, one could not really feel oneself in the presence of light social satire.

As imaginative achievements these novels seem never to have been taken with excessive seriousness. Between spasms of public lecturing, to which they were very prone indeed, the characters generally performed like jerky automata, and the style, at its best, was astringent. But an especially interesting feature in a young novelist was the theme of sensual exhaustion, combined with loathing of the conscious mind. The problem posed by this conjunction was simply: Where do we go from here? For all the talk about love and sex in the Huxley novel, the topic's only resource against withering into verbiage was the plunge into sadism, diabolism and (since these alternatives cannot be taken too seriously) buffoonery. Consciousness—scientific consciousness particularly—was treated from the beginning as a band of steel compressing and distorting men out of all their instinctual life, out of their wholeness as human beings. Of all the filthy tricks life plays on people in *Antic Hay,* the worst are played on Shearwater the physiologist, who has used his books to fence himself off from what they should be teaching him. He is left riding a stationary bicycle to infinity in a sweatbox, a Dantesque emblem of the self-punisher. More interesting and inward is the figure of Philip Quarles, a novelist in *Point Counter Point,* whose function in the book is imitated from Gide, but whose muscle-bound intellection evidently mirrors dilemmas intimate to Huxley himself. Not only does Quarles's mind seal him off from personal intimacy of any sort; it seems to get seriously in the way of his writing novels. Thinking about how to describe "The Kitchen in the Old House," he is drawn to locating it in time as well as space, to give "a hint of its significance in the general human cosmos." The sentence that emerges is: "Summer after summer, from the time when Shakespeare was a boy till now, ten generations of cooks have employed infra-red radiations to break up the protein molecules of spitted ducklings ('Thou wast not born for death, immortal bird, etc.')." This attempt at a synoptic view of things only served to produce effects of grotesque and inconclusive discord. That is not far from summing up the main quality of the fiction Aldous Huxley wrote during the 1920's. Clever, cool and meticulously informed about an enormous number of specific details, he could bring together themes and perspectives of amazing diversity, but out of the collocation emerged little except disorder, despair, isolation and a sense of the bizarre. Friends remember as characteristic of him a drawling, intense phrase: "How extraordinary!" It is not bad as a response to the highest achievements of his prose fiction.

Aldous Huxley was just 34 when *Point Counter Point* appeared. Although it was not his last novel, it was his last major effort in the form, and his last real attempt at a synthesis in the shape of fiction. He continued to write, and write brilliantly in a number of genres, but there is an inescapable sense of the scrappy and disparate about the last 35 years of his life. He produced some admirable travel books; he turned out elegant informal essays on topics in art, literature, manners, morals and whatnot; he wrote tracts on pacifism, an exposition of occult philosophy, a treatise on how to improve the sight, an account of psychedelic experiences, a biography of Richelieu's gray counterpart Father

Joseph, a study of diabolic possession among some French nuns during the 1630's, an anti-Utopia (*Brave New World*) and a moralistic motion-picture script (*Ape and Essence*). Apparently the very real charm of his conversation lay in his capacity to dart in an instant from the metrics of Catullus to the mating habits of the jellyfish to the sewage systems of the world's larger cities to the epistolary style of St. Catherine of Siena. But the qualities that make for delightful conversation make just as readily for cluttered and incoherent books, a collection of fossilized literary curiosities. It was a special quality of T. H. Huxley to be avid after the meaning of a particular, insistent on knowing its relation to a schema; in his grandson Aldous the opposite quality was carried to almost parodic lengths.

