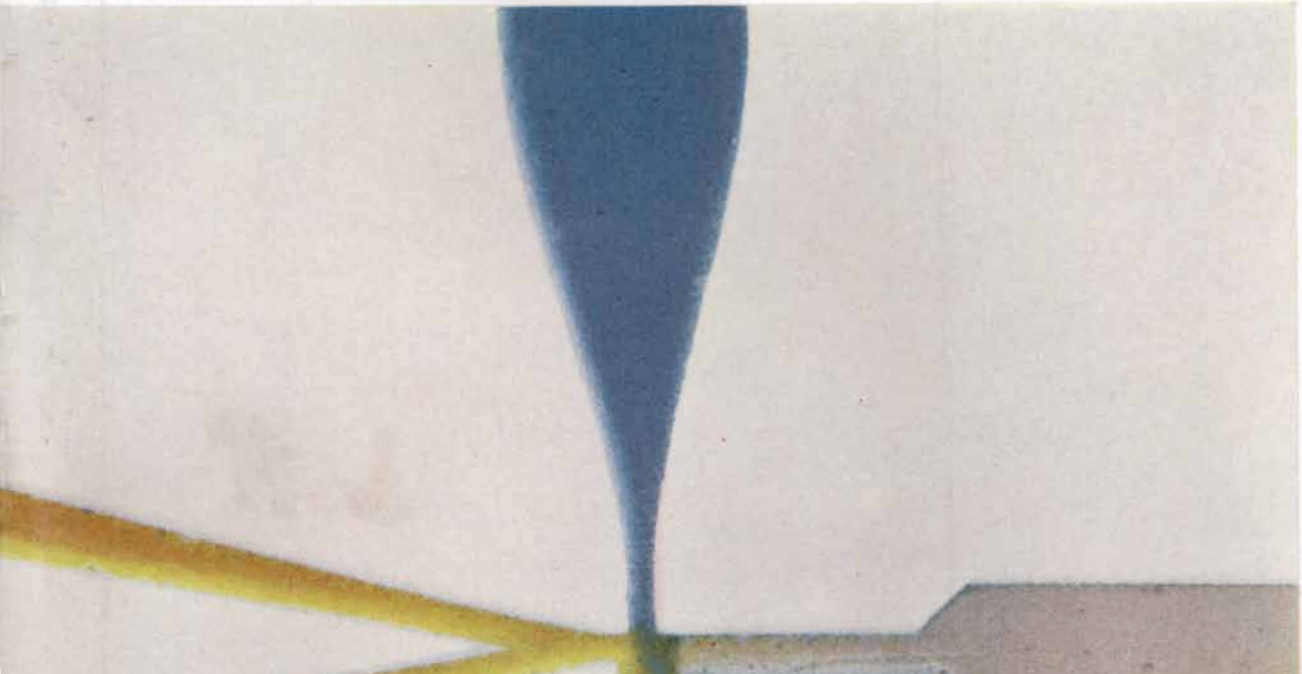
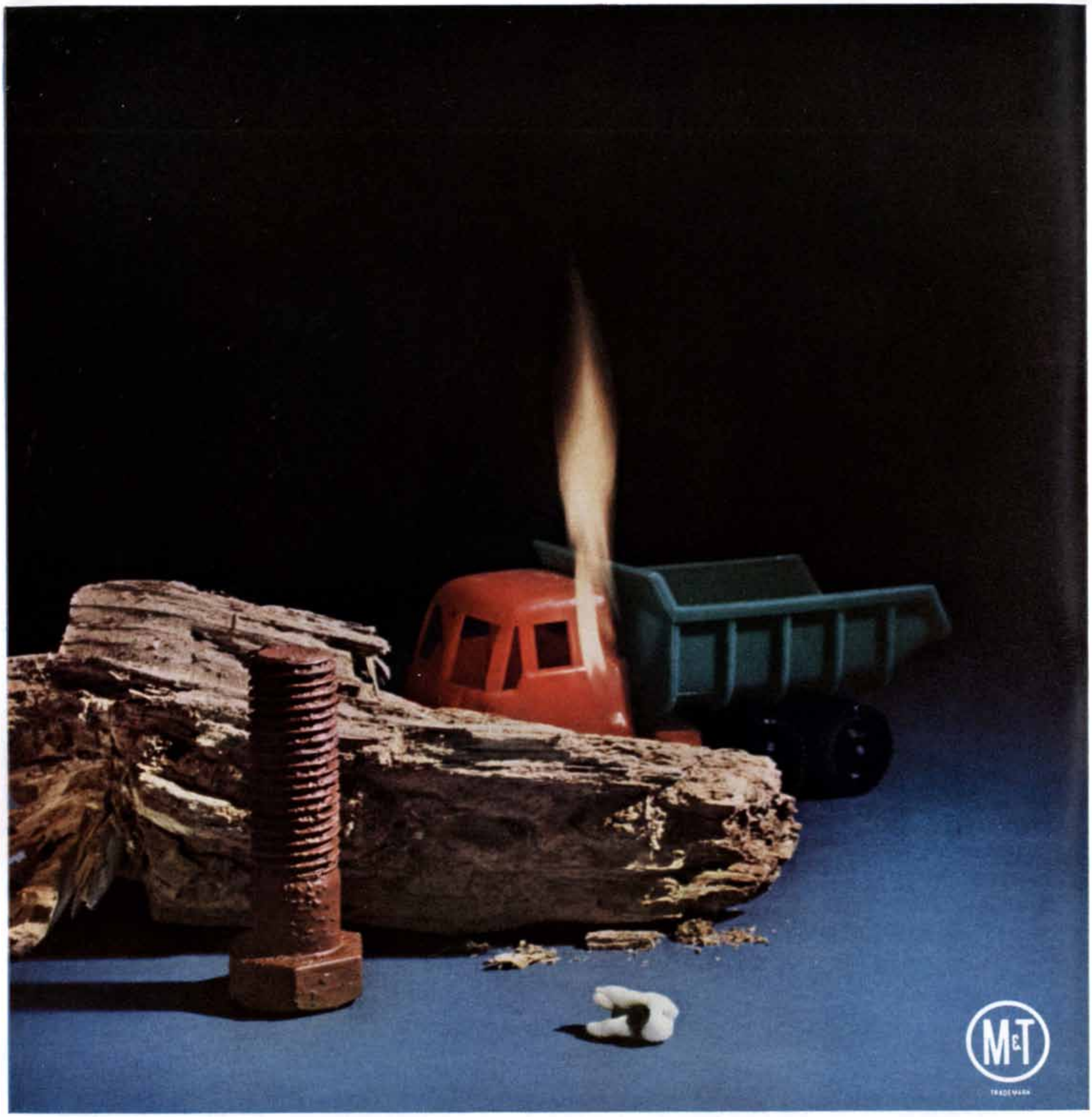
SCIENTIFIC AMERICAN



FLUID CONTROL DEVICE

SIXTY CENTS

December 1964



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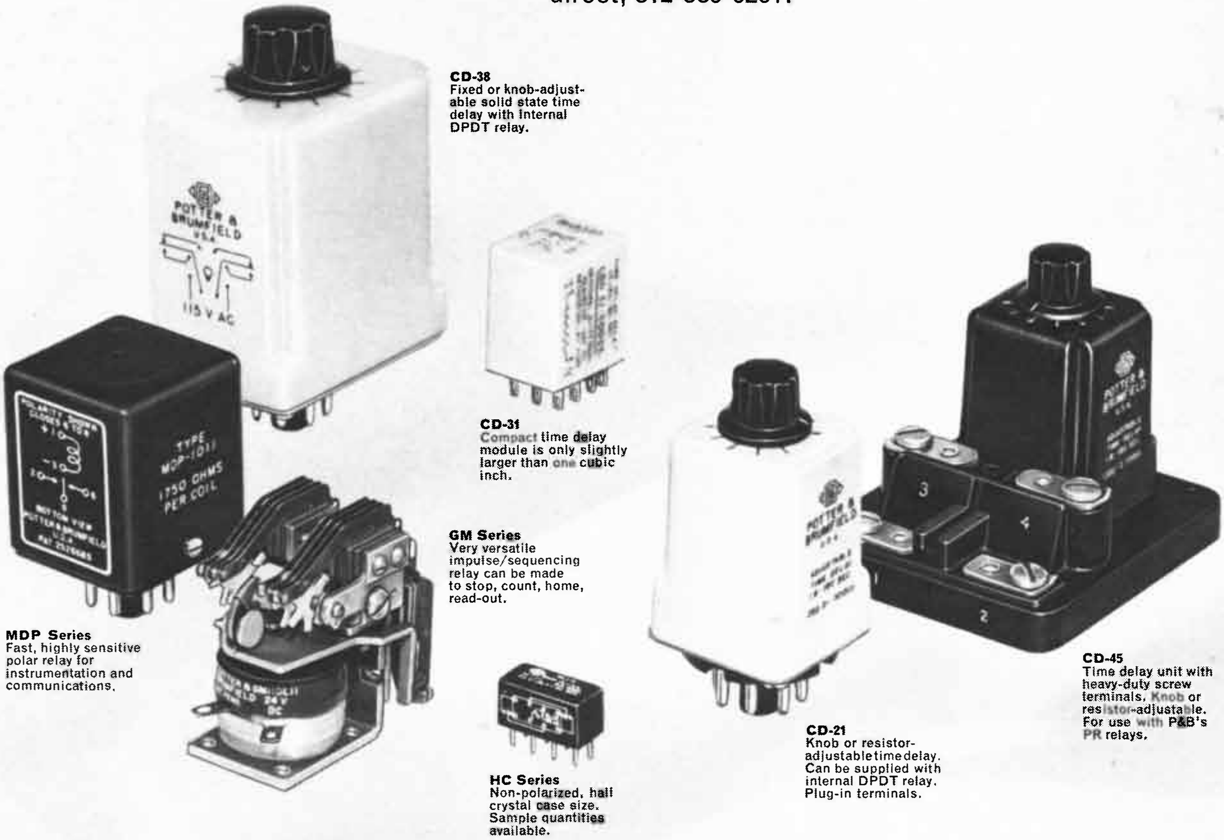

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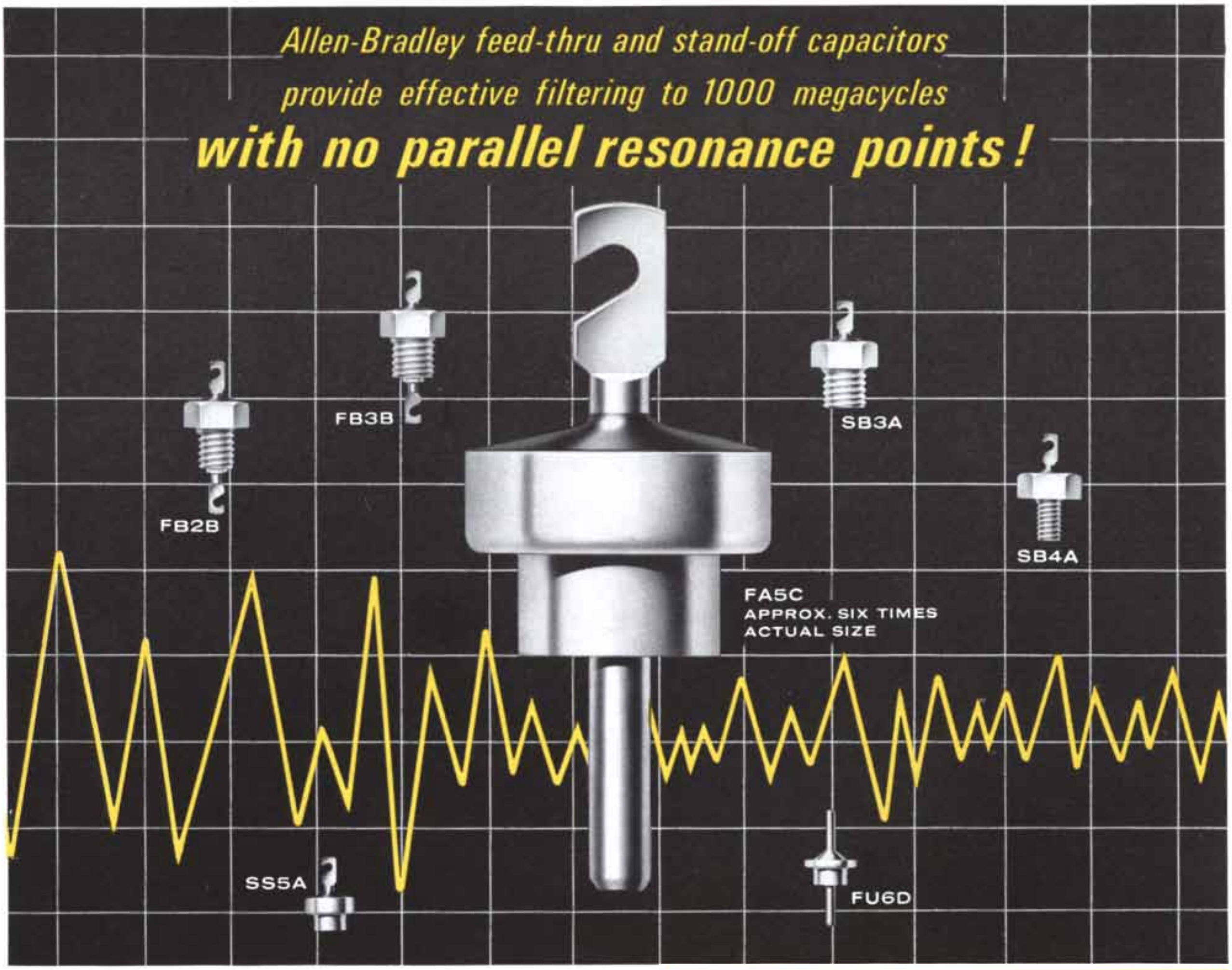

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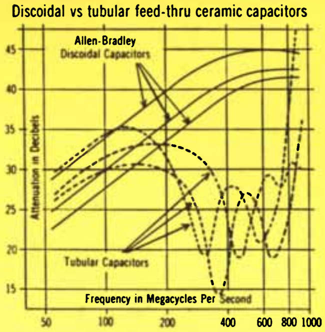
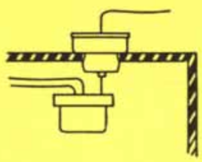
NEWEST DESIGN

TYPE FW5N FEED-THRU CAPACITOR

OVER TWICE ACTUAL SIZE





New Hollow Eyelet Design Provides Direct Lead Filtering

Illustration shows how transistor lead is filtered by passing it through the Type FW5N. The lead is soldered to one capacitor electrode and the other electrode is soldered to the metal enclosure.

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QUALITY ELECTRONIC COMPONENTS

Established 1845 **SCIENTIFIC AMERICAN** December 1964 Volume 211 Number 6

ARTICLES

DEPARTMENTS

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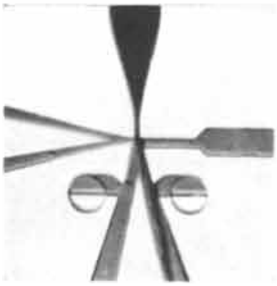

THE COVER

The photograph on the cover shows a fluid switching device called a "nor-or gate," which is used as a logic element in an all-fluid digital computer (see "Fluid Control Devices," page 80). The device consists of a solid block of glass in which shallow channels have been chemically etched to allow the passage of a fluid. (Ordinarily the working fluid is air, but in this case colored water has been used for the sake of clarity.) The channels were etched by a special optical fabrication technique, developed by the Corning Glass Company. The empty channels are wet and appear gray. The blue water at top is the main power stream. The narrower channels at left are the control jets: either one "or" the other, on being activated, can switch the power stream from the left to the right output channel at bottom. If neither one jet "nor" the other is activated, the asymmetrical construction of the interaction region, in addition to the atmospheric pressure exerted through the open channel to the right of the power-stream nozzle, will switch the power stream to the left output channel. In the photograph the control jet at top left, which contains yellow water, is on, causing the power stream to turn green and to be deflected into the right output channel. Circular holes are air vents.

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Cover photograph by William Vandivert

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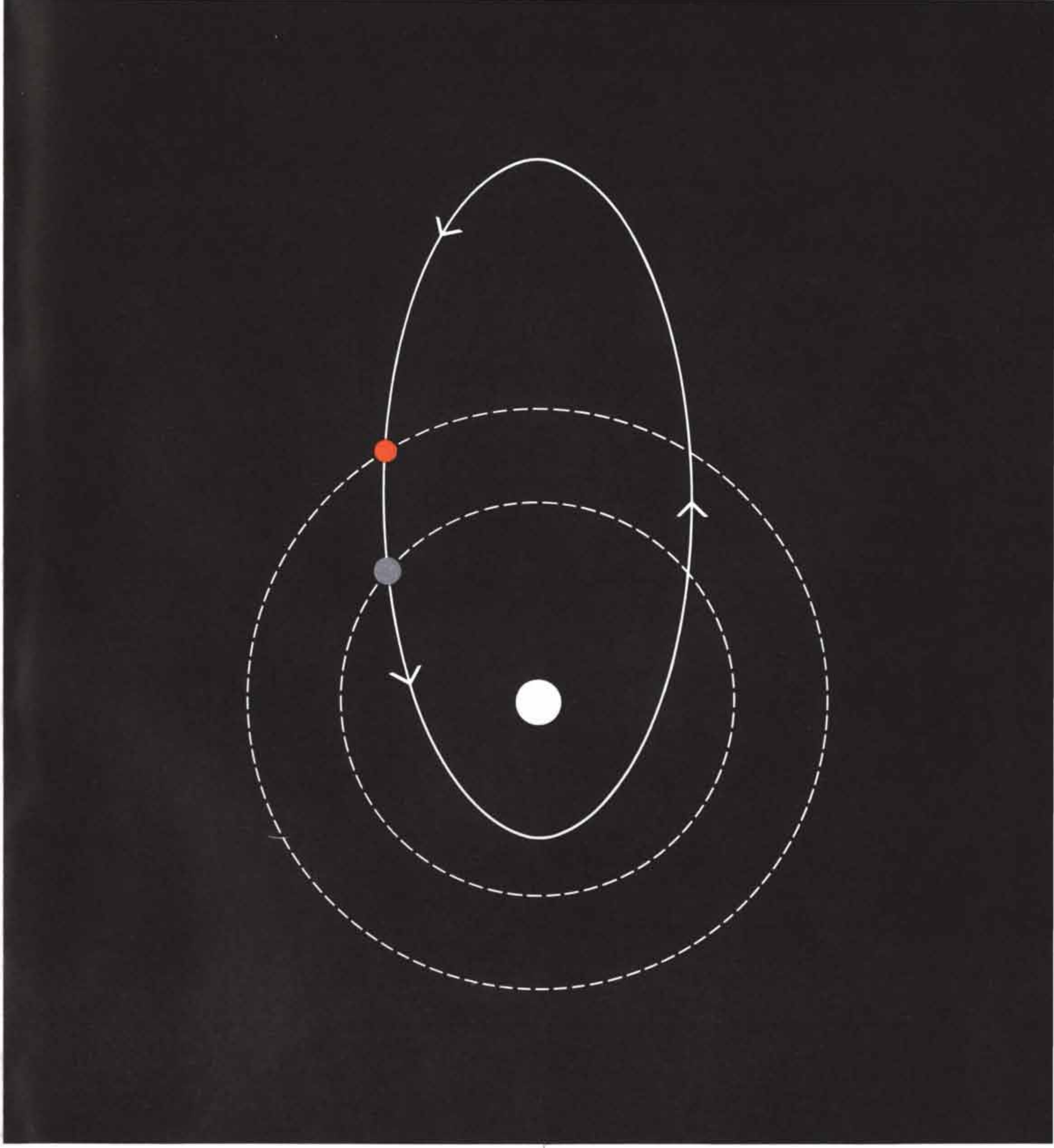
Grumman's across-the-board space capabilities: 1965-1975

PRESENT LEM WORK
As part of the current work on LEM (Lunar Excursion Module) and lunar exploration vehicles, two huge LEM simulators are now in operation at Grumman—one for lunar landing and one for rendezvousing with the Apollo Command Module. All NASA astronauts have already been indoctrinated on these simulators and are currently rehearsing for actual landing and rendezvous.

ADVANCED SPACE MISSIONS
Many logical extensions of the LEM program are in study phase at Grumman. Current projects involve post LEM lunar exploration, scientific and logistics establishment of lunar bases. Other advanced space work at Grumman includes military vehicles, space research centers, repair service and planet launch platforms.



MARS MISSIONS

Before manned Mars landings can be accomplished, a wide variety of knowledge must be obtained through probes, orbiters, and hard and soft landers for proper exploration of the planet and its environment. Grumman is doing basic work on such projects for televised examination of permanent and transient surface markings, and analysis of ambient atmospheric conditions on Mars. Under study are vehicles for Mars orbiting and landing.

ORBITAL SPACE STATIONS

Feasibility of interplanetary staging bases has long captured the imagination of space scientists and engineers. The ultimate mechanics of such strategic bases are undergoing prolonged and careful scrutiny at Grumman. Experience gained from the LEM program will vastly enhance the possibility of success in these studies.

GRUMMAN *Aircraft Engineering Corporation • Bethpage, L.I., New York*

LETTERS

Sirs:

Although we scientists often pride ourselves that our familiarity with the "scientific method" enables us to form more rational political views and to raise the level of political discussions, most of our writings on the problems that confront our nation today resemble the monologues that men in politics use. We state our views and desires but do not point out the areas of disagreement with our opponents, or the extent, or the reasons therefor. No fruitful scientific discussion could proceed on such a basis, and in the following paragraphs, in which I comment on the article "National Security and the Nuclear-Test Ban," by Jerome B. Wiesner and Herbert F. York [SCIENTIFIC AMERICAN, October], I hope to come closer to a dialogue. Thus I shall attempt to specify both the areas in which I agree with the authors and those in which I disagree, and to give my reasons for disagreeing.

In the early stages of writing this letter it appeared that only the views expressed by Wiesner and York on policies, attitudes and technical questions would have to be discussed. It soon became apparent, however, that there is a third subject that could not be disregarded: the inferences the daily press drew from the article and the extrapolations it attached thereto.

Turning first to *questions of broad policy expressed in the article itself,* there is much with which it would seem a vast majority of our colleagues can agree. The principal area of agreement concerns the success of the test-ban treaty. One would have to be blind not to see that the tensions between the U.S.S.R. and our country have much relaxed since this treaty has been in effect. It would be stretching a point to say that the cessation of testing is only the consequence, and not at the very least partially a *cause,* of the relaxation of tensions. As to the delay that peaceful uses of atomic explosives suffer as a result of the test cessation, the article says, "Promising as peaceful uses of nuclear explosives may be, the world could forgo them for a time" in exchange for a quieter international atmosphere, and I can only concur.

On the other hand, it would be a mistake to overlook the fact that the test-ban treaty is the result of extensive negotiations in which *both* parties made significant concessions. There is no evidence that generous acts of the U.S. through which it unilaterally weakens itself have any but adverse effects on the policy of the U.S.S.R. Nor does the insistence on *mutual* concessions have to create an unfriendly atmosphere. On the contrary, the constant pressure on our government, by means of public statements, to give in, raises false hopes in the negotiators of the U.S.S.R. The thwarting of these hopes, and the irritation of our own negotiators because of these pressures, do create an unhappy atmosphere. It is to be hoped that the article by Wiesner and York, with its insistence on a comprehensive test-ban treaty but without equal insistence on policing and inspection, will not have such an effect. It certainly counsels moderation not only to our government but also to that of the U.S.S.R. (An apt description of the adverse circumstances under which our negotiators often labor was given by R. Gilpin in his *American Scientists and Nuclear Weapons Policy*.)

Another statement of the article with which few will quarrel is that "if the great powers continue to look for solutions in the area of science and technology only, the result will be to worsen the situation." It is unfortunate that the subtitle of the article abbreviates this to "there can be no technical solution to the problem of national security." This subtitle, whether written by the authors or by a somewhat careless editor, printed as it is in large italics, could give the impression, and has given the impression to some of the daily press, that technical problems will play no further role in the future. This is, of course, not the meaning of the statement quoted. In fact, the sentence "Today as never before national security involves technical questions" stands just three inches below the subtitle.

Actually the great powers have never confined themselves to looking for solutions in the area of science and technology only but have initiated extensive negotiations toward easing tensions. As we have seen, some of these were successful.

If one is asked whether one agrees or disagrees with the policies recommended by the article, one soon discovers that the article does not recommend any policies. It leaves its reader with a sense of frustrated disorientation coupled with the impression that the past policies of this country were fundamentally wrong and something fundamentally new has to be tried. Some passages even carry the implication that our defense preparations have aggravated the danger to our freedom, independence and survival. "Ever since shortly after World War II the military power of the U.S. has been steadily increasing. Throughout the same period the national security of the U.S. has been rapidly and inexorably diminishing." Does this suggest that the decrease of our security is a *result* of the increase of our military power? To some who wish to think so it apparently does; to the people of countries whose military power did not grow adequately—to the people of Czechoslovakia, Hungary and Tibet—it would not. When I maintained in a discussion with one of the top scientific negotiators of the U.S.S.R. that the U.S. used its early atomic monopoly with great restraint, he answered, "I don't know. We wanted to do many things that [as a result of your atomic strength] we [the U.S.S.R.] could not." I am afraid that the borders of Stalinist Russia would have moved *much* farther to the West in Europe had the military power of the U.S. not been "steadily increasing."

Furthermore, is it really true that the national security of the U.S. has been "rapidly and inexorably diminishing"? If one thinks only in terms of physical

Scientific American, December, 1964; Vol. 211, No. 6. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller Jr., vice-president and treasurer.

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

Advertising correspondence should be addressed to Martin M. Davidson, Advertising Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Subscription correspondence should be addressed to Jerome L. Feldman, Circulation Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

Offprint correspondence and orders should be addressed to W. H. Freeman and Company, 660 Market Street, San Francisco, Calif. 94104. For each offprint ordered please enclose 20 cents.

Microfilm correspondence and orders should be addressed to Department SA, University Microfilms, Ann Arbor, Mich. 48107.

Subscription rates: one year, $7; two years, $13; three years, $18. These rates apply throughout the world. Subscribers in the United Kingdom may remit to Midland Bank Limited, 69 Pall Mall, London SW 1, England, for the account of Scientific American, Inc.: one year, two pounds 11 shillings; two years, four pounds 14 shillings; three years, six pounds 10 shillings.

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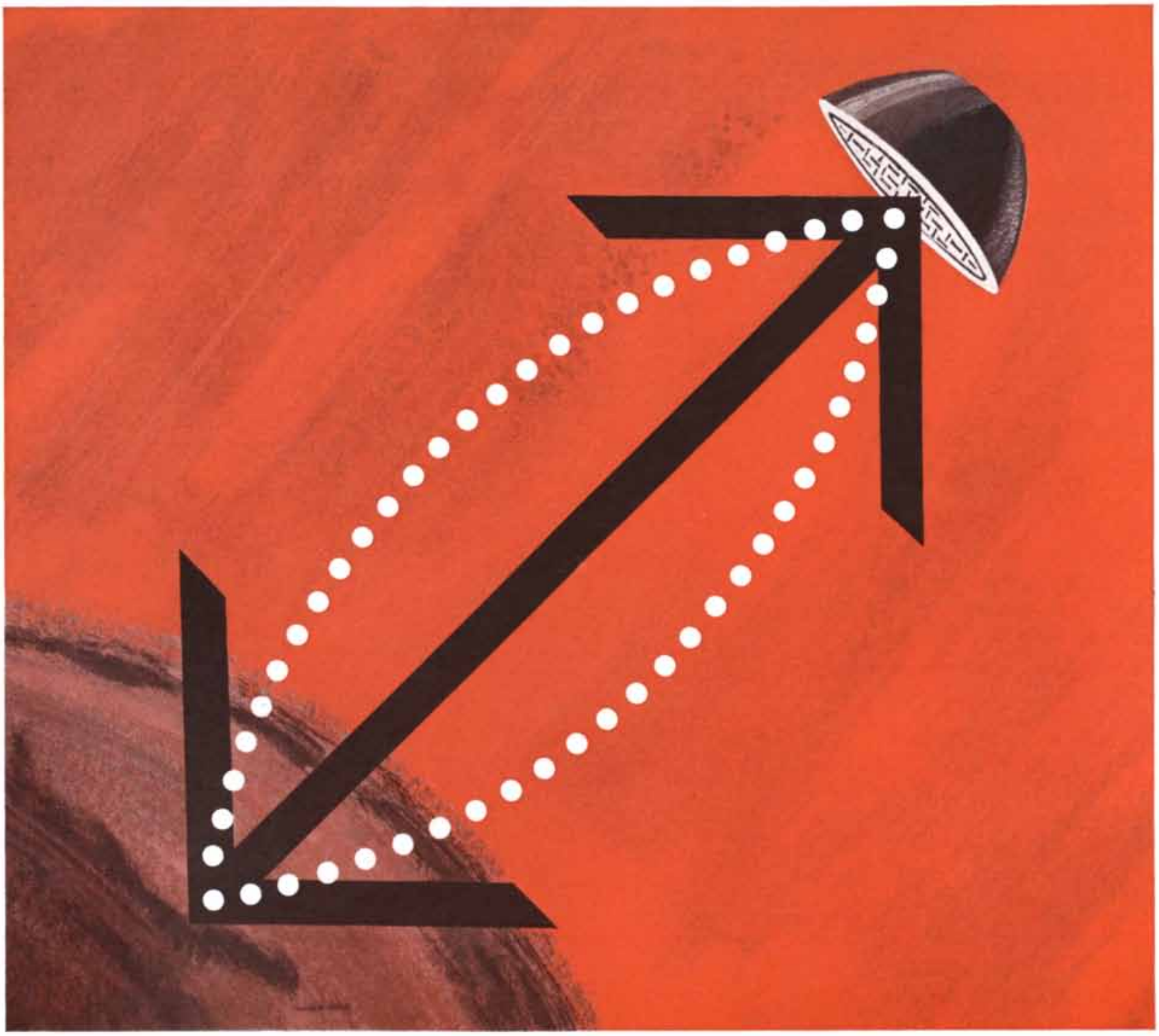
URGENT: Boost the flow of data from space–by steering it!



An "electronic boomerang" transmission system technique, developed by our Sylvania subsidiary for the Air Force, can potentially increase both the quantity and quality of data sent to earth from satellites.

How? A fixed set of antennas in the satellite electronically steers transmissions back to earth along the same path traveled by a signal transmitted from a ground station requesting data.

This boomerang effect is far more efficient than conventional wide-aperture antenna systems, in that pointing of the antenna beam is inherently automatic and normally requires no expenditure of primary power.

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Communications systems—on earth and in space—a way the capabilities of GT&E, directed by Sylvania Electronic Systems, contribute to the nation's well-being. Sylvania Electronic Systems, Division of Sylvania Electric Products Inc., 40 Sylvan Rd., Waltham 54, Mass.

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GT&E SUBSIDIARIES: Telephone Operating Cos. • GT&E Laboratories • GT&E International • General Telephone Directory • Automatic Electric • Lenkurt Electric • Sylvania Electric Products possibilities, in terms of a fanatical enemy who takes seriously Lenin's dictum "Better only one-third of the world's population surviving if those are then good communists," the security has decreased. But is that a valid picture? Have we not spoken of the relaxation of tensions before? True, we still hear the threats of burying us, alone or in collaboration with the Chinese brothers, the praise of the "irreconcilable class hatred that exposes and strikes the enemies of our social system," and the glorification of the sparks flying from the sabers of cavalrymen (both in Khrushchev's speech on culture of March 8, 1963). But one also hears, with an increasing volume, the realization of the need for coexistence and of peaceful competition. One does not have to shut one's ears to the threats in order to hear also the voice of reason and adjustment. Furthermore, is it not clear that the realization of the need for coexistence is in large measure the result of the understanding that the sparks flying from the sabers of cavalrymen can ignite other fires? A U.S. that is not only strong but *evidently* strong is in the interests of all: it is reassuring to the West and should turn the interest of the rulers of the East away from domination and toward the true welfare of their people. Are there no signs that it is at least beginning to do so?

To put the preceding point more pragmatically: Although the worst conceivable alternative may have become worse with the progress of time, the probability of such an alternative has decreased sharply. As a result, from the point of view of the most likely turn of events, the security of the U.S. has probably greatly increased, particularly in the course of the past few years.

Let us now turn to the *technical points of the article*. I am sorry to say that I find it more difficult to agree with them than with the general statements discussed before. The first remark that comes to mind is that the alleged need for developing the 100-megaton bomb was not the only, in fact not the principal, argument against the test-ban treaty. Personally I feel that this treaty was worth what we paid for it, and that it benefits both the U.S. and the U.S.S.R. It would be only fair toward those who opposed the treaty, however, to state that they were chiefly concerned with the testing of certain defense measures against antiballistic missiles, not with the development of the 100-megaton bomb.

Nevertheless, we must recall in connection with this bomb that the U.S.S.R. found it worthwhile to break the test moratorium in order to test it. In addition, the statement of the article that "on any scale of investment, the combination of larger numbers and smaller size results in greater effectiveness of the missile system" cannot be maintained. The cost of a missile is approximately proportional to the square root of its explosive yield. The illustration in the article that shows a linear relation is incorrect (and is contradicted in the text). Hence the yield is proportional to the square of the cost. The range of destruction is proportional to the cube root of the yield and hence to the 2/3 power of the cost. Finally, the area of destruction is proportional to the *square* of the range of destruction and hence to the 4/3 power of the cost. It follows that if one disregards soft targets that can be destroyed by a single smaller bomb, the cost effectiveness of weapons actually *increases* somewhat with their yield. Even this is not the complete picture. A hardened defense installation can be destroyed with a smaller explosion only if this takes place closer by and at lower altitudes. It is easier to prevent such an explosion by antimissile measures, or otherwise, than an explosion at the larger distances and high altitudes at which a very large bomb can still destroy the installation.

Drs. Wiesner and York state that we do not need tests in order to design a 100-megaton bomb. This is true but disregards the time element. The time schedules for the production of a bomb with the characteristics that exploit the inherent advantages of size are extremely long in the absence of tests. If the bomb should be needed, it would be meager comfort to know that, given only a few more years, we could have had it.

The cases for and against the big bomb remain unproved and I personally cannot become enthusiastic about it. I do feel strongly, however, that the rejection of defense measures, in particular the rejection of civil defense, is unjustified. Drs. Wiesner and York recognize that the instability that has to be overcome is due to the "overbalance [of] the scales in favor of the attacker rather than defender." If this is so, a wholehearted effort should be made to redress the overbalance. It does not seem, however, that they have explored the possibilities of civil defense even halfheartedly. Most readers will be struck by the contradiction between the postulates that, on the one hand, the

retaliatory installations are invulnerable and, on the other hand, that shelters are useless. In fact, when discussing civil defense, the authors say: "The only kind of shelter that is being seriously considered these days, for other than certain key military installations, is the fallout shelter." They then proceed to show that fallout shelters by themselves do not suffice to render the position of the defender strong enough. Although they do not state this explicitly, they give the impression that they would not be opposed to abandoning altogether the fallout shelter program as insufficient. The opposite alternative, to strengthen the civil defense program by the installation of blast shelters at important locations, is dismissed all too easily with arguments that are in no way convincing. Thus the writers mention the danger of a short warning time in a surprise attack but do not mention that a complete surprise is difficult to achieve, and in fact the two world wars did not break out without warning. In addition, the shelters could well be located in such a way that they could be reached by most people in the 15-minute warning time the writers concede. Similarly, the writers mention the possibility of chaos and disorientation in shelters but fail to mention that these dangers are much greater if no shelters exist. They do not mention either that the history of past disasters does not bear out their fears of antisocial behavior as long as proper leadership is provided. During the siege of Budapest people stayed in shelters for many weeks but continued to cooperate and help each other. The authors emphasize throughout the article that, in contrast to an attack of World War II, a nuclear attack that is 10 percent effective would be considered successful. This would hardly be the case if the population were well sheltered. Hence a combination of antiballistic missiles and shelters seems to hold more promise of reducing the "overbalance" of offense over defense than any other measure known to me.

Finally, and perhaps most importantly, the authors do not mention that no nation will dare to disarm if its population remains exposed to the awesome dangers the authors so well depict. Hence civil defense is also a prerequisite to disarmament.

Let us come finally to the "extrapolations" contained in the *reports of the daily press.* Many of these were crude exaggerations that may have served a useful purpose, however, by attracting attention to the article. They were encouraged by the mode of communication of the article, which made most of its points by implication. However, the result often approached the bizarre. Even *The New York Times* headline reads "Disarmament Is Called the Answer to 'Stalemate,'" as if it were desirable to have a checkmate ending to the game. The words "stalemate" and "disarmament" occur once each in the article, the former toward the middle and the latter as the last word.

A more nearly justified "extrapolation" made from the article is that no further methods of offense or defense need be explored, that is, that military science is a complete and closed book. Even this is only implied by the article. To evaluate it, it may be useful to recall similar statements about other areas, in particular about physics. These were made around the turn of the century, before the advent of atomic theory, before virtually any knowledge of the nucleus, before quantum and relativity theories, before any inkling of the results of almost all areas that are at present at the center of interest of research in physics. Statements of this sort mean partly that those who make them have, at the time of making the statements, no promising ideas in the field about which they speak. Others may have such ideas, and those making the statements may themselves conceive such ideas at a later time. The statements in question also appear to herald the impending initiation of new lines of endeavor. In the case of physics this was the turn toward microscopic phenomena; in the area of "weaponry" it may well be the exploration of a more effective defense.

Having stated the areas of disagreement, it would be well to reemphasize the agreement with what appears to be the main thesis of Wiesner and York: the importance of not relying on physical power alone. It is a truism that the purpose of power is only the achievement of certain goals, called national objectives. However, military power, like police power, works best when it works through its presence rather than by active involvement, and when it is supporting persuasion to follow rules of conduct that are just and reasonable. Certainly included is the rule to leave our country free to follow its own path of independence and individual freedom.

EUGENE P. WIGNER

Princeton University
Princeton, N.J.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1914: "One of the great surprises of the war, at least for the general public, has been the complete inactivity of the battleships and battle cruisers of Great Britain and Germany. When war was declared and the mighty fleet which had just been reviewed by King George disappeared suddenly to the eastward, the world awaited with breathless interest the first tidings of that long-talked-of battle between dreadnoughts, which was now apparently about to be fought somewhere in the North Sea. Although the war is now more than four months old, the public is still awaiting that Homeric contest. When we bear in mind the enormous size and strength of the two navies, it will be seen that such cruiser and submarine actions as have taken place must be regarded as mere outpost affairs which have had practically no effect upon the first-line fighting strength either of Great Britain or Germany. The dreadnoughts of the two navies total together nearly half a hundred ships. For four months they have been within a few hours' steaming of each other and keyed up to the highest pitch of fighting efficiency. Yet in all this time not a single gun has spoken! To the naval strategist this silence is the token of a victory as complete as any that could be won by the shock of 12-inch salvos and the wrecking of armor belts, turrets and barbettes; for it is the unspoken evidence of the persistent, remorseless pressure of the most remarkable blockade in all the history of naval warfare."

"A paper was presented at the French Academy of Sciences relating to researches made by M. Maurice Curie, nephew of the late scientist, upon the different atomic weights of lead. The radio-active theories according to which certain bodies, such as radium or uranium, can evolve in the course of time and become transformed to other elements place the metal lead as the last term of the series of changes. Another very curious idea is that if, instead of taking the radium-uranium family, we consider the thorium group, it is found that the last term of the evolution series is a body whose atomic weight is still very near that of lead. It was therefore of fundamental interest to verify these conclusions and see whether the metal lead which is found in uranium ores and the metal which is found in thorium ores have or have not the same atomic weight as the lead extracted from galena. M. Curie made such researches and found that ordinary lead from galena has an atomic weight of 207.01, whereas lead from uranium ores shows a clearly inferior value of 206.5. Metal from thorium ores gives a higher value of 207.1. The conclusions of theory are thus confirmed, and it is admitted that there are several varieties of lead having different atomic weights, according to the initial metal from which they were derived. A new field of research is thus opened, and perhaps other metals will be found to present distinct atomic weights according to their origin, showing that the phenomenon of transmutation is much more general than is supposed."

"A correspondent of one of the London daily papers at Copenhagen speaks of a report from Hamburg to the effect that two unusually large submarines have been completed for the German navy and are making trial trips at the mouth of the Elbe. According to the report these submarines are four times the size of any existing vessels of this type, with a radius of action which will enable them to keep at sea for 40 days without having to replenish their oil tanks and stock of stores or even have recourse to the submarine tender. It is quite conceivable that, in view of the enormous offensive power of such a craft, the Germans may be springing a surprise in underwater craft similar to that which they gave with the 16-inch gun in siege artillery."

Scientific American.

DECEMBER, 1864: "Canal boats in North Carolina are armed with the Gatling gun as a protection against guerillas. The Gatling gun is a novel piece of ordnance: it consists of six chambers, which are made to revolve around a central barrel by means of a crank. The charges are poured into a hopper and the gun is self-loading. It will throw from 75 to 100 balls per

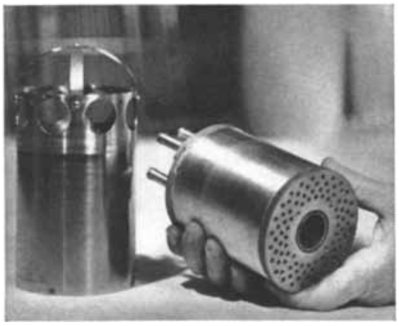
Report from

BELL LABORATORIES

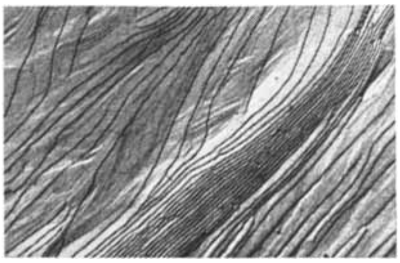
NEW MATERIALS FOR COMMUNICATIONS

At Bell Telephone Laboratories we believe that progress in communications technology depends directly on our ability to understand the fundamental behavior of materials, to synthesize new materials with special properties, to improve existing ones, and to specify their use in Bell System communications equipment. The six examples shown below illustrate research and development of this kind.

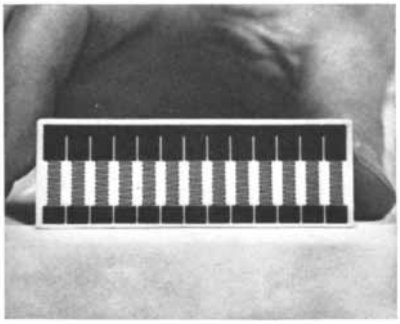
Bell Telephone Laboratories
Research and Development Unit of the Bell System



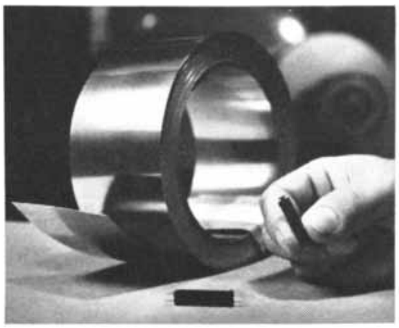
SUPERCONDUCTOR. Experimental 75 kilogauss superconducting solenoid. Wire consisting of compacted niobium and tin in a niobium jacket is wound and later heated to form niobium-tin compound (Nb_3Sn), which has a transition temperature of 18° Kelvin and a critical field greater than 200 kilogauss. Compound and wire-forming technique were developed at Bell Laboratories.



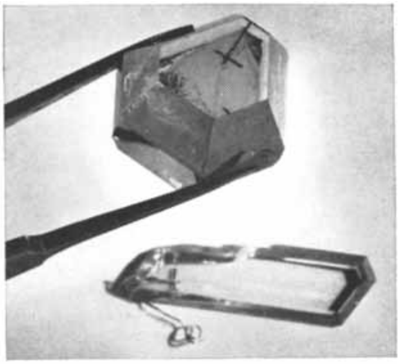
INSULATOR. Electron microscope photograph of polyethylene, 9800 diameters magnification, showing overlapping ribbon-like crystals, a structure characteristic of many polymers. At Bell Laboratories, studies of the formation of such groups of crystals have contributed to an understanding of the electrical and mechanical properties of these materials.



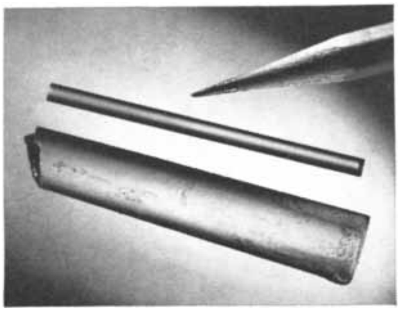
THIN-FILM RESISTORS. Tantalum thin-film resistors (zigzag patterns above) offer new possibilities for reliable, low-cost circuits. Bell Laboratories people discovered how to fabricate films routinely with values precise to one part in five thousand, and with expected aging during a 20-year life of less than one part in a thousand.