The two fables of social degeneration, *Brave New World* (1932) and *Ape and Essence* (1948), illustrate nicely this quality of fragmented vision. In the first book, as is well known, Huxley takes as his satiric target the adjusted society that has successfully reduced its members, in the name of social efficiency, to interchangeable mechanical parts. To show off the degraded artificiality of this social machine he introduces into it our old friend the noble savage, who is so shocked by the whole thing that he turns, with a minimum of difficulty, into a tormented, masochistic Christian. Whether one believes in this metamorphosis or not, its point is evidently to link qualities that are "heroic," "natural" and "human" (in a sense not far removed from "neurotic") against the efficient, ignoble mechanisms of the conditioned reflex and the engineered social value. *Ape and Essence* simply reverses the scheme and stands the satire on its head by introducing a civilized New Zealand scientist into a society of degenerate savages supposed to have grown up amid the ruins of Los Angeles after World War III. The technology of these tribesmen is pitifully primitive, their religion is a brutal combination of orgies, crude taboos and sadistic ritual; they are, in effect, simply the noble savage of *Brave New World,* multiplied manyfold and seen in a hostile rather than a favorable light. It is obviously no part of a social satirist's obligation to preserve strict logical consistency from book to book. But the shrill, exaggerated quality of these two satires, their frank manipulation of the heroic foil in the first book to serve as villain in the second, is, to say the least, disquieting. It seems likely that Huxley could play for melodramatic effect with these crude and superficial images of technology and Christianity, material and spiritual values, because, underneath, his mind was moving in another direction entirely.

That shift of spiritual balance can be observed, almost in the act of occurring, in the middle of *Eyeless in Gaza* (1936). This effort is one of the most fractured and inchoate of Huxley's fictional works but also one of his most interesting. Particularly in the first part, it is full of cruel caricatures of various easily identifiable Huxleys and friends-of-Huxleys; its protagonist is a barely disguised Aldous Huxley who has no misgivings at all about transcribing long swatches of his private diary; at the end all pretense of fiction is abandoned and the book becomes simply a sermon on the redemption of human nature. The main satire grows from a juxtaposition of various instinctual, promiscuous females with a number of bloodless intellectual males—"Higher-Lifers," as the narrator calls them, idea-mongers, cute raconteurs, word-tiddlers, arch and knowing quotation-cappers, professional converters of feelings into phrases. The intellectuals are simply grotesque, as Huxley's London intellectuals had traditionally been, but somewhere around the middle of the book a guru named Miller starts emerging from the shadows to preach a healing and revivifying doctrine compounded of pacifism, inner light and self-purification if not self-abnegation. Samson (= Anthony Beavis = Aldous Huxley), grinding in the mill of Western culture with slaves, has found a new inner light. It is not clear whether Huxley anticipated pulling the temple down on the Philistines or recognized that a kind of suicide was involved in doing so. But that being a Huxley, that is, a priest of the free intelligence, was not enough for him is very clear indeed.

Huxley thirsted for the anonymous dark of the subconscious, and that nontheistic Buddhist absorption into the cosmos which seems to represent one of the handier ways to get rid of the burden of self. James Miller of *Eyeless in Gaza* had the protective coloration of a Quaker missionary-doctor, but the tide of feeling to which his disciple abandoned himself at the end of the book was flowing irresistibly to the East. An acute reviewer in the *Times Literary Supplement* compared Huxley's situation at the end of *Eyeless in Gaza* with that of J. K. Huysmans after *À Rebours,* poised before the dilemma of the crucifix and the revolver, but for Huxley the options could have been symbolized less dramatically by the lotus and the laboratory. In opting for the lotus he did not carry forward, he directly rejected his grandfather's hard-bitten rationalism.

Every dynasty is bound to come on some of its members sometimes as not simply a privilege but a burden. Long before Aldous there had been noncompeting Huxleys, victimized by their heritage or actively resentful of it. Even old T. H. Huxley, for all his ferocious intellectual efficiency, had been haunted, like so many other Victorian giants, by the demon of melancholia, a demon that had to be walked to death in compulsive, week-long demonstrations of pedestrian endurance. London and committees and offices and paper work and lectures represented for him an "incubus of thought" that could be exorcised only by mindless activity. Masterful brains are apt to make trouble for the people they inhabit, and for others who have to live in close proximity to them. It is not easy to imagine circumstances where they would make more trouble than in a closely knit and proudly self-conscious family, securely entrenched within an intellectual elite. We have had lately, in the biography of Lytton Strachey, a partial revelation of the dark and tragically twisting rivers flowing beneath the too civilized landscape of the Bloomsbury group. This is not to say, "Aha, the pious old frauds, now it comes out that they were really all monsters." It is to suggest that civilized, imaginative man often lives several different lives at once, and that a formal account of what happened to him in the public forum may be less than half of his real biography. Someday perhaps we shall have such a biography of the Huxleys, and if some of them emerge from it seeming a little less like Kewpie dolls and a little more like vampire bats, that fact may well heighten rather than diminish our sense of their accomplishment.

Short Reviews

YAMS, by D. G. Coursey. Humanities Press, Inc. ($9.50). Drive in the thickly inhabited rain forest belt of West Africa and you will pass plot after plot of dense vines, sometimes climbing stakes, sometimes trained to trees or to cornstalks. These vines are the staple crop of the region, the white yam. For 1,000 miles, north of the swampy coast and south of the dry savanna, east from the Ivory Coast to the Cameroons, the yam is the staff of life. The great 20-pound rootlike starchy tubers (these true yams, species of the genus *Dioscorea,* are not the sweet potatoes we often call yams in the U.S.) are everywhere, in markets and stored on the farm. West to the Atlantic rice is the staple; east too, where the Bantu peoples have spread, yams are less important. In the valleys of the rivers Bandama, Volta and Niger, however, man's proper food is yam.

Yam is not a really cheap food. In calories per man-day, and in shillings per pound in the market, it is several times dearer than its more protein-rich competitor, rice, or its still starchier, cheaper rival, cassava. It is the deep digging for the heavy tubers at harvesttime that adds to the man-day cost. The cost in woman-days is high too; boiled yam is delicious, but more prized is the smooth pounded yam *fufu* beloved of West Africans, costing the housewife hard work as she stands heavily over the mortar pounding yam afresh for each meal. Yam-pounding is a domestic act as rich in evoking the home as rolling piecrust or kneading bread is for us, and it is more often gracefully figured in art. Coursey's monograph, with maps and drawings, analyses and calendars, tells all about the yam—all the yams. It gives an account of their history and economics, their agronomy and botany, their pathology and pests, their nutrition, storage and processing, and of the importance of the yam for the "civilizations of the yam." It is true (although one should not too simply impute cause and effect) that in the yam belt all four of the great forest states of West Africa arose in the last millennium: Ife, Benin, Ashanti and Dahomey. The book makes a strong case for the proposition that the yam represents the ancient independent invention in West Africa of a new form of agriculture—like rice, maize, barley and wheat elsewhere—enabling man to spread into a new habitat, in this case the rain forest, some 2,000 years ago. There are some yams of a different but related kind in southeast Asia, which with the Caribbean is the only other region where this large group of crop plants is important.

The increase of the nutritional disease kwashiorkor in West Africa—apart from the famine of war—is partly due to the relative decline of the yam. The poorer city people, displaced from the land, seek the cheapest calories they can find. Cassava, which is distinctly inferior in amino acid content, is selling better and deceiving its users into thinking their children are fed.

The new-yam festival of our fall months has for a long time been the chief feast of the year in the West African yam belt. No one can eat the new yams until the elaborate ritual ceremony is complete, and there are authentic cases of prisoners "voluntarily starving to death, rather than eat yam, when they were unaware whether New Yam had yet been eaten in their own villages." The theft of yams is a crime worse than theft of other property of greater monetary value. "In Ibo traditional law, adultery is merely a civil offense under normal circumstances, but if committed in a yam field it immediately becomes a criminal affair, as the yams will be offended."

The final chapter of this path-breaking study describes the interesting industry of extracting from yams the crude steroids from which the hormones of the Pill and of the adrenocortical complex are synthesized. The center of the industry is Mexico, and lately China. It is not the cultivated yams but related bitter and inedible wild species that are used. Local extraction yields by simple means a percent or two of a multiple-ring starting material, diosgenin, from which, by a clever mix or syntheses both by microorganisms and by larger chemical engineers, the related active compounds can be made.