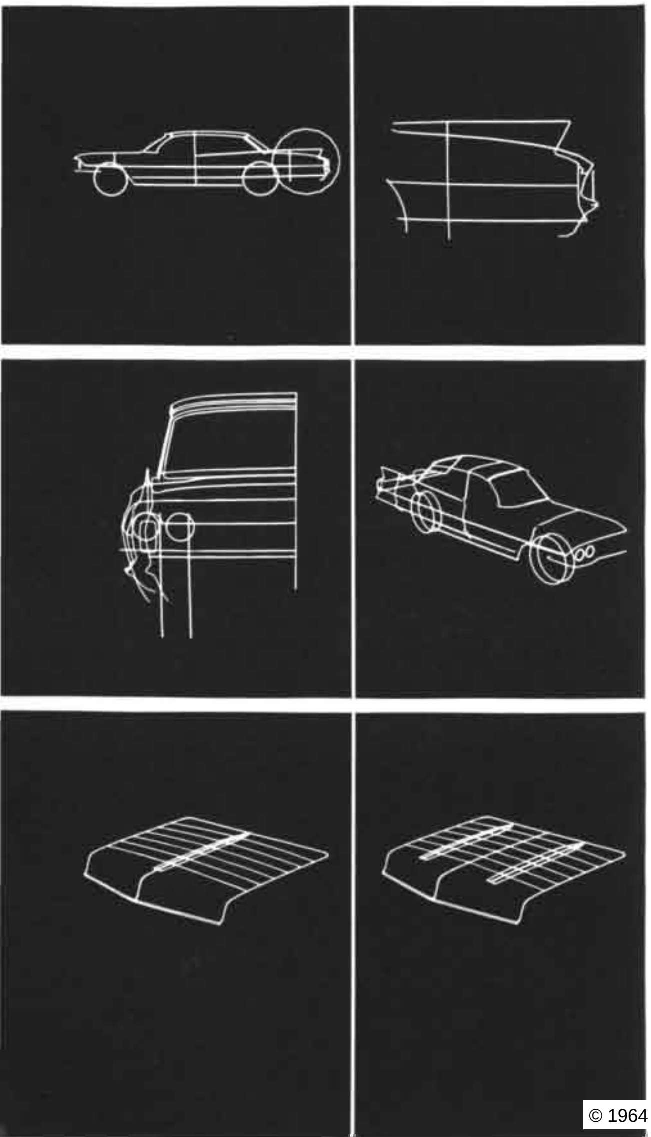
MAGNETIC MATERIAL. Remendur, latest member of a large family of high-performance magnetic materials developed at Bell Laboratories, is shown here in sheet form and as element of new telephone switch. A malleable, ductile cobalt-iron-vanadium alloy, Remendur has a remanence of 21,500 gauss.



SEMICONDUCTOR. Beginning in the 1930's Bell Laboratories people carried out extensive studies of semiconductors—studies that led to the invention of the transistor. Photograph shows crystals of zinc oxide, a semiconductor with piezoelectric properties, grown at Bell Laboratories by a hydrothermal method.



LASER MATERIAL. Among many materials developed at Bell Laboratories is nickel-doped magnesium fluoride, shown here as grown from melt and in polished rod form. Laser action in this material generates lattice phonons as well as a beam of coherent infrared photons.



One of a series briefly describing GM's research in depth

Design Augmented by Computers

. . . is a current important focus of research at the General Motors Research Laboratories. Recently, for example, we announced our experimental GM DAC-I system (Design Augmented by Computers), a large computer complex under development since the late 1950's.

Still in the prototype stage, this new design system enables the designer to walk into our man-computer communication laboratory with a drawing . . . work on a design problem using an immense reservoir of programs and data stored in the computer . . . and walk out with one or more new drawings under his arm.

These amazing capabilities have come from a string of noteworthy advances in computer hardware and software tied neatly into an operational on-line system. For example, a program-controlled image processor can read free-form curves from drawings directly into the computer. A graphic console permits dynamic two-way "conversational communication" of graphic information between designer and computer. Intricate programming systems permit efficient time-sharing of the computer's central processing unit and space-sharing of its core memory. Permanent photographic copies of new designs are available within 30 seconds.

The General Motors DAC-I system is currently being studied by GM's Fisher Body and Styling Staff designers to determine the feasibility of utilizing man-computer teams in the design of automobiles. It's another example of how General Motors is opening the door to a more productive, more creative tomorrow.

General Motors Research Laboratories

Warren, Michigan

Top photo shows a designer at the graphic console of the GM DAC-I system. Underneath are computer-produced displays of what he sees when he enlarges, changes views or modifies a design stored in the computer memory.

minute, the number of discharges depending upon the speed with which the crank is turned."

"The *Army and Navy Gazette* of London says:—'We are informed that in the construction of Mr. Reed's new ship, the *Lord Warden*, there will be employed at least 500 tuns of toughened steel manufactured under the process known as Bessemer's. The advantages derived from the employment of this improved material are so obvious that it is daily attracting increased attention from the authorities at Whitehall. We are told that this cast steel is much tougher and stronger than wrought iron and less liable to fracture. In consequence of its extreme toughness a shaft may be reduced in weight and yet lose nothing of its required strength. Also there is less friction with steel than with iron. Thus steel shafts work with greater ease than those of iron, and lastly, experience has proved that the durability of steel shafts is three times as great as that of iron.' "

"D. Appleton & Co. of New York have just published *The Correlation and Conservation of Forces*, a series of expositions by Prof. Grove, Prof. Helmholtz, Dr. Mayer, Dr. Faraday, Prof. Liebig and Dr. Carpenter, with an introduction and brief biographical notice of the chief promoters of the new views by Edward L. Youmans, M.D. This volume is devoted to the elucidation of a new philosophy of forces and unfolds the sublimest and most harmonious views of the order of the universe to which the human mind has yet attained. The authors are among the ablest men of science in Europe and their names are a supreme guarantee of the interest and authoritativeness of the work. The founders of the new doctrines are in this case also its expositors and the book combines in an unparalleled degree the philosophy of the original discoverer with thorough simplicity and popularity of statement. Dr. Faraday says that the conservation of force is the highest law of physical science which our faculties permit us to perceive. Herbert Spencer says it is the highest law of all science. Prof. Tyndall says that these discussions open a region which promises possessions richer than any hitherto granted to the intellect of man. No one who cares to understand the great tendencies of modern thought and the majestic advance of science into new regions can afford to be without this work."


60 sec.
50 sec.
40 sec.
30 sec.
20 sec.
10 sec.

How will the cyan know when it's had enough magenta?

The silver halide will tell it.

What happens inside a packet of Polacolor film during the minute it takes to make a color picture?

The illustration on the left gives you some idea. It shows the progress of the development at 10-second intervals. But, of course, it isn't close to being the whole story.

In essence what happens is that 93 minutes of color laboratory processing have now been compressed into 60 seconds of activity inside the film packet.

Many people, to be sure, couldn't care less about the hows and whys of this major achievement in photographic history. They are quite content with the results—the clear, rich colors, the delicate, accurate skin tones of the pictures they get in just 60 seconds.

But for the curious (and if you're still reading, you're one) here are the salient details.

The film negative is a sandwich of many layers—among them layers which contain three dyes: cyan, magenta and yellow. Each dye is combined in a unique molecule with a developer. (This is a major difference between Polacolor film and other color films. Their dyes have to be manufactured during the lengthy processing period and variations in processing can result in variations in the colors of the dyes.)

Each of these 3 dye-developer molecules inhabits a separate layer of the negative. A layer of silver halide is placed next to each of these layers, in this manner: blue-sensitive silver halide goes over the yellow dye; green-sensitive silver halide over the magenta dye; red-sensitive silver halide over the cyan dye.

Each layer of silver halide molecules controls the dye layer under it. If the silver halide remains unexposed after the picture is taken, the dye beneath it can pass through and deposit itself on the positive or final picture. However, if the silver halide is exposed, it traps the dye beneath it. For example, should the green-sensitive silver halide be exposed, it would block the magenta dye from getting into the finished picture.

What starts the colors moving in the first place? An alkaline viscous processing reagent. It starts the process and keeps it going.

What stops the process? A special timing layer in the positive (where the picture is printed). This layer holds up the reagent until the last few seconds of processing. Then it permits the reagent to seep through and meet large acid molecules imbedded deep in the positive. This neutralizes the alkaline reagent, thereby stopping the process.

Bear in mind that all these components exist in a film packet only thousandths of an inch thick. So the problem of controlling them becomes infinitely delicate, infinitely complex. To explain it, let's take a hypothetical picture. Something all blue in color.

When we snap our picture, the shutter opens and blue light floods in from the subject. This exposes the silver halide in the blue-sensitive layer. The silver halide in the red- and green-sensitive layers remains unexposed.

As we pull the film packet from the camera, the packet passes through a set of rollers. These rollers squash a pod filled with the reagent and spread it evenly between the positive and the negative.

The reagent activates the dye-developer molecules. They begin migrating toward the positive. But the yellow dye can't go anywhere. It's trapped at the exposed blue-sensitive silver halide layer.

However, the magenta dye (beneath the *unexposed* green-sensitive silver halide layer) and the cyan (beneath the *unexposed* red-sensitive silver halide layer) *are* free to migrate. And they do.

They deposit themselves on the positive, where they combine to form a shade of blue. The exact shade will depend, again, on the silver halide. (And so the headline says.)

If the shade of blue photographed has a suggestion of green in it, some of the silver halide in the green-sensitive layer will be exposed. Then, less of the magenta under this layer will get through to the final print. The cyan will still come through full strength, because it is under the completely unexposed red-sensitive layer of silver halide. And thus the picture will be a deeper (more green) blue.

Once the colors are deposited on the positive, we're in the last few seconds of processing. Now the alkaline reagent is allowed to seep through the timing layer and meet with the immobile acid molecules. With the neutralizing action, the process is terminated and we peel apart the film packet to see our picture.

All of this has taken place in the processing of a simple picture with one color in it. When the picture is, for example, a child's face or a field of flowers, the process is infinitely more complex.

Obviously, some formidable problems had to be solved in the development of 60-second Polacolor film. In effect, we had to come up with a completely new color process, basically unlike any that had existed before.

Our success—not merely in a technical sense, but by esthetic standards as well—has added a new dimension to color photography as practiced by professionals and amateurs alike.

POLAROID CORPORATION

THE AUTHORS

R. H. SIMPSON and JOANNE S. MALKUS ("Experiments in Hurricane Modification") are meteorologists associated with Project Stormfury, a current program of hurricane-modification experiments sponsored jointly by the U.S. Weather Bureau, the U.S. Navy and the National Science Foundation. Simpson is deputy director for operations of the Weather Bureau's National Meteorological Services and director of Project Stormfury. After studying at Southwestern University and Emory University, he joined the Weather Bureau in 1940. He acquired a Ph.D. in meteorology from the University of Chicago in 1959. In 1955 he was appointed the first director of the Weather Bureau's National Hurricane Research Project, of which Project Stormfury is an offspring. Mrs. Malkus is professor of meteorology at the University of California at Los Angeles and a member of the advisory panel of Project Stormfury. A graduate of the University of Chicago, she obtained a Ph.D. in meteorology there in 1949. After teaching for several years at New York University, the University of Chicago and the Illinois Institute of Technology, she joined the staff of the Woods Hole Oceanographic Institution, where she directed the aircraft meteorology program.

EUGENE M. SHOEMAKER ("The Geology of the Moon") is chief of the Astrogeology Branch of the U.S. Geological Survey. He is also a research associate at the California Institute of Technology. A graduate of Cal Tech, Shoemaker received an M.A. and a Ph.D. from Princeton University in 1954 and 1960 respectively. He joined the Geological Survey in 1948 and was appointed to his present post in 1961. He spent a one-year stint in 1963 as director of the Division of Manned Space Sciences for the National Aeronautics and Space Administration.

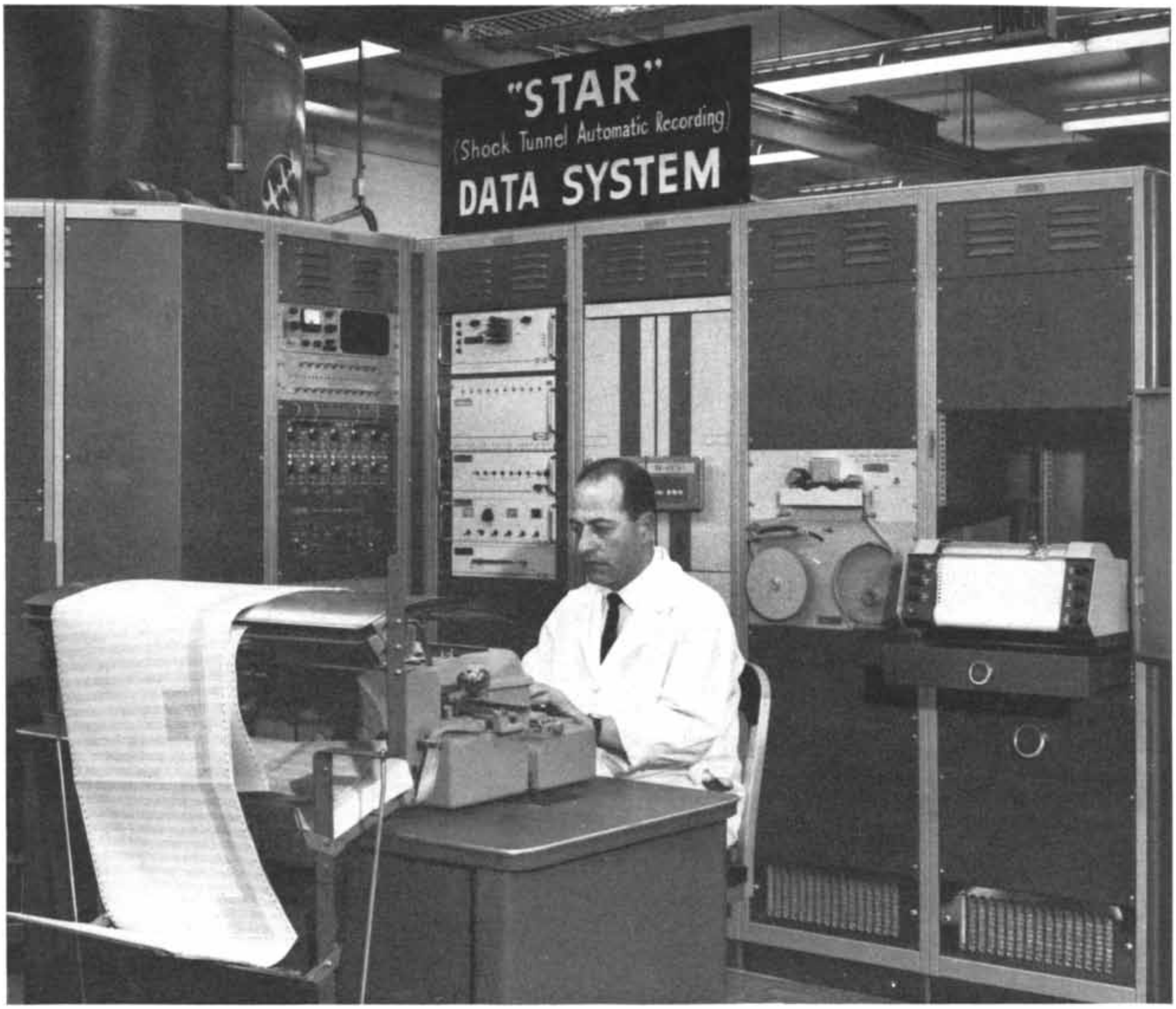
EDWARD F. MacNICHOL, Jr. ("Three-Pigment Color Vision"), is associate professor of biophysics at Johns Hopkins University. He also does research at the U.S. Naval Medical Research Institute in Bethesda, Md. A graduate of Princeton University, MacNichol received a Ph.D. from Johns Hopkins in 1952. From 1941 to 1946 he worked in the radiation laboratory of the Massachusetts Institute of Technology. He joined the Johns Hopkins faculty in 1949.

HANS NEURATH ("Protein-digesting Enzymes") is professor and chairman of the department of biochemistry at the University of Washington. A native of Austria, Neurath received a Ph.D. in colloid chemistry from the University of Vienna in 1933. After a year of postdoctoral work at the University of London, he came to this country in 1935 to do research in biochemistry at the University of Minnesota. Neurath taught and did research at Cornell University and the Duke University School of Medicine until 1950, when he was appointed to his present posts.

STANLEY W. ANGRIST ("Fluid Control Devices") is assistant professor of mechanical engineering at the Carnegie Institute of Technology. He acquired a B.S. from Texas Agricultural and Mechanical College in 1955 and an M.S. and a Ph.D. from Ohio State University in 1958 and 1961 respectively. Angrist's first book, *Direct Energy Conversion,* will appear in the spring.

OLAF H. PRUFER ("The Hopewell Cult") is associate professor of anthropology at the Case Institute of Technology. A native of Berlin, Prufer was graduated from Harvard University in 1956. He went on to obtain an M.A. and a Ph.D. in anthropology from Harvard in 1958 and 1961 respectively. He joined the Case faculty in 1959. From 1959 to 1961 he was also curator of anthropology at the Cleveland Museum of Natural History. Prufer first became interested in archaeology, he writes, "when I was about 12 years old, during the war. At that time I scrounged around in the Rhine Valley near Baden-Baden (which had been part of Roman Germany) in order to locate a Roman camp that was reputed to have existed there. I did not find it, but instead I found the hilt of a Bronze Age sword sticking out of the ground in a plowed field. As far as I can tell, this discovery, which at the time seemed most exciting to me, dates the beginning of my archaeological interests." Prufer has since done archaeological fieldwork in India, Germany and the U.S. The work described in his article was supported by a grant from the National Science Foundation.

G. J. V. NOSSAL ("How Cells Make Antibodies") is deputy director for



Republic Aviation's shock tunnel data system uses PB250 computer and Raytheon digital equipment

Raytheon PB computer acquisition creates strong new EDP source

By its recent acquisition of the Packard Bell computer division, Raytheon has clearly announced its intention to become a significant factor in the fields of scientific and real time computers.

Included in the acquisition is one of the most advanced computers currently available to the engineering/scientific community. The Model PB440 is characterized by a unique dual memory stored logic concept which provides unusual operational speed and efficiency as well as unparalleled flexibility. This enables the user to duplicate in one machine the individual capabilities of a number of presently available computers. A second model, the PB250, one of the first solid state computers marketed, is presently used in more than 160 applications and offers low cost, general purpose computation capability.

The combination of Raytheon data processing equipment with PB computers is not as new as the formal organizational merger. For over a year, for example, a shock tunnel automatic recording data system has been in operation at Republic Aviation Corporation which combines a PB250 computer with Raytheon multiplexers, analog to digital converters and power supplies.

Such key elements of scientific data systems have been a part of Raytheon digital product lines for several years. Extremely high speed in their operation, they complement perfectly the similar, extremely accurate equipments acquired from Packard Bell.

As producer of the specialized onboard computers used in the Polaris and Apollo programs, Raytheon has developed advanced packaging techniques which will find application in other computers designed for broader industrial and scientific purposes. The PB computer acquisition provides a commercial outlet for techniques which were prompted and developed by government needs. Raytheon Company, Lexington, Mass.

RAYTHEON

immunology of the Walter and Eliza Hall Institute of Medical Research in Melbourne, Australia. After receiving his medical degree from the University of Sydney in 1954, Nossal spent two years as a resident at the Royal Prince Alfred Hospital in Sydney before joining the Walter and Eliza Hall Institute to study virology with its director, Sir Macfarlane Burnet. "To my surprise," Nossal writes, "and I must admit to a certain degree to my disappointment, Sir Macfarlane's interest had switched almost completely away from virology to the newly developing field of immunology. He rapidly set me to work on problems concerned with immunological tolerance. The next coincidence happened toward the end of that year. Sir Macfarlane had just come forward with his clonal selection theory of antibody formation, and I suggested to him that I try to develop a technique that I thought at the time would be a critical test of the hypothesis. This was an attempt to study antibody formation by single cells in vitro. By sheer coincidence Joshua Lederberg, at that time visiting Fulbright Professor at the University of Melbourne, was spending several weeks at the Institute, ostensibly to study influenza-virus genetics. Lederberg was most captivated by my suggestion and I had the great good fortune that he offered to collaborate with me in getting the project off the ground. We spent an exciting six or eight weeks working together and laying the foundations for much of my future work." After receiving a Ph.D. in experimental medicine from Melbourne in 1959, Nossal spent two years at Stanford University doing further research with Lederberg into the genetics of antibody formation. He was appointed to his present post in 1961.

F. REIF ("Quantized Vortex Rings in Superfluid Helium") is professor of physics at the University of California at Berkeley. Reif was born in Vienna in 1927 and came to this country in 1941. After receiving an A.B. from Columbia College in 1948, he went on to obtain an A.M. and a Ph.D. in physics from Harvard University in 1949 and 1953 respectively. From 1953 to 1960 he taught physics at the University of Chicago, where he also did research at the Institute for the Study of Metals. He joined the Berkeley faculty in 1960. His chief research interests have been in solid-state and low-temperature physics, particularly in superconductivity and in the superfluidity of liquid helium.

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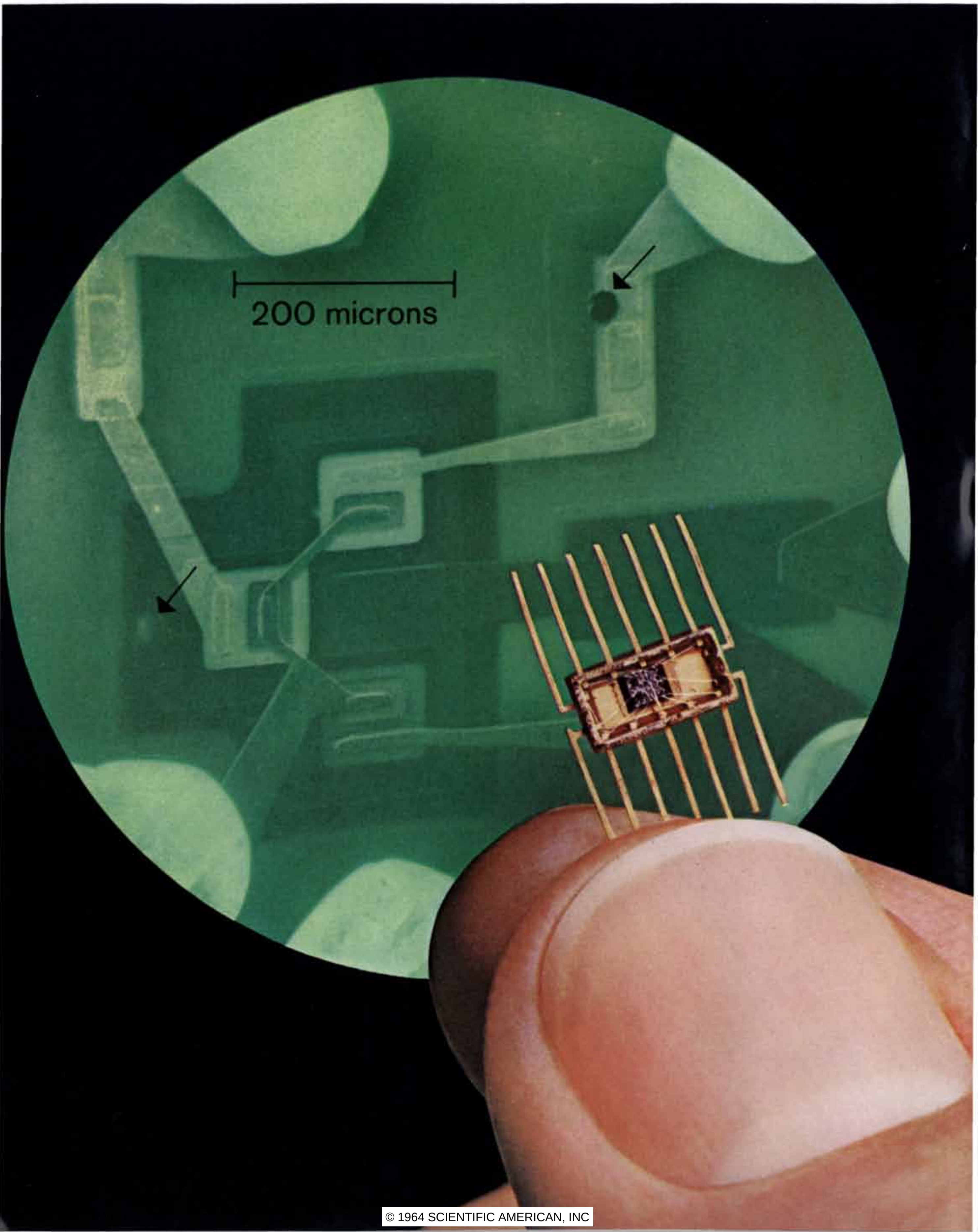

rubs the sciences together

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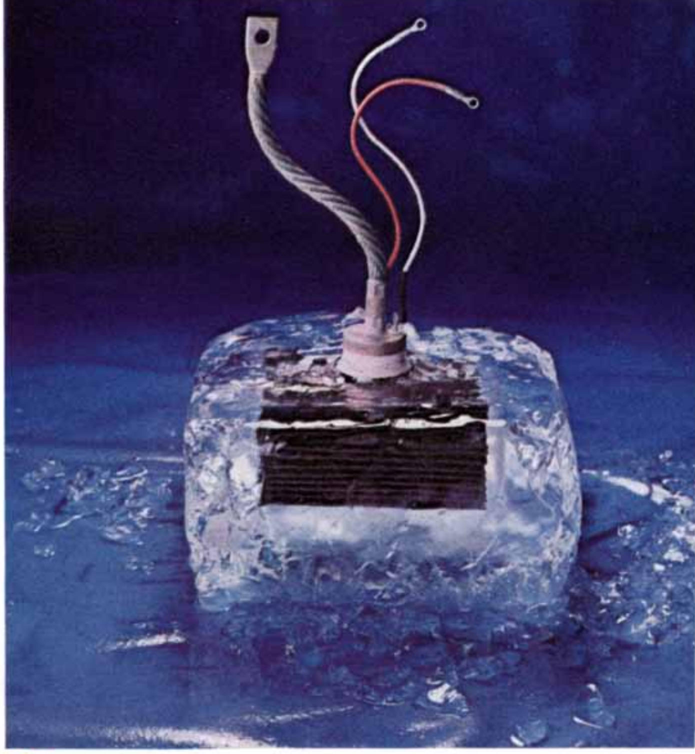
Within the Westinghouse Electronic Components and Specialty Products Group, molecular electronics meets microscopy, magnetics, metallurgy, cryogenics and other solid-state technologies. The result is a unique interdisciplinary approach to design and product problems—across an unusually wide range of components, materials and scientific equipment. Next time, for a broader perspective, bring *us* your problem.



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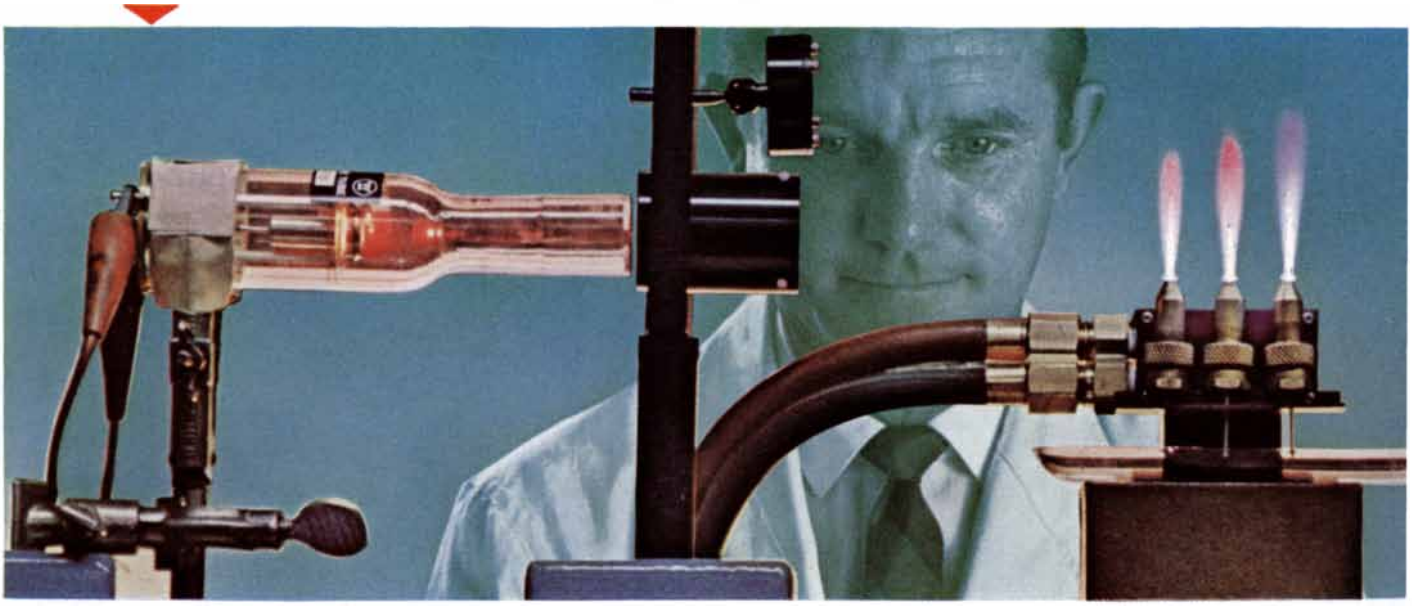
Fast, accurate analyses of trace elements in body fluids are now being performed in hospital labs by atomic absorption spectroscopy using Westinghouse hollow-cathode tubes. Concentrations less than one part per 10 billion can be *measured* in a few seconds from a 1 cc. sample. Before this method, it took hours or even days and many tedious steps. Westinghouse makes over 170 types, including several multi-element hollow-cathode tubes. Oil refiners use them to detect catalyst-destroying poisons; oceanographers to measure trace metals in the ocean; soil scientists to identify common elements and rare earths; geologists to assay precious metals. How about you?



From integrated circuits to hollow-cathode tubes, Westinghouse offers systems-oriented solutions to component problems. You'll find many answers in Westinghouse tubes, semiconductors, integrated molecular circuits, electronic capacitors, instruments and detection equipment, cryogenic systems, transformers, magnetic alloys and magnets, and X-ray systems. For facts and attention to your problem, write S. N. Donahoe, Marketing Manager, Westinghouse Electronic Components and Specialty Products Group, Box 868, Pittsburgh 30, Pennsylvania. J-09004-2

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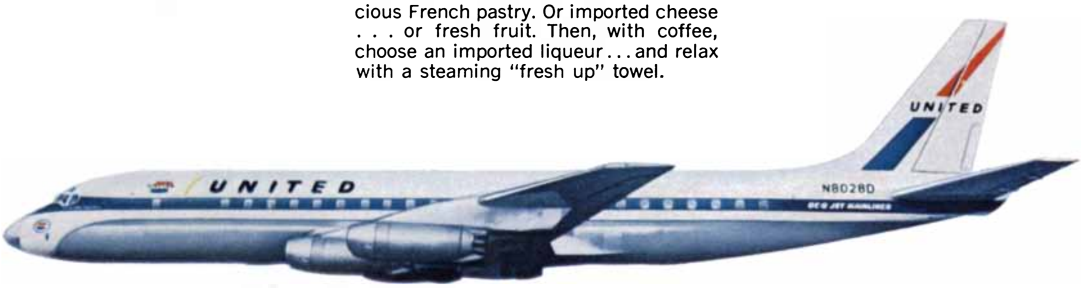

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Established 1845 SCIENTIFIC AMERICAN December 1964 Volume 211 Number 6

Experiments in Hurricane Modification

By "seeding" a cluster of clouds near the center of a hurricane with silver iodide crystals it may be possible to trigger a self-sustaining chain of events leading to a reduction in the storm's wind speed

by R. H. Simpson and Joanne S. Malkus

There can be no doubt that the tropical hurricane is one of man's most dangerous natural enemies. During the hurricane season that has just ended, two successive storms, Cleo and Dora, destroyed property valued at more than $300 million in the state of Florida alone. In 1963 a single hurricane, Flora, killed more than 7,000 people and caused more than $500 million in property damage as it swept across Haiti and Cuba. Until a decade ago the prospect of mitigating in any way the vast destructiveness of these storms was purely conjectural. In recent years, however, research on hurricanes has been intensified, and as a result many of their principal features are now at least partially understood [see "Hurricanes," by R. H. Simpson, Scientific American, June, 1954, and "The Origin of Hurricanes," by Joanne Starr Malkus, Scientific American, August, 1957]. It is now possible to construct a crude physical-mathematical model of a mature hurricane. The fact remains that hurricane research throughout this period has been primarily observational and exploratory. At present man's best defense against hurricanes is still limited to the twin strategies of reconnaissance and forecasting.

This article deals with an entirely different approach to the hurricane problem. Instead of merely observing the formation of a hurricane and plotting its course, we and our colleagues have attempted to interfere in a critical area with the delicately balanced forces that sustain a mature hurricane. The basic technique is not new: it involves "seeding" a certain cluster of clouds near the "eye," or center, of the storm with tiny crystals of silver iodide in order to release the latent heat energy of the clouds. In this way we hope to trigger a self-sustaining chain of events that will lead to a reduction of wind speed near the eye. To date experiments of this kind have been performed on two hurricanes; on both occasions the experiments have yielded interesting and useful results. (It might be remarked in passing that these are among the few experiments ever performed on an atmospheric phenomenon larger than a single cumulus cloud.) It is still too early to say whether or not the experiments will ultimately lead to a practical method for averting the disastrous effects of hurricanes, but in view of the extent of the damage inflicted year after year by these storms even a small reduction in their intensity would warrant a large expenditure of effort and funds. At the very least the graduation of hurricane research from an observational discipline to an experimental one seems certain to result in a considerable improvement in forecasting.

A mature hurricane is a relatively self-contained system of atmospheric circulation. It can be defined briefly as a large cyclonic system in which the speed of the winds exceeds 75 miles per hour. Most hurricanes have a diameter of between 100 and 800 miles and a lifetime of from one to 30 days. In the Northern Hemisphere the winds rotate in a counterclockwise direction, owing to the effect of the earth's rotation. The energy on which a mature hurricane subsists is provided by the evaporation of warm water from the surface of the tropical seas where hurricanes are born and bred. The heat energy generated by the evaporation process is stored in the form of water vapor, most of which rises in a ring of towering cumulonimbus clouds surrounding the calm eye of the hurricane. As these clouds grow upward, the water vapor condenses into rain and thus releases nearly 90 percent of its latent heat energy. The remainder is retained unless the moisture finds an environment in which it can freeze. A lesser amount of energy is generated and later released by the same process in the long, spiral "rainbands" that give a hurricane its characteristic appearance on a radar screen.

It is only when one begins to calculate the total energy required to maintain a mature hurricane by the evaporation-condensation cycle that the true dimensions of the task facing any would-be modification experimenter become apparent. In a single day a medium-sized hurricane releases as much energy through condensation as the simultaneous explosion of 400 20-megaton hydrogen bombs. Roughly 3 percent of this energy, or the equivalent of 12 bombs, is converted into the energy of the winds. Obviously no human resource

EYE OF HURRICANE ESTHER is seen from directly overhead in this mosaic of photographs made from an altitude of more than 60,000 feet by a U-2 weather-reconnaissance plane. The five photographs that compose the mosaic were made on September 17, 1961, as Esther was some 400 miles north of Puerto Rico. Eye-wall clouds (*shadowy area at top*) are more than 45,000 feet high. Darker areas are patches of ocean visible through holes in cloud layer at bottom of eye. Eye is about 18 miles wide at its bottom.

is capable of competing with such a formidable enemy in any head-on confrontation. Instead one must search these storms for an Achilles' heel, some internal instability that can be triggered in such a way as to set off a predictable chain of events leading to a reduction in the storm's intensity.

Do hurricanes possess such Achilles' heels? Their notoriously erratic behavior suggests that they do. A hurricane can develop, collapse or completely reverse its course in less than half a day, often for no apparent external reason. Such behavior could be explained by postulating the existence of certain internal instabilities susceptible to small triggering influences. Paradoxically, the very existence of these instabilities, which gives aspiring hurricane-modifiers their main hope, also constitutes a major obstacle in the way of any clear-cut experimental result. Since the natural fluctuations in hurricane behavior are so large and so poorly understood, it would be difficult to establish whether a given change is the result of human intervention or whether the hurricane would have behaved in the same way of its own accord.

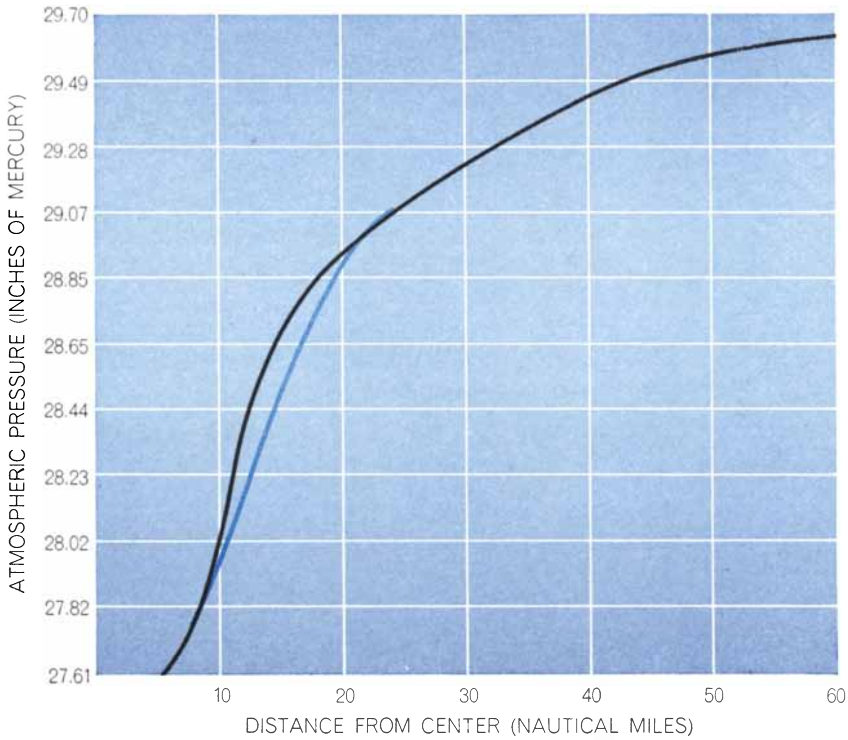
In most areas of research, when the experimentally produced effects are no larger than the natural "noise" level, the experimenter either has recourse to "controls" or he can conduct a long series of similar experiments. Individual hurricanes seem to differ far too much to offer any hope that one might find a comparable pair of them. Moreover, the small population of hurricanes suitable for experiment means that a statistically significant repetition of the same experiment might require more than a century. Recognizing these inherent handicaps, we have based our current set of experiments on a line of reasoning derived from the large store of information about hurricanes accumulated over the past decade. Our general plan is to test each step in this line of reasoning both in and out of the hurricane context.

The object of our experiments is the heart of the hurricane's heat engine: the towering cumulonimbus clouds that form the wall of the eye. These clouds are seeded from the air with silver iodide crystals in a manner calculated to disrupt the balance of forces controlling the position of the clouds, so as to cause their rearrangement and outward migration. A hurricane is essentially a huge atmospheric pump that sucks air inward near sea level and then expels it at great heights. Since most of the warm air ascends in the eye-wall clouds, their outward migration would cause an increase in the radius of ascent of the warm air; this in turn should result in a reduction in the angular momentum of the storm and hence in the maximum speed of its winds. The situation is analogous to the familiar classroom demonstration in which the instructor stands on a rotating piano stool with two weights held close to his body; by extending his arms outward he can slow his velocity of rotation.

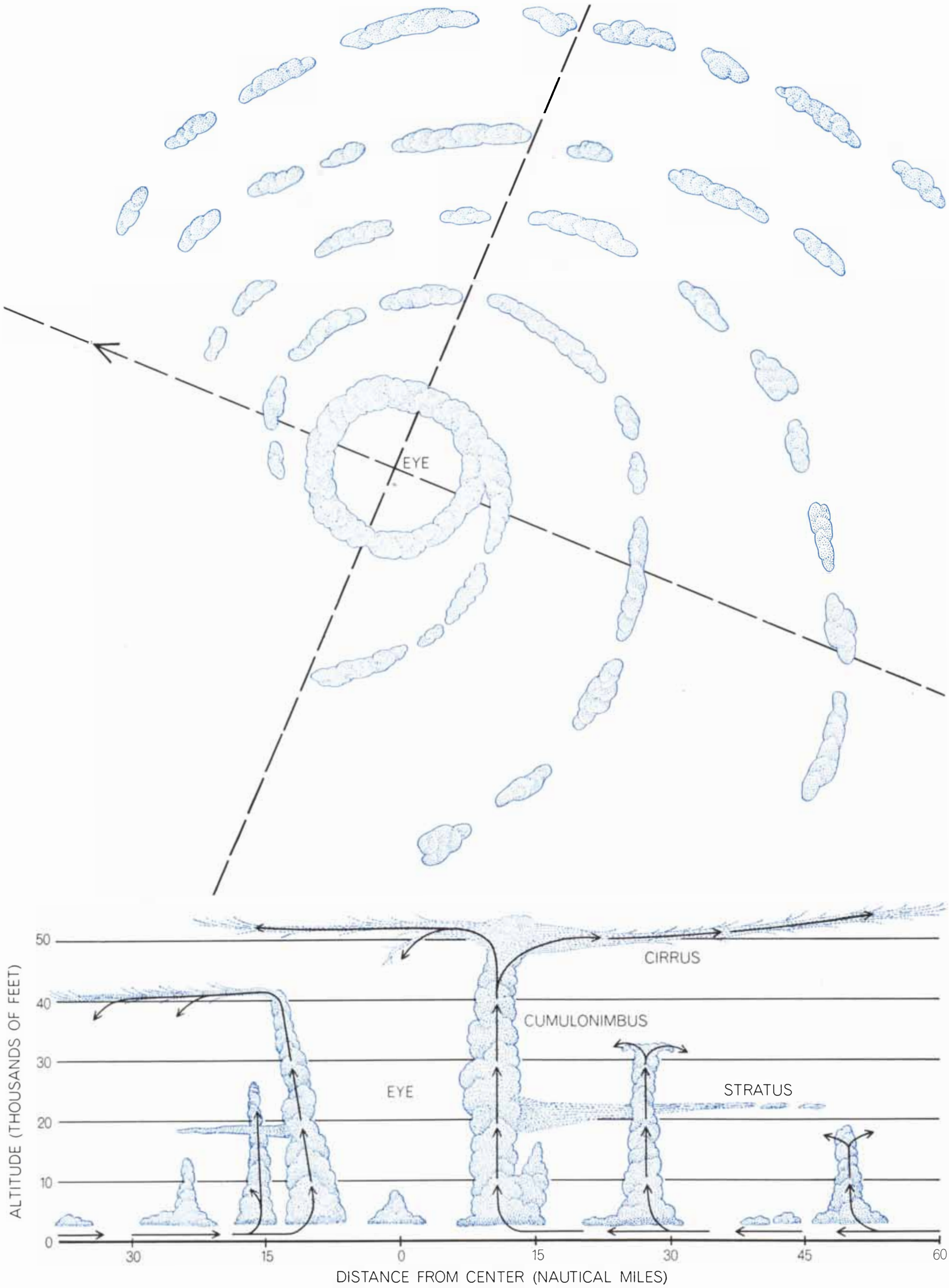
How can seeding the eye-wall clouds lead to their outward migration? Before answering this question it is necessary to review some of the historical background of cloud seeding and particularly its application to hurricane research.

All standard techniques for the modification of clouds involve some scheme for converting the supercooled water droplets in a cloud into snow or ice. Supercooled water is liquid water that has been cooled to below zero degrees centigrade; even in the clouds at the tops of mature hurricanes, where the temperature is generally colder than −35 degrees C., water sometimes fails to freeze. At temperatures nearer the nominal freezing point (zero degrees C.) the water will turn to ice only in the presence of suitable freezing nuclei. Often these are insufficient to convert a large part of the water into ice when the temperature is warmer than about −20 degrees. Between this temperature and zero, however, the water droplets can be made to freeze by artificially seeding the cloud with ice or some ice-like substance.

The two substances most commonly used to induce freezing artificially are frozen carbon dioxide ("dry ice") and silver iodide. Dry ice creates ice crystals by chilling the adjacent air to a temperature at which water can freeze spontaneously. Silver iodide apparently acts as a freezing nucleus because its crystal structure closely resembles that of ice. It is not yet understood whether seeding with silver iodide causes the water droplets to evaporate and then sublimate directly onto the silver iodide crystals or whether the seeding simply causes the existing water droplets to freeze. In any case it is known that when a cloud of supercooled water droplets is seeded with silver iodide, it be-



RADIAL PRESSURE GRADIENT in a mature hurricane (*black curve*) produces forces that are normally balanced with the centrifugal force of the storm, permitting the air to whirl around the low-pressure storm center (*left*) without flying outward. The region in which the pressure exhibits its sharpest radial decline is in the eye-wall clouds (*between 10 and 15 miles from the center*). By seeding these clouds it is hoped that the slope of the pressure curve can be depressed by 15 to 20 percent (*colored curve*), thereby upsetting the precarious balance of forces that support the structure of a full-fledged hurricane.