THE STORY OF JODRELL BANK, by Sir Bernard Lovell. Harper & Row, Publishers ($5.95). Twenty-five miles south of the city the University of Manchester owned a plot of land as horticultural gardens for the department of botany. Two cheerful gardeners worked there full time. After the war first a couple of surplus military trailers, then an improvised fixed wire-screen bowl and in 1957 what was and still is the world's largest fully steerable radio telescope rose there—the strangest of flowers. The great bowl in its battleship trunnions has become a symbol of our times as ubiquitous as the Eiffel Tower once was. This book, as candid and peppery as its distinguished author, is the narrative of the man whose faith and determination built the dish. The bursar of the university and the designer of the structure add graceful forewords: deep cooperation no less than quarrel was part of the story. There is not much radio astronomy or structural design in this book; there is a good deal about budgets and grants, bids and delivery dates, subdivision developers, strikes and slowdowns, an ingenious lady hoaxer, corporation infighting, engineering sloth and arrogance, and the ways of a distant and traditional bureaucracy. With Sputnik and the American rejoinders to it, Jodrell Bank, for a time unmatched at tracking space probes, became an international asset, eagerly sought out by both sides; adjoining teleprinters clicked away to Los Angeles and to Moscow.

Mark I—it has a sleeker, smaller neighbor now—seems out of a crude and heroic age. No electronic computers worked on the structural design, no competitions, no careful site-study preceded the location. Sir Bernard and John Clegg spent 1,000 pounds building almost by hand the 218-foot fixed wire bowl; then they dreamed of a real dish. P. M. S. Blackett applauded, and he served as chief of staff for the long tactical approach to the committee that granted funds. In 1950 Lovell had guessed his 250-foot parabola would cost £100,000; everyone knew that figure might double. The designer, H. C. Husband, made his design study. The formal application in 1951 sought £250,000. The first full grant in the spring of 1952, shared by the Nuffield Foundation, was awarded for £333,000. The telescope cost in the end £650,000, and it was well worth it. The deficit and its awful burden, however, sound the drone beneath the personal themes of this book. The debt was paid off—out of public appeals, out of U.S. payments for tracking time and through the generosity of the Nuffield Foundation and Lord Nuffield personally—only in 1960. The British universities through this narrow gate first entered the domain of big science.

The telescope has been a huge success; the first substantial repairs and improvements (particularly resurfacing) are currently being made on the 11-year-old instrument, "a most beautiful sight silhouetted against the evening sky."

ENCYCLOPÆDIA BRITANNICA: OR, A DICTIONARY OF ARTS AND SCIENCES, COMPILED UPON A NEW PLAN. Encyclopedia Britannica, Inc. ($79.50). In celebration of the 200th anniversary of the first Edinburgh publication of this perennial reference, its present-day Chicago publishers have prepared a three-volume facsimile of the father of them all. The physical reproduction is beguiling: paper spotted with age, bound in gentlemanly leather (quite synthetic, with equally synthetic wormholes) and of course with the precise typography and rich engravings of the original, all the long *f*'s and copper-plate gatefolds included. Not a word has been added or modified.

A casual study of the treasure gives one a good look at the intellectual world of the kind of men who must have talked of Lord North and the Colonial dissent. Their view of space was not cramped: the fixed stars spread out around our modern solar system, the nearest of them at the proper distance. "It is highly probable, that each star is a sun to a system of worlds moving round it... a plurality of worlds is rational, and greatly manifests the power... of the great Creator." Our earth is pretty well filled in too, although the words Bering and Vancouver are not yet on the maps, the Niger is blank and one lake occupies the Rift Valley. New Holland and New Zealand are present, if a bit indefinite. World enough they knew but not time. Their world was created in 4007 B.C.; the Ark (depicted as a huge floating warehouse, and calculated to hold with ease its few hundred species) was set adrift in 2351 B.C. Geology is not entered; it is exhausted by Mines and Mineral Ores.

Most of the entries are dictionary-like, but the weight of the books is in the detailed do-it-yourself articles: Anatomy, Medicine ("If the hands do not begin to swell remarkably, the [small-pox] patient will suddenly leave the world"), Obstetrics (called "Midwifery" and illustrated fearsomely with much show of forceps), Surgery ("We begin with the operation of phlebotomy, because it is of all the most general"). These four step-by-step practical articles alone occupy an eighth of the entire work. There is plenty as well on Gunnery, Agriculture (with a column on the culture of turnips, and complete with the "new husbandry" of horse-drawn wheeled drills and harrows), Navigation and Book-keeping. Metaphysics and Grammar are also strongly presented. The sketchy treatment of textiles, mainly under Cloth, shows the realization that this was by then a specialized industry; the Ship (called the "noblest machine that ever was invented") is handled with love, but only as an onlooker would wish. Shipbuilding has gone beyond the enterprising individual. All in all, there is a pretty good match between the contents and the confident, energetic, tough-minded and ambitious merchant class at which the set was aimed.

INTERNATIONAL ZOO YEARBOOK: VOLUME 8, edited by Caroline Jarvis. The Zoological Society of London ($18.75). This annual is a well-known publication in the zoo world, but it deserves a much wider readership among biologists and indeed among all who are fascinated by animals. Each year's issue contains a special symposium (this year on breeding canids and felids, from the Indian wolf to the snow leopard, next year on reptiles in captivity), a section of short papers on new developments by zoo people the world around, a reference section that lists in detail almost 900 collections of wild animals (zoos, bird parks, aquariums and so on) from Rosario to Shanghai and the species kept there, and a special technical account of animal-marking and zoo-record problems. The husbandry of diverse forms is always fascinating, and here it is told like it is. In San Diego they were blessed by the birth of a pygmy chimpanzee. The parents had long been friendly with Principal Keeper Cryster, but the infant did not prosper. Its little mother, weighing 50 pounds, would hardly suckle the baby and expressed no milk. The infant was put on Simulac after the mother had been sedated with drugged orange juice. "Sixty-one and a half hours after birth [the keeper] lay down on the hay bedding. Since he had been constantly attending the mother . . . for the past two days he was very tired. The soft bed was too difficult to resist and he fell asleep. The mother chimpanzee . . . lay next to Cryster on the floor." All are doing well, but the baby had to be bottle-reared.

Barcelona acquired a two-year-old male West African gorilla a couple of years ago, quite ordinary except that he was white, "skin and hair both being completely devoid of pigmentation . . . a light blue iris . . . very transparent." He had a set of baby teeth in good condition. No other albino gorilla is known; a few cases of pigment missing in some particular area of neck, hands or feet are recorded. The mythology of the Fang people in the Cameroons includes an albino chimpanzee, and human albinism is found there very rarely, about one case in 10,000 of the population. Nfumu, which means "white" in the Pamuè tongue, is a lively and high-spirited animal, adapting to new food and to people with exceptional speed. Perhaps his poor eyesight and strange appearance had brought neglect by his fellows in the wild; he was particularly sensitive to affection and attention. A year ago a rare pair of gorilla fraternal twins was born in Frankfurt; their behavior protocol seems, up to 10 weeks, very much like Ilg and Gesell.

Perhaps the best papers are on the killer whales. These huge cetaceans (they come up to 10 tons or more full grown, but nobody has kept one that big, since no proper tanks are yet available) are the biggest animals in captivity, even though the largest of the six now kept are mere 18-foot young females weighing less than two tons. Their mouth can easily hold a man; how their huge teeth gleam! They are in fact friendly, intelligent, playful and something of a born performer. The taking, training and care of the killers is described. "The baby whales were easy to feed and were each given one gallon of whipping cream three times daily, mixed with a multiple-vitamin supplement, human baby food, warm water and small amounts of fish." Clearly maritime kings ought to give their rivals a killer whale, not a white elephant.