HURRICANE MODEL has been idealized from nearly a decade of observations by the U.S. Weather Bureau's National Hurricane Research Project. Plan view at top shows the characteristic spiral bands of rain clouds that closely parallel the pattern of wind currents in a hurricane. Large arrow indicates the direction of the storm's movement. Side view at bottom represents a section perpendicular to the storm's direction. Most of the energy conversion that powers a hurricane takes place in towering eye-wall clouds.

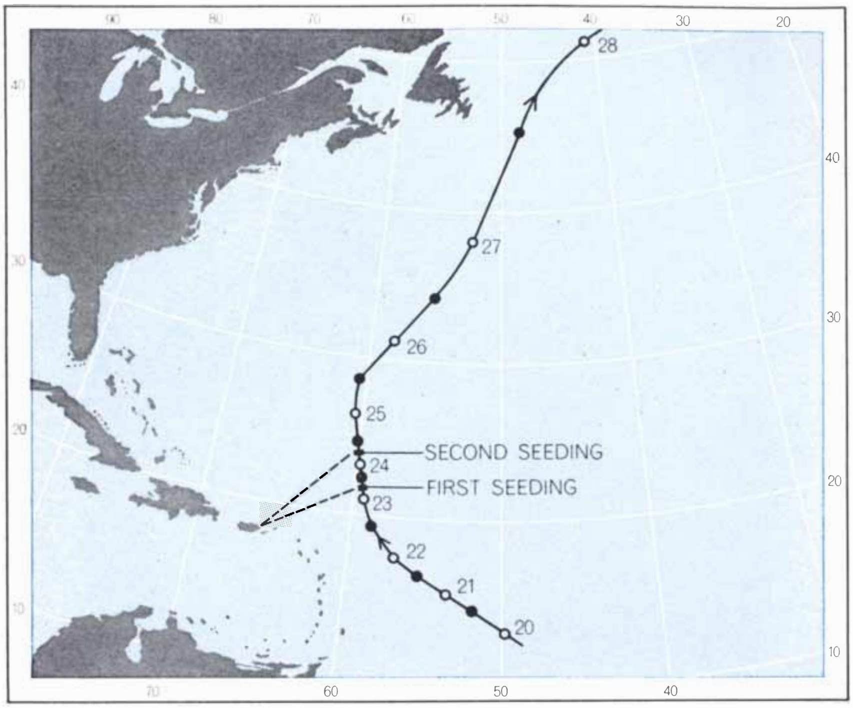
comes filled with snow crystals and latent heat is released in the process. In a cloud that contains two grams of supercooled water for every cubic meter of air the conversion could increase the temperature of the surrounding air by more than 1 degree C.

The practice of modifying clouds by artificial seeding began in 1946, when Vincent J. Schaefer of the General Electric Research Laboratory discovered that dry ice could be used to transform supercooled stratus clouds into snow. Schaefer's earlier laboratory experiments had stimulated his colleague Irving Langmuir to calculate the nucleation properties of dry ice and to predict its effect on clouds. Shortly afterward another colleague, Bernard Vonnegut, demonstrated the remarkable seeding properties of silver iodide crystals. These discoveries led to the organization of Project Cirrus, a five-year program for testing the possibilities of weather modification by seeding various types of cloud. Project Cirrus was carried out under the direction of the General Electric group and was supported by several Government agencies.

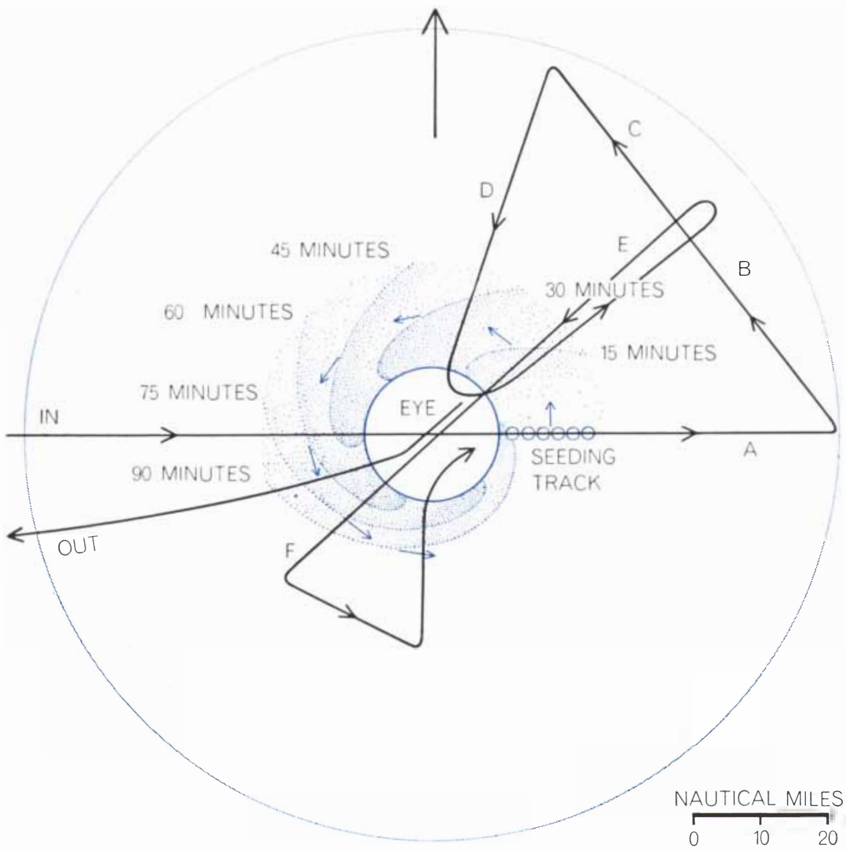
Among the numerous Project Cirrus seeding experiments was the first attempt at hurricane modification, conducted in 1947. This first hurricane experiment was purely exploratory. No testable predictions could be made about the possible outcome of the seeding; at that time data on tropical storms were so lacking that the amount of supercooled water in a hurricane, to choose only one factor, could not even be guessed. The Project Cirrus group planned to seed a young storm "just to see what happened"; they hoped that the cumulonimbus clouds might somehow be dissipated before having had an opportunity to become organized into a well-defined system.

Instead of seeding a young storm, however, the Project Cirrus aircraft dropped 80 pounds of dry ice on a moderately strong hurricane that was heading seaward about 400 miles off the Florida coast. The hurricane had a large eye, about 30 miles in diameter, and its eye-wall and rainband clouds towered as high as 60,000 feet. The dry ice was dispersed along a 110-mile inward track that terminated just outside the eye wall. Stratus clouds in this region were subsequently converted to snow over an area of about 300 square miles.

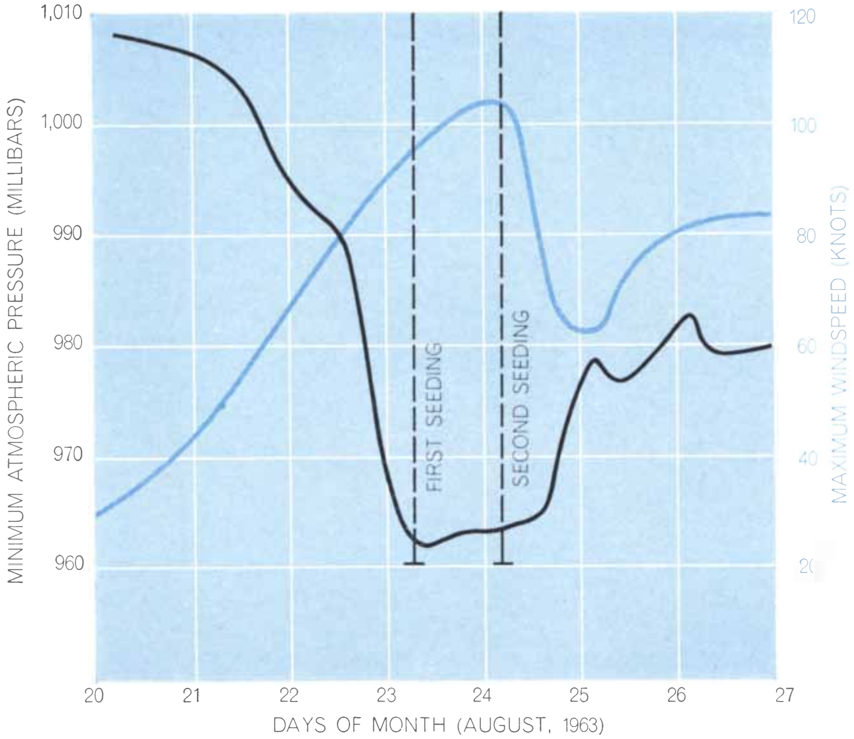
Unfortunately neither of the two Project Cirrus aircraft was equipped to monitor the dynamic and structural



HURRICANE BEULAH was the second hurricane seeded in the current Project Stormfury series of experiments. The map shows the path of the storm and its position at the time of the two seeding operations on August 23 and 24, 1963. The aircraft conducting the experiment were based at Roosevelt Roads in Puerto Rico. The numerals indicate days of the month. Open circles denote position of hurricane at noon; black dots, position at midnight.



BEULAH WAS SEEDED on August 24, 1963, along a straight track across the eye wall perpendicular to the direction of the hurricane's motion. Flight paths of Weather Bureau monitoring aircraft are depicted. Spiral lines indicate the spread of silver iodide crystals.



CHRONOLOGY of Beulah's development and decay covers the seven-day period during which continuous surveillance was maintained. The changes observed shortly after the second seeding are striking: maximum wind speed dropped more than 30 knots and pressure at storm's center rose about 15 millibars. (A millibar is equal to 1,000 dynes per square centimeter.) Problem of relating cause and effect is not a simple one, however, since the natural fluctuations that occur in hurricanes are at least as large as those shown here.

changes taking place inside the hurricane or to make systematic "before and after" photographs of the changing cloud patterns. The only criterion for judging the effect of the seeding was the gross behavior of the hurricane during the succeeding days. As it turned out, the experiment became the subject of considerable controversy; shortly after the seeding the storm abruptly reversed its course and 43 hours later moved into Georgia, where it caused considerable damage. The fact that in any event the large-scale wind systems surrounding the hurricane would probably have blocked its continued seaward course further complicated attempts to evaluate the effect of the seeding.

The whole Project Cirrus experience taught that rigid precautions must always be taken to tamper only with storms that cannot conceivably strike land within a reasonable time. Unfortunately this restriction limits the number of Atlantic hurricanes available for modification experiments to only one or two a year. The Project Cirrus experiment also showed that unless some provision were made to monitor the continual changes in the hurricane's structure, wind speed and direction—both before and after seeding—it would be impossible to evaluate objectively the results of *any* modification experiment. It became clear that future experiments would have to be based on a sound foundation of knowledge regarding the internal mechanisms that power a hurricane. If cloud seeding was to be the technique employed in the experiment, we had to learn the relation between cloud dynamics and storm dynamics in order to make a knowledgeable prediction as to how altering one might subsequently alter the other.

These considerations in large part motivated the establishment in 1955 of the U.S. Weather Bureau's National Hurricane Research Project and the launching in 1960 of its offspring, Project Stormfury, which was set up to carry out the current series of modification experiments. The latter project is an interagency effort, supported jointly by the Weather Bureau, the Navy and the National Science Foundation.

The characteristic feature that distinguishes a hurricane from most other tropical storms is its warm central core; weaker disturbances are generally cooler at their centers than in their outer regions. Depending on the intensity of the hurricane, the temperature at the center ranges from 3 to 16 degrees C. higher than the surrounding air. It is this warm central core that drives the entire circulation of the storm. Moist air is drawn in at the bottom and spewed out at the top, releasing heat energy as the water vapor condenses into rain. The circulation is maintained by a sharp decrease in atmospheric pressure inward toward the center. Since the atmospheric pressure above the hurricane does not vary appreciably from the core outward, the pressure differential inside the storm exists because the warm air in the core is lighter than the cooler air surrounding it. The cumulonimbus clouds around the eye of the hurricane contribute to the high temperature of the core by the condensation of water vapor in their updrafts. Often the air in these updrafts rises faster than 50 miles per hour, mixing very little with the surrounding air on its way to the top of the storm.

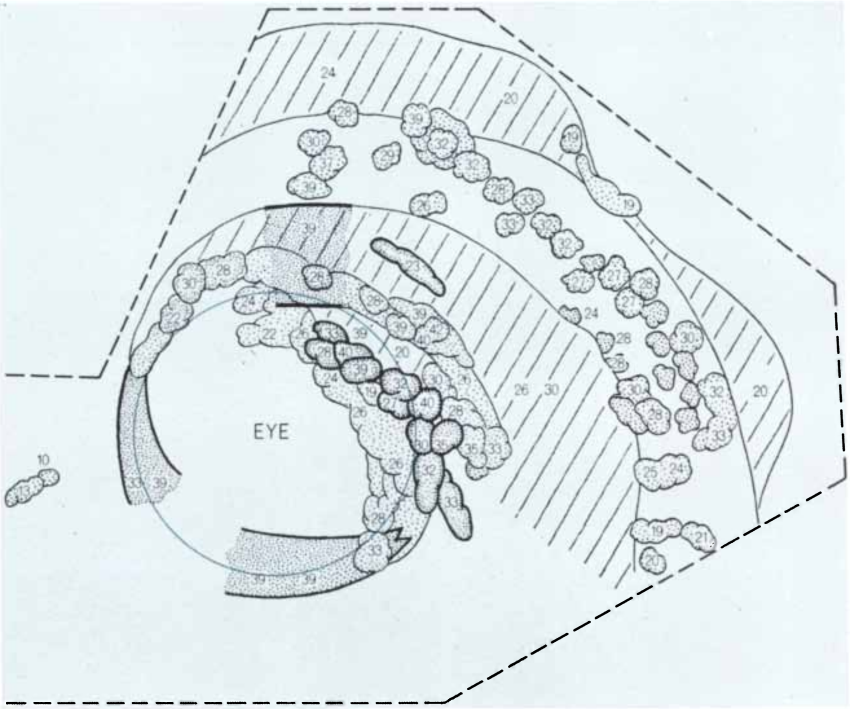
Although it may seem odd, our present experiments have the immediate objective of making these chimneys of hot air even hotter by seeding them with silver iodide. By releasing the latent heat stored in the cumulonimbus clouds of the eye wall, the seeding should have the effect of raising the temperature in this critical region by about 2 degrees C., thus further lowering the atmospheric pressure at the very point where it exhibits its sharpest decline. Although the anticipated drop in pressure would be only a few tenths of 1 percent, this would be enough to flatten the slope of the curve that relates pressure to radial distance by about 15 to 20 percent [*see illustration on page 29*].

A little consideration will show that the slope of the pressure curve on page 29 is proportional to the force acting inward toward the center of the storm. Normally this force, or pressure gradient, is balanced with the centrifugal force of the storm's rotation, permitting the air to whirl around the storm center at a high speed without flying outward. Such a delicate balance would be drastically upset by a 15 to 20 percent reduction in one of the opposing forces. The sudden outward motion induced by such a change could conceivably set off the self-sustaining disruption we wish to produce in the entire wind system. In other words, if the wind speed decreases sharply enough with distance away from the center of the storm (as it appears to do in many hurricanes), the region in which clouds are produced, once its outward migration is initiated, may continue to move outward—even into rising pressure. The magnitude of many of these changes can be estimated in advance, but we were not yet able to predict the distance the eye-wall clouds would migrate outward, nor the consequent amount of wind-speed reduction. Nor were we able to say whether or how soon a hurricane might regain its equilibrium after such a shock. We proposed to answer both questions by actually performing the experiment and at the same time to test each link in our Stormfury hypothesis by careful measurements at several altitudes, before and after seeding.

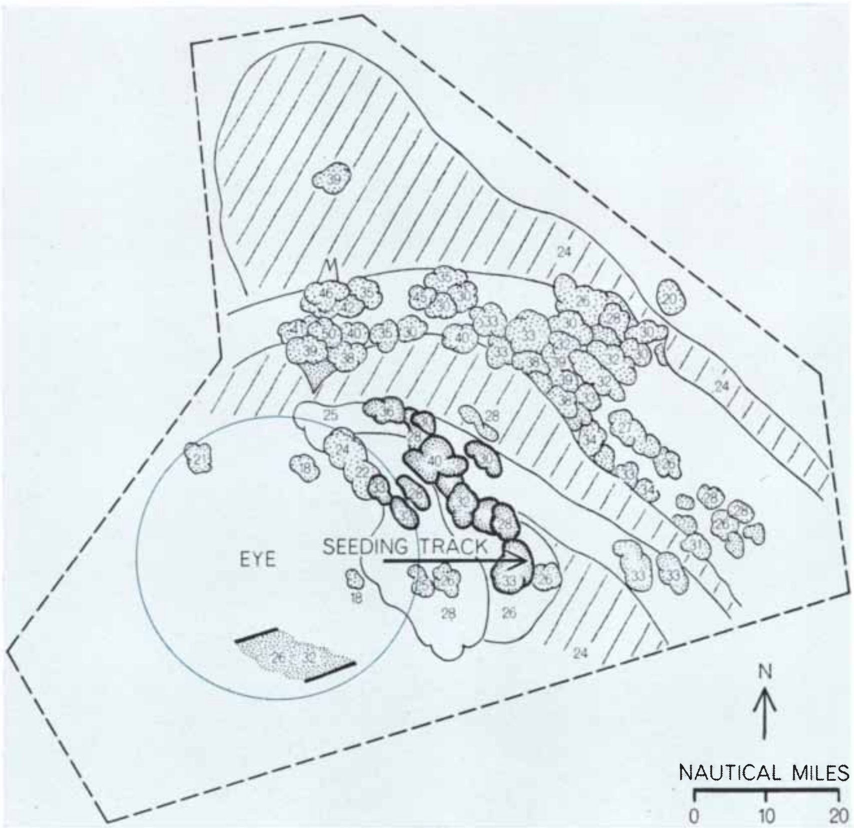
Two technical innovations helped to make our proposed experiment feasible. The first was the invention of an improved silver iodide generator that could be dropped like a bomb from an airplane. This generator, which can fill a cloud with many more particles than are commonly used in rainmaking efforts, was developed by Pierre St. Amand of the Naval Ordnance Test Station at China Lake, Calif. Several of the generators could be dropped in a radial track across the eye wall, so that the strong cyclonic winds would carry a dense sheet of silver iodide crystals counterclockwise around the center of the storm [*see bottom illustration on page 31*]. We found that the silver iodide would make a complete circuit of the eye in an hour or two if it was not rained out of the clouds or ejected from the top of the storm.

The second factor contributing to the feasibility of our plan was the Navy's ability to coordinate by radar the precision maneuvering of 10 specially equipped aircraft. This task was accomplished by stationing a "flight controller" aboard one of the radar-equipped planes (a Super-Constellation), from which the other aircraft would be guided along their prescribed flight paths with respect to the moving eye of the storm.

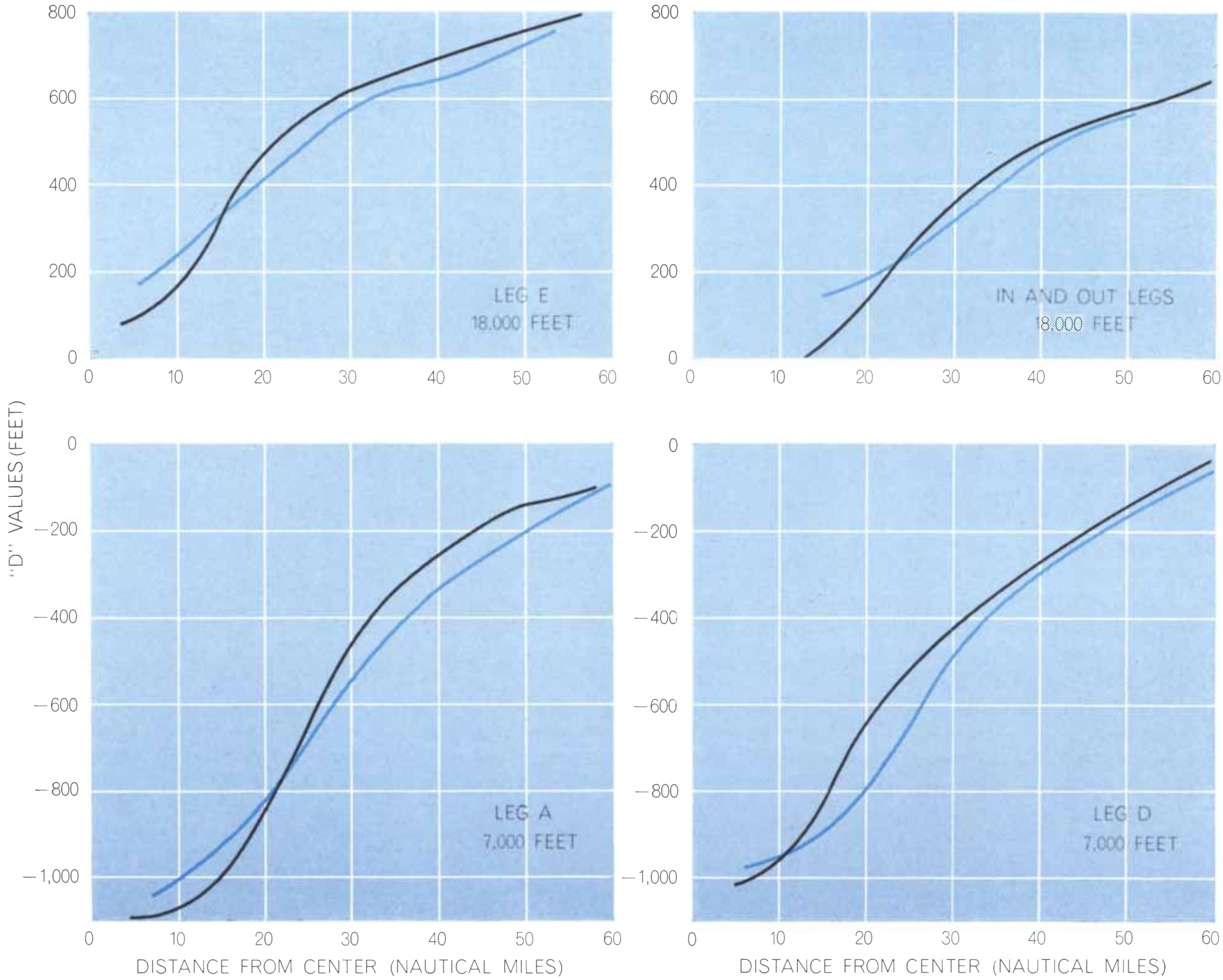
Three Weather Bureau aircraft are employed to make detailed measurements of the core structure for a period lasting from two and a half hours before seeding to two and a half hours after seeding. The three planes, two DC-6's and a W-57, fly almost identical flight paths and make substantially the same observations at altitudes of 7,000, 18,000 and 40,000 feet respectively. They measure wind speed, air pressure, temperature, humidity, liquid-water content, number of freezing nuclei and cloud structure. At lower altitudes a B-26 makes special cloud and rainband studies. Additional monitoring is pro-



BEFORE SEEDING on August 24, 1963, the large cumulonimbus clouds around the eye of hurricane Beulah were crowded together in what appeared to be a stable configuration. The drawings on this page were derived from radar data that gave the height of each cloud, its lateral extent and its distance from the aircraft; the clouds were then plotted on a map with respect to the plane's flight path. Small numbers denote height of each cloud in thousands of feet. Crosshatched areas represent stratus clouds; gray areas are cirrus clouds.



AFTER SEEDING with silver iodide crystals Beulah's eye wall was observed to dissipate and then re-form about 10 miles farther away from the center of the hurricane. The nearest rainband to the north also moved outward and its cloud towers grew considerably higher.



SLOPES of pressure surfaces were obtained before seeding (*black curves*) and after seeding (*colored curves*) in several radial directions outward from the center of Beulah; the specific directions correspond to legs in the flight paths of the monitoring aircraft (*see bottom illustration on page 31*). In each case the region of maximum slope migrated outward and was reduced. Average reduction in pressure in region from 40 to 60 miles from the center was 16 percent, which is in good agreement with predicted value. "D" values are altimeter corrections that measure in feet difference in air pressure from that at sea level in standard atmosphere.

vided by a second Super-Constellation, which circles the eye wall and drops instruments by parachute in order to measure the air pressure near the eye of the storm. Two high-flying aircraft are used to photograph the changing cloud patterns from above [*see illustration on page 28*]. The ninth and 10th aircraft (both Navy A3B's) do the actual seeding of the eye-wall clouds.

Our first opportunity to conduct a full-scale modification experiment came on September 16, 1961, when hurricane Esther was intercepted some 400 miles north of Puerto Rico. Our second experiment was run last year on hurricane Beulah. Since the results of the two experiments were essentially the same (with one probable exception) we shall discuss the more recent one in detail and refer to the first only insofar as it differed significantly from the second.

Hurricane Beulah was first detected on August 19, 1963, as it emerged from the vast unmonitored region east of the Lesser Antilles into an area that is normally patrolled by reconnaissance aircraft. The map at the top of page 31 shows the path of the storm and its position at the time of the two seeding operations on August 23 and 24. On August 23 the storm was still immature and unsteady; the eye wall was an open semicircle of cloud that was rapidly changing shape. A sudden shift occurred just before seeding, with the result that the silver iodide was dropped in an almost cloud-free region and probably entered the eye wall too late for the results to be observed along the flight paths flown by the Weather Bureau aircraft. We shall therefore concentrate our attention on the events of August 24, when the experimental objectives were more fully achieved.

The illustration on page 32 presents the chronology of Beulah's development and decay for the seven-day period during which continuous surveillance was maintained. The changes observed shortly after the second seeding are striking: the maximum wind speed dropped more than 30 knots and pressure at the storm's center rose about 15 millibars. (A millibar is a unit of atmospheric pressure equal to 1,000 dynes per square centimeter.) From this observation alone we are no more justified in concluding that the seeding was responsible for the observed changes than we would be if we were to conclude that the 1947 hurricane reversed its course as a result of the Project Cirrus experiment. In the case of the Beulah experiment, however, we were able to compare the measured changes in the storm's core with the quantitative predictions of the Stormfury hypothesis.

The illustrations on page 33 are "before and after" drawings of Beulah's cloud structure derived from radar data obtained by the two DC-6's. These particular radar screens gave side views of the storm, so that the height of each cloud, its lateral extent and its distance from the aircraft could be readily deduced from the radar data; the clouds were then plotted on a map with respect to the plane's flight path. As the top illustration on page 33 shows, the cumulonimbus clouds around the eye wall were crowded together in what appeared to be a stable configuration prior to seeding. After the silver iodide crystals were released just upwind of the most concentrated portion of the eye-wall clouds, the cloud pattern underwent a large-scale transformation [*see bottom illustration on page 33*]. The eye wall was observed to dissipate and then re-form about 10 miles farther away from the center of the storm. The nearest major rainband to the north also moved outward and its cloud towers grew much higher.

This large-scale, outward migration of clouds shortly after seeding was entirely consistent with the original Stormfury hypothesis. Nonetheless, we were still unable to establish a definite causal relationship, since next to nothing is known about the natural fluctuations of cloud patterns in hurricanes. We must therefore refer also to the detailed measurements supplied by the monitoring aircraft to determine if the predicted internal changes actually occurred.

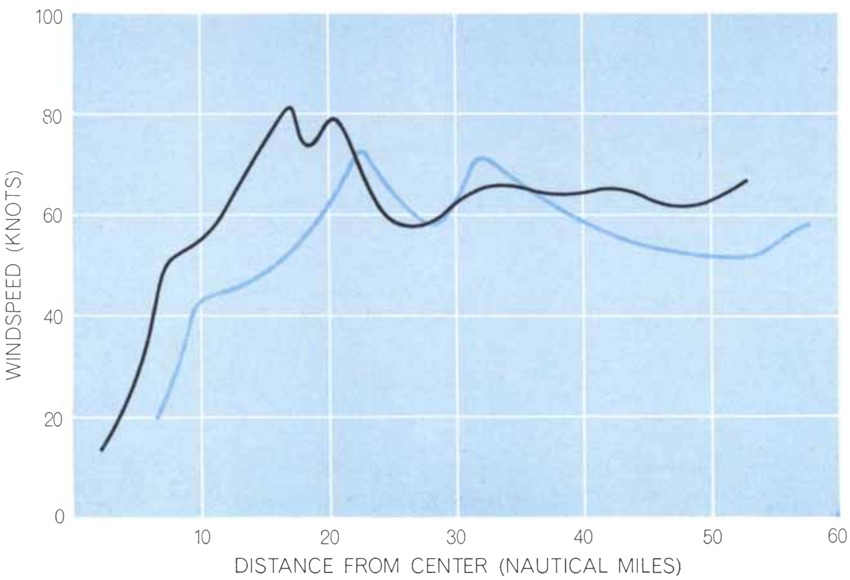
The graphs on the opposite page depict the pressure curves obtained in several radial directions outward from the center of Beulah, both before and after the seeding. In each case the region of maximum slope migrated outward and was reduced. The average reduction in pressure gradient in the region from 10 to 40 miles from the center was 16 percent, which was in good agreement with the predicted value. The graph at the right shows the variations in wind speed along one of these radial directions. Again the region of maximum wind speed moved outward and the wind speed itself diminished after the seeding. The average reduction in wind speed was 14 percent, and the outward migration of the maximum region ranged from four to 10 miles. All these changes were also consistent with the Stormfury hypothesis, but they were well within the range of the normal fluctuations.

One way to test for causality is to determine if a given set of experimental results is reproducible. Looking back to the hurricane Esther experiment of 1961, we found that almost all the results of that seeding were comparable to those obtained by the Beulah experiment. In the case of Esther, however, seeding was followed by the progressive disappearance of a large part of the eye wall from the screen of a radar set operating with 10-centimeter waves [*see top illustrations on next two pages*]. The 10-centimeter return from the eye-wall region downstream from the seeding track began to disappear about 20 minutes after the silver iodide generators were dropped; 40 minutes later the eye wall had vanished over a sector 160 degrees wide. About an hour after seeding the eye-wall clouds in this sector began to reappear on the 10-centimeter screen. Throughout this period a three-centimeter radar set on the same aircraft continued to show a complete eye wall.

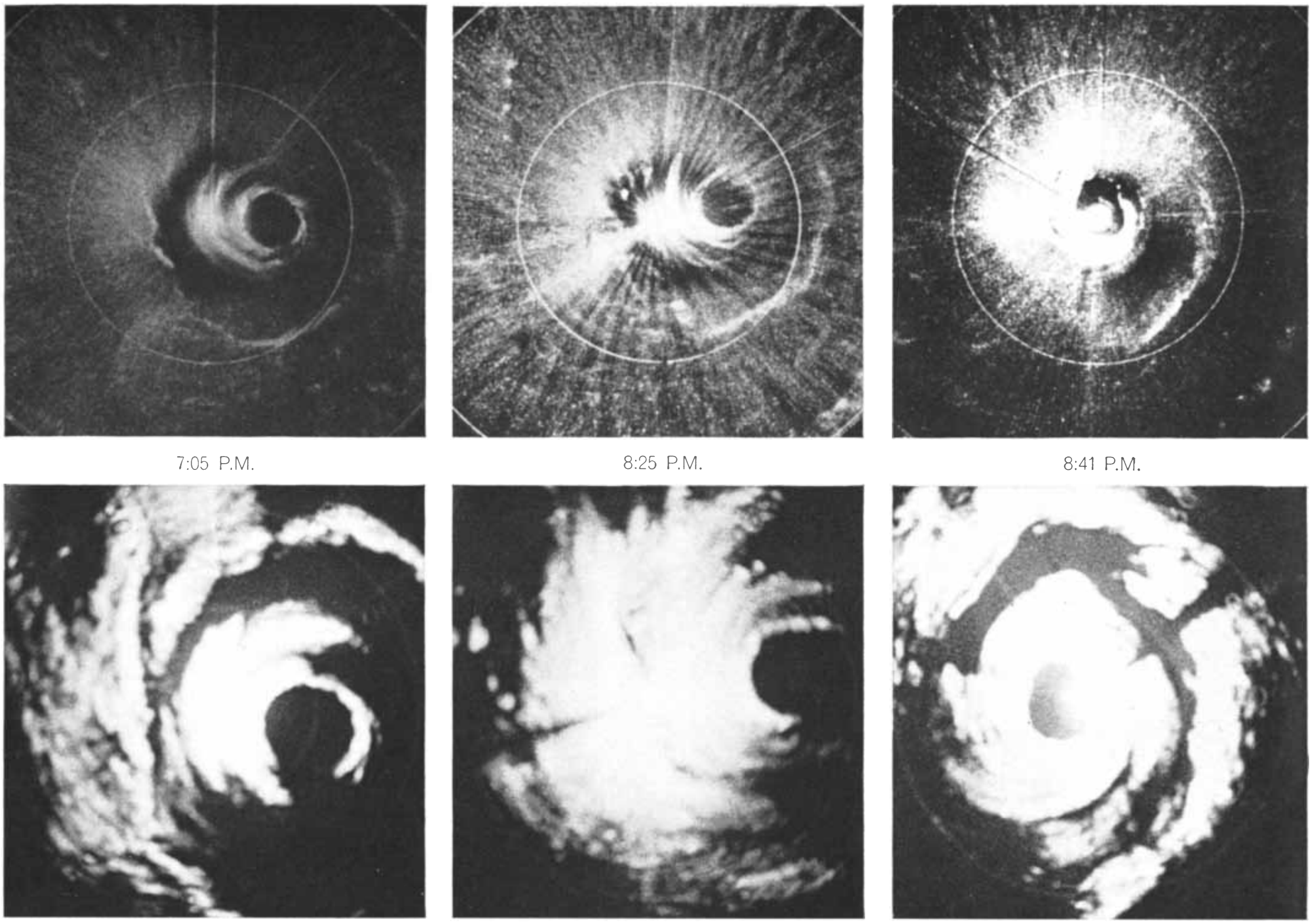
The difference in the reflectivity of the eye-wall clouds on the two radar sets could have occurred if the seeding had caused the raindrops in the clouds to be replaced by smaller drops whose diameters were less than about 300 microns (the critical size for 10-centimeter reflectivity). The alternative explanation is that the seeding converted the bulk of the precipitation from liquid drops to some ice form that was less reflective for 10-centimeter than for three-centimeter waves. Before accepting the freezing explanation, however, it is necessary to point out that the 10-centimeter radar antenna was not tilted up far enough to view only clouds above the freezing altitude. In the case of Beulah any difference in radar reflectivity was much less apparent, and the quality of the radar photography was inadequate to resolve the issue.

Further repetitions of the Stormfury experiment might require centuries before we could separate statistically the man-made changes from the large natural fluctuations. A three-pronged attack on this formidable problem is planned. First, the 1964 hurricane season was devoted entirely to studying natural fluctuations in unmodified storms; from these data a reference library of various types of storm biography will be compiled. Second, a greatly intensified Stormfury experiment is tentatively scheduled for the 1965 season. This experiment will consist of five or six seedings of the same storm, repeated every few hours.

The third prong of the attack consists of a series of experiments involving individual clouds outside the hurricane context. Such experiments are comparatively easy to control and may suggest new approaches to hurricane modification. The first tests in this new series were performed in August, 1963; several supercooled cumulus clouds were seeded with silver iodide, producing quite spectacular results [*see bottom illustrations on next two pages*]. The clouds



WIND-SPEED CURVES were obtained before seeding (*black curve*) and after seeding (*colored curve*) along one of the radial directions outward from the center of Beulah (the direction corresponding to Leg E). Again the region of maximum wind speed moved outward and wind speed itself diminished after the seeding. Average reduction in wind speed was 14 percent, and outward migration of maximum region ranged from four to 10 miles.

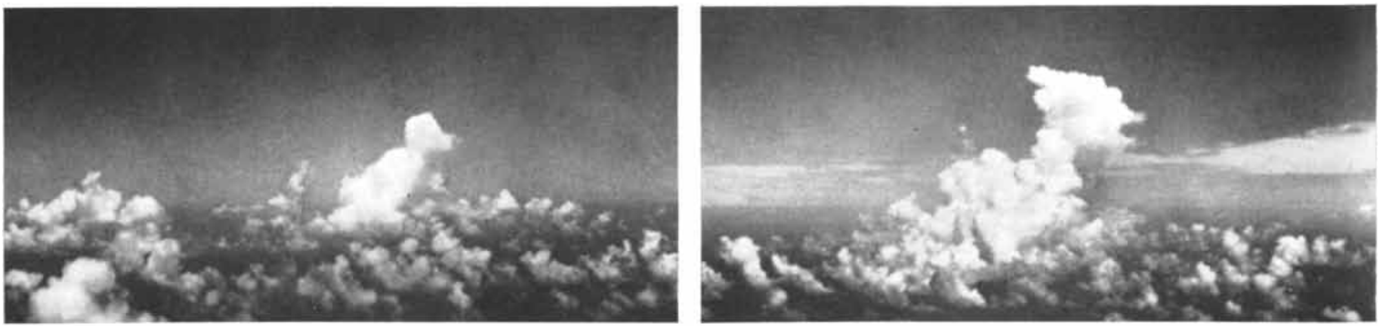


RADAR IMAGES of hurricane Esther were received simultaneously by two different radar sets aboard the same airplane on September 16, 1961. Both sets gave a plan view of the storm. On the set operating with 10-centimeter waves (*top row*) seeding was followed by the progressive disappearance of a large part of the eye wall. The vanished region reappeared on this set about an hour after the

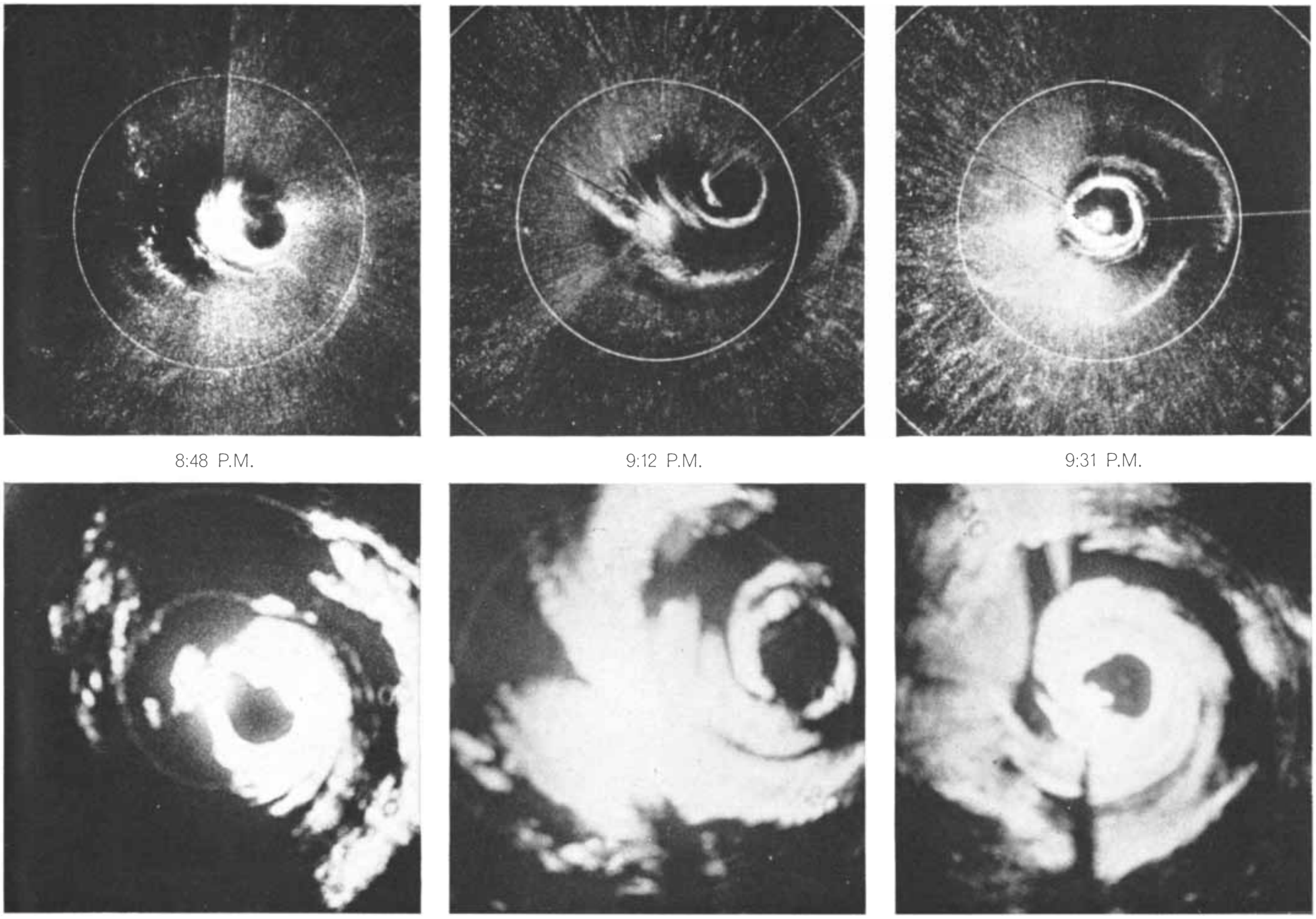
grew explosively after seeding, with the growth taking place in two distinct stages. For the first 10 minutes or so after seeding the clouds grew upward an additional 10,000 to 20,000 feet. Then they expanded horizontally, more than doubling their original diameter in the next few minutes. The giant clouds produced by the seeding operation usually persisted for at least another half hour.

The results of the individual cloud tests demonstrated the effectiveness of the silver iodide generators in freezing the supercooled water in the clouds. The tests also raised the question, however, of whether such freezing occurs naturally in some hurricane clouds at temperatures warmer than −40 degrees C. If this actually occurs, the heat released by freezing may play an important role in the natural storm, and it might be better to prevent rather than to encourage its release. So far no technique for preventing freezing in clouds is known, but a quantitative modification hypothesis could be developed from the existing data in the event that some such technique is discovered.

The experiments carried out by the Stormfury project do not guarantee the mitigation of hurricane disasters;



EXPLOSION of a supercooled cumulus cloud after being seeded with 25 silver iodide generators took place in two stages. The first photograph shows the cloud immediately after seeding. For the first nine minutes after seeding the cloud grew upward an additional



seeding was completed. Meanwhile a radar set operating with three-centimeter waves (*bottom row*) continued to show a complete eye wall. The difference in the reflectivity of the eye-wall clouds could have occurred if the seeding converted the bulk of the precipitation from liquid drops to some ice form that was less reflective for 10-centimeter than for three-centimeter radar waves.

indeed, they may never do so. What is more to the point, however, is that we are now able to perform actual experiments in a full-scale atmospheric laboratory in order to evolve and test various modification hypotheses. It seems certain that weather forecasting in general can be greatly improved by applying a known force to an atmospheric phenomenon and measuring the results—rather than patiently waiting to observe only what nature chooses to reveal.

Of course entirely different modification experiments are conceivable, some not even involving clouds. For example, preventing evaporation from the sea's surface could remove a source of heat vital to the maintenance of the hurricane's warm core. As yet we know of no technique that could suppress evaporation over large areas of stormy sea, but even if we did, the Stormfury experience shows that technique alone is not enough. The high natural "noise" level in hurricanes makes an experiment worthwhile only if it is based on a testable hypothesis that predicts at least some of the outcome quantitatively. Further development of this combined theoretical and experimental approach is needed if hurricane modification is to become more than a vague hope.

14,000 feet (*second photograph*). After 19 minutes it began to expand horizontally (*third photograph*), almost doubling its original diameter by 38 minutes after seeding (*fourth photograph*). Object at extreme right is the wing-tip fuel tank of the control aircraft.

THE GEOLOGY OF THE MOON

With the technique of stratigraphy the geologist can ascertain the relative age of lunar features. The resulting interpretation of the moon's surface is supported by the *Ranger* pictures

by Eugene M. Shoemaker

Geology is fundamentally a historical science. From the study of stratigraphy—the layering of materials—the sequence in which major events have occurred on the solid surface of the earth can be deciphered. To determine such a sequence the geologist utilizes the principle of superposition: when one geologic feature is superposed on another, the first feature is normally younger than the second. For several years my colleagues and I in the U.S. Geological Survey's Branch of Astrogeology have applied this principle, together with some new techniques, in a study of the geology of the moon. Our work, which has been based on telescopic observations, photographs and measurements, will be greatly aided by high-resolution photographs obtained from spacecraft such as *Ranger 7*.

The investigations completed thus far have enabled us to establish a geologic time scale for major events on the moon. We have also undertaken to work out, within broad limits, a correlation between lunar and terrestrial geologic time. We expect that the study of lunar geology will help to answer some long-standing questions about the early evolution of the earth. The moon and the earth are essentially a two-planet system, and the two bodies are probably closely related in origin. In this connection the moon is of special interest because its surface has not been subjected to the erosion by running water that has helped to shape the earth's surface. The chances are therefore good that the geologic record of very early events is still preserved on the moon.

To describe our work I shall first discuss in some detail the topographic characteristics of the typical large lunar crater Aristoteles, because the close examination of such characteristics reveals the keys to deciphering lunar stratigraphy. Then, working backward in lunar geologic time, I shall show how we have applied these keys in one large area of the moon, the Mare Imbrium and its environs. After the major events that have occurred in the area of the Mare Imbrium have been placed in their proper chronological order, it will be appropriate to venture some speculation about the nature and causes of these events. Finally I shall describe our effort to correlate lunar and terrestrial geologic time.