THE NEUROSCIENCES: A STUDY PROGRAM. Planned and edited by Gardner C. Quarton, Theodore Melnechuk and Francis O. Schmitt. The Rockefeller University Press ($17.50). Ponderous yet attractive, this book presents 67 survey papers, plus a few helpful introductory and generalizing essays, that formed the content of an intensive study program. The program was carried out in the summer of 1966 for about 100 research men in many fields in and around biology, in addition to the authors. The aim was to present the background of all we know about the way the brain works; in this volume (other programs may yet come) the emphasis is biochemical and molecular. A third of the space is given to general molecular biology, from the double helix and the genetic code to the role of ions in nerve impulses. There are some splendid electron micrographs. Then the scale changes, and we find a dozen papers on neurons and their circuitry, chemistry and signals. There is no doubt of it: the naïve days of a generation ago, when a neon-tube flip-flop was a good neuron model, have gone, and we have the more timely analogy of the integrated circuit chip with plenty of leads in and out. Finally, the topic becomes the whole brain, the split brain or the drugged brain, and we study it waking and sleeping, dreaming, generating potentials or learning. The center of attention is man, but octopus and even protozoon are not omitted.

The brain as a black box remains somewhat offstage, and models made by the simulators and the logicians are altogether absent. Within these limitations the work is very full indeed, and the distinction of so many participants almost—alas, not quite—guarantees the pertinence and richness of their papers. It is a study program of daunting weight and diversity.

There are bacteria that form rafts which then constantly rotate. An infant without any brain above the medulla can survive for a month or two, and has a well-working set of sucking and grasping reflexes and the rest, but he has no way to respond to or make known his internal needs, so that he does not suck enough. Maybe memory is helical molecules. Maybe. One is warned that the Golgi stain that marks the dendritic circuitry in the dramatic cortical maps made by Santiago Ramón y Cajal before World War I affects only 1 percent of the neurons seen in the focal plane, "for unknown reasons." There is a lot more to know, even if you master this large bargain book. Somehow the subject does not yet display the aura of success.

THE LICHEN SYMBIOSIS, by Vernon Ahmadjian. Blaisdell Publishing Company ($5.75). The Swiss botanist Simon Schwendener showed in 1867 that lichens, in spite of the tens of thousands of species named in the books, were not independent plants at all but associations of an alga (usually a green one) and a fungus (usually one of the ascomycetes). The fungus forms a matted layer of filaments on bark or rock, and near the top of the tangled mat there is a layer of spherical or filamentary algae, covered over with a tight protective layer formed by thickened filaments of the fungus. Victorian sentimentality (Is there a psychoanalyst in the house?) led one botanist to lament "this unnatural union between a captive Algal damsel and a tyrant Fungal master." There are other such lifelong associations of fungus and alga in the sea; there the algae may live inside the hollowed filaments of a branching fungus. In lichens the partners do not only benefit mutually; both are changed, the algae generally remaining smaller and less characteristic in form, the fungi regularly developing complex fruiting bodies rarely formed without the partner.

The author is an experimenter who has managed to learn how to cultivate separately both the algal and the fungal partners, how to unite them, and for the first time in 1966 how to cause the newly united partners to grow more or less in the natural way. It takes patience. Lichens are among the slowest-growing organisms in nature; a rock lichen in the forest is often older than the biggest tree around. They grow rather less than a millimeter per year. The trick of synthesis is dynamic; it depends on a "continuous balanced rate of growth" of the two partners. If one brings a lichen from the wild state into the laboratory, it usually finds conditions too lush and grows rapidly, soon to dissociate into separate growths of the two partners. The partnership is not highly specific; in the wild a lichen fungus may cast spores that find a place to grow up with a new captive "damsel," not at all like dad's. Ahmadjian's compact account tells the story, and just how to do the culturing.