Aristoteles, which is far to the north on the moon along the margin of the Mare Frigoris, is about 55 miles in diameter from rim crest to rim crest. It is portrayed vividly in the middle photograph at the top of pages 44 and 45. This photograph, one of the finest ever obtained of the moon, was made by George Herbig two years ago with the 120-inch telescope at the Lick Observatory. The photograph clearly reveals some features of the crater that are typical of many lunar craters of this size. Among them are a series of terraces on the inner wall of the crater and a crater floor that is noticeably smoother than the surrounding terrain but dotted with low peaks. I call attention to the photograph, however, primarily because it shows with unusual clarity the kind of detail needed for unraveling the lunar stratigraphy. These details appear mainly on the rim of the crater and on the lunar surface outside the rim.

Looking at the rim, one sees a distinctive hummocky terrain. Near the crest of the rim the hummocks are irregular and more or less randomly arrayed hills. Moving outward from the rim the eye discerns that the hummocks and depressions gradually become linear ridges and valleys, arranged almost radially around the crater. The relief of the ridges gradually diminishes until, at a distance from the rim crest roughly equivalent to the diameter of the crater, it disappears.

Extending outward from the perimeter of the Aristoteles' rim are a myriad of small, closely spaced craters. These craters, which look like a series of gouges on the lunar surface, we have called secondary craters. They are secondary in the sense that they form a pattern that shows they are associated with a single large crater to which we refer as a primary crater.

The secondary craters are the most important features for establishing superposition on the moon's surface. Such craters typically have low or irregular rims; in some cases the rims cannot be distinguished at all. The secondary craters also are shallower in proportion to their width than are most of the other small craters scattered over the surface of the moon. With increasing resolution the larger secondaries are found to be several craters strung together. This too is characteristic of secondaries.

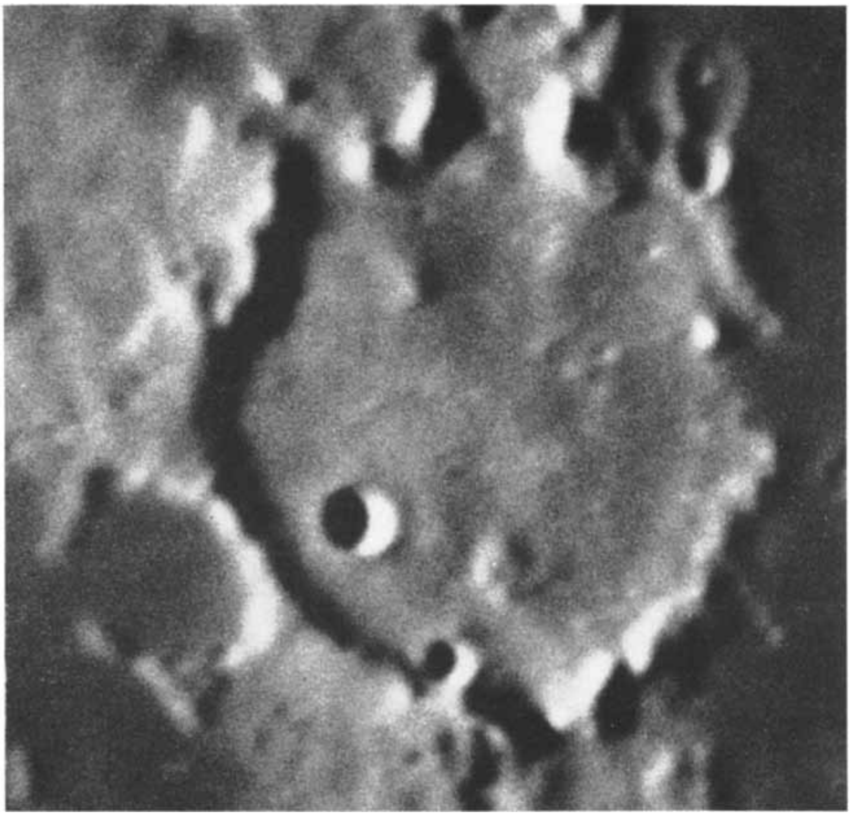
In the upper part of the photograph the secondary craters associated with Aristoteles can be traced out onto the plainlike area that is the surface of the Mare Frigoris. From the principle of superposition it is evident that the formation of secondaries represents an event or series of events that occurred after the formation of the mare. The event or events that created Aristoteles and its secondaries took place later than the event that created the mare. By tracing the secondaries as they appear on top of some lunar features and as they are covered by or disappear below others one can use the principle of superposition to establish the age of a primary crater with respect to other features of the lunar landscape.

It is now possible to turn to the application of the principle of superposition to the unraveling of the stratigraphy of the region around the Mare Imbrium. I shall begin by discussing two primary craters just south of the mare. They are Copernicus and Eratosthenes. In the photograph at top right on page 45 Copernicus is at the lower left and Eratosthenes at right center.

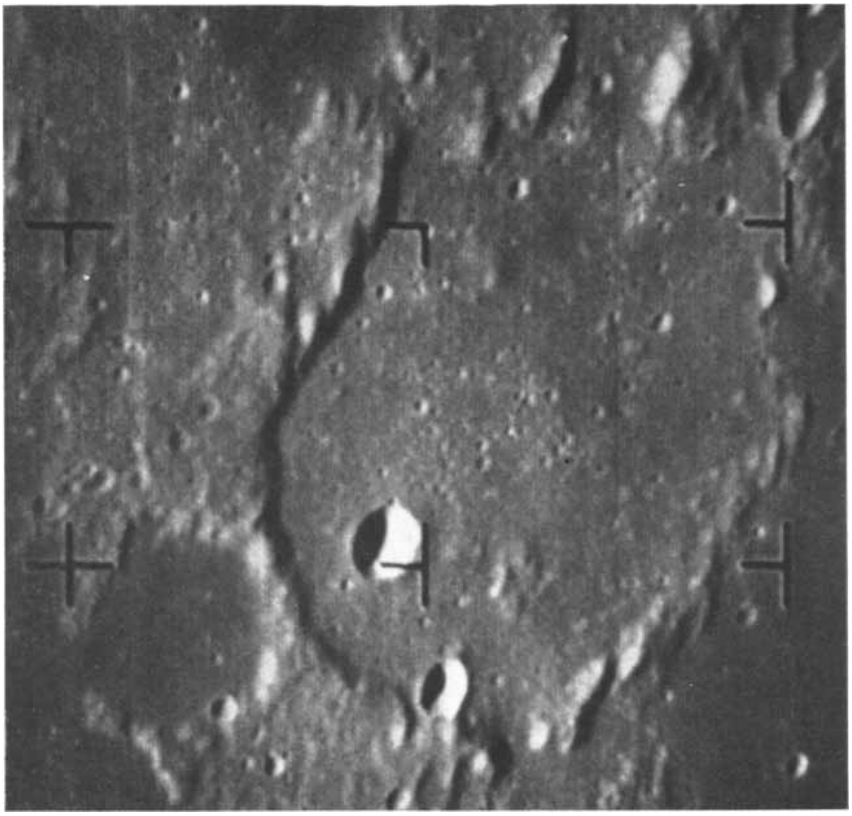
Copernicus, which is about the same size as Aristoteles, is one of the most prominent "ray" craters on the moon. The rays are the bright streaks extending out from the crater rim like a huge splash. In the photograph one can see that Copernicus has many of the same features that characterize Aristoteles: terraced inner walls, a roughly circular floor of generally low relief with a few scattered peaks, and finally a rim with rounded hills and ridges combined in a hummocky array that lacks obvious alignment near the crest of the rim but continues gradually outward into a system of elongated ridges and depressions with a faint radial alignment. Again the relief of the ridges diminishes until at a distance of about one crater diameter from the rim it disappears and gives way to the swarm of secondary craters. A continuous bright halo surrounds Copernicus and is coincident with its rim.

The ray system, which extends more than 300 miles outward from Copernicus, consists mainly of arcs and loops of highly reflective material on a generally dark part of the lunar surface. In their reflectivity the rays are essentially an extension of the bright crater rim. When examined in detail, the major arcs and loops are found to consist of feather-shaped streaks, arrayed side by side or in echelon, with the long axes of the streaks arranged almost radially with respect to the center of the crater. Within the rays, and predominantly at the ends of the ray elements nearest Copernicus, are the elongated secondary craters. One thing shown by the *Ranger* photographs (for the rays associated with the crater Tycho) is that many small secondary craters, too small to be resolved by telescopes on earth, occur at the near end of each ray element.

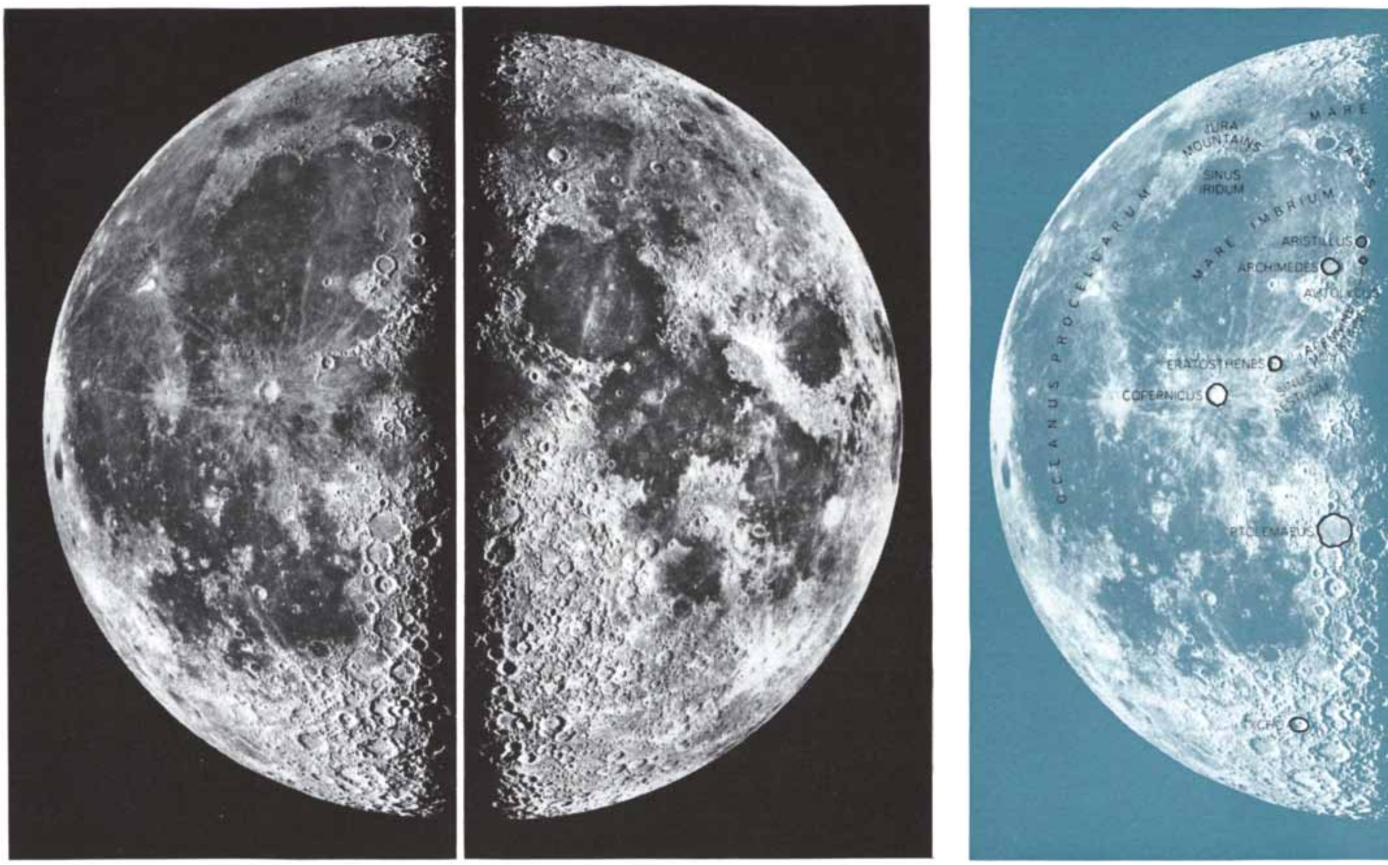
The rays override virtually every feature in their path. Under full-moon illumination, when the rays are most easily observed, Eratosthenes is found to be among the features overlain by the rays of Copernicus; the rays extend up the rim and also run across the floor of Eratosthenes. In fact, even part



GUERICKE AREA of the moon appears in a photograph made with the 100-inch reflecting telescope on Mount Wilson. The photograph indicates the amount of lunar detail visible in terrestrial observation, which is limited by the turbulence of the earth's atmosphere.



SAME AREA appears in a photograph made on July 31 from the *Ranger* 7 space vehicle at a distance of about 470 miles from the moon. The field of view in this photograph and photograph at top differ somewhat because angle of view and illumination were not identical.



FACE OF MOON as seen from the earth is shown in these photographs made with the 36-inch telescope at the Lick Observatory. The two hemispheres of the moon were photographed separately in order to obtain the best illumination in each. The photographs are printed so that lunar features appear as they would in a telescope that did not invert them. In the reproduction of the photographs at right the major features discussed in this article are identified. The article is chiefly concerned with the Mare Imbrium

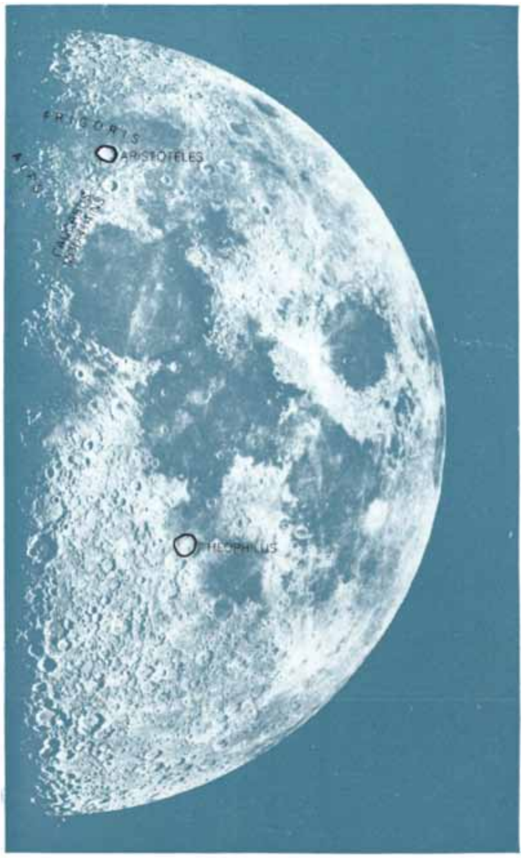
of the continuous bright rim of Copernicus overlaps the rim of Eratosthenes. From this superposition, then, it can be seen that Copernicus and its associated rim-and-ray system and secondary craters are younger than Eratosthenes. The rim-and-ray system constitutes a deposit that partly conceals the underlying and preexisting parts of the moon's surface. We have established Copernicus as the characteristic locality for the whole system of rim deposits of ray craters on the moon. The primary ray craters vary in age from one crater to the next, but they are nearly everywhere younger than other features on the moon's surface. My colleagues and I refer to the period of time during which these craters and their associated rim deposits were formed as the Copernican period.

Eratosthenes proves, on close examination, to be a crater much like Aristoteles and Copernicus. It has terraced inner walls, a hummocky rim and a distinctive pattern of secondaries. Unlike Copernicus and Aristoteles, however, Eratosthenes has no readily visible rays. The significant thing about Eratosthenes is the stratigraphic clue provided by the rim deposit and the secondary craters: they are superposed on the dark, smooth material in the Mare Imbrium north of the crater and in the Sinus Aestuum to the south. Clearly Eratosthenes is younger than the stuff of the maria. This stratigraphic succession holds wherever one studies the lunar surface: the mare material is partly overlain by rim material from dark, rayless craters such as Eratosthenes, and this dark crater-rim material is in turn overlain by material from craters of Copernican age. We refer all rim deposits of rayless craters that are superposed on mare material to the Eratosthenian system, and the period of time during which they were formed is called the Eratosthenian period.

For the next steps backward in lunar geologic time I invite the reader to examine the photograph at top left on page 44. It shows the crater Archimedes in the Mare Imbrium. One can see from the photograph that the smooth mare surface on the west, north and east sides of the crater comes very close to the crest of Archimedes' rim, and that mare material also occupies most of the crater interior. In the photograph at top right on page 43 one can see that the hummocky rim is exposed on the south side of the crater and that part of the swarm of secondary craters associated with Archimedes can be traced on the rolling surface that extends south into the Apennine Mountains. None of the Archimedean secondaries, however, are superposed on the mare; the pattern terminates abruptly at the margin of the mare.

Thus the relative age of three stratigraphic units can be established: (1) the material that forms the rolling upland in which the secondaries of Archimedes are excavated, (2) the crater-rim deposit of Archimedes and (3) the mare material. It is evident that the crater was created after the material of the upland was formed but before the mare material appeared. Similarly, the occurrence on the mare surface of rays and secondaries of the nearby craters Aristillus and Autolycus shows that they were formed at a more recent time than the mare.

Now I shall ask the reader to back off, as it were, and consider the region



and its environs. "Mare" is the Latin word for "sea," which the dark areas of the moon resemble. "Sinus" means "bay." Lunar craters are usually named for historical figures.

of the Mare Imbrium as a whole, bearing in mind what I have said about the typical configuration of large lunar craters. It is apparent in the photographs at the left and in the middle at the top of the next two pages that the ring of mountains around the Mare Imbrium, including the Apennine and Caucasus Mountains and the Alps, bears a strong resemblance to the rim of a crater. That, indeed, is what the Mare Imbrium seems to occupy: an enormous crater resembling Archimedes but an order of magnitude larger. The topography of the mountain ring is conspicuously hummocky, like the rim deposits of Aristoteles, Copernicus and Archimedes, but on a coarser scale.

Within the Mare Imbrium is a circle of low, isolated peaks about 500 miles in diameter. The circle defines the edge of a deep basin, filled with mare material, that has been called the Inner Imbrium Basin. Nothing older than mare material is exposed within the Inner Imbrium Basin. The mountain ring defines the larger Imbrium Basin, the center of which is slightly offset from the center of the Inner Imbrium Basin. The hummocky topography of the mountain rim can be traced out from the edge of the inner basin to a distance a little greater than the diameter of the basin. At this distance many large, vaguely defined craters covered with hummocky material can be discerned. At larger distances from the Imbrium Basin the hummocky material becomes rolling and relatively smooth, and smaller and smaller craters can be found that are covered with a layer of such material. This layer extends as far south as the crater Ptolemaeus, which is almost completely blanketed by it. Some craters as small as a few miles across on the floor of Ptolemaeus, and covered with the smooth layer, can just be made out in good photographs as very shallow depressions with gently rounded rims. The Imbrium Basin is thus encompassed by a great regional deposit that is coarsely hummocky at the crest of the mountain ring and smooth farther from the center of the basin.

My colleague Richard E. Eggleton has estimated the variations in thickness of this deposit south of the Imbrium Basin by ascertaining the diameters of the smallest buried craters with a detectable outline on the surface of the deposit. The technique provides an idea of the thickness of the deposit because there is a relatively consistent relation between diameter and depth of small, young primary craters that have not been buried. Hence the smaller the buried crater that can be detected, the thinner the covering layer. Eggleton found a thinning of the regional layer with increasing distance from the Imbrium Basin.

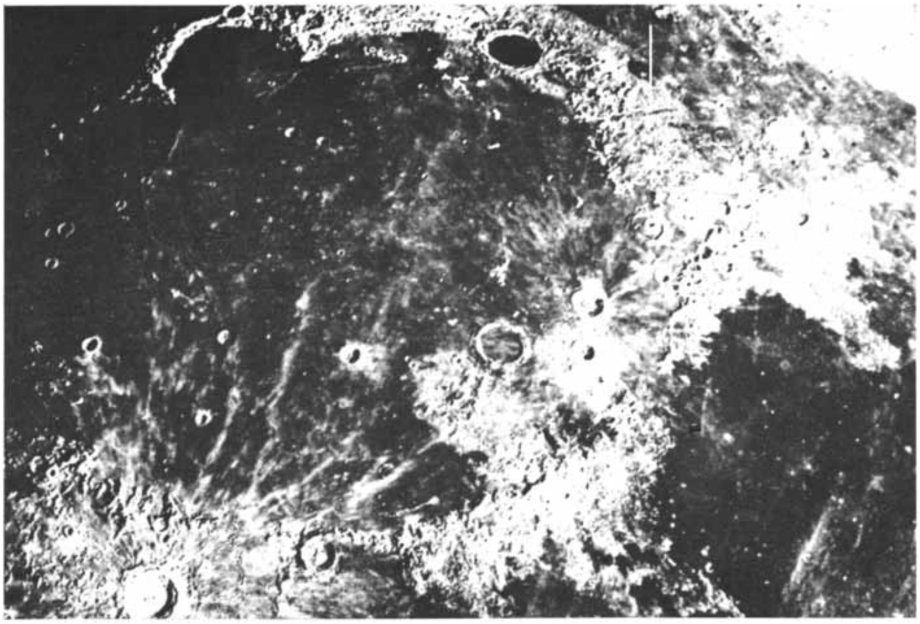
This layer we refer to as the Apenninian series because of the extensive exposure of the material in the Apennine Mountains. The top of the layer is the surface on which the secondary craters of Archimedes are formed. The rim deposits of all craters younger than the Apenninian series but partly or wholly covered by mare material constitute, with the mare material that covers them, the Archimedean series. The Apenninian series and the Archimedean series combined make up the Imbrian system, and the period of time represented by the deposition of the entire Imbrian system is the Imbrian period [*see illustration below*]. Imbrian time is divided into two epochs, corresponding to the two series of deposits that make up the Imbrian period. The rocks and features of the lunar surface on which the Imbrian system was deposited are referred to as pre-Imbrian.

It is now appropriate to recapitulate the lunar geology that can be deciphered in the region of the Mare Imbrium from earliest times to the latest, occasionally venturing some speculation about the nature of the forces that shaped the lunar surface. I should like to emphasize the distinction between what I have said up to now, which sets out the stratigraphic relations that can be demonstrated by examination of the lunar surface, and what I shall say next, part of which must be classified as educated guessing.

At some distance from the Imbrium Basin pre-Imbrian terrain can be seen to have a complex relief that includes ridges, valleys and craters. The ancient rocks of this terrain probably have diverse origins and a complex history. Recent lunar geologic mapping by my colleagues in the U.S. Geological Survey has shown that the pre-Imbrian rocks can be divided into several stratigraphic units where they are exposed in the lunar southern hemisphere beyond the margin of the Apenninian series. Some of these units are regional deposits, like

PERIOD	EPOCH	EVENTS
COPERNICAN		Formation of ray craters.
ERATOSTHENIAN		Formation of craters of which rays are no longer visible.
IMBRIAN	ARCHIMEDEAN	Extensive deposition of mare material of the Procellarum Group. Formation of post-Apenninian craters older than at least part of the Procellarum Group.
	APENNINIAN	Events related to the formation of the Mare Imbrium basin.
PRE-IMBRIAN		Not yet formally divided.

LUNAR TIME PERIODS are shown according to the system established by the U.S. Geological Survey. The chart shows the periods chronologically, with the earliest at bottom.



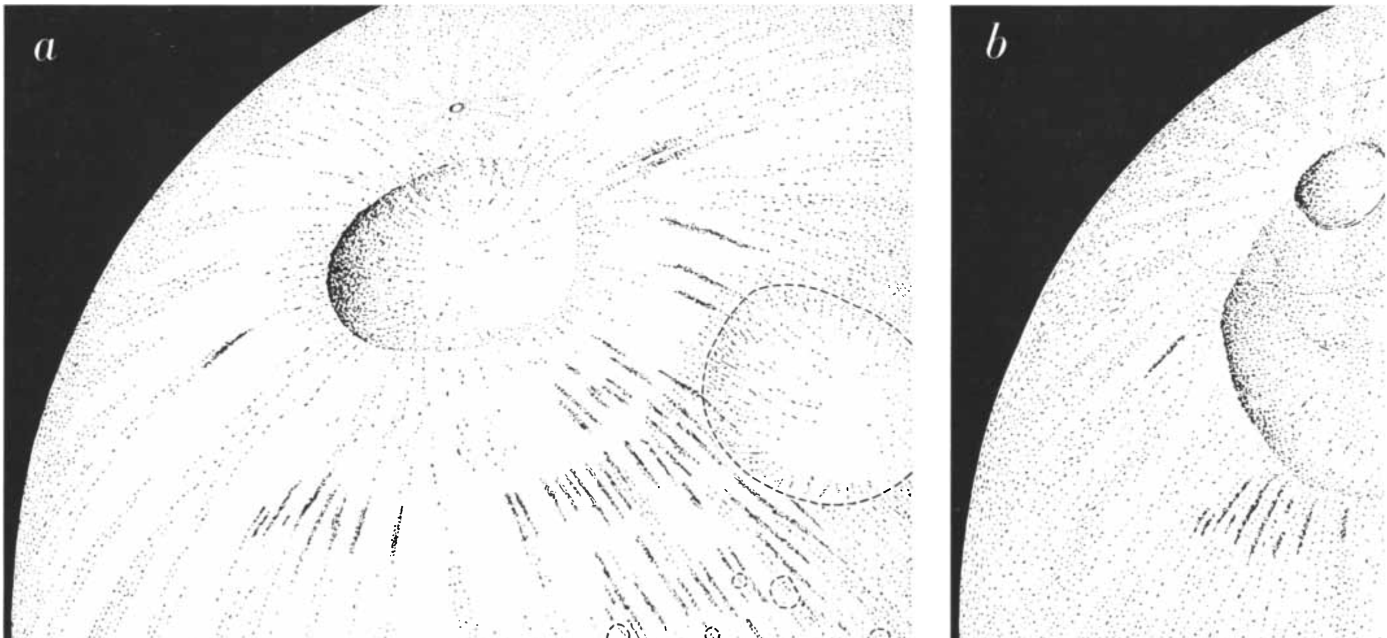
IMBRIAN EVENT is reflected in the environs of the Mare Imbrium. The hummocky terrain atop the adjacent mountains and the tendency of prominent radial features such as Alpine Valley (*arrow*) to intersect in the mare suggest that mare occupies what was originally a large crater.

EARLY ARCHIMEDEAN epoch included the event that created crater now occupied by Sinus Iridum, which

the Apenninian, surrounding huge basins still older than the Imbrium Basin.

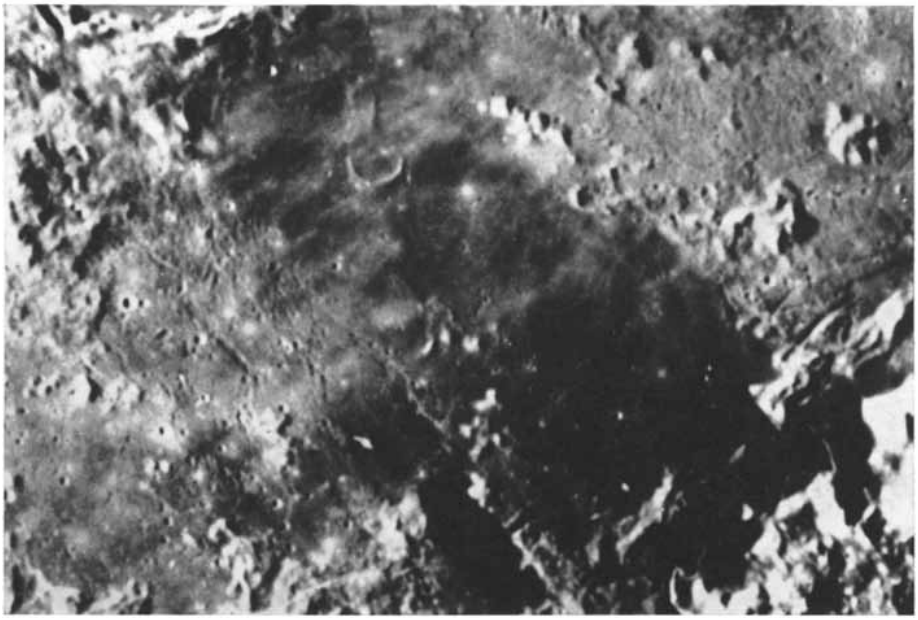
The formation of the Imbrium Basin and the deposition of the Apenninian series are the first events that can be documented in detail in the region immediately surrounding the Mare Imbrium. Since the basin, with its great mountainous rim and surrounding hummocky deposits, appears to be essentially a scaled-up version of a crater such as Aristoteles or Copernicus (or, more specifically, such as Archimedes, which is also partly filled with mare material), one can attack the question of its origin by considering the origin of smaller and younger craters.

The characteristic hummocky rim deposit of primary craters can be explained as material ejected from the crater by forces generated during impact. The distinctive pattern of rays and secondary craters around the primary craters suggests that the secondaries are created by the impact of clots of lunar material ejected from the primaries. Rays, then, are composed of material splashed out of secondaries. Similar features appear in patterns around terrestrial craters known to have been made by the im-



SEQUENCE OF EVENTS in the Mare Imbrium area is depicted schematically. At *a* is the situation immediately after the Imbrian event; at top is the Inner Imbrium Basin, with Alpine Valley nearby and other linear features associated with the Imbrian event

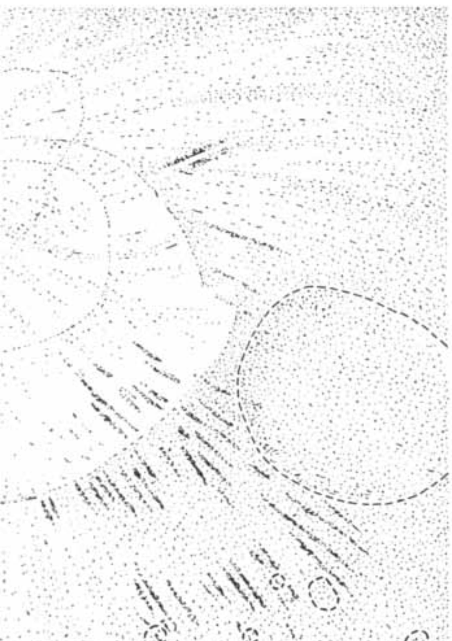
is bulge near top left. Secondary craters from Iridum event are superposed on material of Imbrian event.

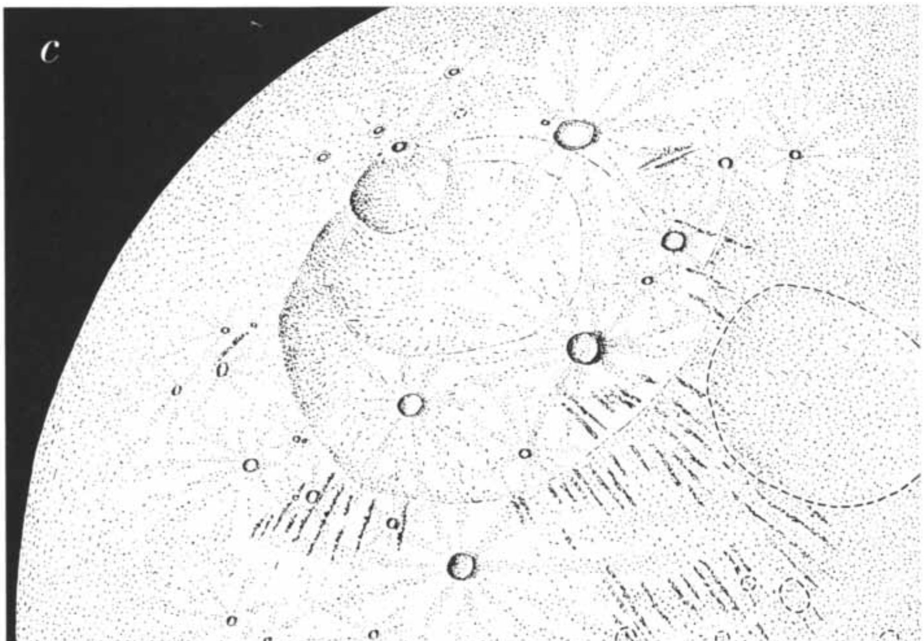


LATER ARCHIMEDEAN TIME is represented by Archimedes, the southern rim of which appears at top left. Its secondary craters appear abundantly on Imbrian material directly below the crater, but they stop abruptly at mare material (*lower right*), showing a clear stratigraphic relation.

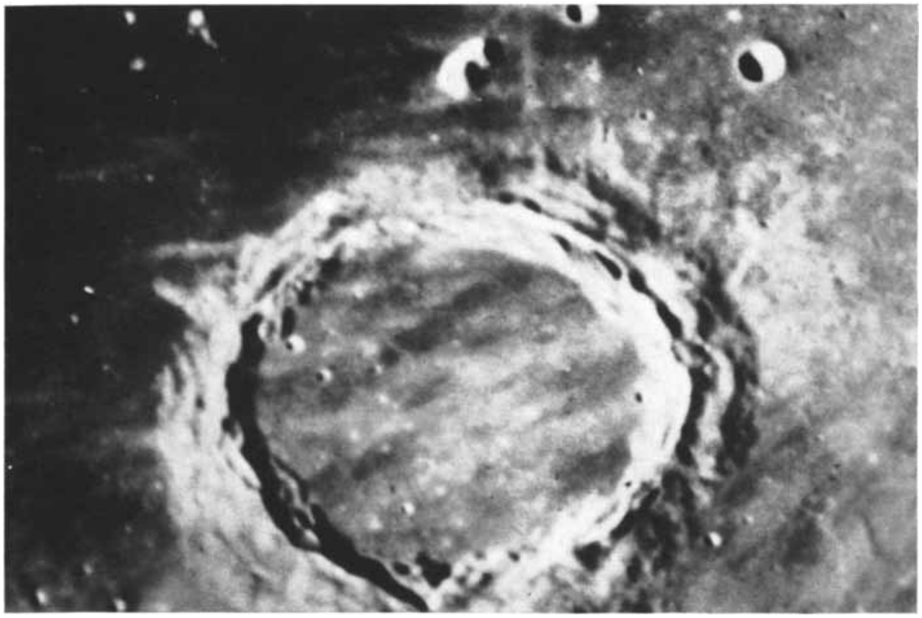
pact of interplanetary bodies; the features also appear around the man-made craters produced by chemical or nuclear explosions. Hummocky rims grading out into low ridges, and secondaries in arc- and loop-shaped rays, do not occur around any known terrestrial volcanic craters that otherwise resemble lunar craters. The Imbrium Basin was also probably formed by impact, but by a body an order of magnitude larger than those that formed Aristoteles and Copernicus.

Many smaller craters were next formed on the Imbrium Basin and its surrounding Apenninian rim during the Archimedean epoch. Among the largest of the Archimedean craters is the Sinus Iridum, whose rim is the Jura Mountains and whose secondaries are scattered far to the north, on both sides of the Mare Frigoris. The Sinus Iridum was formed early in the Archimedean epoch; at least one Archimedean crater can be distinguished that was buried under the Jura Mountain rim deposits. Several younger Archimedean craters are superposed on the Jura Mountains. These relations are outlined in the series





shown overriding older features. At *b* is the situation a short time later, after the Iridum event; slumping has produced an outer basin around the Inner Imbrium Basin. At *c* is the situation in later Archimedean time, before the deposition of mare material.



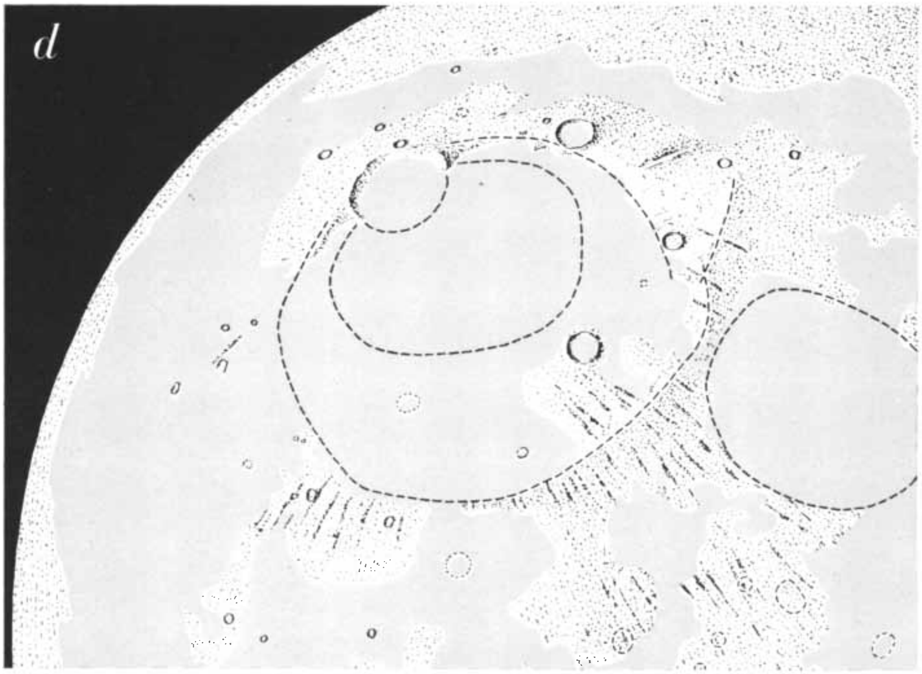
FLOODING BY MARE appears clearly in this closer view of Archimedes. Presence of mare material both inside and outside the crater shows that Archimedes predates the mare. Deposits from nearby craters Aristillus and Autolycus appear on mare material; they are younger than mare.

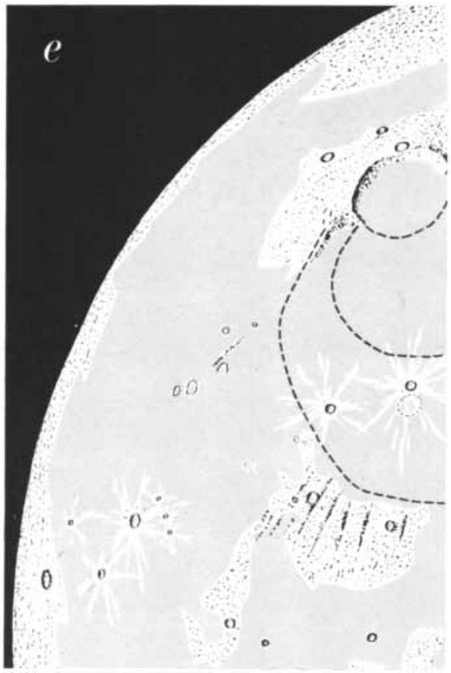
CRATER ARISTOTELES appears with unusual clarity in this photograph. Aristoteles is a ray crater of

of illustrations at the bottom of the preceding two pages.

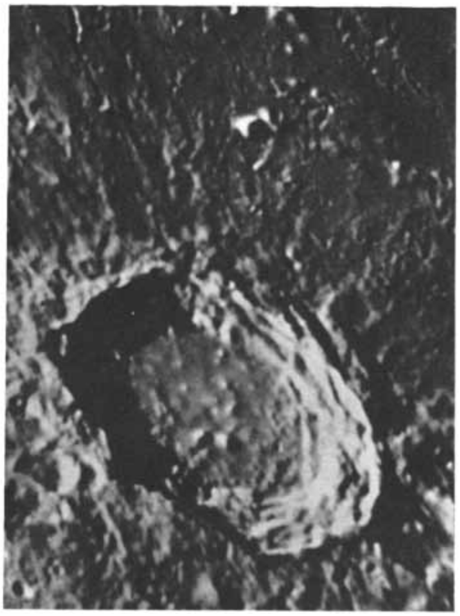
A great crescent-shaped segment of the lunar crust lies between the Inner Imbrium Basin and the outer mountain ring directly on the opposite side of the inner basin from the Sinus Iridum. I believe the edge of the inner basin represents the crest of the original Imbrium crater rim, and that the crescent-shaped segment of the original rim collapsed to form the present larger Imbrium Basin. This collapse may have been triggered by the event that formed the Sinus Iridum. The crescent may be somewhat analogous, on a much larger scale, to the terraces, probably formed by slumping, on the inner walls of primary craters such as Aristoteles.

Late in the Archimedean epoch the widespread filling of lower-lying areas by the mare material occurred; it is depicted in the first of the series of illustrations below. We have called this material the Procellarum Group from the most extensive exposure of the material in the Oceanus Procellarum. It is noteworthy that the mare material follows rather closely the curvature of the moon and fills to a nearly common level the





LATER SEQUENCES of lunar geologic history are continued from the preceding two pages. At *d* is the scene after low-lying areas had been filled in with mare material at a time of apparently widespread flooding. The succeeding Eratosthenian period is de-



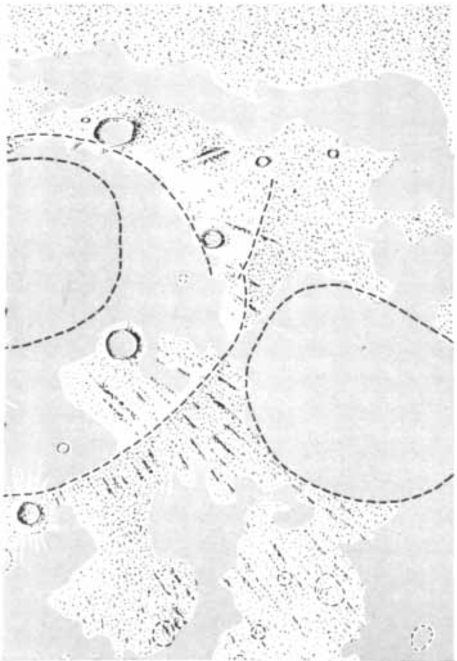
Copernican age; rays do not show in this illumination. Rim relief and pattern of secondary craters are clear.

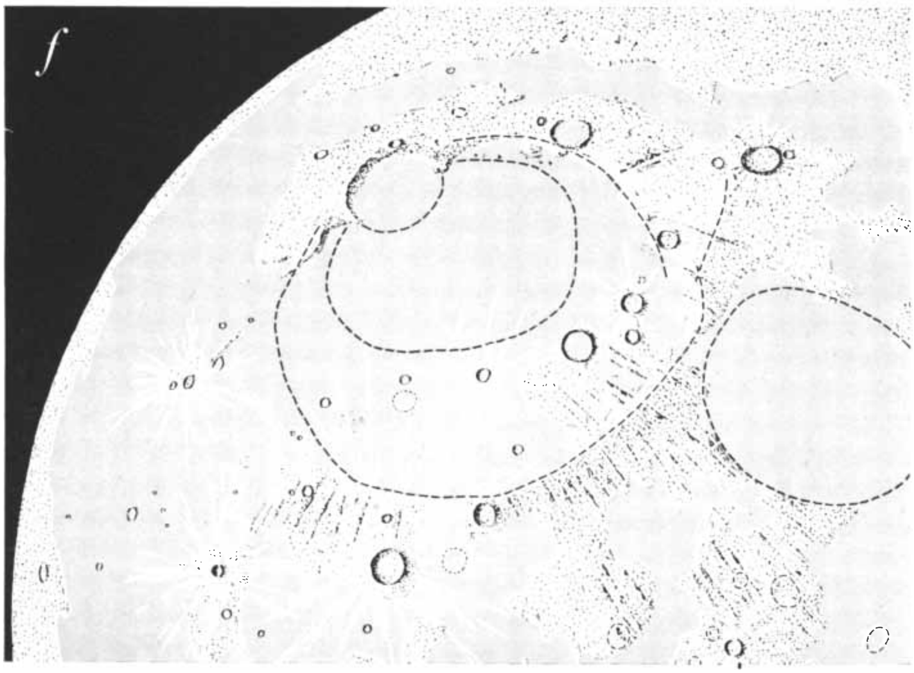
COPERNICUS AND ERATOSTHENES appear in a light that brings out the relief associated with them. The white streaks are rays from Copernicus (*left*). In other photographs the rays can be seen to override Eratosthenes. It is evident that Copernicus is younger than Eratosthenes.

preexisting depressions in the lunar surface, such as the floor of Archimedes, wherever they extend below the level finally reached by the mare material.

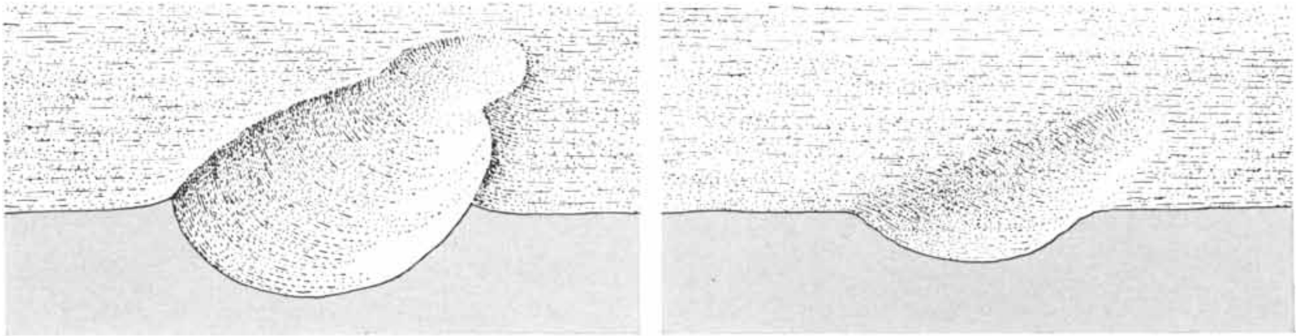
To account for this phenomenon of filling of low areas to what appears to have been an approximately hydrostatic level, one must adopt the hypothesis that the mare material was once fluid or fluidized and that it rose from the interior of the moon. Probably it was volcanic material, extruded on the surface through many vents. The general flooding by mare material of nearly all significant depressions present in late Imbrian time indicates the occurrence at one time of widespread melting inside the moon. The melting took place long after most of the depressions filled by mare material were formed. Much of the emplacement of the mare material appears to have been completed at about the same time, since the distribution of Eratosthenian and Copernican primary craters on the mare material of the lunar surface is relatively uniform.

It is significant that the lunar mountains such as the Apenninian, which are more than 20,000 feet high, did not collapse at the time of the widespread in-





pictured at *e*; it is distinguished by craters whose radial features are superposed on the mare material. At *f* is the present situation; craters of Copernican age have rim deposits and radial features, particularly rays, that overlie most other features and so are younger.



EFFECT OF EROSION is depicted in this comparison of a Copernican secondary crater (*left*) with an Eratosthenian secondary crater. Among the mechanisms that could account for the erosion are repeated secondary cratering aided by bombardment by micrometeorites. The erosion necessary to produce an effect such as that depicted, eliminating a Copernican rim, is between 30 and 60 feet.

ternal melting. The persistence of the relief suggests that the moon, like the earth, is a differentiated body, having a light crust overlying a denser material. My argument in favor of this hypothesis is that the mountains must have stood because they were buoyed up isostatically; in effect they "floated" on a layer with a higher specific gravity than the mountain rocks.

The Eratosthenian system consists of the floor material and the rim deposits of Eratosthenes and a large number of other craters and their associated secondaries that overlie the mare material and other Imbrian material. They are in turn overlain by material from craters of Copernican age. In contrast to the Copernican craters, the Eratosthenian craters lack visible rays. An examination of the lunar ray patterns around different craters discloses a wide range of reflectivity of both the rays and the bright halo of the crater rim. Copernicus, Aristillus and Theophilus illustrate a sequence of craters accompanied by rays ranging successively from bright to faint. Wherever a rayless crater or one with very faint rays occurs in an area with bright rays from another crater, the bright rays are invariably superposed on the dark crater or the dimmer rays. In almost no instance is a darker ray pattern of one crater superposed on a brighter ray of another. Sequences of this kind suggest that rays fade with age. Eratosthenes is evidently at the other end of the spectrum from Copernicus; the Eratosthenian craters probably all had rays that have since disappeared, although the secondary craters are still readily visible.

Several processes could account for the fading of the rays. Bombardment by high-energy radiation could cause darkening of the surface material. One of the most likely processes is erosion and mixing of the ray material with the underlying dark material by the bombardment of meteorites and the fragments that dug the secondary craters. The *Ranger* photographs provided evidence on this question by showing that most very small lunar craters are rounded at the edges and that the moon's mare surface is abundantly peppered with small, secondary craters that range down to the smallest objects that *Ranger*'s cameras were able to resolve—objects as little as 1½ feet in diameter. These small secondary craters contribute to the erosion and redistribution of material of the older and larger craters.

Prior to the flight of *Ranger* my colleague Michael Carr made a study of an area in the Mare Imbrium where the secondaries from Copernicus and Eratosthenes that can be resolved by earthbound telescopes overlap. The Copernican secondaries, which are younger, have relatively sharp raised rims, whereas the Eratosthenian craters are almost invariably rimless [*see illustration above*]. The amount of wearing down needed to eliminate the rim of the typical Copernican secondary that can be resolved by telescopes is about 30 to 60 feet. This can be completely accounted for by repeated cratering by very small secondaries. Such cratering by fragments striking the moon at low angles transports material from areas of positive relief, fills in areas of negative relief and leaves the original forms rounded off.

The Copernican system consists chiefly of floor, rim and ray deposits of ray craters. The *Ranger* photographs have tended to confirm the ballistic, or "splash," model I have been discussing for the origin of the rays. In the high-resolution *Ranger* photographs the rays are revealed to be interspersed with a great many small secondary craters. The largest of the secondaries tend to lie at the near ends of ray elements, the ends nearest the primary crater. Precisely such a pattern of ray elements and secondaries occurs on earth around man-made nuclear craters.

There is one exception to the finding that the deposits of ray craters are the most recent, or stratigraphically uppermost, deposits on the moon. Certain small craters with dark, low, smooth rims, which we have called dark-halo craters, can be found in clusters around Copernicus, around Theophilus, which is a crater much like Copernicus, and in other restricted locations on the moon. Such craters are locally superposed on Copernican crater-rim deposits and are younger than those deposits. In some cases they occur along a telescopically resolvable rille: a long, narrow trench on the moon's surface. These dark-halo craters resemble terrestrial craters of the maar type (a crater of explosive origin that does not produce lava); in my opinion they are the products of volcanic action. One of the characteristic features of volcanism is that it takes place in distinct areas and does not occur randomly everywhere at a given period in geologic time. Such a pattern of local clustering appears in the location of the dark-halo craters.

With the development of a lunar stratigraphy and a lunar geologic time scale it becomes desirable to determine if a correlation can be established between lunar and terrestrial geologic time. One means of doing this at present is to estimate the rate of cratering that has occurred on the earth and to determine what the rate of cratering should have been on the moon. Since the earth and the moon have been exposed to essentially the same flux of interplanetary objects over most of geologic time, an extrapolation of the estimated terrestrial cratering rate backward in time for the moon would make it possible to put some broad limits on the age of lunar features. In such an extrapolation it is of course necessary to make appropriate allowance for differences between the earth and the moon in size, gravitational potential and atmosphere.

We and other investigators have undertaken by various means to estimate the rate of cratering on the earth due to the impact of interplanetary objects. One approach I have taken has been to study the Mississippi Valley region, which has been geologically stable since Cambrian time, or for approximately the past 500 million years, to determine the distribution of impact structures. Another approach has been to ascertain the number and size of meteorites observed to have fallen in populated areas over the past 50 years.

By the study of the meteorite inflow and the geologic record of cratering one can arrive at a series of estimates about the rate of terrestrial cratering. It can be expected that an object the size of the meteorite that fell in Siberia in 1947 (300 to 500 tons in mass) and formed a "strewn field" of small craters will strike the land area of the earth about once every 20 years. A crater such as Meteor Crater in Arizona, which is a little less than a mile across, can be expected to be formed on the North American continent on the order of once every 10,000 years. A new crater the size of the giant Ries Basin in Germany, which is about 18 miles in diameter, can be expected on the continental areas of the earth about once every five million years.

One can then extrapolate the size and frequency distribution of terrestrial craters back over the 4.5 billion years of the earth's existence and ascertain if the calculated rate would account for the primary craters on the moon. Alternatively, one can take the size and frequency distribution of primary lunar craters and divide it by the age of the earth to see if the terrestrial and lunar cratering rates match. Either method accounts reasonably well for the number of primary craters appearing on the lunar maria, that is, the craters of Eratosthenian and Copernican age.

The extrapolation I have described requires allowing a very long time to account for the total number of Eratosthenian and Copernican craters. On this basis it is necessary to estimate that the oldest craters of the Copernican system date back about two billion years and those of the Eratosthenian system several billion years. On the basis of these estimates, if one assumes that the moon and the earth are the same age, the two most recent periods of lunar geology have occupied the greater part of lunar history.

If this dating is correct, however, it does not leave enough time to account for all the rest of the lunar primary craters at a constant rate of cratering. This is particularly evident when one studies the distribution of craters and finds that there are as many craters of Archimedean age per unit of area where the Imbrian system is exposed as of Eratosthenian and Copernican ages combined. Furthermore, there are 10 times as many large craters per unit area on the exposed pre-Imbrian terrain in the southern part of the moon as there are Copernican and Eratosthenian craters. The discrepancy suggests that the rate of cratering was much higher in the earlier stages of lunar history than it has been since.

A hypothesis I prefer for the purpose of explaining this situation is that in their earliest stages the moon and the earth were encountering in space debris left over after the consolidation of the planets. These hypothetical objects have been called planetesimals. It would take about 100 million years for the earth and the moon to sweep up the planetesimals in their paths around the sun. Imbrian and pre-Imbrian terrain may bear the record of the terminal phase of the sweepup—a record that on the earth has been lost by erosion, sedimentation and mountain-building.

Objects big enough (several tens of miles in diameter) to form a crater the size of the Inner Imbrium Basin may have been represented among the planetesimals. In later geologic time the objects forming the largest craters were probably asteroids and the nuclei of comets. On the basis of the near approaches of small asteroids to the earth and moon that have been observed in the past 35 years, one would expect approximately the number of hits needed to form the largest Copernican and Eratosthenian craters.

This account of lunar geology must of necessity be only a sketchy preview of the fascinating story that will unfold as the U.S. and Soviet lunar exploration programs evolve. The U.S. program calls for the first attempted landings of an unmanned exploratory vehicle called *Surveyor* on the moon within the next two years and a series of Lunar Orbiter flights starting at about the same time. These latter spacecraft will orbit the moon closely and make photographs with resolution like that obtained in the final *Ranger* pictures but covering much larger areas of the lunar surface. The culmination of all these efforts will come when the first manned vehicle reaches the moon, presumably before the end of this decade, and the occupants can test directly some of the hypotheses presented here.

EVIDENCE OF EROSION appears in this *Ranger 7* photograph of secondary craters in a ray of the crater Tycho. The evidence is in the rounding of nearly all the craters. *Ranger* made this photograph at a distance of approximately 20 miles from the surface of the moon.

THREE-PIGMENT COLOR VISION

Direct measurements of the absorption of light by individual cells show that color is discriminated in vertebrate retinas by three pigments segregated in three kinds of cone receptor

by Edward F. MacNichol, Jr.

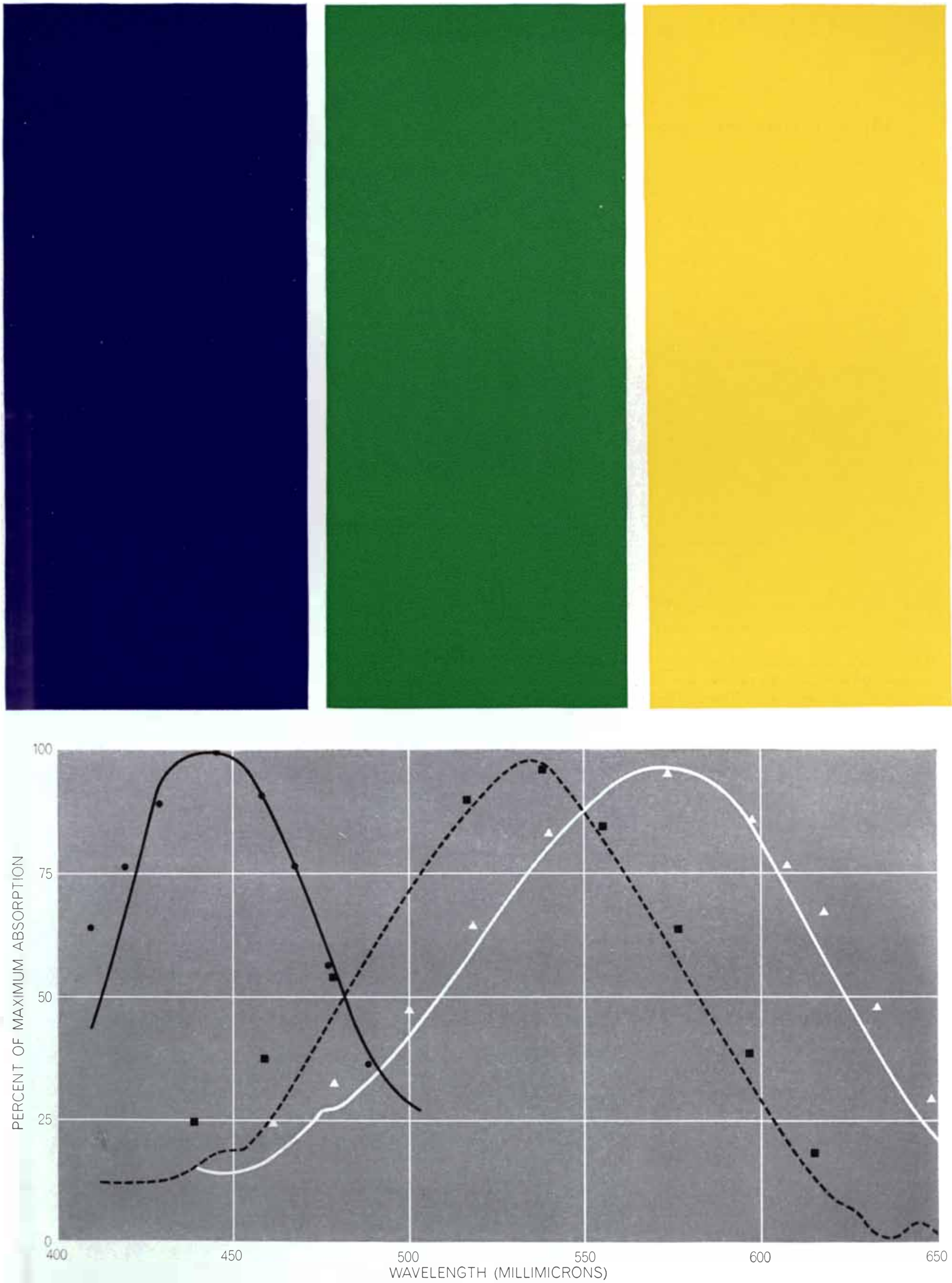
Investigations completed during the past two years have established that color vision in vertebrates is mediated by three light-sensitive pigments segregated in three different kinds of receptor cell in the retina, and that one of these pigments is primarily responsible for sensing blue light, one for sensing green and one for red. These findings solve one of the central problems of color vision: the nature of the primary receptors that discriminate light of various wavelengths. Large questions remain to be answered: How is the information from the receptors coded in the retina? How is it transmitted to the brain? How is it decoded there?

In 1802 the English physicist Thomas Young suggested that the retina probably contains three different kinds of light-sensitive substances, each maximally sensitive in a different region of the spectrum, and that the information from the excitation of each substance is separately transmitted to the brain and there combined to reproduce the colors of the outside world. Over the years investigators accumulated a great deal of information on the mechanisms of vision without being able to prove or disprove Young's simple postulates. They learned that rod-shaped and cone-shaped receptor cells in the retina contain pigments that are bleached by light, that the rods are responsible for vision in faint light and that the cones distinguish colors. Psychophysical experiments, in which a human subject is presented with visual stimuli and asked to tell what he sees, established that any color could be matched by a combination of three colors in different parts of the spectrum. This supported Young's trichromatic theory, but other psychophysical studies seemed to support different theories. The fact is that psychophysical investigation tells only what the visual system can do and not how it does it.

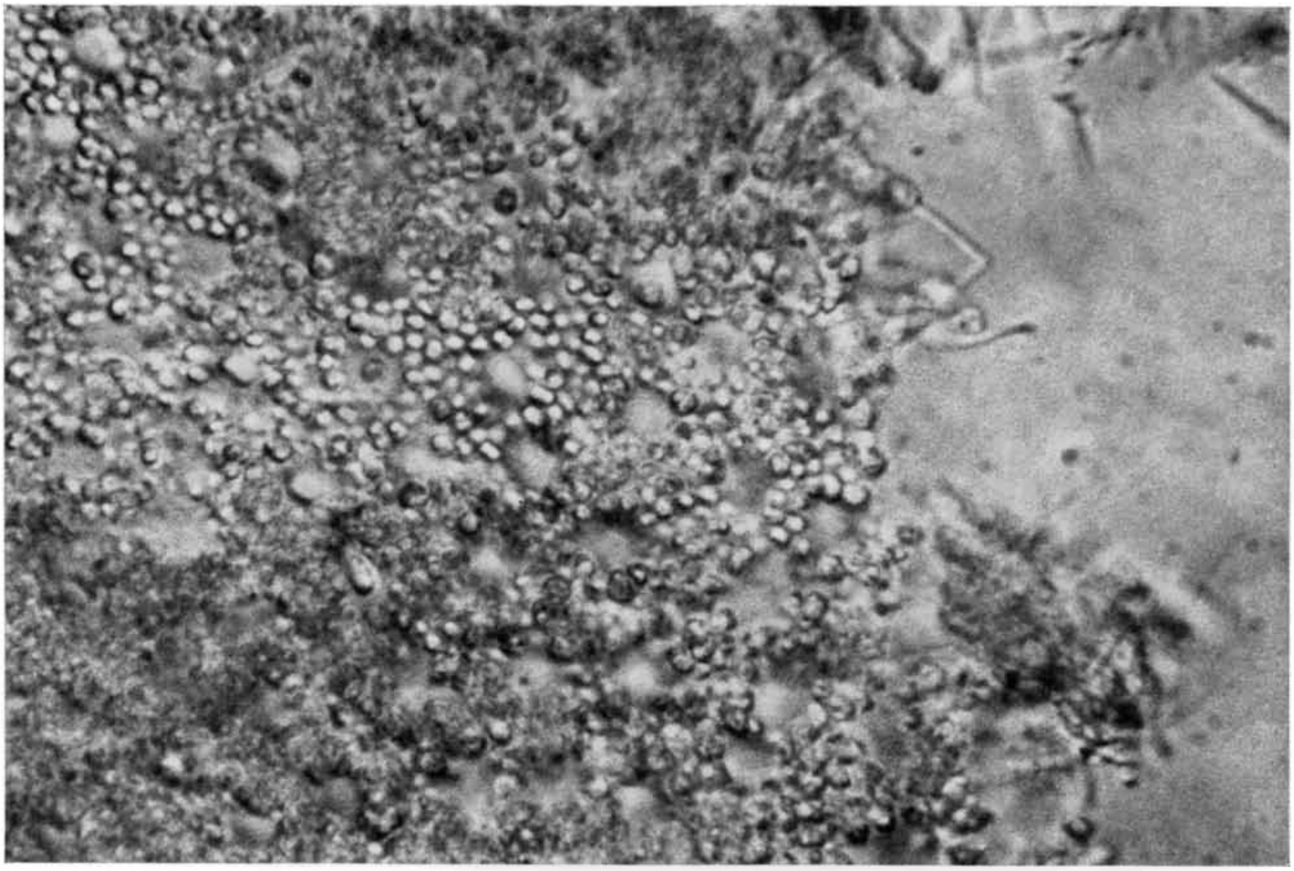
To learn what happens at various steps along the visual pathway one must measure directly the effect of light on the receptor cells and the generation of electrical impulses in the retinal nerve cells. Spectrophotometric measurements of individual cone cells in the retinas of the goldfish, the rhesus monkey and man, conducted in our laboratory at Johns Hopkins University and also at Harvard University and the University of Pennsylvania, have now confirmed Young's three-receptor hypothesis. Electrophysiological studies of nerve cells in the retina, on the other hand, suggest that Young was wrong about the transmission of color information to the brain along three discrete pathways.

A physiologist seeking to learn what message the eye sends the brain, and how, would like to start at the beginning—with the impact of light on a photoreceptor. Unfortunately the lack of suitable techniques ruled out this systematic approach: single-cell spectrophotometry has been possible only in very recent years. Electrophysiological methods, on the other hand, have been applicable since 1938, when H. K. Hartline, then at the University of Pennsylvania, isolated individual optic nerve fibers in the retina of the frog. Each such fiber originates in a single ganglion cell: a nerve cell that collects information from a large number of receptors. Hartline found that the ganglion cells responded to light by emitting showers of nerve impulses, and he classified the cells as "on," "off" or "on-off," depending on whether they responded to the onset or to the end of illumination or to both. In 1939 the Swedish physiologists Ragnar A. Granit and Gunnar Svaetichin and the Finnish physicist Alvar Wilska developed microelectrodes that could record directly from a cell, and since then microelectrode techniques have been used to trace nerve messages through many parts of the visual pathway as well as in other parts of the nervous system.

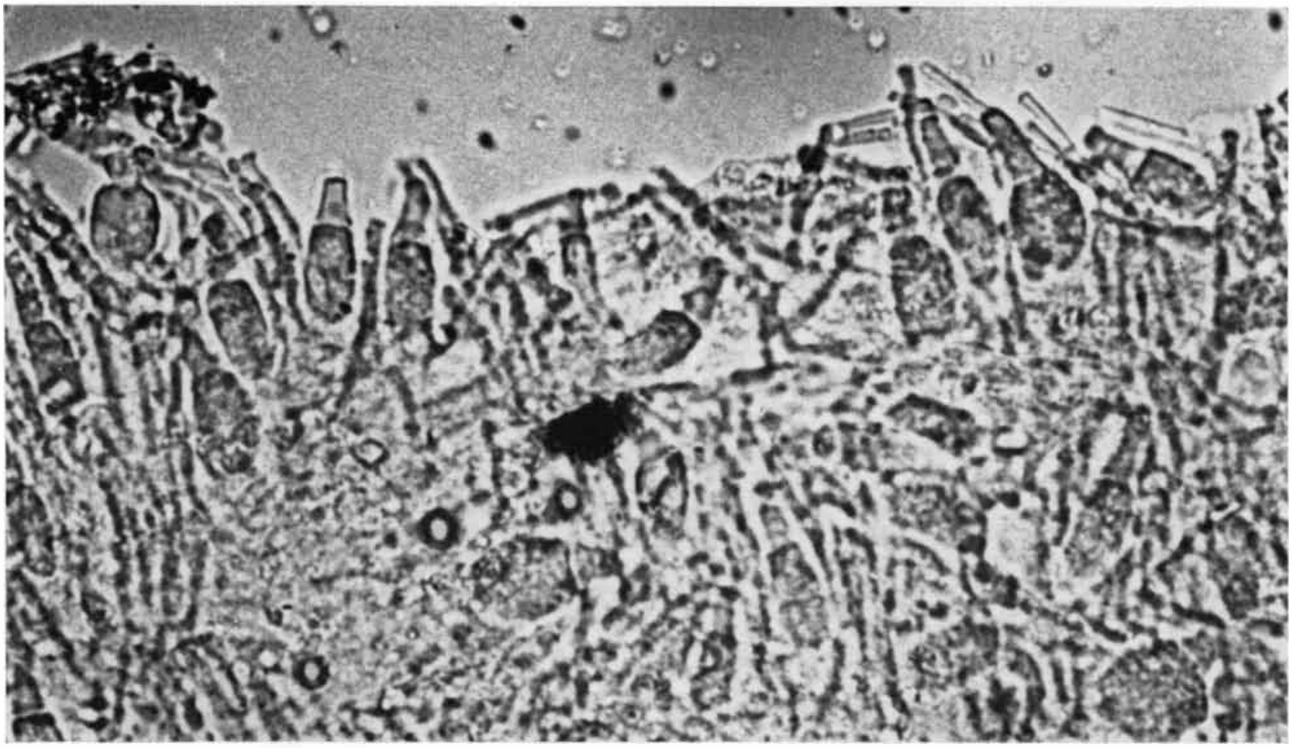
The ganglion cells are "third order" nerve cells, two steps behind the receptor cells along the visual pathway (although in front of them anatomically; the receptor cells are at the back of the translucent retina). With the development of micropipette electrodes after World War II it became possible to probe more precisely into individual cells, and in the 1950's Svaetichin recorded, in the retinas of certain fishes, the most peripheral localized sign of electrical activity discovered up to that time: slow changes in potential in response to flashes of light. These S-potentials, as they came to be called, were of two types and were quite different from anything previously reported. One, which Svaetichin called the luminosity response, took the form of a sizable negative resting potential that increased in the presence of light; the wavelengths that are most effective in this regard are distributed in a broad peak across the center of the spectrum. The luminosity response has since been found in a large number of fishes and in the cat and the frog, and it probably occurs in all vertebrates. The other intraretinal response was similar in some respects: it was a steady negative resting potential that became more strongly negative when the stimulating light was at the short-wavelength, or blue, end of the spectrum. As progressively longer wavelengths were used for illumination, however, the responses diminished in amplitude until a neutral point was reached at which there was no sustained change in potential; any



COLOR VISION in primates is mediated by three cone pigments responsible for sensing light in the blue, green and red portions of the spectrum. Their spectral-sensitivity curves are shown here; the color panels above correspond to the peak sensitivities: 447 millimicrons (blue-violet), 540 (green) and 577 (yellow). Although the "red" receptor peaks in the yellow, it extends far enough into the red to sense red well. Symbols accompanying curves trace shapes of hypothetical pigments with peaks at each wavelength (*see text*).



HUMAN RECEPTOR CELLS are seen end on in this photograph of a retinal specimen on the stage of the spectrophotometer that measures their light absorption. The well-defined small circles are the rod and cone outer segments, the parts of the receptors that contain the visual pigments. The rods are the more closely packed. The specimen is oriented so that the test beam of colored light comes through a cone outer segment (*green spot at middle left*) and the reference beam passes through an empty area (*right*).



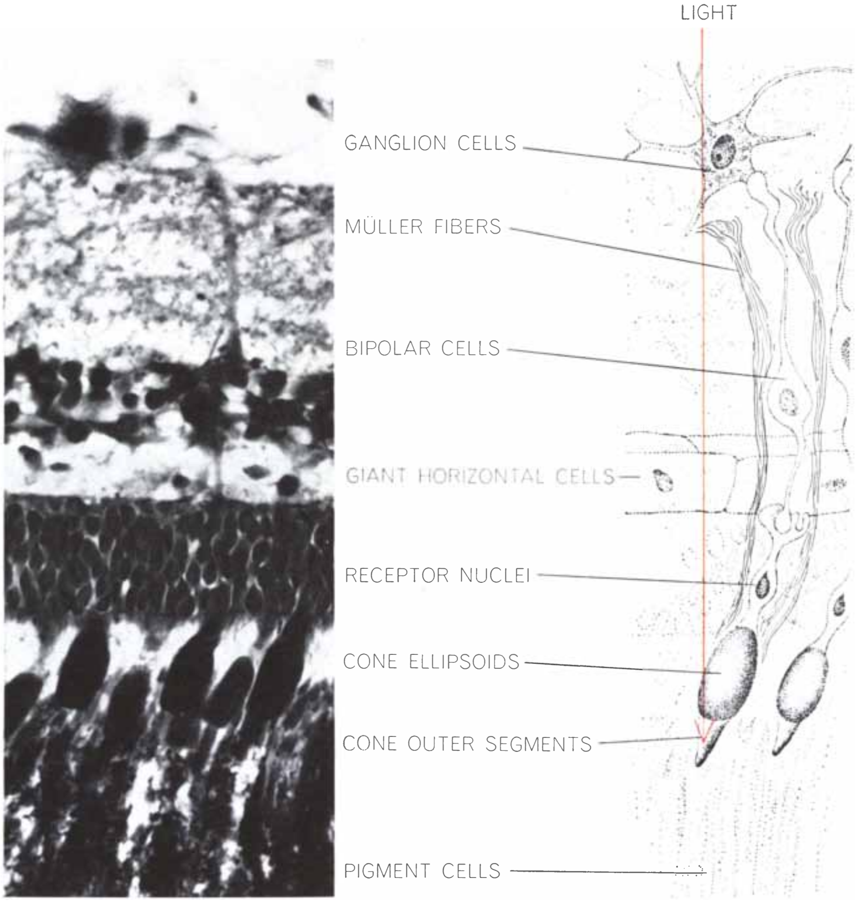
GOLDFISH RECEPTORS are seen from the side in a piece of retina squeezed between two cover slips and placed in the spectrophotometer. The three-micron test and reference beams (*green spots*) pass through a cone outer segment (*upper left*) and a clear area.

increase in wavelength from that point on produced a positive potential! This unusual "chromatic" response suggested a possible mechanism of color vision. In 1957 I joined Svaetichin at the Venezuelan Institute for Scientific Research and we undertook a detailed study of both the nature and the exact source of the S-potentials.

We found the luminosity response in a number of different fishes but the chromatic response only in species that swim at levels to which a broad band of wavelengths, or colors, penetrates: no deeper than about 100 feet. The chromatic response of some fishes showed a negative peak in the green portion of the spectrum and a positive peak in the red; in other species the peaks were in the blue and yellow. Among the species we tested only the mullet (*Mugil*) had both the "green-red" and the "blue-yellow" response. Further analysis of these chromatic responses showed that each was made up of two opposed processes—negative in the blue or green and positive in the yellow or red—combined algebraically. The independence of the two processes was demonstrated by adaptation experiments. Illumination of a retina with a steady blue light, for example, diminished the chromatic response in the short-wavelength region and increased it in the yellow or red. Similar experiments did not change the shape of the luminosity response, only its amplitude. Clearly the chromatic response was made up of two distinct components, whereas the luminosity response was unitary.

To visualize the sites of origin we filled the micropipettes with dye that was forced out into the retinal tissue by electrophoresis after each recording. By sectioning and examining the specimens we could trace the luminosity response to the region just beyond the endings of the cone cells, where the fish retina has a layer of giant horizontal "glial" cells. The large size of the area in which the luminosity response arises, and the fact that it signals a change in brightness anywhere in an extensive area, seem to confirm its origin in these giant cells.

The chromatic response arises in the next layer of the retina. Genyo Mitarai of the University of Nagoya in Japan, working with Svaetichin, has secured evidence that they come from the so-called Müller fibers, which surround the "second order" nerve cells known as bipolar cells. The Müller fibers—like the giant horizontal cells—are glial elements: supporting or nutritive structures often seen in association with nerve cells.

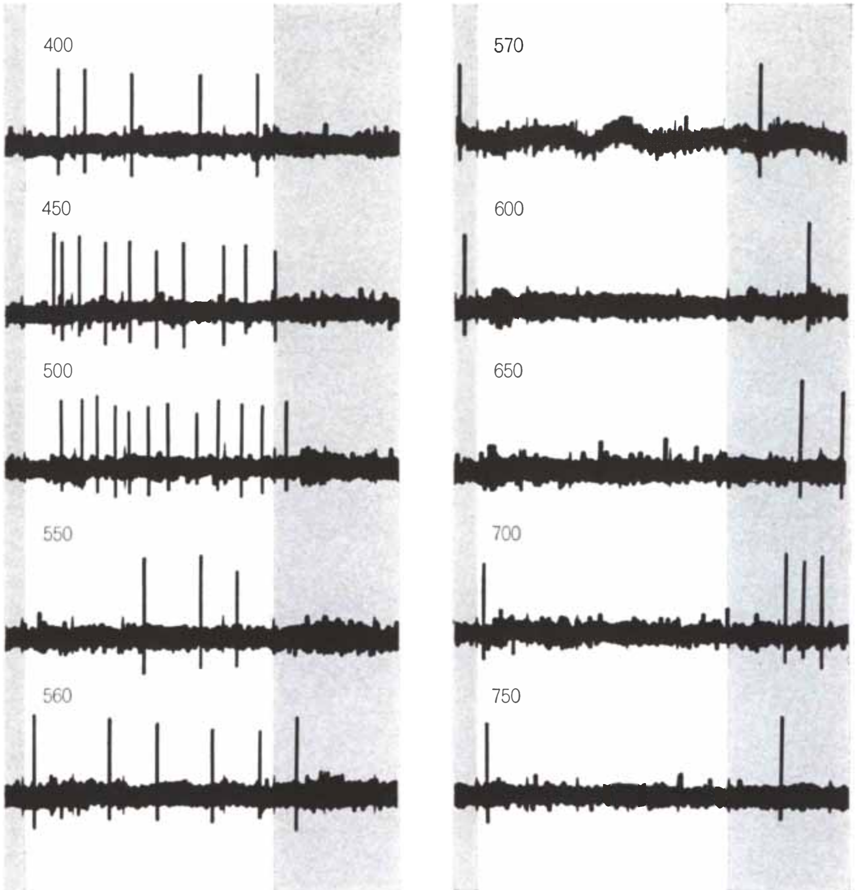


GOLDFISH RETINA, magnified about 1,000 diameters, is seen in section in the photomicrograph (*left*). The various elements of the retina are identified in the drawing (*right*). They have been rendered schematically in an effort to suggest the connections between them on the basis of the information available from recent electron microscope studies.

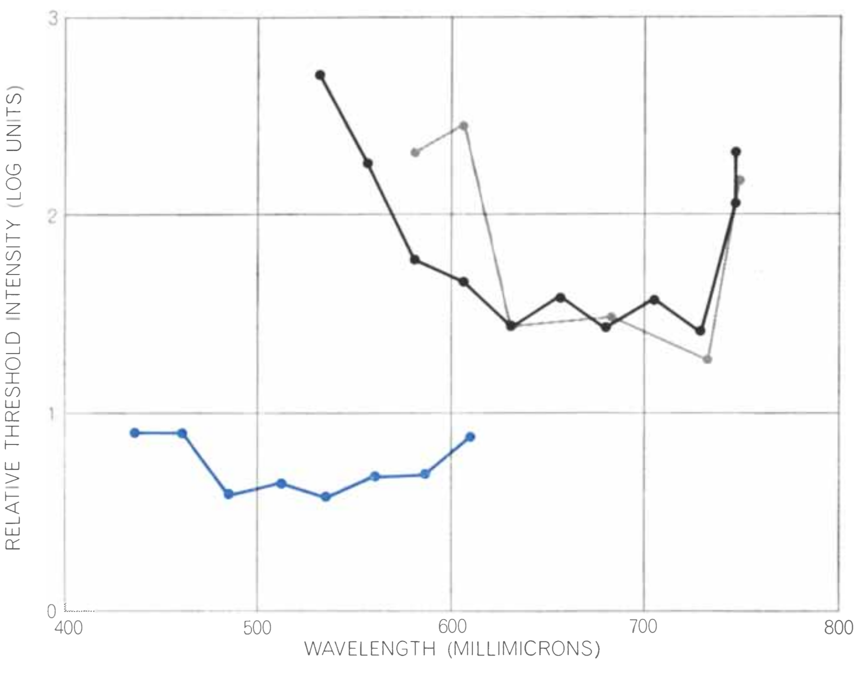
The S-potentials are quite different from the shower of short-lived "spike" impulses ordinarily emitted by nerve cells; Svaetichin has suggested that these slow changes in potential are signs of metabolic changes in the glial structures in which they originate, induced by the activity of adjacent nerve cells and able in turn to alter the nerve cells' activity. Glia have usually been assumed to play a passive role in the nervous system, but Holger Hydén of the University of Göteborg has shown that metabolic events in glial cells are correlated with certain forms of nervous activity and may even control them [see "Satellite Cells in the Nervous System," by Holger Hydén; Scientific American, December, 1961]. This is a challenging area for further experimentation.

Whatever their exact explanation, if these intraretinal S-potentials did have something to do with color vision, we thought they should be correlated with the discharge patterns of the ganglion cells, which appear to be the only source of messages from the retina to the brain. Russel L. DeValois of Indiana University had found that spontaneously active nerve cells in a visual center of the monkey brain increase their rate of discharge when the eye is stimulated by light at one end of the spectrum and decrease it when the eye is stimulated by light at the other end. No one, however, had obtained chromatic responses from the monkey retina for comparison. Together with M. L. Wolbarsht and H. G. Wagner of the Naval Medical Research Institute I studied the effects of wavelength on the responses of retinal ganglion cells in the goldfish (*Carassius auratus*), which had been shown to have a well-developed color sense.

First we established that the goldfish retina does produce both the luminosity and the chromatic S-potentials, both of them qualitatively the same as in the fishes we had studied previously. Then we went on to record with microelectrodes inserted into the ganglion cells. Most of these cells responded with a burst of impulses when a white light was turned on and an-



GANGLION-CELL RESPONSE varies with the wavelength of the stimulus, a half-second flash of light (*white area*). At short wavelengths (*left*) there is an "on" response, a burst of impulses during illumination. At long wavelengths (*right*) there is an "off" response instead. (Spikes at left side of some long-wavelength records are from preceding stimuli.)



THRESHOLD CURVES show the intensity necessary to elicit "on" and "off" responses from a ganglion cell at different wavelengths. The "on" response (*color*) was obtained at short wavelengths, the "off" (*black*) at long wavelengths. In the overlap region the "off" response required a higher-intensity stimulus. Gray curve traces the inhibition threshold.

other burst when the light was turned off. Colored light brought a response that in the manner of the chromatic response was peculiarly dependent on wavelength. At short wavelengths, where the chromatic response was large and negative, a typical ganglion cell produced vigorous "on" discharges; at intermediate wavelengths, where the chromatic potential went to zero, there was a transition from "on" to "off"; at long wavelengths, where the chromatic response was large and positive, the "off" responses reached a maximum and there was a suppression of activity during illumination [*see top illustration at left*]. The short wavelengths caused excitation; the long wavelengths had an inhibitory effect during illumination that was followed by an "off" discharge that seemed to be a "postinhibitory rebound," a common phenomenon in nervous systems.

In addition to wavelength, the intensity of the stimulus also had an effect on the discharge. If we held the wavelength constant and increased the intensity of the illumination, the response pattern changed from excitation ("on") to both excitation and inhibition ("on-off") and eventually to inhibition alone ("off"). This held true only in a limited band of wavelengths.

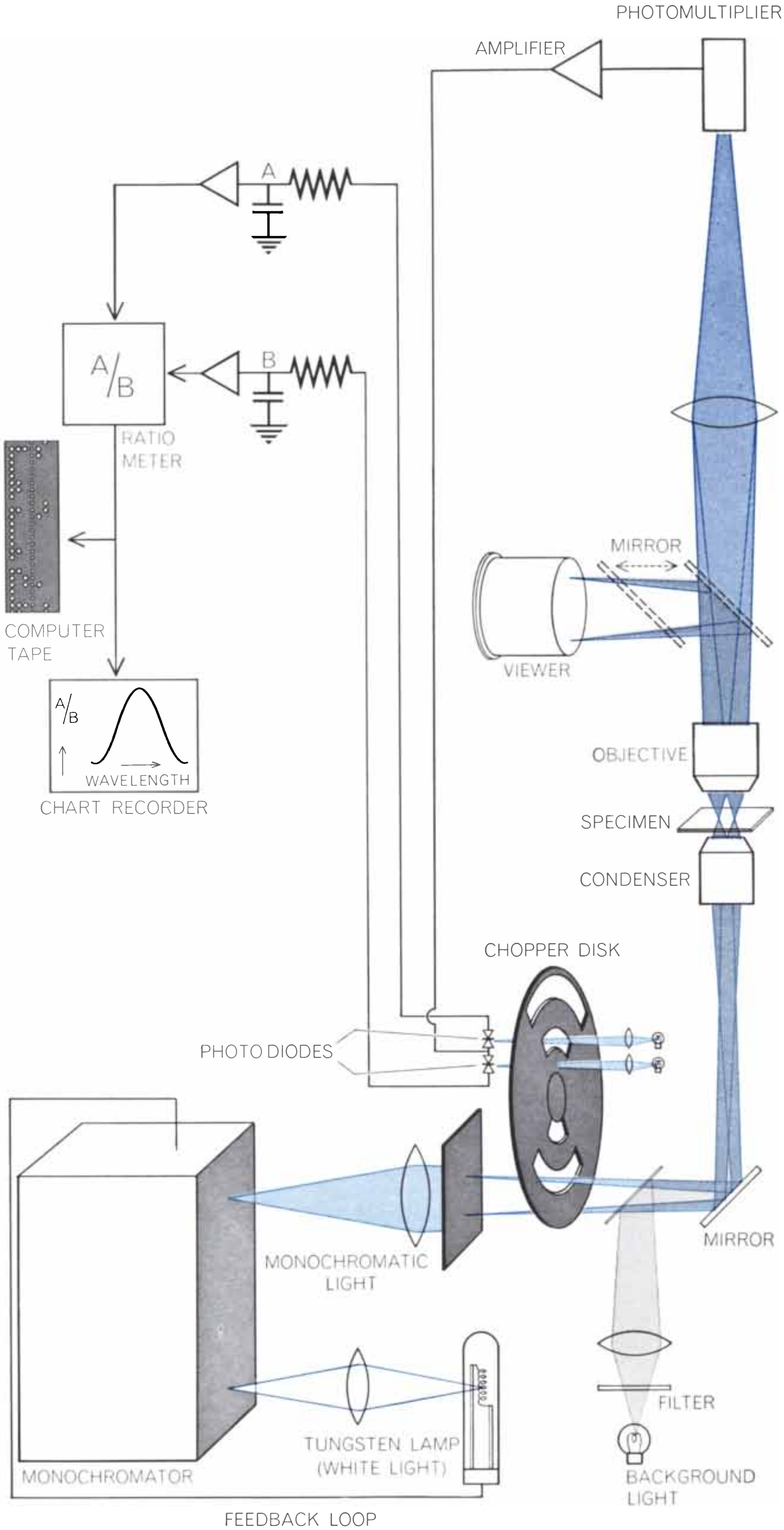
The relation of these two factors—wavelength and intensity—became more evident when we ran a series of threshold experiments, adjusting the intensity of the stimulus to produce a constant response at various wavelengths; the intensity thus became a measure of the sensitivity of the process at a given wavelength. Measurements on a single ganglion cell usually defined two distinct luminosity functions of wavelength: the intensities for a constant "on" and for a constant "off" response. In one of our early experiments [*see bottom illustration at left*] the two curves overlapped from 530 to 610 millimicrons. It was in this region that a change in intensity was effective in converting "on" patterns to "off" patterns. The gray curve in the illustration traces the intensities that caused complete suppression of all activity during illumination; it is the "inhibition" curve. In the overlap region it illustrates the effect of increasing intensity mentioned above. Beyond that it coincides closely with the "off" response, again suggesting that the latter is a rebound phenomenon.

Experiments in which either the short-wavelength or the long-wavelength process was selectively light-adapted provided further evidence for the independence of the two processes and the idea that the "off" system is inhibitory in nature. Adaptation with red light, for example, depressed the "off" response and increased the sensitivity of the "on" process. The latter, moreover, could now be obtained throughout the spectrum: it had been released from inhibition.

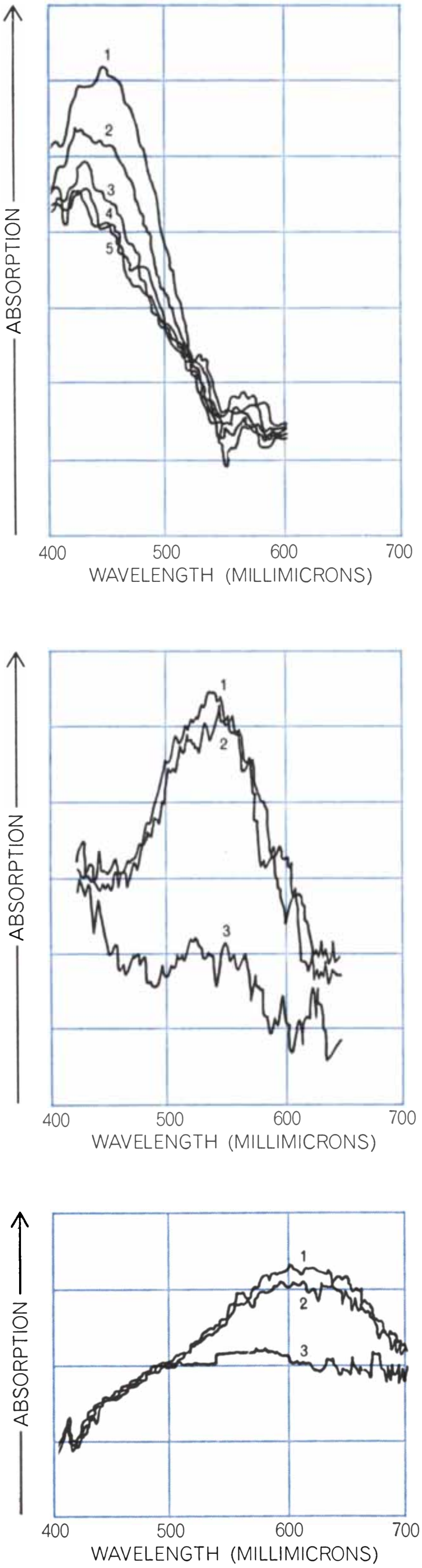
The ganglion cells I have been discussing are "green-on, red-off" cells. We found others that gave an opposite response ("green-off, red-on"), but in both cases the "off" response was associated with the inhibition of nerve-impulse activity during illumination, whether it was spontaneous activity, the result of background illumination or a carry-over of the "on" burst elicited by a previous stimulus.

Our results made it clear that in the goldfish information with regard to wavelength is carried up the optic nerve in the form of discharges from ganglion cells that are acted on by groups of receptors having sensitivities in different parts of the spectrum. These groups of receptors, presumably acting through the second-order bipolar cells, exert either excitatory or inhibitory effects on the ganglion cells. A given ganglion cell may, for example, be excited primarily by a group of red-sensitive receptors and inhibited mainly by a number of green-sensitive receptors. Other cells would be conversely affected. Some ganglion cells show no wavelength dependence but have about equal "on" and "off" thresholds throughout the spectrum; one would expect that they receive equal numbers of excitatory and inhibitory connections from each type of receptor. A few cells maintain a discharge throughout illumination; these presumably have only excitatory connections. Others discharge in the dark and are inhibited throughout prolonged illumination; they may only have inhibitory connections. David Hubel and Torsten Wiesel at the Harvard Medical School have found similar color-coded "on" and "off" responses in the optic nerve fibers of monkeys. The kind of coding we discovered in the retinal ganglion cells of fishes presumably holds true in man as well.