Lichens are humble enough; their economic importance is small. The caribou feed on them, and in hungry times so can people. They are not toxic, although they are often bitter and irritating. Their role in forming soils from rock is well publicized but is probably insignificant. They can pick up metal ions by chelation, and tend to concentrate fallout strontium and cesium, which via the caribou have shown up in the bodies of Alaskan Eskimos. As an intermediate step between simple organisms and more complex ones, however, lichens will surely become increasingly important to biology, particularly in a time when the organelles of cells begin to appear as DNA-carrying symbionts of a most ancient alliance.

This is a clear, engaging, brief and knowing technical book. There are too few like it.

A DICTIONARY OF ENGLISH WEIGHTS AND MEASURES FROM ANGLO-SAXON TIMES TO THE NINETEENTH CENTURY, by Ronald Edward Zupko. The University of Wisconsin Press ($10). There are 3,000 entries in this work, a couple of hundred of which contain clearly dated citations in Latin or Middle English or in the fine statutory phrases of Victorian times, fully defining and illustrating the terms used in the other entries. Historians of economics or of science will find the book indispensable to their understanding; the general reader cannot fail to find it by turns touching, amusing and illuminating. It displays the stuff of meaning and thus is not a bad guide to epistemology. There is the tale of the three barleycorns that made the inch—what kind, where grown ("after the fatness and leanesse of the land, where it was sowen upon"). Consider that commonplace quantity, the hundred. It was "generally numbered 100, but larger amounts were not uncommon: 106, lambs and sheep in Roxburghshire . . . ; 120, the long-hundred, for canvas, eggs, faggots, herrings, linen cloth, nails, oars, pins, reeds, spars, stockfish, stones, and tile; 124, cod, ling, haberdine, and saltfish; 132, herrings in Fifeshire; 160, 'hardfish'; and 225, onions and garlic." All of this is documented, and is in itself a compact list of 16th-century trade.

The writing is clear and direct, and the whole design is simple, attractive and usable. The scholar's apparatus is still handily present, in annotated bibliography, statutes, years of reign, but Zupko and his editors have made something lively out of an esoteric Ph.D. thesis. Let us raise them a toast in a mutchkin of brown Milwaukee ale (two mutchkins equals one choppin; two choppins equals one stoup, or 1.707 liters).

THE MIND OF A MNEMONIST, by A. R. Luria. Translated by Lynn Solotaroff. Basic Books, Inc., Publishers ($4.95). Jorge Luis Borges wrote a haunting tale of the life and death of a poor Uruguayan named Funes "the memorious," who could recall everything, including the course of the foam once raised by an oar dipping into the Río Negro. He gave numbers names, recalling each by a phrase. He saw no good or value in the idea of a logical notation. It was the world's richness that made him melancholy: "To think is to forget differences, to generalize." In this strange and equally haunting narrative a distinguished Russian psychologist recounts the life of a real man he worked with for almost 30 years: one S., "a Jewish boy who, having failed as a musician and as a journalist, had become a mnemonist . . . yet remained a somewhat anchorless person, living with the expectation that at any moment something particularly fine was to come his way." Here is a sample of S. at work. In late 1937 they read to S., who knew no Italian, the first four lines of *The Divine Comedy, Nel/ mezzo/del/cammin . . .*, with pauses between words. Fifteen years later, without forewarning, he recited the verse with exact stress and pronunciation, including an error made by the first reader. He freely gave his method: a set of strange images he attached to the sounds at the first reading. For the Italian word *nel* he had thought of seeing the ballerina Nel'skaya as he stood in a corridor paying his dues at a club to which they both belonged. And so on. S. had a long-term memory without a flaw, once it had been imprinted, but he had a very limited capacity for the general, for the abstract or even for connected meaning itself. Funes was like that; Borges' source, real or unconscious, and certainly not the present narrative, must have been a similar case. Like Funes, S. gave names, often poetic, always sensuous and concrete, to symbols and ideas. The book evokes S. and his times; it is less a case study than another short story, but a story that is vividly and touchingly real, from which Luria emerges as artist, scientist and friend.

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