At this point in our investigation we had identified, at the level of the S-potentials and again at the level of the ganglion-cell discharge, elements of an "opponent color" coding system. The 19th-century German physiologist Ewald Hering had developed a color-vision theory based on such a process, perhaps involving a yellow-blue, a red-green and a black-white receptor. Her-



MICROSPECTROPHOTOMETER measures the absorption of light by a single cone. Monochromatic light, held to a constant flux by a feedback loop, is formed into two beams. A rotating chopper disk allows the "test" (*A*) and the "reference" (*B*) beams alternately to pass through the specimen to the photomultiplier tube. Depending on which beam is passing through, photodiodes switch the photomultiplier output into a test or a reference channel. The transmissivity of the specimen, *A* over *B*, is recorded and punched on tape.



RAW DATA for blue (*top*), green (*middle*) and red (*bottom*) cones were recorded with varying gains and light intensities. The blue curves were done as described in the text and required correction for bleaching. Green and red curves *1* and *2*, recorded at low intensities, bleached very little; after deliberate flash bleaching, the final curves (*3*) were recorded. Subtracting the last from the first curves yields difference spectra.

ing's theory attempted to account for two-color phenomena—such as the fact that red and green (or blue and yellow) vary together in sensitivity and never appear subjectively mixed—that could not be easily explained by a trichromatic system of the sort suggested by Young and elaborated by Hering's contemporary Hermann von Helmholtz. There seemed to be no way to confirm or disprove either theory except by examining the sensitivity of the actual receptors at various wavelengths. This meant measuring the absorption characteristics of the pigments in the cones across the entire visible spectrum.

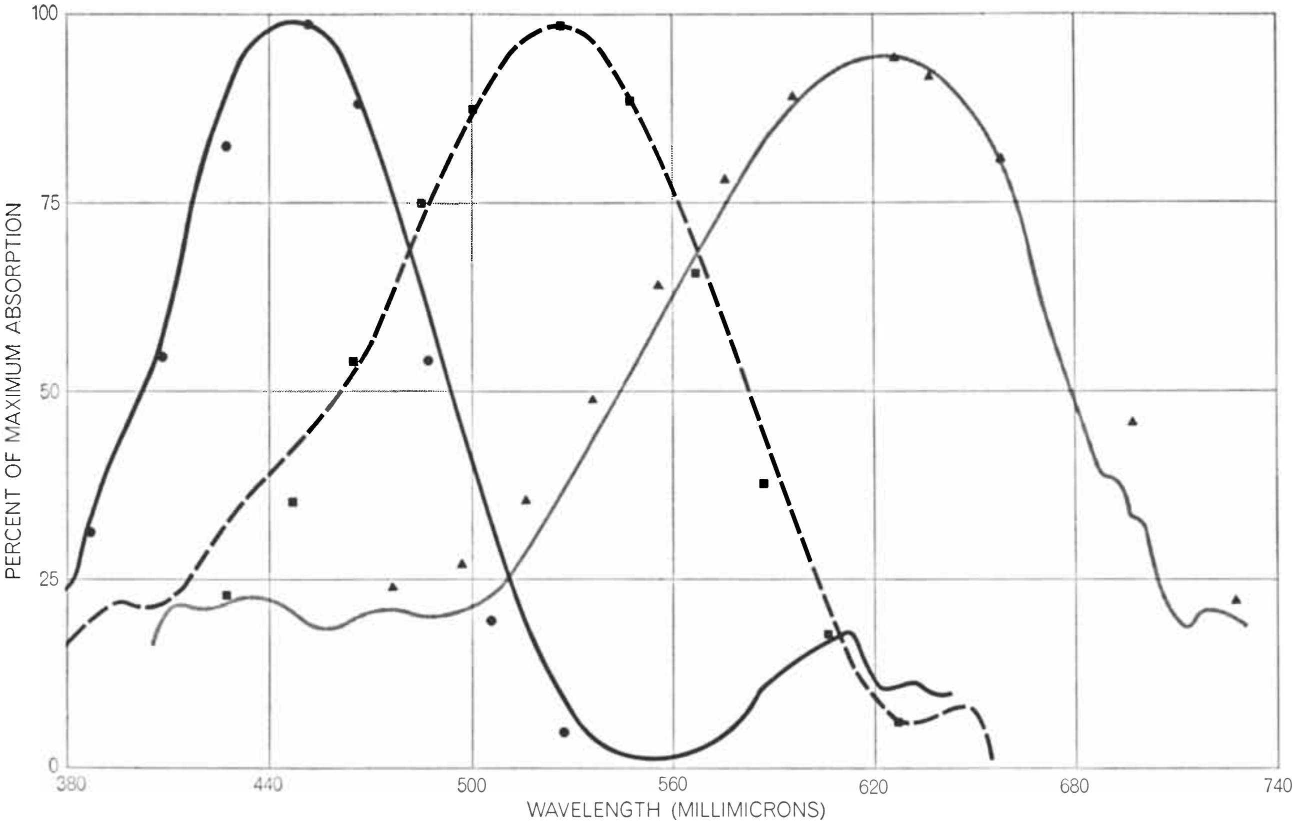
Cone pigments are difficult to extract and have yet to be separated from one another by standard biochemical methods. By analyzing a solution of chicken-retina pigments after partial bleaching, George Wald and his colleagues at Harvard University were able to distinguish a cone pigment, which they called iodopsin, from the known rod pigment rhodopsin, but this method has not been successful in mammals. The first successful method of distinguishing the various cone pigments *in situ* was devised by F. W. Campbell and W. A. H. Rushton at the University of Cambridge in 1955. They measured the intensity of light beamed into the human eye and reflected out again by the pigmented layer at the back of the retina. By selective bleaching and by comparing data from normal and color-blind people Rushton was able to identify two different pigments in the fovea, the central region of the retina where the cones are closely packed and there are no rods. One pigment, which he called chlorolabe, was most sensitive in the green part of the spectrum and another, erythrolabe, had its peak sensitivity in the yellow [see "Visual Pigments in Man," by W. A. H. Rushton; SCIENTIFIC AMERICAN, November, 1962]. At Harvard, Wald and Paul K. Brown were able to approach the problem even more directly, measuring with a spectrophotometer the absorption of light by dissected monkey and human foveas. They too were able to identify a green-sensitive and a red-sensitive pigment. Neither this method nor Rushton's, however, could specify whether the pigments were segregated in separate receptors or were mixed in a single receptor, nor could either method present clear evidence for any blue-sensitive pigment.

The best way to settle the question was somehow to measure with a spectrophotometer the absorption spectra of the pigments in individual cone cells. This is simple conceptually but quite difficult in practice. The outer segment of a cone cell, which contains the pigment, has a diameter ranging from perhaps five microns to less than two microns in various species; the small amount of pigment present in each cone requires that the beam of light passed through it be of low intensity, and the quantized nature of light then makes for "photon noise" in the record. Nevertheless, two Japanese investigators, T. Hanaoka and K. Fujimoto, did manage in 1957 to examine single cones in the retina of the carp; they detected what appeared to be five or six different pigments, each in a different cone. For some reason they did not pursue this line of work. Brown at Harvard and Paul A. Liebman at the University of Pennsylvania made spectrophotometric measurements on the outer segment of frog rod cells, but their instruments were apparently not yet able to detect the pigments in the outer segment of cones, which are much smaller. William B. Marks and I set out to design an instrument sensitive enough to measure the absorption curves of goldfish cones.

Our microspectrophotometer directs two beams of colored light through a specimen of retinal tissue to a photomultiplier tube. The "test beam" passes through the outer segment of a cone; the "reference beam," through a clear area. The photomultiplier measures the amount of light transmitted by the cone pigment compared with the amount in the unobstructed reference beam [*see illustration on preceding page*]. Light generated in a monochromator passes through two small apertures in a piece of metal foil; the two resulting beams are focused on the specimen, a piece of goldfish retina squeezed flat between two glass cover slips. In order to keep the retina dark-adapted, or unbleached, we orient the specimen under infrared background illumination, viewing it with an infrared image converter.

A mechanical "chopper" alternately selects the test and reference beams for passage through the specimen to the photomultiplier; photodiodes on the chopper alternately switch the corresponding signal from the photomultiplier into a chart recorder that takes the ratio of the two signals. This ratio, a measure of the relative absorption of the cone pigment across the visible spectrum, is simultaneously digitized and punched on tape to be analyzed and corrected by computer.

The simple absorption spectrum of a



GOLDFISH CONE PIGMENT spectral sensitivities are shown by these curves, the averages of eight difference spectra peaking in the blue, 10 in the green and nine in the red. The small symbols outline the curves for hypothetical "Dartnall pigments" (*see text*).

visual pigment is distorted by the presence of extraneous nonbleaching pigments, by the wavelength-dependent scattering caused by particulate matter and by diffraction and chromatic aberration in the optical system. The usual way of minimizing such effects is to record an absorption spectrum, bleach the specimen with white light, record another absorption spectrum and subtract it from the first. If colored products are not created in the process (often they are and must be corrected for), the resulting "difference spectrum" should provide the true spectral absorption curve of the bleachable pigment. This method requires that the intensity of the test beam be low in order not to bleach the pigment during a scan. In the early stages of his investigation Marks found that he had to step up the intensity of the beam in order to overcome photon noise; therefore he allowed the test beam to bleach the pigment, making several scans [*see top record in illustration on opposite page*] and subtracting the last from the first to get a difference spectrum. The peak of such a spectrum was displaced from the correct wavelength because there was progressively less pigment available at successive points in the scan. Marks worked out a correction procedure: he estimated the fraction of the original pigment remaining at each wavelength and divided the calculated difference at that point by the appropriate fraction. With W. E. Love, Marks wrote a computer program to perform the calculations, make the corrections and plot the corrected difference spectrum.

When a large number of difference spectra recorded in this way were printed together, it was evident that they fell into three groups with peaks in the blue, green and red. When he averaged the curves in each group, Marks came up with the three goldfish cone pigment spectra shown above, with peaks at wavelengths of about 455, 530 and 625 millimicrons. For evidence whether or not these curves represent the spectral sensitivities of three cone pigments, Marks compared them with the curves for three hypothetical visual pigments with peaks at these wavelengths. These curves are based on a translation of the curve of rhodopsin to the specified wavelengths according to a graph devised in 1953 by H. J. A. Dartnall of the Institute of Ophthalmology in London. Iodopsin and other visual pigments discovered since then have conformed to such curves. Our goldfish curves conform rather well, although not perfectly.

The primary conclusion we could draw from the goldfish investigation was that it unequivocally verified Young's three-receptor prediction, at least in one species known to be capable of color vision. Liebman has since performed similar experiments, employing light intensities that do not cause appreciable bleaching. He has provided independent confirmation of the work by developing curves that are in generally good agreement with Marks's results. Marks was also able to determine the density of the pigment in the cones: it is about a million molecules per cubic micron, or nearly the same as in the density of the rhodopsin in the rods. Since his measurements were made at right angles to the axis of the cones and could be repeated at several points in an outer segment with identical results, they showed further that the pigment is present throughout the outer segment (not concentrated in a minute granule, as Rushton had once suggested) and that such optical effects as filtering and focusing cannot play a significant role in color perception.

We were anxious to extend our investigation to individual human cone cells, not only because of the implicit interest of the human visual system but also because of the large amount of psychophysical data with which one can compare objective experimental results. William Dobelle, a graduate student, was able to obtain some human retinas through the cooperation of an eye bank, and along with them we used material from the rhesus monkeys *Macaca nemistrina* and *M. mulata,* obtained from the Naval Medical Research Institute. Monkey and human cones, like the cones of other primates, are much smaller than fish cones, measuring only about two microns in diameter at the base of the outer segment. If these cones were squeezed flat, as they were in the goldfish experiment, the light beam penetrated them from the side and not enough pigment molecules lay in its path to register a signal far enough above noise. Dobelle and Marks finally learned how to mount a piece of retina so that the cones are vertical and the beam of light traverses the main axis of the receptor, thus encountering more pigment molecules. They took specimens from the region of the retina just outside the fovea, where the cones are separated by closely packed rods, from which they can easily be discriminated, and proceeded to obtain difference spectra in the same way described earlier for goldfish cones.

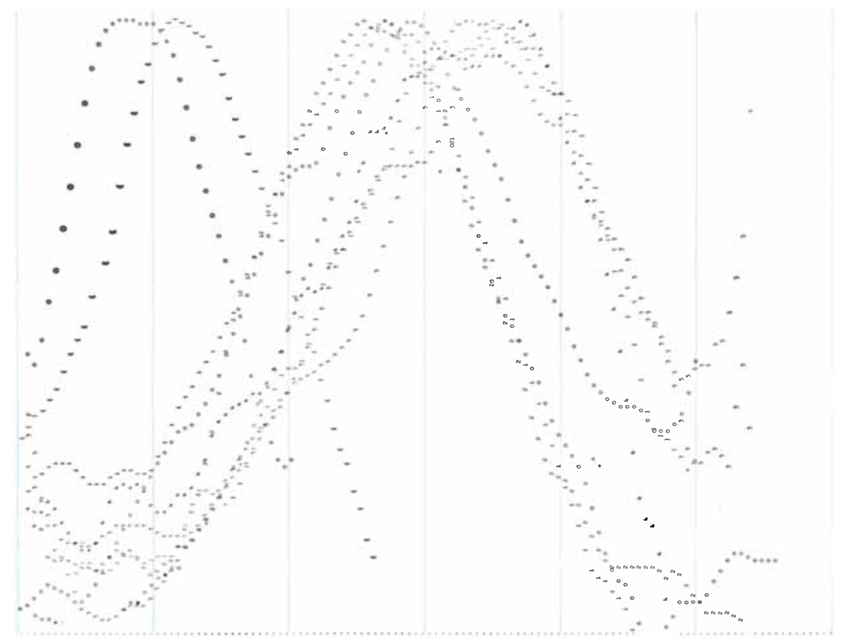
When the computer printed out the corrected spectra for 10 primate cones, the curves fell once again into three clearly defined groups [*see illustration below*]. Marks has since made some corrections in these original results; the best averages to date for the three receptors are shown in the illustration on page 49, together with samples of the colors to which each receptor is most sensitive. The fact that in primates the "red" receptor's spectral curve peaks not in the red part of the spectrum but in the yellow seems remarkable but was not surprising. It had already been indicated by psychophysical results, notably those of W. S. Stiles of the National Physical Laboratory in England, who found a "red" maximum from 575 to 587 millimicrons. Although the curve peaks in the yellow, it extends far enough into the red to sense red light unambiguously. That is, these cones are at least substantially more sensitive to red than are the green receptors, and that is all that is necessary if red light is to stimulate the retina to send a message the brain can interpret as "red."

At about the same time as we were investigating primate cones, Brown and Wald at Harvard modified the instrument with which they had examined frog rods and primate foveas so that it could record from individual cones. Their measurements of four cones in a single human retina also revealed three distinct absorption curves, although the peaks of the curves were somewhat different from ours: 450, 525 and 555 millimicrons. This could have been because there are in fact substantial differences among individual cones of the same type or because the methods by which Brown and Wald produced and corrected their spectra were different from ours. Liebman has also obtained data from individual human cones, but we have not yet been able to analyze his results. Many more measurements will have to be made before the exact spectral sensitivities of primate color-vision pigments are determined.

Single-cell microspectrophotometry develops the curve of whatever pigment material is in an individual cone, and not necessarily the curve of an individual pigment. Recently Wald performed a series of psychophysical experiments to determine if the color sensitivity of the living human eye corresponds to the single-cone data. He measured threshold sensitivities after selective adaptation and derived three curves with peaks at 430, 540 and 575 millimicrons —in closer agreement with our spectrophotometric data than with his own. Since these pigment-specific curves obtained from the entire population of receptors agree so well with our cone-specific spectrophotometric data, it seems likely that there are indeed three types of cone, each of which contains principally one of three pigments.

Electrophysiological evidence of what goes on in the vertebrate receptor cell has been difficult to obtain, but last winter Tsuneo Tomita of Keio University in Japan recorded slow potential changes that he is fairly sure originated in receptors in the retina of the carp, which is closely related to the goldfish. These signals vary in response to illumination by light of different wavelengths. They seem to reach a maximum amplitude at three points in the spectrum. And the three peaks correspond rather well with those Marks derived for the pigments of the goldfish cones.

All the evidence for a three-color, three-receptor cone system comes up against the earlier electrophysiological evidence for an opponent-color system farther along the visual pathway. Color vision is apparently at least a two-stage process, consistent with the Young-Helmholtz theory at the receptor level and with the Hering theory at the level of the optic nerve and beyond. Each receptor does not have its private route to the brain; three-color information is somehow processed in the retina and encoded into two-color on-off signals by each of the color-sensitive retinal ganglion cells for transmission to the higher visual centers.



PRIMATE CONE difference spectra are shown as plotted from spectrophotometer tapes by a digital computer. One blue and one green human cone and eight rhesus monkey cones are represented. These curves, after correction, are the basis of the illustration on page 49.

Kodak reports on:

culmination of a pinhole . . . excitement in Bimini

This magazine is assumed to reach the reader at a time of year when he faces a decision on how to prove once more to the satisfaction of his family that they live in an affluent society. Let us here express the hope that the level of his contribution to that society during the year now closing permits his presentation to them of the most up-to-date camera and projector to represent no disproportionate devotion to material possessions.

The KODAK INSTAMATIC 800 Camera culminates the line that Giambattista della Porta started in the 1550's with a pinhole in one wall of a darkened room to capture the look of the adjacent countryside.

You press the button. It does the rest. Just tell it where in the four-dimensional world of time and space is your center of interest for the nonce. It does not impale itself on unimaginative assumptions about "average conditions." It doesn't expect you to answer a lot of fool questions. It assumes you'd rather be thinking of something more interesting at the key moment than of light levels and relative apertures and matching shutter speeds. So it adjusts itself. Only if you have set it an impossible problem does it beg you for a bit of attention by displaying a little flag. With its $f/2.8$ lens and a shutter that slows itself down when you run out of lens speed, you may have to make a special effort to see the flag and doubtless will. Those who deny taking delight in simple entertainments often sound unconvincing. *Some* gadgetry *is* worth respect, as awarded from results.

The KODAK CAROUSEL 800 Projector is the other wing needed to fly the course properly.

It encourages neatness at the payout from the pleasures of the chase, obviates the fumbling observed at times on occasions of slide projection, reduces the probability that the best slides of any given sequence have been filed beneath the pile of last year's receipted phone bills.

Each show of 80 slides has its book-like place on the shelf. At show-time drop the spillproof tray onto the machine like a phono record. Gentle, non-jamming gravity feeds the slides. Spin to any slide, any time. Or let the machine run itself, 5, 8, or 15 seconds to a slide. Or run the show from a long cord, backing up on demand from the audience to linger longer at a scene passed too swiftly with the impetus of your narrative. Or put the narrative on tape, add music to taste, and synchronize to the slide show by means of a recorder and CAROUSEL Programmer with taped signals changing the slides.

Find the Kodak dealer who has an INSTAMATIC *800 Camera and a* CAROUSEL *800 Projector ready to show you. Be resolute. Time is short.*

The horse is a mammal

2,4-Dinitroso-1,3-naphthalenediol (EASTMAN 9503) has demonstrated, bare-eyed, the presence of 10^{-9} g. of iron in one of those acrylamide gel discs that make up the characteristic disc-electrophoretic fingerprint of a protein mix. The reagent was devised by a very smart man we know. He and a buddy thought up disc electrophoresis in the first place.

Last winter he vacationed on Bimini, which has the Lerner Marine Laboratory as one of its charms. After a quick snooze in the sun, he sought exercise first in skin-diving and then in phylogeny. He had his disc-electrophoresis kit along. An amazing observation resulted from a colleague's offer of octopus serum. The protein pattern resembled the mammalian serum pattern even more than the uncanny octopus eye resembles the mammalian eye.

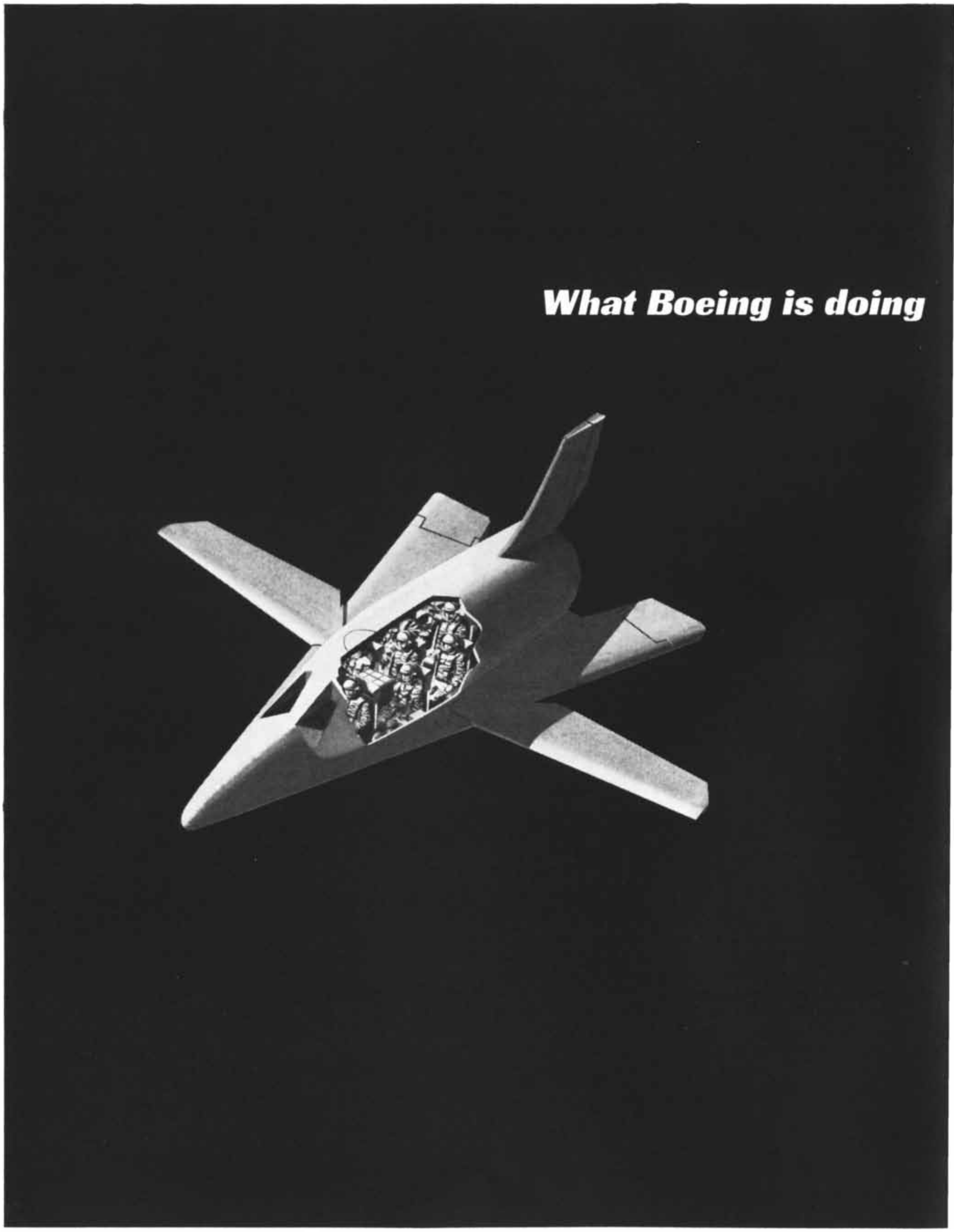
Excited by this new evidence of interphyletic convergence, our smart friend upon his return home prepared to clinch it by proving that the disc corresponding to the iron-bearing protein transferrin in mammals would in the mollusk's serum respond selectively to a sufficiently sensitive reagent for iron. Of iron reagents there are plenty; none he could find, however, performed as well under the special conditions encountered in disc-staining as the one named above, which he extrapolated from the literature, his experience, and the sheer force of reason. After he told us what it was, we made him some that he found better than his own product.

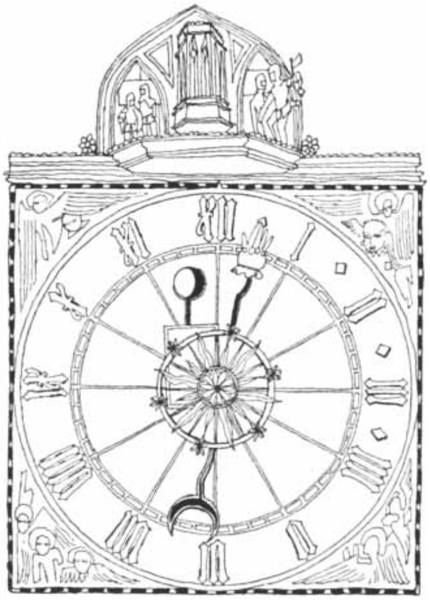
This is now offered by Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company), which also offers the other compounds needed in disc electrophoresis, as well as all the other EASTMAN *Organic Chemicals needed in numberless other endeavors. Separately and without charge, the same organization continues to offer the authors' description of the theory of disc electrophoresis and their illustrated directions for the procedure, now supplemented for iron. Ours has been a proud role in publicizing their method around the world.*

It is therefore distressing to have to report that no publication on cephalopod phylogeny is in immediate prospect from our friend. Not only is he smart but also frank, lucky, and grateful to have learned in time of some misbegotten horse serum that he was confusing with the colleague's octopus samples.

This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science

How to be at home in orbit





SCIENCE AND

The Nobel Prizes

The 1964 Nobel prizes in science were awarded for studies of cholesterol and the metabolism of fats, for establishing the principle of the maser (including the optical maser, or laser) and for the determination of the molecular structure of penicillin and vitamin B_{12}.

The prize in physiology and medicine was awarded jointly to Konrad E. Bloch of Harvard University and Feodor Lynen of the University of Munich; Lynen is also director of the Max Planck Institute for Cell Chemistry. The two men have independently studied how animal cells produce cholesterol, the substance from which the body manufactures the sex hormones and the hormones of the adrenal cortex. Cholesterol is also found in the arterial plaques associated with atherosclerosis and coronary disease. Bloch and Lynen discovered that animal cells manufacture cholesterol, which has the formula $C_{27}H_{46}O$, from the simple acetate ion ($C_2H_3O_2^-$) in a complex sequence of some 36 steps. Lynen was also cited for clarifying the role of the vitamin biotin in the metabolism of fats.

The prize in physics was awarded to Charles H. Townes of the Massachusetts Institute of Technology for the theory and construction of the maser and to two Soviet physicists who independently had the same idea: Nikolai G. Basov and Aleksandr M. Prokhorov. Basov is deputy director of the Lebedev Physics Institute of the Soviet Academy of Sciences; Prokhorov is a member of the same institute.

The maser exploits the fact that an excited electron can be triggered into releasing a photon of energy on demand rather than at random. This occurs when the excited electron is struck by a photon having the same energy as the one it is destined to emit. In other words, the emission can be stimulated; moreover, the stimulated photon emerges in phase, or in step, with the triggering photon. The problem solved by Townes and the two Soviet workers was how to design a system that contained a preponderance of electrons in a particular excited state rather than in the normal "ground" state. Given such a system, a cascade of photons all alike and all in phase can be triggered by a photon of appropriate energy. Working at Columbia University with James P. Gordon and Herbert J. Zeiger, Townes built the first maser in 1954. The device was soon widely exploited for amplifying weak microwave signals.

In 1958 Townes and Arthur L. Schawlow described a device in which photons of light, rather than microwave photons, could be amplified by stimulated emission. Such a device—the first laser—was built two years later by Theodore H. Maiman, working at the Hughes Aircraft Company. Since then the intense, coherent light beams created by the laser have provided a wealth of new optical phenomena and have shown potential value in medicine, chemical technology and communications.

The prize in chemistry was awarded to Dorothy Crowfoot Hodgkin of the University of Oxford for her application of X-ray crystallography to determining the structure of complex organic molecules. During World War II Mrs. Hodgkin headed a group that established the structure of the penicillin molecule when the antibiotic was in short supply and it seemed that it might be necessary to produce it synthetically. In 1955 she reported the structure of the still more complex molecule of vitamin B_{12} (empirical formula $C_{63}H_{88}$-$CoN_{14}O_{14}P$), which prevents pernicious anemia.

The Fifth-Nation Problem

President Johnson has appointed a task force to report on steps the U.S. and other countries might take to prevent the further spread of nuclear weapons. His designation of the special study group, which will be headed by former Under Secretary of Defense Roswell L. Gilpatric, reflects the concern of Government officials and scientists who have been considering the significance of the Chinese nuclear test. A number of nations have the technological and industrial potential for developing nuclear weapons, although the effort would exert varying degrees of strain on their resources. One deterrent has been the partial nuclear-test-ban treaty, which forbids the testing of nuclear weapons in the atmosphere, underwater or in space. France and China refused to sign the treaty in 1963: in effect they declined to acquiesce in and institutionalize the big-power nuclear stalemate, something the other nonnuclear nations were willing to do. Now there is widespread concern that the Chinese achievement may lead some of these countries to decide that they must have their own nuclear weapons. The result could be to break down the test-ban treaty and eventually build up pressure on the three original nuclear powers to resume testing themselves. More important, it is assumed that the proliferation of nuclear weapons would greatly increase the instability of the precarious balance of national power and thus multiply the chances of an accidental nuclear conflict.

The first potential "*n*th country" to grapple publicly with the question of whether or not to build its own bomb was India, the nation most directly affected by China's possession of nuclear weapons and at the same time most identified with a policy of opposition to nuclear armament on moral grounds. India has three research reactors in operation, two power reactors under construction, an accumulation of plutonium-enriched spent fuel and a spent-fuel processing plant already on stream extracting the plutonium. Indian scientists were quoted as saying they could test a bomb in 18 months; Homi J. Bhabha, the country's leading nuclear physicist, said that a stockpile of bombs could be accumulated for about $20 million. At a meeting in November of the ruling Congress party there was a sharp debate on the issue, which ended with a decision not to make the bomb.

Prime Minister Lal Bahadur Shastri said: "We should try to eliminate the terror of nuclear weapons rather than make them."

The Chinese test provided evidence of considerable technological and industrial capacity. According to the U.S. Atomic Energy Commission, the fission device had a yield of about 20 kilotons and was detonated by implosion rather than by the more primitive gun-barrel method. And its fissionable material was not plutonium but uranium 235, presumably manufactured by the gaseous-diffusion process. The construction of a gaseous-diffusion plant requires a high degree of technical skill and its operation consumes large amounts of electric power. Writing in *Science*, the U.S. chemist Philip H. Abelson pointed out that the enriched uranium available from such a plant gives a country "great flexibility in nuclear technology." Abelson further observed that since enriched uranium makes possible the production in reactors of tritium, a key constituent of thermonuclear bombs, "in view of the Chinese achievement thus far there is no basis for hoping that they will not achieve a hydrogen bomb—perhaps in the latter part of this decade."

A Fifth Force?

In an effort to explain a recent experiment that threatens to upset the deeply held concept of time-reversal invariance, physicists are speculating that there may be a previously unrecognized fifth force in nature. The four well-established forces, in order of decreasing strength, are the nuclear force, the electromagnetic force, the weak force (associated with the decay of certain particles) and gravitation. The concept placed in jeopardy states that the four forces are indifferent to the direction in which time is flowing. In other words, the forces that shatter a teacup when it is dropped are entirely adequate to put it together again.

Time-reversal invariance was called into question by an experiment conducted at the Brookhaven National Laboratory by Val L. Fitch, James H. Christenson, James W. Cronin and René Turlay of Princeton University. The experiment showed that the neutral K_2 meson occasionally decays into two pi mesons instead of the three pi mesons required if the "CP" rule is to be obeyed. The rule states that particle reactions are indistinguishable from their antimatter mirror images. ("C" stands for charge conjugation, which relates matter to antimatter; "P" stands for parity, which relates a system to its mirror image.) On the basis of existing theory the two-pi decay and the CP rule can be reconciled only by sacrificing time-reversal invariance.

Rather than sacrifice time-reversal invariance, physicists have been struggling to find an explanation that would preserve it. One of perhaps a dozen alternatives proposed so far is that the "forbidden" two-pi decay is the first tangible manifestation of a new natural force that is even weaker than gravity. One group of physicists associated with this idea consists of T. D. Lee of Columbia University, Jeremy Bernstein of New York University and N. Cabibbo of the European Organization for Nuclear Research (CERN). Much the same idea has been put forth independently by John S. Bell of CERN and J. K. Perring of the British Atomic Energy Research Establishment.

The proposed force would have one sign (representing a basic characteristic) if produced by ordinary matter and an opposite sign if produced by antimatter. Assuming that our entire galaxy consists of ordinary matter, which seems likely, the potential of fifth-force energy at the earth's surface should be almost entirely that produced by ordinary matter. If such an asymmetrical force field exists, its effect on particles of ordinary matter should be distinguishable from its effect on antiparticles. In fact, its strength and asymmetry would be just enough to convert an occasional neutral K_2 meson into a neutral K_1 meson, which can decay into two pi mesons without violating the CP rule.

The proposal can be tested by raising the energy of the decaying neutral K_2 particles. If the fifth force is well behaved, the number of two-pi decays should increase by a factor of 100 if the energy of the decaying particles is raised by a factor of 10. Experiments to make this test are now being undertaken at Brookhaven and CERN.

Noisy Quiet Sun

During the International Year of the Quiet Sun, the worldwide program of astronomical and geophysical observations begun 11 months ago, the sun has been rather noisy: astronomers and physicists engaged in the program have been observing an unexpectedly large number of sunspots and solar flares.

The International Year of the Quiet Sun (more properly International Years, because it will continue until the end of 1965) was planned by participants in the International Geophysical Year, whose studies called for a second round of observations to be made during the calm phase of the 11-year sunspot cycle. Had they perhaps been wrong, in scheduling the new program, to assume the regularity of that cycle?

No, indicates Martin A. Pomerantz, chairman of the U.S. Committee for the IQSY. Writing in *Physics Today*, Pomerantz explains that a low point in the occurrence of sunspots did come early this past fall, even though it was the first such minimum phase of this century in which the monthly average of sunspots did not fall below five.

Pomerantz attributes the large number of spots and other unanticipated solar phenomena to the "residual activity" of the previous cycle; this idea is supported by the fact that the pattern of some of the current sunspot formations resembles the pattern of earlier formations. Pomerantz also points out that the declining cycle was of unprecedented turbulence, with a monthly average of more than 200 sunspots during its maximum phase.

The high level of solar activity has nonetheless increased the value of the IQSY rather than decreased it, Pomerantz says. The periods of solar inactivity have been long enough and quiet enough for all observational purposes, and the occasional outbursts of activity represent a bonus: "events to whet the appetite of any IQSY physicist."

Primitive Metallurgy

Artifacts unearthed at a Neolithic village site in Turkey this past summer indicate that man may have recognized the useful properties of copper as long ago as 7000 B.C. The excavation, at Cayonu in eastern Turkey, a few miles from ancient copper mines at Maden, was jointly directed by Halet Çambel of the University of Istanbul and Robert J. Braidwood of the University of Chicago. In May the investigators uncovered small beads of the copper ore malachite and part of a metal drill that had been shaped by grinding down a nugget of native copper. Although these discoveries occurred in levels that predated the first use of pottery at Cayonu, Miss Çambel and Braidwood were initially not greatly impressed; there was no evidence that the early craftsmen realized they were working with a novel material, and the objects could equally well have been made out of a nonmetallic mineral.

The excavators then found three tiny

RECENT findings

RESEARCH LABORATORIES

Ford

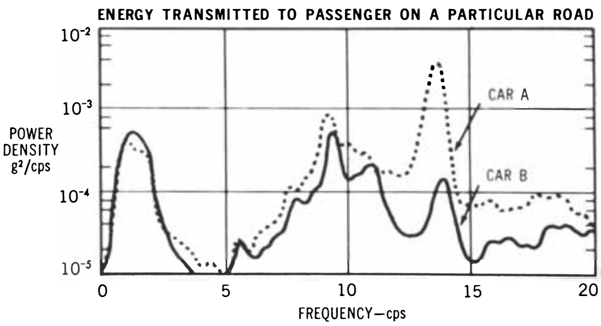
MOTOR COMPANY

POWER SPECTRAL DENSITY AND CAR RIDING COMFORT

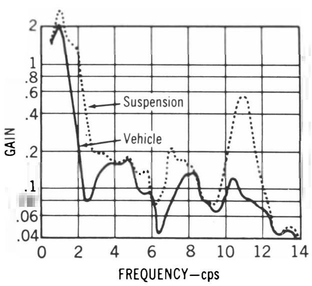
Spectrographic measurement of automotive vibration is being related to human sensitivity to provide a firm basis for improving riding comfort.

The randomness of road irregularities has consistently challenged automotive engineers to find a way to deal with this variable as it relates to riding comfort. To meet the challenge, Ford Motor Company research engineers developed a procedure using tape recordings and digital computer analysis methods to measure the power spectral density, or vibratory energy transmitted to the vehicle and the passenger throughout the frequency spectrum.

It was also desirable to translate this information into human terms. How should human reaction to the vibratory energy in the different frequency ranges be weighted to assure designing for the best ride? To find out, Ford Motor Company engineers developed special measuring apparatus, and constructed mathematical models of the human body which were correlated with subjective tests of human sensitivity.

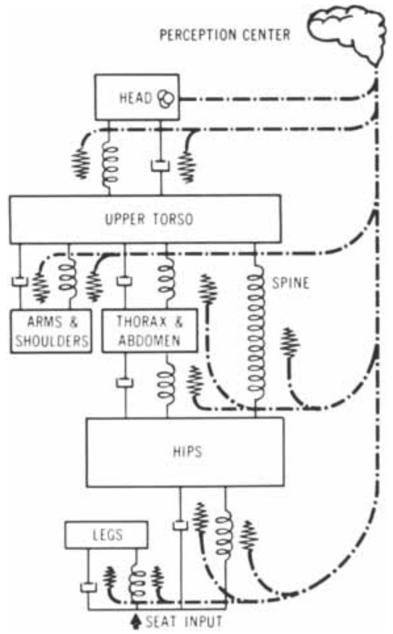


This curve shows measurements of the energy present at various frequencies on two cars with different suspension designs, over the same stretch of road. The powerful peak at 1 cps is due to the resonance of the car mass on the suspension. Another peak around 10 cps is due to resonances of the wheels and other unsprung masses; and the sharp peaks at higher frequencies are resonances caused by body and chassis flexibility. Although the two cars are seen to be comparable at lower frequencies, they are quite different in the amount of high frequency "shake."



ENERGY TRANSFER FUNCTION CHARACTERISTIC OF A PARTICULAR CAR ON ANY ROAD

The energy present in the car divided by the energy present in the particular road profile used for testing, measures the vibration transmissibility of a particular vehicle or suspension design. The characteristic curve is independent of the road itself.



This mathematical model of the human body was used to compute sensitivity to various frequencies. These data have been confirmed by "jury" tests of people subjected to known vibratory inputs, both on-the-road, and in the laboratory. Greatest human sensitivity is in the 3 to 7 cps range. Minimum transmission of energy in this range is a major development goal.

As a result of this work it is now possible to develop a dynamic "fingerprint" of a vehicle. The engineer may then interpret from this information the inherent degree of comfort present to permit a confident selection of an optimum design.

PROBING DEEPER TO SERVE BETTER

Ford

MOTOR COMPANY

The American Road, Dearborn, Michigan

pins, completely oxidized but apparently made of copper. Two of them, each half an inch long and a sixteenth of an inch in diameter, were pointed at one end; the third was pointed at both ends and bent at more than a right angle. Making such shapes as these from native copper would require cold-hammering, a technique only a few steps removed from full metallurgy. The discoverers are now awaiting laboratory analyses to determine if the three pins are indeed copper. If such is the case, Miss Çambel and Braidwood point out, it will prove that 9,000 years ago the people of Cayonu were "using metal as metal rather than as another object such as stone and wood."

Dangerous Dust?

Dust consisting of fine fibers of asbestos, which are insoluble and virtually indestructible, may become a public health problem in the near future. At a recent international conference on the biological effects of asbestos sponsored by the New York Academy of Sciences, participants pointed out on the one hand that workers exposed to asbestos dust are prone in later life to develop lung cancer, and on the other hand that the use of this family of fibrous silicate compounds has expanded enormously during the past few decades. A laboratory curiosity 100 years ago, asbestos today is a major component of such building materials as shingles and roofing papers, floor tiles, insulation, wallboard and piping and is an important ingredient in such products as gaskets, brake linings and calking compounds. World production of asbestos in 1962 exceeded three million tons, and industries in the U.S. consumed 25 percent of the total.

One result of this increasing use is that asbestos dust is frequently encountered in ordinary daily life. J. G. Thomson of the University of Cape Town Medical School in South Africa reported to the conference on 500 consecutive autopsies performed in Cape Town and 500 in Miami, Fla., on individuals over the age of 15. Smears were taken from the bottom of the lungs; in both South Africa and the U.S. characteristic "asbestos bodies" were found in 20 percent of the females and 30 percent of the males. Some of the males showed asbestos bodies in such abundance that occupational exposure to asbestos dust appeared probable; in 80 percent of all positive cases, however, the incidence was low enough to suggest that the asbestos bodies were present as a result of general atmospheric contamination.

It is not clear what the tumor-producing factor in asbestos is. Of the three asbestos silicates in general industrial use, two contain traces of iron and the third has relatively high concentrations of nickel and chromium. All three metals are known to be carcinogenically active. Two of the asbestos minerals contain appreciable amounts of natural hydrocarbons, some of which are also carcinogenic.

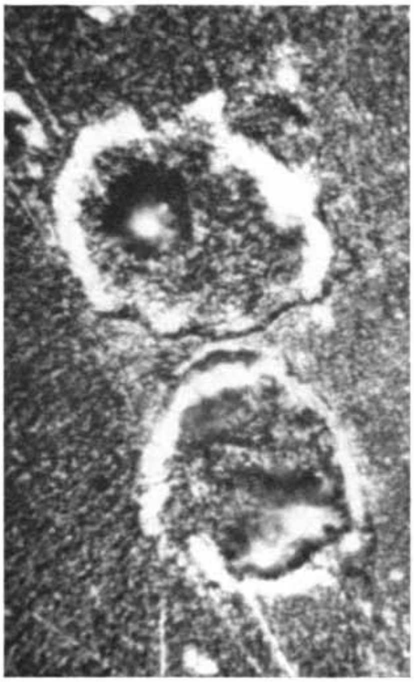
The Opossum as a Player

An opossum playing possum is genuinely feigning death, three researchers at the Children's Hospital of Los Angeles have decided on the basis of electroencephalograph records. The "opossum state" is well established in American folklore. Under attack the little marsupial suddenly slumps into a motionless ball with its head down, its mouth open and its eyes fixed in a glassy stare. Such behavior obviously functions as a defense mechanism: seeming to be dead, the animal is left for dead, and it revives when the coast is clear. There has been some doubt, however, whether the opossum is actually feigning death or is in an involuntary cataleptic state induced by physiological changes caused by the attack.

Allen C. Norton, Anthony V. Beran and George A. Misrahy report in *Nature* that they implanted electrodes on the skulls of 15 opossums (*Didelphis virginiana*). They induced the opossum state in these animals by shaking them with an "artificial dog jaw," a device resembling a large pair of pliers, and at the same time playing recorded barking sounds through a loudspeaker. When first attacked, an opossum would hiss and growl and try to fight back at the jaw, but then suddenly all activity would cease and the animal seemed to be dead for as long as two or three minutes. Electroencephalograph records taken before, during and after the artificially induced opossum state showed no change except perhaps a heightened arousal level caused by the attack and persisting after revival. To simulate the natural situation more closely the experimenters allowed real dogs to shake "naïve" animals into an opossum state that lasted five or six minutes. Again there was no difference in the brain waves during the state and after recovery. Finding no evidence of unusual brain activity, the investigators concluded that "the folklore is correct; the animal is merely 'playing possum.' "

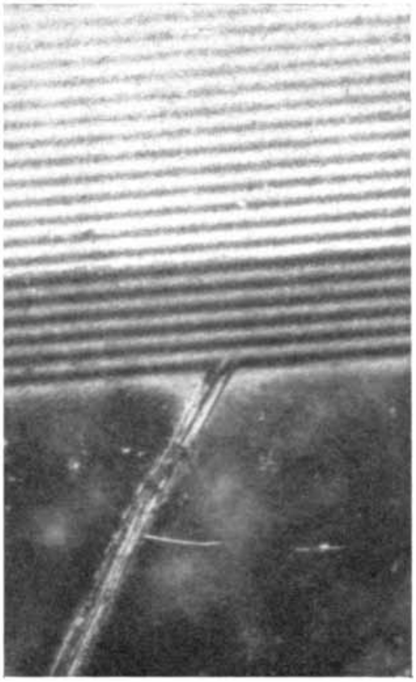
New technologies that are moving forward —faster—with HVEC Particle Accelerators

simulation of space environments



Simulation of micrometeoroid impact on materials . . . by accelerating micron-sized carbonyl spheres to hypervelocities . . . is one way HVEC Particle Accelerators are being used effectively to research the effects of space environments on missile parts and men.

solid-state "genetics"



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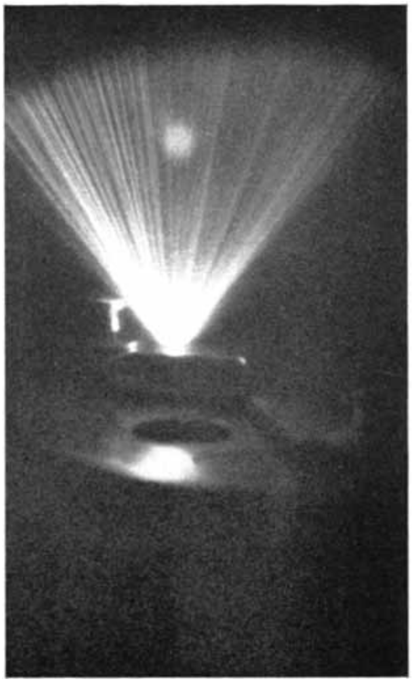

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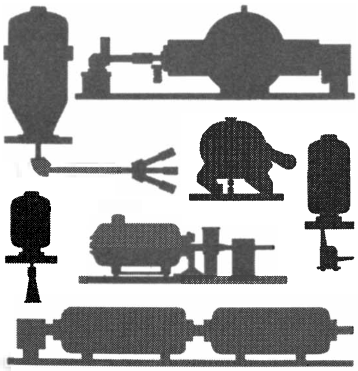

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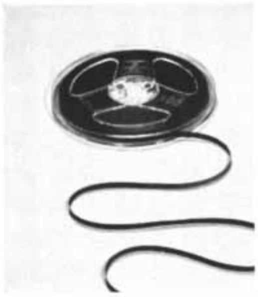
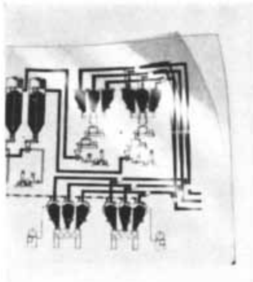
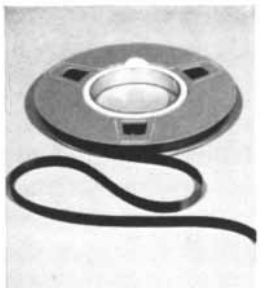






Protein-digesting Enzymes

These enzymes, which are themselves proteins, play an essential role in the process of digestion. The study of their molecular structure provides clues as to how all enzymes produce their catalytic effects

by Hans Neurath

A problem that fascinates biochemists is how the living cell performs with such speed and precision a multitude of chemical reactions that otherwise occur with immeasurable slowness at the same temperature and pressure. It has long been known that the secret is to be found in the remarkable catalysts created by the living cell. A catalyst is defined as a substance that promotes a chemical reaction without itself being used up in the process. The biological catalysts that mediate all the chemical reactions necessary for life are called enzymes. All enzymes are proteins, although some work in concert with the simpler inorganic or organic compounds known as coenzymes. Each enzyme is tailored to accelerate one specific type of chemical reaction, and since the cell must carry out thousands of different reactions it must have the services of thousands of different enzymes.

One important class of enzymes has the task of degrading, or digesting, other proteins. Because the process is also termed lysis (from the Greek word for "loosing"), these enzymes are called proteolytic. Present in all living organisms, they degrade cellular proteins as part of the cell's metabolic cycle. They also take apart the protein molecules that the organism ingests as food and make the subunits available for constructing the new proteins the organism needs for its own sustenance.

The molecules of proteins are complex structures composed of hundreds or thousands of amino acid subunits of about 20 different kinds. These subunits are linked together in various proportions—exact for each protein—to form polypeptide chains. The term "peptide" refers to the bond that is formed when two amino acids link together and in the process release a molecule of water. The portion of the amino acid molecule that remains in the polypeptide chain after the loss of the atoms in water is termed an amino acid residue.

Proteolytic enzymes have the ability to restore the elements of water by a process of hydrolysis that involves only the protein, the proteolytic enzyme and the water in which both are dissolved. Protein hydrolysis occurs when the peptide bond, which links a carbon atom on one amino acid residue with a nitrogen atom on the next, is broken. Simultaneously the hydroxyl ion (OH^-) of a water molecule is added to the carbon end of the broken protein chain and the remaining hydrogen ion (H^+) is added to the nitrogen end [*see top illustration on page 70*].

Like all other chemical reactions, protein hydrolysis involves an exchange of electrons between certain atoms of the reacting molecules. In the absence of a catalyst this exchange occurs so slowly that it cannot be measured. It can be accelerated by the addition of acids, which increase the supply of hydrogen ions, or of bases, which provide hydroxyl ions. The acids and bases act as true catalysts: they are not consumed in the process. If a protein is boiled in a concentrated acid, it will decompose completely into free amino acids. Such conditions would obviously destroy a living cell. Proteolytic enzymes produce the same result even faster and with no harm to the organism. And whereas hydrogen ions act indiscriminately on all proteins and on all peptide linkages in any protein, proteolytic enzymes are specific, acting only on certain kinds of linkage.

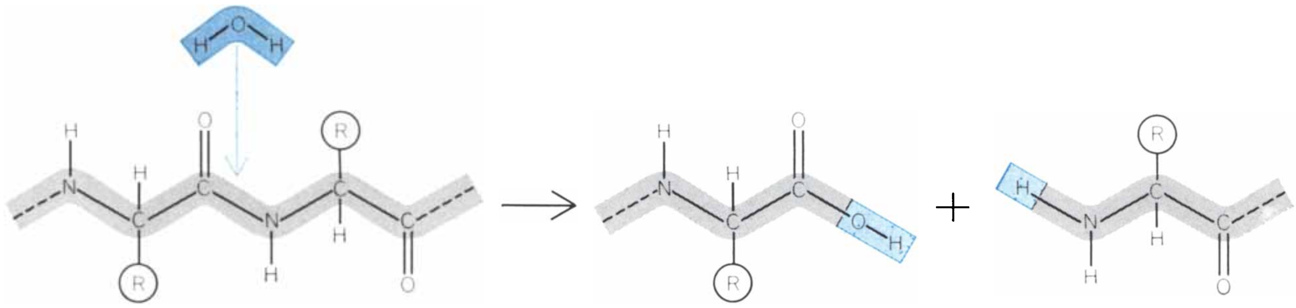
Since proteolytic enzymes are themselves proteins, their action is directed toward the same compounds from which they are made. What, then, differentiates a protein that is a proteolytic enzyme from the protein the enzyme digests? How does a proteolytic enzyme exert its catalytic function without destroying itself or the cell in which it originates? An answer to these fundamental questions would do much to clarify how all enzymes perform their functions. In the 30 years since a proteolytic enzyme (trypsin) was first isolated and crystallized (by Moses Kunitz of the Rockefeller Institute) proteolytic enzymes have served as prototypes in studies relating protein structure to enzyme function.

Because of their role in one of man's most important functions, that of nourishing himself, the proteolytic enzymes of the digestive tract have a long history of investigation, surpassed perhaps only by the study of the enzymes involved in the fermentation of alcohol by yeast (from which the term "enzyme," meaning "in yeast," is derived). Among the digestive enzymes, those secreted by the pancreas—trypsin, chymotrypsin and the carboxypeptidases—are the most completely analyzed and best understood. Hence they will serve to illustrate what is now known about the specificity, structure and mode of action of all proteolytic enzymes.

The proteolytic enzymes of the pancreas are synthesized in the form of precursors called zymogens, and they are stored in the pancreas in intracellular bodies known as zymogen granules. In the zymogen form proteolytic enzymes are inactive and so are prevented from exerting their destructive action on the protein components of the tissue in which they originate. Activation takes place after the zymogens are secreted into the small intestine, where a certain enzyme makes small but important changes in the structure of the zymogen molecule. Such changes will be considered in more detail later in this article.

As I have indicated, proteolytic en-

CHYMOTRYPSINOGEN MOLECULE, the inactive precursor of the protein-digesting enzyme chymotrypsin, may look something like this. This drawing, based on a model built by the author, shows the hypothetical route of the molecule's central chain composed of 246 amino acid subunits, often referred to as residues. The model takes into account many of the known chemical features of this enzyme secreted by the pancreas. The three-dimensional conformation is dictated, in part, by sulfur-sulfur linkages, or disulfide bridges, which tie the molecular chain together at five points. The molecule becomes an active enzyme when split by trypsin at the point indicated by the black ring. Three gray rings show secondary cleavage points. The active site of the molecule is believed to lie in a small region that includes two residues of histidine and a residue of serine, all three shown in dark color.



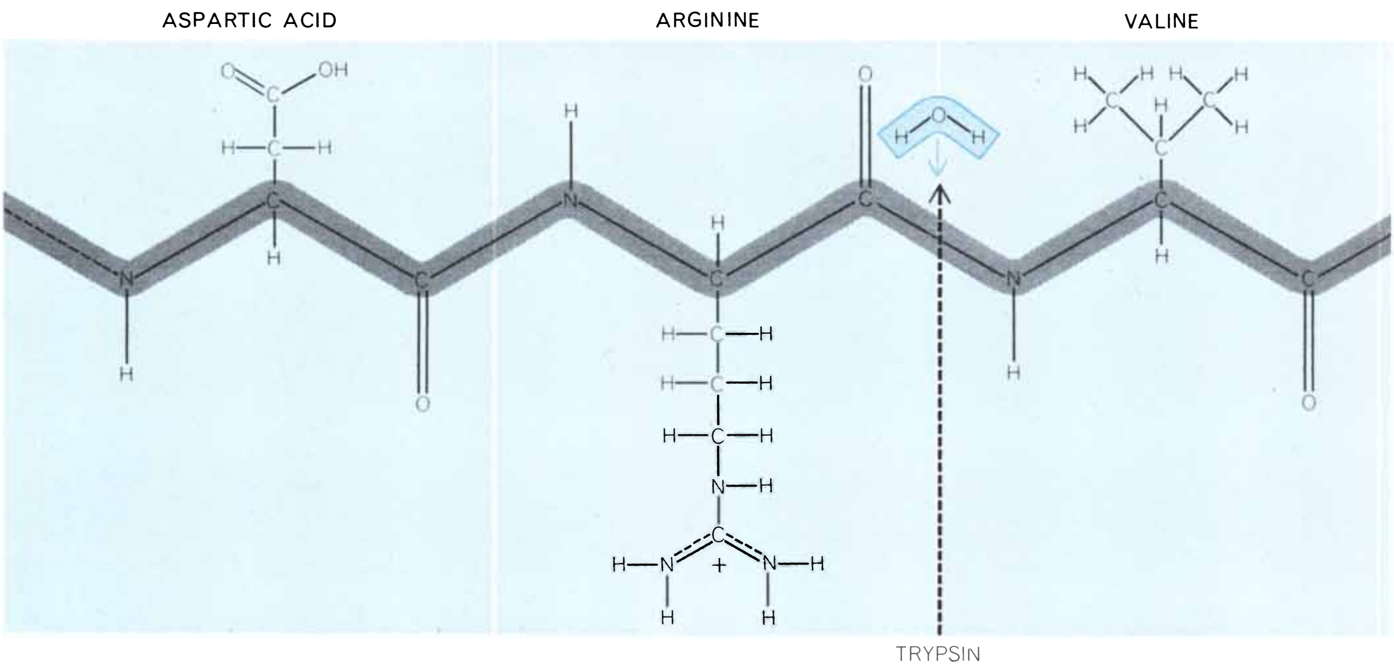
CLEAVAGE OF A "PEPTIDE" BOND is the fundamental step in the degradation, or digestion, of a protein molecule. A peptide bond is the carbon-nitrogen linkage formed when two amino acids are united with the simultaneous release of a molecule of water. The reverse process, peptide hydrolysis, is shown here. Without a catalyst, hydrolysis is immeasurably slow. The letter "R" represents any of the various side groups found in the 20 common amino acids from which the polypeptide chains of proteins are assembled.

zymes are highly selective in their catalytic effect. An enzyme such as trypsin will hydrolyze certain bonds in a protein molecule but will have no measurable effect on certain others. The explanation is that, although all peptide bonds are chemically similar, their immediate environment is modified by the chemical nature of the amino acid residues on either side of a given bond. Each of the proteolytic enzymes requires a specific chemical environment in order to catalyze the hydrolysis of a peptide bond.

Trypsin, for example, hydrolyzes only peptide bonds whose carbonyl group (C=O) is contributed by an amino acid (e.g., arginine or lysine) that has a positively charged side group. Chymotrypsin acts preferentially on peptide bonds whose carbonyl group is adjacent to an amino acid (e.g., tyrosine or phenylalanine) that has a six-carbon ring in its side group. In contrast, carboxypeptidases exclusively hydrolyze the last peptide bond in a polypeptide chain. Carboxypeptidase *A* acts preferentially on peptide bonds adjacent to terminal amino acid residues with a six-carbon-ring side group, and carboxypeptidase *B* on those adjacent to terminal residues (e.g., lysine or arginine) whose side groups end in an amino group (NH_2). An illustration of the specificities of these enzymes toward a hypothetical polypeptide is shown at the bottom of these two pages.

Broadly speaking, trypsin and chymotrypsin cleave peptide bonds that occupy internal positions in the polypeptide chain, and hence they are referred to as "endopeptidases." Carboxypeptidases, which cleave the outermost peptide bonds, are called exopeptidases. As we shall see, it happens that the two endopeptidases, trypsin and chymotrypsin, operate by a common mechanism that is different from the one involved in the action of carboxypeptidases.

A typical protein molecule containing several hundred amino acid residues in a linear sequence will have many peptide bonds that can be attacked by an enzyme such as trypsin. The enzyme can hydrolyze the chain at every peptide bond adjacent to an arginine or a lysine residue, giving rise to polypeptide fragments with arginine or lysine residues at the ends. If the same protein is exposed to the action of a carboxypeptidase rather than trypsin, the terminal peptide bonds will be hydrolyzed sequentially, giving rise to free



SPECIFICITY OF PEPTIDE BOND CLEAVAGE is an important characteristic of enzyme action. Three of the principal "proteolytic," or protein-digesting, enzymes are trypsin, chymotrypsin and carboxypeptidase *A*. Each will split only peptide bonds that are in

amino acids one at a time until a peptide bond is reached that does not meet the specific requirements of the attacking enzyme. Through the combined action of endopeptidases and exopeptidases a protein can be digested into fragments of various lengths and ultimately degraded into free amino acids. This process is physiologically significant: it provides both free amino acids and larger fragments for absorption through the intestinal wall. The selective hydrolysis of proteins by proteolytic enzymes has also been an important experimental tool for the determination of the amino acid sequence of proteins [see "The Chemical Structure of Proteins," by William H. Stein and Stanford Moore; SCIENTIFIC AMERICAN, February, 1961].

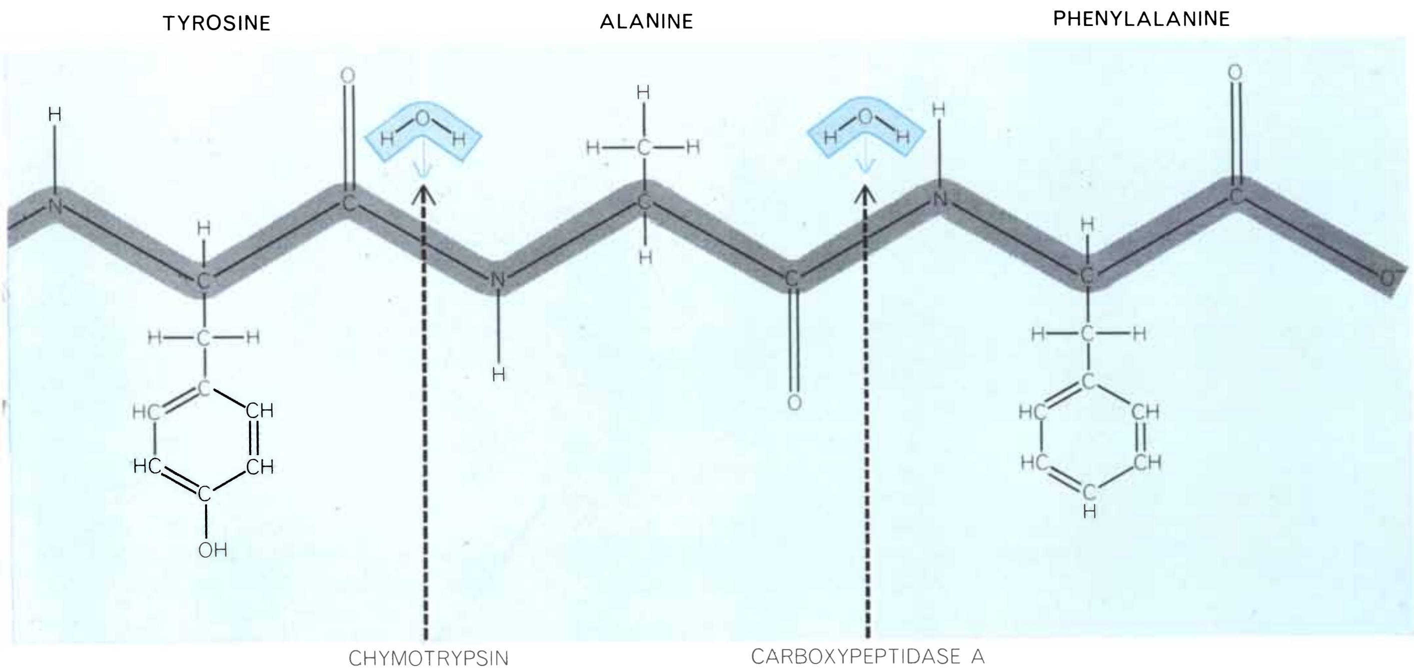
A major step toward understanding the specificity of proteolytic enzymes was taken some 25 years ago at the Rockefeller Institute, when Max Bergmann, Joseph S. Fruton (now at the Yale University School of Medicine) and their associates found that relatively simple synthetic compounds with only one or two peptide bonds were also susceptible to hydrolysis by proteolytic enzymes. They found, for instance, that trypsin rapidly hydrolyzes a compound designated *N*-acyl argininamide, whose molecular structure is derived from the amino acid arginine [*see upper illustration on next page*]. Molecules of this kind have an amide (a nitrogen-containing group) where arginine has a carboxyl group (COOH); at the other end they have an acyl group (a derivative of an organic acid, such as acetic acid) where arginine has its primary amino group. The hydrolysis of such molecules by trypsin yields *N*-acyl arginine and ammonia.

Several years later my associates George Schwert, Seymour Kaufman, John Snoke and I, then working at the Duke University School of Medicine, were able to narrow down still further the minimum structural elements required in a molecule that could be hydrolyzed by trypsin. We found that when the nitrogen of the amide group in *N*-acyl argininamide is replaced by oxygen, the resulting esters are hydrolyzed even more rapidly than the original amide compound. These synthetic compounds, like all other substances on which enzymes act, are commonly called substrates.

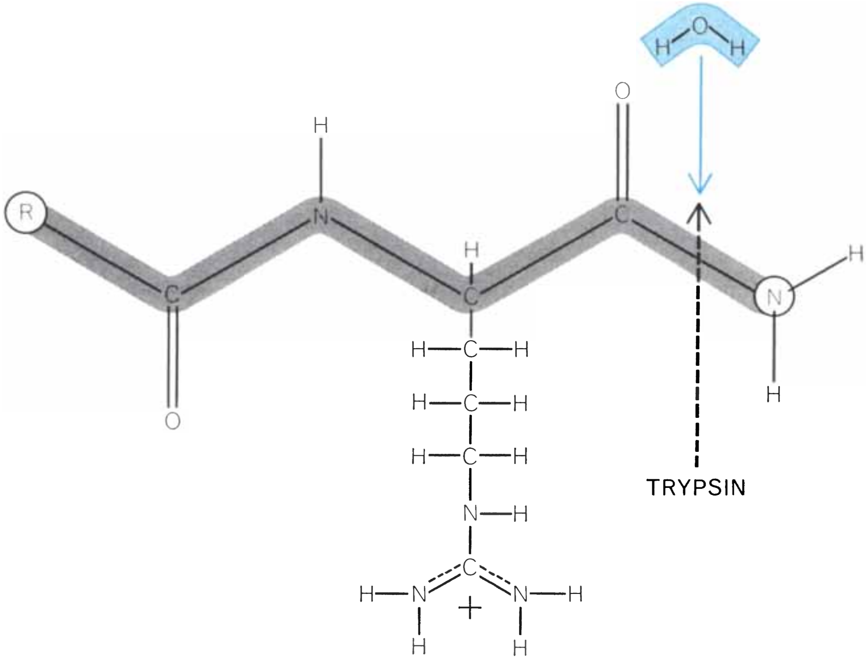
The recognition that substrates of such relatively simple and specified properties are attacked in the same way as complex proteins has helped considerably in clarifying how proteolytic enzymes work. It was immediately evident that the large size of the natural substrate molecule does not play a unique part in the action of proteolytic enzymes. Furthermore, synthetic substrate molecules with a limited number of reactive groups have provided a tool for testing the contribution of each structural element of the substrate to the specificity of the enzyme, just as a set of keys can be used to determine the precision and uniqueness of a lock. A great many investigations of this kind, extending the work of Bergmann and his associates, have been conducted in numerous laboratories, particularly those of Emil L. Smith at the University of Utah College of Medicine, of Carl Niemann at the California Institute of Technology and in our own laboratory at the University of Washington. These studies have provided a rich catalogue of information relating the structure of synthetic molecules to their interaction with proteolytic enzymes.

This catalogue contains a special section listing a group of compounds that react with both trypsin and chymotrypsin as if they had little regard for the different specificities of the two enzymes. These compounds are highly reactive esters, formed by the coupling of an "aromatic" alcohol (one having a six-carbon ring) with certain organic acids. Let us therefore consider at this point some basic principles of the mechanism of action of these enzymes.

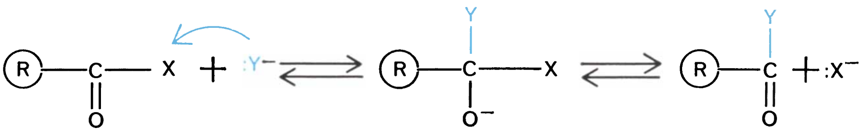
Each atom has only a limited number of electrons that can be shared with surrounding atoms to form chemical bonds. When additional electrons are offered such an atom, it can accept them only by letting go of electrons already being used, causing that bond to rupture. In the hydrolysis of polypeptides, bond breakage is usually initiated by a nucleophile, a compound with electrons to spare [*see lower illus-*



a particular chemical environment. Thus trypsin splits the peptide bond to the right of an arginine residue; chymotrypsin splits the bond to the right of a tyrosine residue; carboxypeptidase *A* splits a terminal peptide bond to the left of a phenylalanine residue.



CLEAVAGE OF SYNTHETIC SUBSTRATES, compounds that are acted on by enzymes, can provide important information about enzyme mechanisms. The molecule shown here, *N*-acyl argininamide, is a derivative of the amino acid arginine and one of the simplest compounds cleaved by trypsin. The acyl group (R·CO) replaces a hydrogen atom normally present in arginine; the amino group (NH_2) at right replaces the hydroxyl group (OH).



CLEAVAGE MECHANISM is believed to require a nucleophile, a reactive group with electrons to spare. The nucleophile represented here by :Y has two lone electrons in its outer shell. The nucleophile reacts with the substrate (R·CO·X) to form an unstable intermediate in which each of the carbon atom's four bonds is linked to another atom or group. When the C·X bond breaks, X is expelled. X is a nitrogen atom in polypeptides or an oxygen atom in esters. An ester is produced when an acid combines with an alcohol.

tration above]. As the electrons are accepted by the carbon atom of the peptide bond, the link between the carbon and the nitrogen is broken and the amide group is detached. An enzyme such as chymotrypsin is believed to promote this reaction because certain groups on the surface of its molecule are effective electron donors.

It is clear, however, that many other features of an enzyme are involved in the process. To begin with, the enzyme binds the substrate to itself and thereby brings the reacting groups of both substrate and enzyme in close contact with each other. The enzyme's reacting groups include effective nucleophiles, such as the five-atom imidazole ring of the amino acid histidine. Other enzyme groups tend to stabilize the intermediate products formed during hydrolysis. One of these is the short but reactive side group of the amino acid serine, which can transiently capture the acid portion of the substrate, forming an ester [*see illustration on opposite page*].

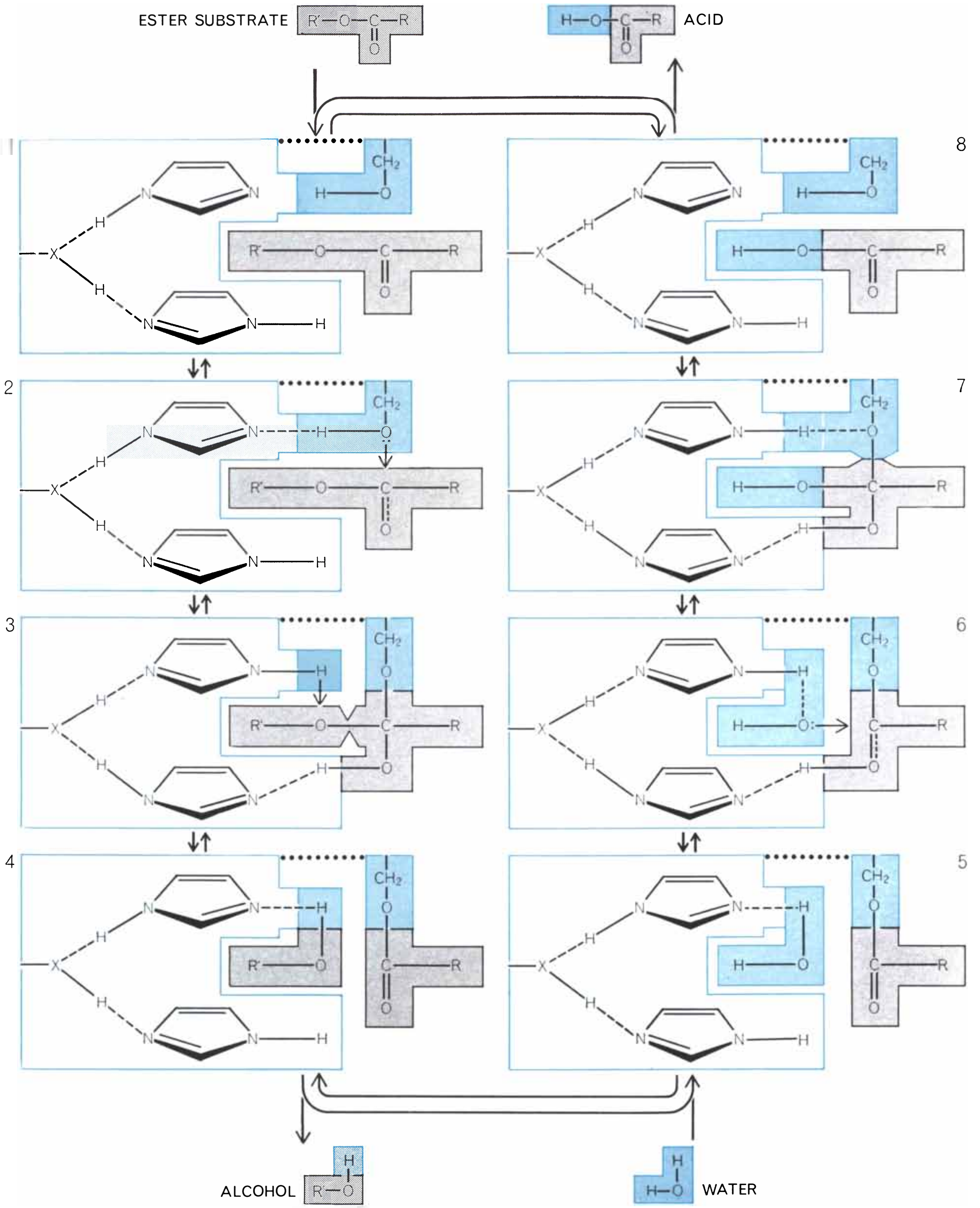
The operation of these factors can be illustrated by the hydrolysis of the synthetic substrate *p*-nitrophenylacetate, which is the acetic acid ester of the aromatic alcohol nitrophenol. That this substrate can be hydrolyzed both by trypsin and by chymotrypsin was shown by B. S. Hartley and B. A. Kilby of the University of Cambridge. The hydrolysis begins when the enzyme encounters the substrate in solution and the two molecules form what is described as an enzyme-substrate complex. In the second step the ester is split into its acidic and basic constituents. The former, or acetyl portion, combines with the enzyme, giving rise to an intermediate called the acyl enzyme; the latter is released as the alcohol nitrophenol. In the third step the acyl enzyme is hydrolyzed by water, which regenerates free enzyme and liberates the acyl group as the corresponding acid (in this case acetic acid).

The first step happens so fast that it cannot be separated from the second; the third step, however, takes place more slowly. The initial burst of activity representing the first two steps can be followed by measuring the liberation of nitrophenol; the measurements are made easier by the fact that this alcohol is yellow. The third step can be followed by measuring the release of the acid. Since it is the slowest step, it governs the overall rate of the process. The mechanism of each of these steps has been studied intensively, notably by Thomas C. Bruice, first at Cornell University and more recently at the University of California at Santa Barbara, and by Myron L. Bender at Northwestern University. A particular effort has been made to identify the specific groups on the enzyme surface that participate in each of the postulated steps.

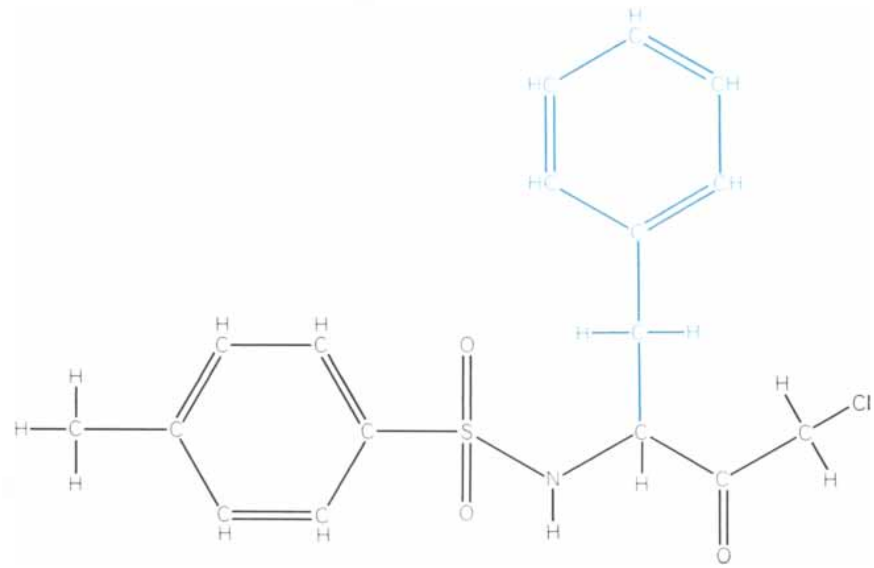
So far two kinds of group have been clearly implicated in the proteolytic activity of trypsin and chymotrypsin. The reaction with *p*-nitrophenylacetate can be stopped at the end of the second step, for instance, by carrying out the reaction in a mildly acidic solution. When the acyl enzyme is removed and analyzed, it is found that the acyl fraction is invariably bound to the hydroxyl group of a serine residue of the enzyme. Although trypsin and chymotrypsin each contain some 30 serine residues per molecule, only one of them is capable of capturing the acyl group during reaction with synthetic substrates. The location of this active serine has been identified within the structure of each of the two enzymes. Because serine is involved in their reactivity, trypsin, chymotrypsin and several other enzymes that function in the same way have been given the name "serine proteases."

The other group that has been definitely implicated as a participant in the enzymatic reaction is the imidazole ring of a histidine residue, which contains three carbon atoms and two nitrogen atoms. It is an effective nucleophile because it can donate two electrons from one of the two nitrogen atoms of the ring structure. Therefore it is believed that the histidine residue partakes in the second step of the reaction by initiating the attack on the peptide bond or the equivalent bond in an ester, and possibly also in the third step by initiating the hydrolysis of the acyl enzyme.

Chymotrypsin contains two histidine



HYDROLYSIS OF ENZYME SUBSTRATE by the active site in chymotrypsin or trypsin may take place as shown here. The active site contains the functional groups of two histidine residues (*light colored area containing two imidazole rings*) and of a serine residue (*dark color*). The chemical nature of the group X is not established. In Step 1 the ester enters the active region. In Step 2 the OH group of the serine residue begins its nucleophilic attack. In Step 3 an unstable intermediate is formed. In Step 4 the ester is cleaved and an acyl enzyme is formed. The alcohol created by the cleavage of the ester is released and is replaced by a molecule of water (*Step 5*). In Step 6 a second nucleophilic attack is launched by the OH group of water. In Step 7 another unstable intermediate is formed. And in Step 8 the acid fraction of the ester is released and the free enzyme is restored to its original active condition. The scheme shown here is based in part on concepts proposed by Myron L. Bender and F. J. Kézdy of Northwestern University.



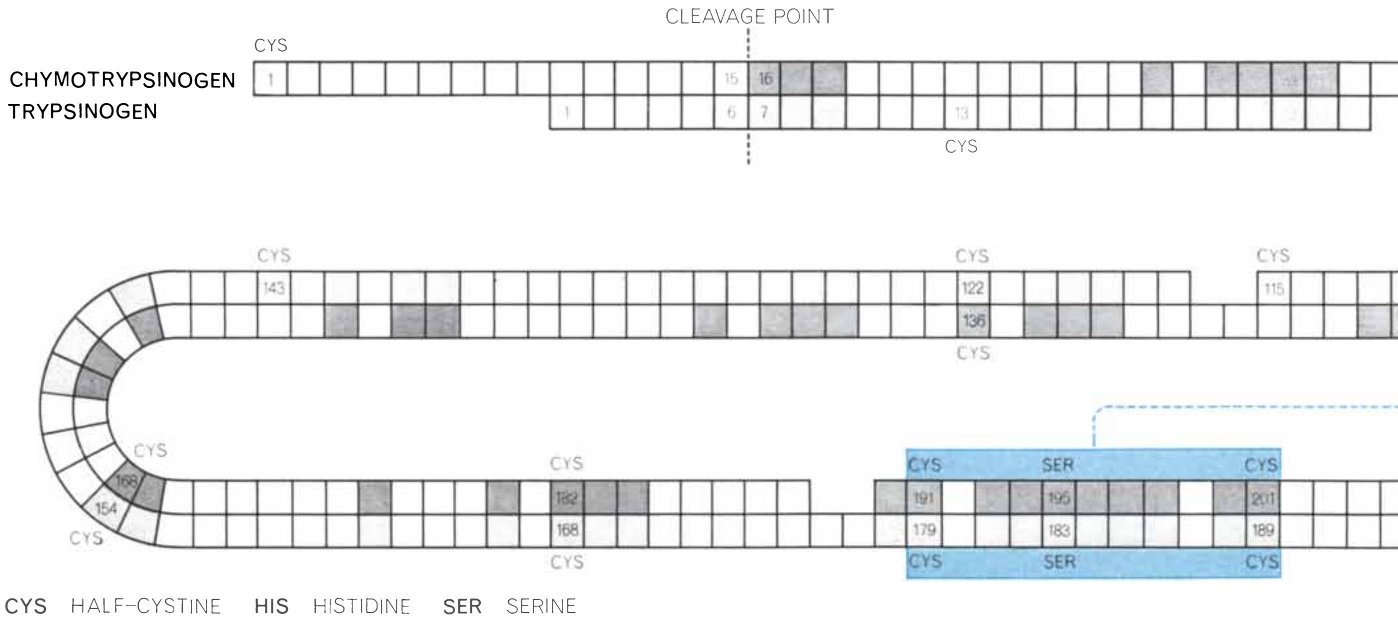
SYNTHETIC ENZYME INHIBITORS can abolish the activity of chymotrypsin and trypsin by reacting with one of the histidine residues in the active site of the enzyme. The compound shown here, *p*-toluenesulfonyl-phenylalanyl-chloromethylketone (TPCK), resembles chymotrypsin substrates and reacts only with chymotrypsin. If the side chain containing the six-carbon ring is replaced by the straight side chain found in lysine, the compound (then known as TLCK) resembles trypsin substrates and reacts only with trypsin.

residues and trypsin three of them. As we shall see, there is reason to believe that not one but two histidine residues are in fact cooperating in this process. One of them pushes the electrons toward the bond being attacked; the other pulls electrons from the opposite side. In this reaction scheme only the second and third steps involve the actual breaking of chemical bonds. The first step, on the other hand, does not necessarily lead to a reaction. This step is dependent on the affinity of the enzyme for the substrate and hence is an expression of enzyme specificity, as distinguished from the catalytic function performed in the second and third steps. The groups on the enzyme that contribute either to specificity or to catalysis constitute what is often termed the active site, or active center. The existence of such a region is hypothetical; the terms suggest that only a portion of the enzyme molecule is involved in enzyme action. The active region is only the relatively small area that comes in direct contact with the substrate. Considerable effort is currently being expended to identify the reactive groups in the active centers of enzymes. Much of the evidence for the existence of such centers has come from investigations of enzyme inhibition, a subject to which I shall now turn.

Enzyme Inhibition

It is to be expected that the functioning of an enzyme will be impaired if any of the groups required for binding or for catalysis are not available to interact with the substrate. Certain naturally occurring inhibitors of trypsin and chymotrypsin have a high affinity for these enzymes, and they have molecules so large that presumably they block off much if not all of the active center. Among these substances are the trypsin inhibitor found in the pancreas and the trypsin inhibitors isolated from the soybean. Other inhibitors structurally resemble a normal substrate but lack the reactive bond in the required position. These substrate analogues are believed to occupy the binding site on the enzyme, thus blocking the normal substrate.

One of the earliest observations implicating a serine residue as a component of the active center of trypsin and chymotrypsin was the discovery



LINEAR SEQUENCES of the amino acid residues of chymotrypsinogen and trypsinogen, the inactive precursor of trypsin, have been established except for one short stretch (84–87) in trypsinogen. When the two sequences are aligned as shown here, it is found that about 40 percent of the positions in the two chains are occupied by the same amino acid residues. These regions of

by A. K. Balls of Purdue University and Eugene F. Jansen of the U.S. Department of Agriculture that the two enzymes are inhibited by a nerve gas, diisopropylfluorophosphate (DFP). Two years earlier Abraham Mazur and Oscar Bodansky of the Medical Division of the Chemical Warfare Service at Edgewood Arsenal had shown that DFP similarly inhibits acetylcholine esterase, an enzyme involved in the conduction of nerve impulses. When the inhibited chymotrypsin was subsequently broken down and analyzed, a phosphorus-containing fragment of DFP was invariably found to be attached to a specific serine residue—the same residue that later was found to be acylated during reaction with *p*-nitrophenylacetate. Thus the chemical modification of a single residue—serine—completely abolished enzyme function.

A clear demonstration that a histidine residue is another constituent of the active site has recently been provided by Elliott N. Shaw and his co-workers at Tulane University. These investigators synthesized compounds that in structure simulate specific substrates but contain, instead of the bond normally hydrolyzed, a group that reacts irreversibly with a histidine residue. For example, the compound *p*-toluenesulfonyl-phenylalanyl-chloromethylketone (TPCK) resembles substrates for chymotrypsin [*see top illustration on opposite page*]. It reacts with a nucleophile in the active center, specifically a histidine residue, completely inhibiting the enzyme. The compound known as TLCK is analogous, except that it simulates specific substrates for trypsin and therefore reacts with a histidine residue in the active center of trypsin only. In addition to serine and histidine, other specific residues seem to be important for the catalytic function of trypsin and chymotrypsin, but their role is still to be clarified.

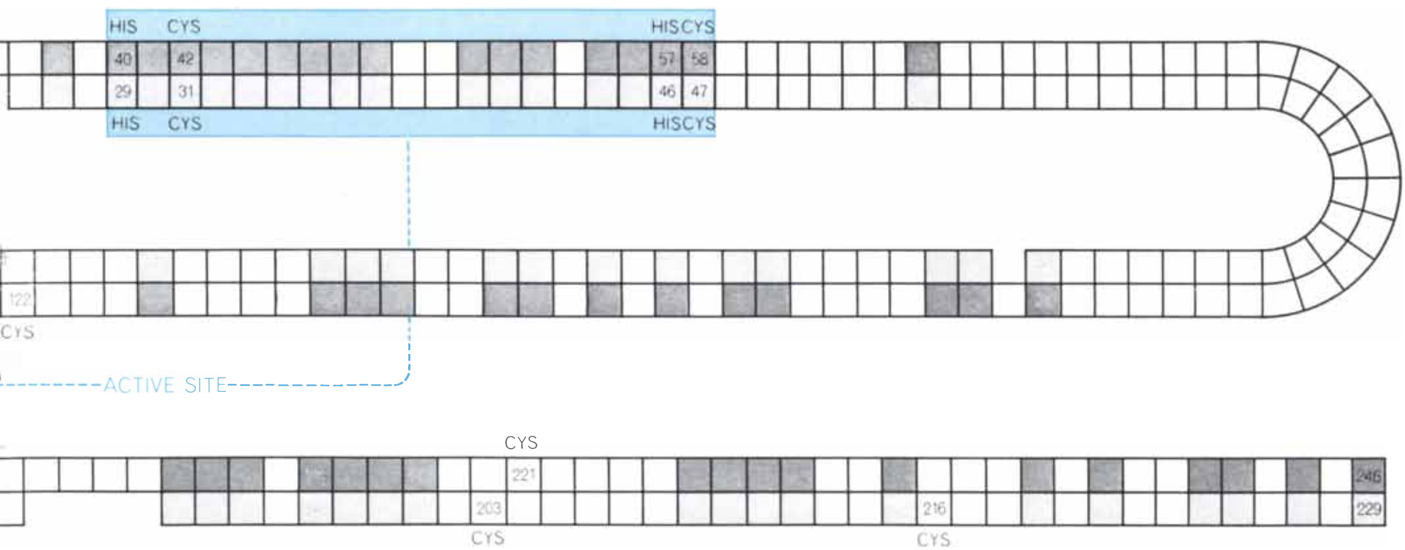
Enzyme Structure

The relation between the structure of the entire enzyme molecule and its active site is not fully understood. In most cases, however, the maintenance of the three-dimensional structure of the entire molecule is necessary for maintaining the conformation of the active center. Hence many processes that change the conformation of the protein are accompanied by a loss of enzymatic activity. Trypsin, chymotrypsin and carboxypeptidases contain some 200 to 300 amino acid residues per molecule, equivalent to between 3,000 and 5,000 atoms. The active site involves only a small fraction of the residues, perhaps not more than 20. In order to appreciate the magnitude of the problem of characterizing the active site, let us consider what is now known about the chemical composition and structure of these enzymes.

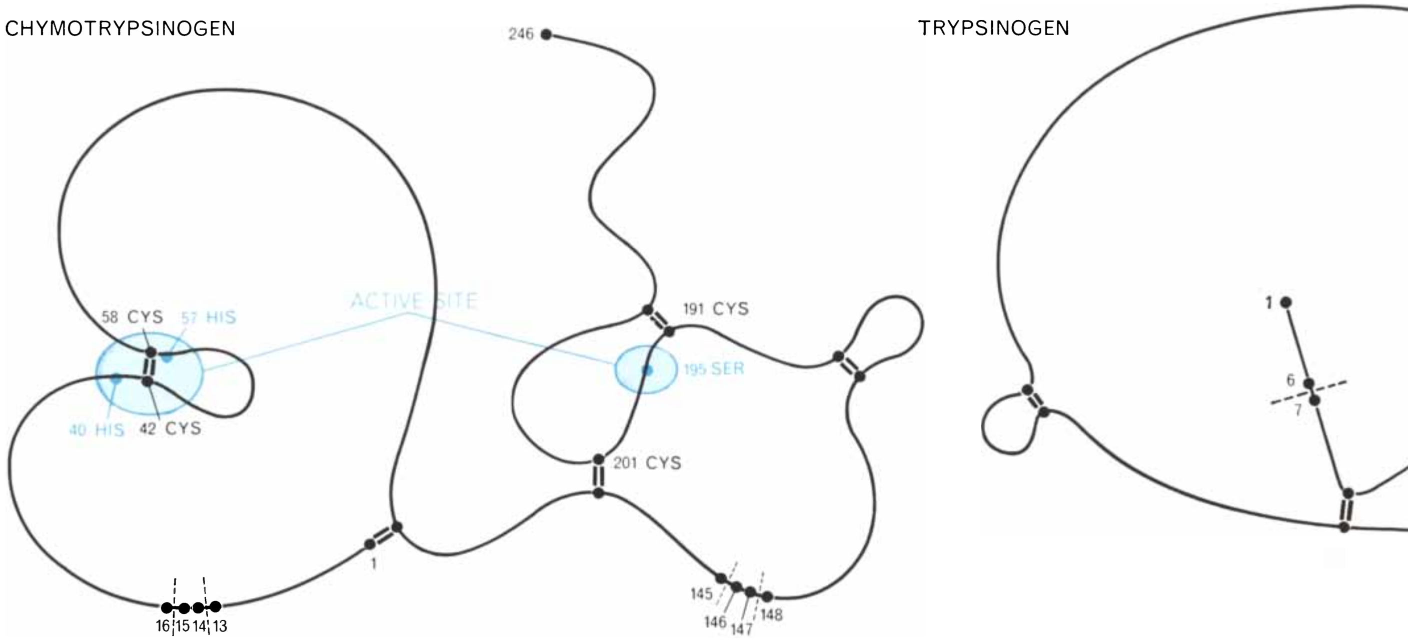
The chemical composition of a compound is usually expressed by the number of atoms of which it is composed. On this basis glucose has the composition $C_6H_{12}O_6$. Chymotrypsinogen—the inactive precursor, or zymogen, of chymotrypsin—has the elemental composition $C_{1,130}H_{1,782}O_{356}N_{308}S_{12}$. This formula tells us virtually nothing, however, about the arrangement of the atoms in the molecule. For such giant protein molecules the composition is usually expressed in terms of the constituent amino acid residues rather than the atoms. Thus the composition of chymotrypsinogen, which contains 246 amino acid residues, can be written: alanine$_{22}$ arginine$_4$ aspartic acid$_9$ asparagine$_{14}$ half-cystine$_{10}$ glutamic acid$_5$ glutamine$_{10}$ glycine$_{23}$ histidine$_2$ isoleucine$_{10}$ leucine$_{19}$ lysine$_{14}$ methionine$_2$ phenylalanine$_6$ proline$_9$ serine$_{29}$ threonine$_{23}$ tryptophan$_8$ tyrosine$_4$ valine$_{23}$.

But even this representation is not adequate to describe the properties of a protein, any more than the formula $C_6H_{12}O_6$ genuinely describes the chemical properties of glucose. A more meaningful representation of the structure of proteins is given in terms of their amino acid sequence, that is, the linear arrangement of the amino acid residues. Such an analysis is a formidable undertaking; until recently it had been accomplished for only one enzyme—ribonuclease, a pancreatic enzyme whose molecule is made up of 124 amino acid residues.

The amino acid sequence of both trypsinogen (the precursor of trypsin) and chymotrypsinogen have been announced within the past year. The trypsinogen molecule is composed of a



homology are indicated by filled squares. The longest homologous sequences involve areas believed to be part of the active sites of the two enzymes. The 10 half-cystine residues in chymotrypsinogen link up to form five disulfide bridges and the 12 half-cystines in trypsinogen form six disulfide bridges. The effect on the two-dimensional geometry of the two enzymes is shown on the next two pages.



HISTIDINE REGION	CHYMOTRYPSINOGEN	40 HIS	41 PHE	42 CYS	43 GLY	44 GLY	45 SER	46 LEU	47 ILEU	48 ASN	49 GLU	50 ASN	51 TRP	52 VAL
	TRYPSINOGEN	HIS 29	PHE 30	CYS 31	GLY 32	GLY 33	SER 34	LEU 35	ILEU 36	ASN 37	SER 38	GLN 39	TRP 40	VAL 41

SERINE REGION	CHYMOTRYPSINOGEN	191 CYS	192 MET	193 GLY	194 ASP	195 SER	196 GLY	197 GLY	198 PRO	199 LEU	200 VAL	201 CYS
	TRYPSINOGEN	CYS 179	GLN 180	GLY 181	ASP 182	SER 183	GLY 184	GLY 185	PRO 186	VAL 187	VAL 188	CYS 189

ACTIVE SITES in chymotrypsinogen and trypsinogen, labeled "histidine region" and "serine region," are almost identical. In each homologous region there are two half-cystine residues (*dark gray*) that form disulfide bridges in the actual molecule and serve to lock the active histidine and serine residues in a fixed position. The disulfide bridges are shown as short double bonds in the schematic two-dimensional representations of the two enzymes. In trypsinogen the heavy bonds indicate the three disulfide bridges whose location is known; the lighter bonds show possible bridge locations. When cleaved between residues 15 and 16, chymotrypsinogen

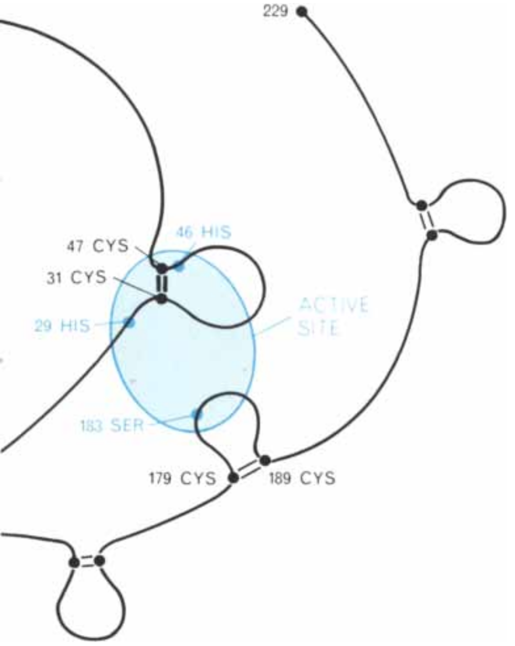
single polypeptide chain of 229 amino acid residues, or 17 fewer than chymotrypsinogen. The amino acid sequence of chymotrypsinogen was established by Hartley at Cambridge and independently by B. Keil and F. Šorm of the Czechoslovak Academy of Science in Prague. The amino acid sequence of trypsinogen was subsequently reported from our laboratory by K. A. Walsh and his co-workers, and a partial sequence was published by the Prague group. In each laboratory some 15 man-years of work have gone into the sequence analysis of each of these two proteins.

Although the amino acid sequence does not reveal the three-dimensional structure of a protein, it provides much information of value to the enzyme chemist. For example, it permits the identification of any residue that participates directly or indirectly in enzyme catalysis. In the case of the zymogens chymotrypsinogen and trypsinogen it also discloses the location of the peptide bonds in the molecule that are cleaved during activation. Chymotrypsinogen is converted to chymotrypsin by cleavage of the bond between the 15th and 16th amino acid residues in the chymotrypsinogen chain. The activation of trypsinogen is accomplished by a cleavage between its sixth and seventh residues. Subsidiary cleavage points in chymotrypsinogen will be mentioned later.

An important feature of linear polypeptide chains is that they are often folded and cross-linked at one or more points. Such cross-links, or bridges, can have an important role in establishing a protein's three-dimensional structure. A cross-link is formed when two sulfur atoms protruding at different points on the polypeptide chain join in a disulfide (—S—S—) bond. The individual sulfur atoms enter the chain appended to cysteine residues, but when two such residues are linked by a disulfide bond, the combination entity is called a cystine residue. The chymotrypsinogen molecule has five cystine (or 10 half-cystine) residues, which serve to tie the molecule together at five different points. The location of these disulfide bridges is shown at the upper left in the illustration above. The trypsinogen molecule has 12 half-cystine residues and therefore six bridges, but only three have been precisely located.

The Active Centers

When the amino acid sequences of chymotrypsinogen and trypsinogen were unraveled, biochemists immediately looked for the location of the histidine



53 VAL	54 THR	55 ALA	56 ALA	57 HIS	58 CYS
VAL 42	SER 43	ALA 44	ALA 45	HIS 46	CYS 47

ALA	ALANINE	LEU	LEUCINE
ASN	ASPARAGINE	MET	METHIONINE
ASP	ASPARTIC ACID	PHE	PHENYLALANINE
CYS	HALF-CYSTINE	PRO	PROLINE
GLN	GLUTAMINE	SER	SERINE
GLU	GLUTAMIC ACID	THR	THREONINE
GLY	GLYCINE	TRP	TRYPTOPHAN
HIS	HISTIDINE	VAL	VALINE
ILEU	ISOLEUCINE		

is converted to the active enzyme chymotrypsin. Cleavage of trypsinogen between residues 6 and 7 yields active trypsin. (The lighter broken lines in chymotrypsinogen indicate secondary cleavage points.)

and serine residues that had been identified with the active centers of the two molecules. In chymotrypsinogen the active histidines are at positions 40 and 57; in trypsinogen, the shorter molecule, they are at positions 29 and 46. In both molecules the spacing between the two histidines is exactly the same. In both there are neighboring cystine residues that tie the polypeptide chain together in such a way that the two histidine residues are brought close together. Thus chymotrypsinogen has a cystine bridge between positions 42 and 58, which gives rise to a loop in the molecular chain. Similarly, trypsinogen has a cystine bridge between positions 31 and 47, forming another loop. Brought into proximity at the entrance to these loops, the two histidines can cooperate in acting as electron donors in protein hydrolysis.

Where in the two structures are the reactive serines? In chymotrypsinogen the reactive serine is at position 195 and in trypsinogen it is at position 183. Again note the similarity in location. And although in each molecule there is a large linear distance between the two histidines and the reactive serine, there is good reason to believe that the three residues actually lie close together in the active region of the three-dimensional molecule.

The resemblance in chemical structure between chymotrypsinogen and trypsinogen goes even further. When the amino acid sequences of the two molecules are compared side by side, after a common starting point has been chosen, it is found that about 40 percent of the amino acid residues are the same in both molecules [*see illustration on pages 74 and 75*]. Moreover, the most striking similarity in sequence occurs in the neighborhood of the histidine residues and the reactive serine [*see illustration at left*].

This marked similarity in structure of two enzymes that operate by the same mechanism but differ in specificity suggests that the two may have evolved from a common archetype. In the course of evolution those elements of the structure that are necessary for enzyme function would have remained unchanged. A similar conservation of chemical character, together with preservation of biological function, had previously been observed in the amino acid sequence of the cytochrome and hemoglobin molecules found in various species of animals [see "The Hemoglobin Molecule," by M. F. Perutz; SCIENTIFIC AMERICAN, November].

The three-dimensional structure of chymotrypsinogen and trypsinogen is still unknown. The method of X-ray crystallography, which has been so successful in determining the three-dimensional structure of hemoglobin and its close relative myoglobin, has proved to be much more difficult to apply to the proteolytic enzymes. The data available so far for chymotrypsinogen and chymotrypsin reveal something that has been facetiously described as "complex but unintelligible." In the absence of direct evidence we have attempted to construct a hypothetical model of chymotrypsinogen that incorporates certain principles we believe to be correct [*see illustration on page 69*]. The model shows, for instance, the close juxtaposition of the two histidines and the active serine, the restrictions imposed by the disulfide bonds, the tendency of water-soluble amino acid residues to be on the outside of the molecule and water-insoluble residues to be on the inside, and the necessity for the peptide bonds cleaved during activation to be readily accessible. How many of the model's features are correct only future research will tell.

The zymogen precursors of proteolytic enzymes are manufactured within the cells of the digestive organs but are converted into active enzymes after they have been secreted by the cells. In all known cases the conversion involves the splitting of a specific peptide bond in the zymogen molecule. Representative examples of zymogen activation, in addition to the activation of chymotrypsinogen and trypsinogen, are the conversion of pepsinogen to pepsin and of procarboxypeptidase to carboxypeptidase. The phenomenon is not limited to proteolytic enzymes; for instance, many of the proteins involved in the process of blood clotting require similar activation, such as the conversion of prothrombin to thrombin, of plasminogen to plasmin and of fibrinogen to fibrin.

Zymogen Activation

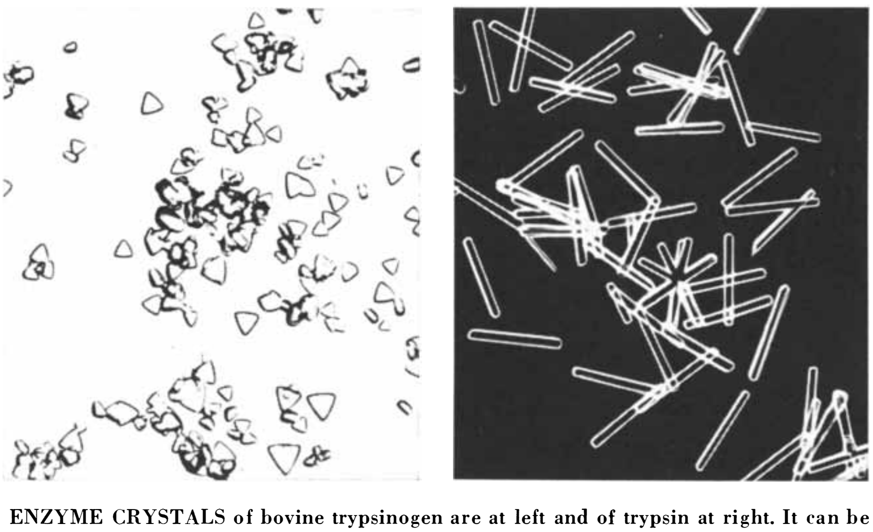
The key enzyme in the activation of pancreatic zymogens is enterokinase, a proteolytic enzyme secreted by the mucous membranes of the intestine. Its prime function is to convert trypsinogen to trypsin; trypsin then becomes the key for the activation of all other pancreatic zymogens. Enterokinase is not, however, the only enzyme that can activate trypsinogen; the activation can be accomplished by trypsin itself and by several other enzymes, some of them found in bacteria. As far as is known, all these enzymes function in the same way: they cleave a specific peptide bond in the polypeptide chain of trypsinogen. In the trypsinogen obtained from cattle the cleavage occurs between the sixth and seventh amino acid residues of the chain. Since each molecule of trypsin released can activate another molecule of trypsinogen, it is apparent that the activation of trypsinogen is a self-accelerating process. Chymotrypsinogen similarly becomes an active enzyme when it is cleaved by trypsin. The cleavage takes place near one end of the chain (between residues 15 and 16) but no fragment is released because residue 1 is tied to the remainder of the molecule by a disulfide bond.

In these activation reactions the hydrolytic effect of trypsin comes to a halt after the first peptide bond has been cleaved. Presumably all other peptide bonds in the zymogen molecule that could have been cleaved are so located within the structure of the molecule as to remain completely resistant to the action of the enzyme. In the activation of chymotrypsinogen, hydrolysis can go a bit further because the chymotrypsin formed acts as a proteolytic enzyme on itself and can cleave three additional peptide bonds; they lie between positions 13 and 14, 145 and 146, and 147 and 148. All the resulting fragments are enzymatically active. But the bond between positions 15 and 16 must first be split by trypsin.

All known zymogens of the pancreas follow the same pattern of activation when they become converted to the active form. The activation requires the cleavage of a peptide bond adjacent to an arginine or a lysine residue near the beginning of the polypeptide chain of the zymogen. Some zymogens, however, must undergo additional transformations before they become activated. For example, the zymogen procarboxypeptidase *A* exists in the pancreatic juice as an aggregate of three large molecular subunits. Only one of these, subunit I, can be regarded as the immediate precursor of the enzyme carboxypeptidase *A*. Subunit II is the precursor of an enzyme that is similar in specificity to chymotrypsin but differs in composition from the chymotrypsin we have been discussing. The nature and role of subunit III is unknown. When trypsin is added to the three aggregated subunits, subunit I is converted to carboxypeptidase *A* only after subunit II has first become activated.

Why and how does the cleavage of a single and specific peptide bond in the zymogen give rise to an active enzyme? At present one can offer only a partial explanation, based largely on reasoning and only indirectly supported by experimental facts. I have mentioned previously that the action of an enzyme seems to involve two steps: the specific binding of the substrate and the subsequent bond-cleaving. Singly or in combination these steps require the proper configuration of groups on the enzyme molecule: the binding site and the catalytic site. The absence of either site or both in the zymogen would preclude enzyme function. Experiments have shown that chymotrypsinogen can bind substrates or inhibitors for chymotrypsin in much the same way that chymotrypsin itself does. These observations suggest that the binding site exists in the zymogen and hence that the catalytic site is not functional unless and until the specific peptide bond is cleaved during activation.

This cleavage is believed to change the conformation of the protein molecule so as to bring the groups involved in the bond-cleaving mechanism into the proper spatial relation. In the case of trypsin and chymotrypsin these groups are the reactive serine residue and the two histidine residues. Since the binding site and the catalytic site together form the active center, however, they must occupy adjacent or overlapping areas. Inasmuch as one of them is already present in the zymogen, it follows that the conformational changes involved in zymogen activation must be localized within a very small region of the molecule. The relation between these two sites is perhaps analogous to the relation of the back and the seat of a folding chair: the back can be regarded as determining the specificity and the seat the function. Obviously it is only after the chair is unfolded that it becomes functional.



ENZYME CRYSTALS of bovine trypsinogen are at left and of trypsin at right. It can be seen that activation of the former produces a striking change in crystal structure. The two photomicrographs were made in 1935 by Moses Kunitz of the Rockefeller Institute.

Although this article has drawn almost exclusively on trypsin and chymotrypsin to illustrate the relation between chemical structure and enzymatic function, it would be wrong to conclude that all proteolytic enzymes utilize the same mechanism for the hydrolysis of peptide bonds. The range of structures essential for catalytic function is not limited to the cooperation of serine and histidine residues. For instance, the proteolytic enzymes of a group found in plants require a free thiol group (SH) for catalytic activity. These include papain, a proteolytic enzyme extracted from papaya juice, and ficin, an enzyme obtained from the fig tree. Papain, commercially used as a meat tenderizer, has a polypeptide chain of some 180 amino acid residues; the chain of ficin is probably somewhat longer.

Other proteolytic enzymes, such as pepsin and certain enzymes found in bacteria, are active only in slightly acid solution. Some aminopeptidases and the carboxypeptidases require the participation of specific metals for enzymatic function. (The former are exopeptidases that cleave only the first bond in a polypeptide chain; the latter are exopeptidases that cleave only the last bond.) The aminopeptidases usually require as coenzymes the ions of such metals as manganese and magnesium. The carboxypeptidases usually contain in their active center a firmly bound atom of a metal such as zinc.

Carboxypeptidase *A* exemplifies the behavior of these metal-containing enzymes. It has a single chain of some 300 amino acid residues; their complete sequence is still unknown. Yet the mode of action of this enzyme and the structure of its active site are remarkably well understood. Bert L. Vallee and his associates at the Harvard Medical School have shown that the natural enzyme contains an atom of zinc that is believed to be anchored to a thiol group somewhere in the chain and to an amino group of the first residue in the chain. When zinc is present, the enzyme will hydrolyze both polypeptides and their corresponding esters. When the zinc is removed, the protein completely loses its enzymatic activity.

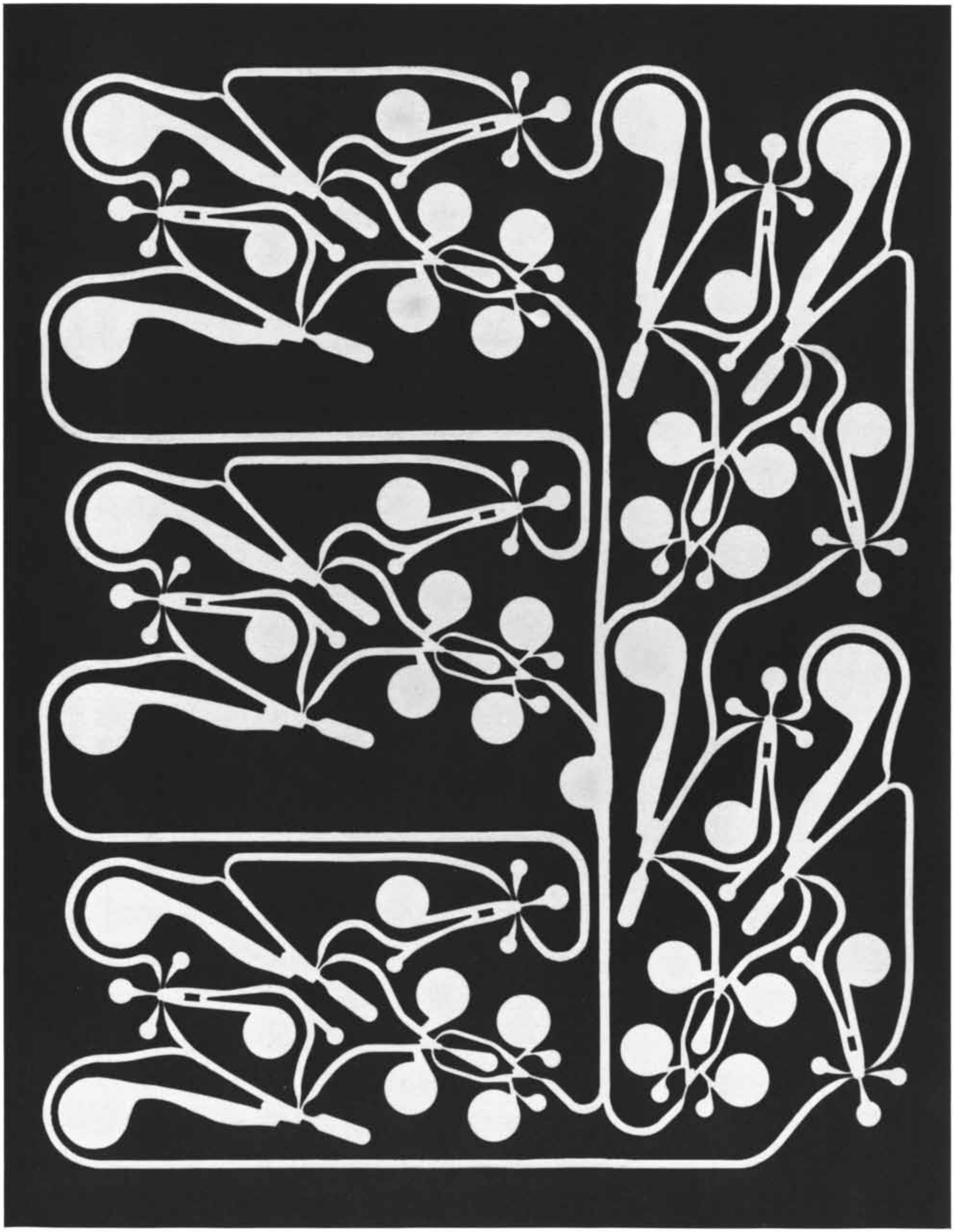
If zinc is replaced by another metal, the specificity of the enzyme is altered. For example, when zinc is replaced by cadmium, the enzyme no longer hydrolyzes peptides but hydrolyzes esters even more effectively than the zinc enzyme does. When zinc is replaced by copper, the enzyme again becomes inactive. Vallee and his associates have shown that it is possible not only to modify the activity of carboxypeptidase by replacement of the metal but also to manipulate the activity and specificity of the enzyme still further by chemical alteration of the active center. Their work has shown that at least five groups must participate in the enzyme's proteolytic activity: the metal, the two amino acid residues to which the metal is bound and two tyrosine residues that, when chemically modified, produce a change in the enzyme's specificity.

The Task Ahead

The foregoing examples were selected to illustrate the range and variety of structures encountered in the search for a chemical explanation of the function and mechanism of proteolytic enzymes. We have only recently determined the linear structure of a few hydrolytic enzymes. We still do not know how they are folded into three-dimensional structures, but we are by no means sure that a three-dimensional model of the molecule will tell us how it functions as an enzyme. Scientific inquiries do not always proceed in an orderly and systematic manner, and perhaps we shall not have to wait until the last detail of the structure of these enzymes is known to understand their function.

The most exciting problem is the elucidation of the structure of the active center. One attempts to do this by "mapping" those groups on the enzyme molecule that are directly involved in enzyme function. The mapping process essentially consists of testing the effect of chemical modification of specific groups in abolishing or inducing enzyme activity. Yet there is no assurance that the notion of an active center is a physical reality and that an isolated structure that reproduced the groupings believed to constitute this site, in the proper spatial relations, would display full enzymatic function. Nature is seldom wasteful, and there is a real possibility that the entire enzyme molecule may be necessary for it to exhibit its full range of function.

Although much remains to be learned about proteolytic enzymes, enough is now known about them to enable investigators to use them to test various hypotheses of the way all enzymes function. It would be fitting if some of the earliest known enzymes, serving one of the most fundamental needs of man, should enable us to understand the mode of action of enzymes in general.



FLUID CIRCUIT performs the operation of dividing by 10 in an all-fluid digital computer: for every 10 input pulses circuit delivers one output pulse. Input pulses enter from above the plane of circuit through circular, bumplike hole attached to straight channel running from top to bottom just to right of center. The 10 identical logic elements, or modules, are arranged in a series of five pairs, three at left and two at right. Each pair contains two steady input streams (*small sausage shapes*), two outputs (*small circular shapes attached to short straight channels*), eight control jets (*small teardrop shapes*) and eight open vents (*large circular shapes*). Shallow channels were chemically etched in Dycril plastic by a special process, called Optiform, developed by Bowles Engineering Corporation. For this photograph the channels were filled with white paint to increase the contrast. Normally the working fluid is air.

FLUID CONTROL DEVICES

They perform the operations of amplification and switching mechanically rather than electrically. For some purposes they are more reliable than their electronic counterparts

by Stanley W. Angrist

In modern usage the word "amplification" ordinarily suggests "electronics." It is on electronic devices that we mainly rely for all sorts of amplification jobs, from the boosting of radio signals to the control of the most massive machinery. The classic example of the principle employed is the simple three-element electron tube, or triode. Any weak, fluctuating voltage applied to the grid of the tube acts on a stream of electrons flowing through the tube, and the resulting modulation of the stream serves to amplify the signal. The tube can do more than merely amplify: a voltage on the grid can also shut off the electron stream or turn it on. On this simple principle an entire technology has been built, including the electronic computer.

Suppose that instead of a stream of electrons one used a stream of liquid or gas and tried to perform these operations mechanically rather than electrically. In place of the grid, precisely controlled jets of fluid directed at the main stream from the sides would modulate or deflect the stream. Thus one might achieve amplification or switch the stream "on" or "off." The idea occurred to engineers many years ago, and several patents on such devices were issued in the 1930's and 1940's. No one showed much interest in exploiting the method, however, because it is so much slower than electronic amplification that its possible uses seemed very limited.

Four years ago the concept was revived in a serious way. B. M. Horton, R. E. Bowles and R. W. Warren of the U.S. Army's Harry Diamond Laboratories and J. R. Greenwood at the Massachusetts Institute of Technology independently made separate studies of techniques of fluid amplification, and they found them promising for certain important applications, including computation and operations in logic. Fluid amplifiers offer some distinct advantages over electronic devices. They are simple in construction, have virtually no moving parts, can be powered by almost any source of energy to pump the fluid, are immune to damage by heat or ionizing radiation (which electronic equipment is not) and would be comparatively inexpensive if mass-produced.

The reports by Horton, Bowles, Warren and Greenwood set off an almost explosive surge of new research on fluid amplification and control. More than a score of large companies and research laboratories are now exploring its development and uses. Some believe that the fluid amplifier will be a far-reaching innovation in technology. It is hardly likely to match the spectacular rise of the transistor, which within 15 years has grown from a laboratory curiosity to a multimillion-dollar industry, but in the long run it may prove to be just as important.

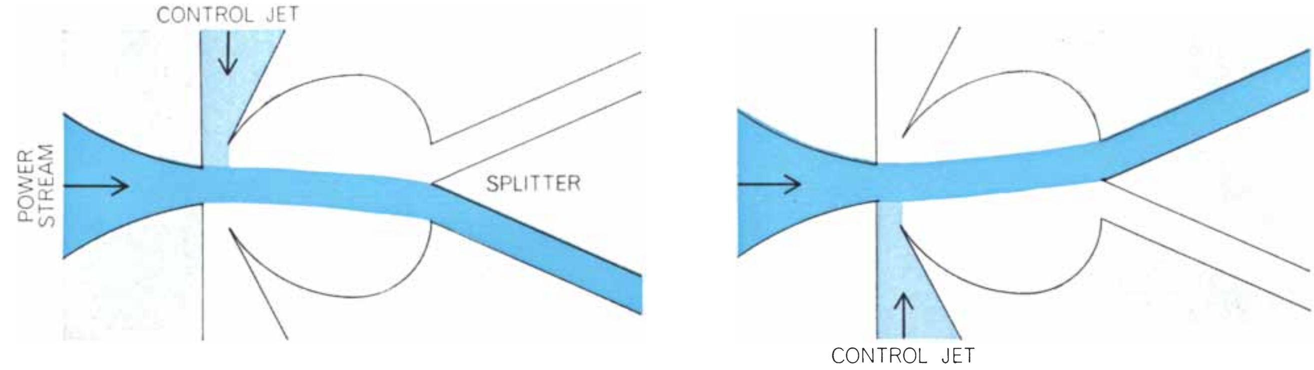
Two different techniques of fluid control are being investigated—one quite simple, the other more complex and more versatile. Let us begin with the elementary system.

Consider a solid block (of steel, plastic or any other suitable material) in which shallow channels have been cut for passage of the fluid [*see top illustration on next page*]. A high-energy stream of fluid, called the power stream, is pumped in through the inlet at one end. The stream passes across a widened chamber (designed, for reasons we shall consider later, to prevent the stream from clinging to one of the channel walls) and arrives at a fork consisting of two outgoing channels separated by a pointed structure called the splitter. If the power stream has not been disturbed and hits the splitter head on, the stream will be divided in two, half of the fluid passing into one outlet channel and half into the other.

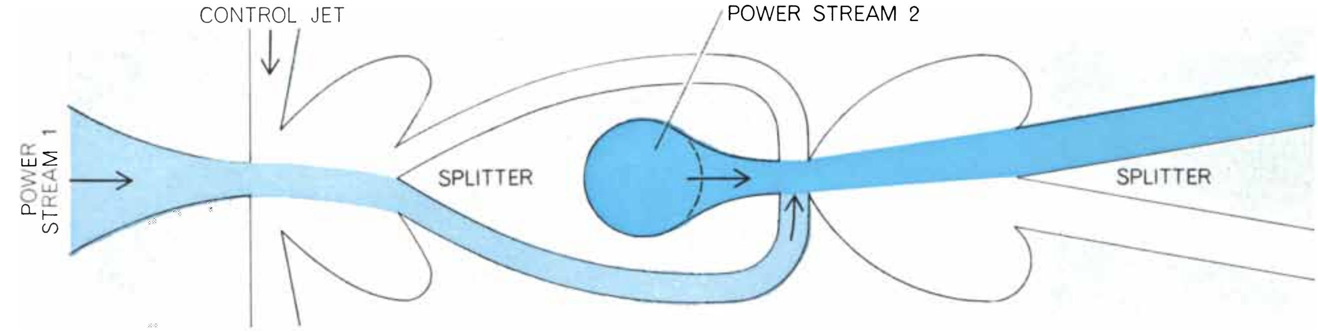
As the power stream enters the system, however, it runs the gamut of two control jets, one on each side. Let us say that one of the jets is turned on and this control stream hits the main stream with a certain momentum. It will deflect the power stream by a certain amount, and the stream will then have a net momentum that is the sum of the original momenta of the power stream and the control stream, taking direction into account, as the geometric diagram on page 83 shows. Given just the right amount of nudge by the control stream, the entire main stream will be bent in the direction of one of the outlet channels and will pass out through that output.

Obviously the output represents an amplification of the energy applied by the control jet, and the gain is equal to the ratio between the power stream's momentum and the momentum of the control jet. The degree of the deflection of the power jet is proportional to the momentum of the control jet. The system is therefore called "proportional control." The control jet's "signal" can be measured in terms of either momentum or pressure, depending on the way the apparatus is set up; if the control nozzle is placed close to the power stream, the main factor deflecting the stream will be pressure rather than momentum.

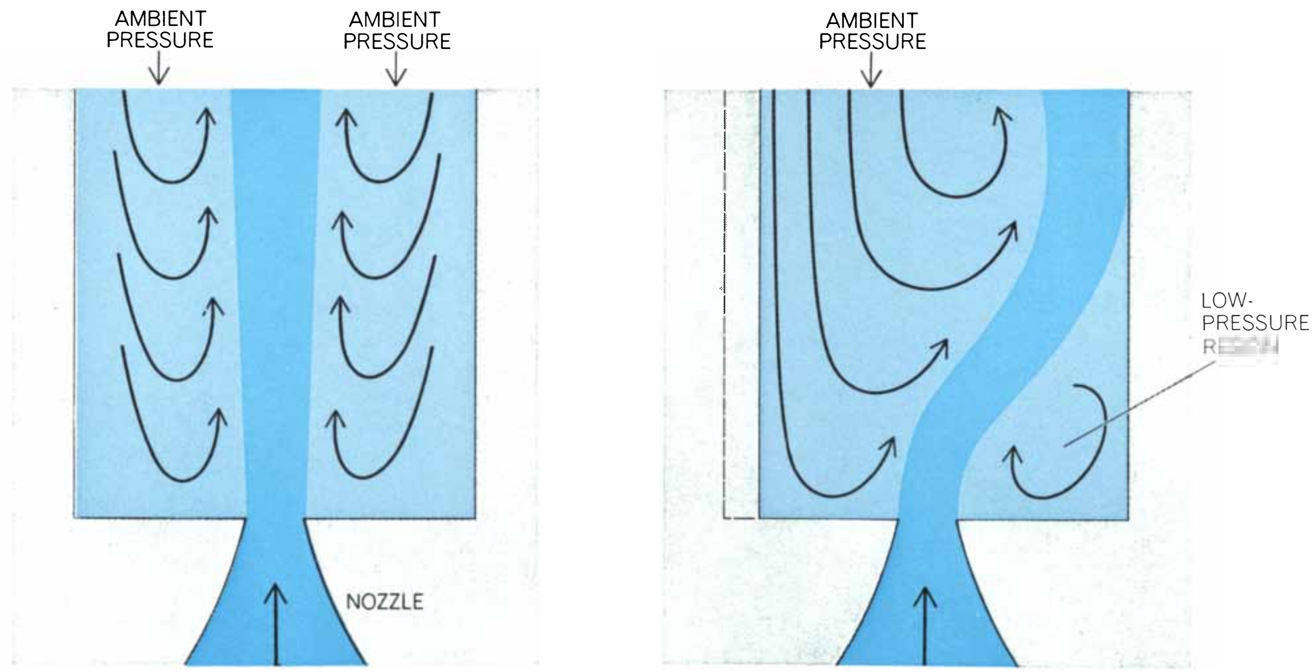
The elementary setup I have described is, of course, only a single-stage affair. It is easy to see that it can be expanded into a multistage system simply by using the output stream of one stage as the control stream for the next [*see middle illustration on next page*]. By making each successive power injection larger than the one before,



FLUID AMPLIFIER consists of a solid block of material in which shallow channels have been cut to allow the passage of a fluid. If the high-energy power stream is not disturbed and hits the splitter head on, the stream will be divided in two, half of the fluid passing into one outlet and half into the other. If either of the two control jets is turned on, however (*left and right*), it will deflect the power stream in the direction of the opposite outlet channel and all of the stream will pass out through that outlet. The heart-shaped chamber in front of the power-stream nozzle is designed to prevent the stream from clinging to one of the channel walls.



TWO-STAGE FLUID AMPLIFIER can be constructed simply by using the output stream of one stage as the control stream for the next. By making each successive power injection larger than the one before, one can build up almost any degree of amplification.



COANDA EFFECT, named after its discoverer, Henri Coanda, is the basis for a wide range of fluid switching devices. At left a high-speed stream of air is injected into a wide container of air. As the stream moves along it entrains air from both sides and becomes broader, carrying more air toward the open end of the container. This process causes the pressure to drop in the zones between the stream and the walls, creating an unstable situation. Any disturbance or change in the shape of the container (*right*) will cause the equalizing return flow of air to push the stream toward one wall, where it will remain locked as long as the stream keeps flowing.

one can build up almost any degree of gain, or amplification, one wishes. That is to say, the small nudge, or signal, applied by a control jet in the first stage can be amplified by successive steps to control a very large power stream indeed in the final stage.

This, then, is the basic outline of the first of the two fluid-control techniques under study. As an instrument of proportional control it performs amplification in the usual sense of the word, and it promises a number of interesting applications, including its use as an element in an analogue computer. The other technique of fluid control does not produce proportional amplification; rather, it corresponds to a triode that turns a flow of electrons on or off. It is essentially like an element in a digital computer.

In this system the fluid power stream, left to itself, locks onto one wall of the channel in which it is flowing, and as a result the stream exits through the outlet on that side. An injection of fluid from the control jet on the same side will cause the stream to swing over to the other side and lock onto the wall there, so that it then flows out of the other outlet. In either case the stream maintains a stable position, flowing only to a particular outlet unless it is switched by a control jet. The reasons for this are inherent in the mechanics of the situation.

Consider a high-speed stream of air injected through a nozzle into a wide container of air. (I call the fluid air to make the example specific; the results to be described would apply to any gas or liquid.) As the stream moves along it will entrain air from both sides and become broader, carrying more air toward the open end of the container [*see bottom illustration on opposite page*]. The stream's pickup of air along its sides, however, causes the pressure to drop in the zones between the stream and the walls of the container. The resulting pressure difference creates an unstable situation: the higher pressure of the surroundings ("ambient pressure") will push air back into the low-pressure zones on both sides of the stream to equalize the pressure.

Suppose now there is some disturbance or asymmetry (say in the shape of the container) that causes the equalizing return flow to push the stream toward one wall. As the zone between the stream and that wall narrows, there is less room for the admittance of counterflow to replace the air being entrained by the stream on that side and therefore the comparative pressure in the zone drops further. Very quickly the stream moves over against the wall. It stays locked onto that wall as long as the stream keeps flowing, because on the wall side a region of low pressure persists near the nozzle, whereas on the opposite side of the stream the ambient pressure pushes the stream toward that region. The phenomenon is known as the Coanda effect—so designated because it was first studied by a Romanian engineer named Henri Coanda in the 1930's.

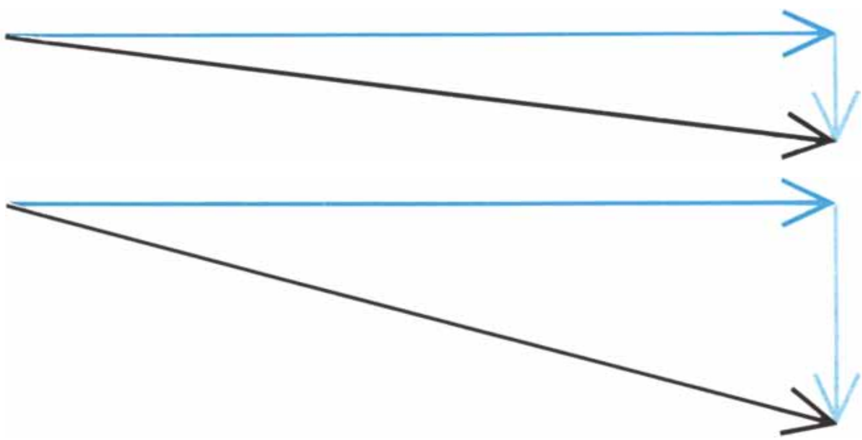
Obviously the stream can be moved away from the wall in either of two ways: by increasing the pressure on the stream from the wall side or by reducing the pressure on the opposite side. This can easily be done by means of control jets on the sides. If the stream is locked onto the right wall, injection of air from the right jet or removal of air through the left jet will cause the stream to swing away from the right wall as soon as the pressure on the right side becomes higher than that on the left. Once the stream has crossed the center line of the channel it will go on to attach itself to the left wall for the same reasons that it originally locked onto the right one. The control jet can then be shut off; the stream will stay locked onto the left side without help.

In the two-outlet type of device the locking of the stream onto the right wall means, of course, that the entire stream exits through the right outlet, and when it is switched to the left wall, it goes to the left outlet. (The Coanda effect explains, by the way, why the proportional-control amplifier must have the channel widened into a heart shape near the power-stream nozzle; this configuration prevents the stream from locking onto a wall.) It has turned out that the behavior of the stream depends a great deal on the distance of the splitter from the power-stream nozzle. Warren of the Harry Diamond Laboratories has investigated this matter in detail [*see illustration on page 85*].

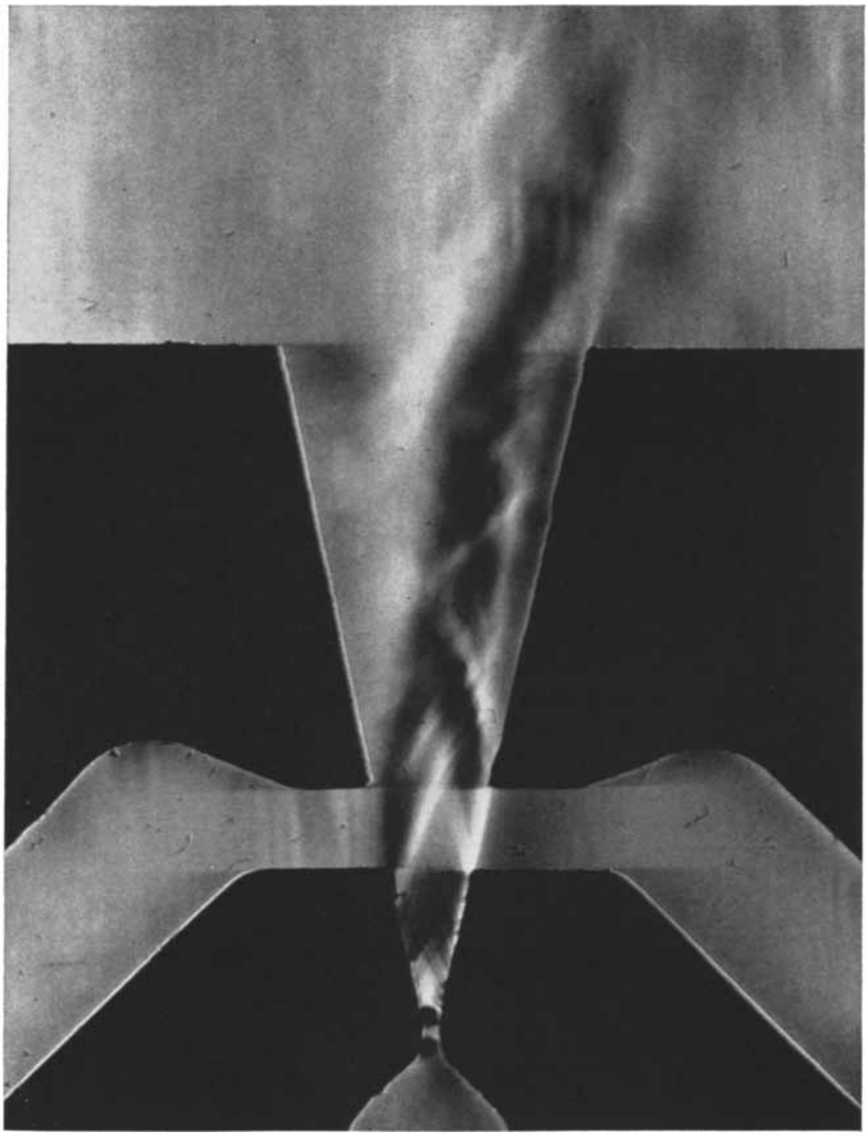
When the splitter is very close to the nozzle (within a distance not more than about twice the nozzle's width), the stream does not lock onto either wall, because the distance is not sufficient for a significant pressure difference to develop. The stream can be directed into one outlet or the other by a pulse injection from a control jet, but as soon as the control injection stops, the stream resumes its normal behavior of dividing at the splitter and flowing to both outlets.

If the splitter is located at a distance amounting to three to five nozzle widths from the nozzle, the stream begins to be influenced by the Coanda effect: in the presence of an asymmetry most of it will flow spontaneously to one outlet. When the splitter is six nozzle widths or more away from the nozzle, the Coanda effect takes full charge. The stream will lock onto one wall and flow only to the outlet it has chosen spontaneously or the one to which it is switched.

Some very interesting effects can be produced by blocking one of the outlets, as the illustration on page 85 shows. In one arrangement such a block will di-



PROPORTIONAL CONTROL, the principle on which the fluid amplifiers at the top and middle of the opposite page are based, is illustrated geometrically. The vector representing the momentum of the control jet (*light colored arrows*) is added to the vector of the power stream's momentum (*solid colored arrows*) to obtain the momentum of the output stream (*black arrows*). Thus the gain, or amplification, produced by the fluid system is equal to the ratio between the power stream's momentum and the momentum of the control jet. The degree of deflection of the power jet is proportional to the momentum of the control jet.



SCHLIEREN PHOTOGRAPH, made by an optical technique that detects density gradients in a gas flow, demonstrates Coanda effect. A high-energy stream of air is locked onto the chamber wall at right after being subjected to a short blast of air from control jet at left.

vert the stream from the outlet it naturally prefers to the opposite one, but when the block is removed the stream will return spontaneously to the preferred outlet! Thus the device exhibits a property that amounts to memory, and it can be put to use for that purpose.

Of the various possible uses of fluid control devices the most intriguing is their application as the basis of a digital computer. The type of device in which the stream locks onto one wall or the other is precisely suited for functioning as an all-around element for such a computer. It gives a binary digital response: the stream can be directed to either of two exit ports, one representing 0, the other representing 1. It can be shifted back and forth from one port to another like a flip-flop switch. Indeed, it can even serve as an oscillator. This can be accomplished by connecting the control jets on the opposite sides of the main stream by a tube that will transmit sound. When the main stream flops from one side to the other, it generates sound waves—a compression wave on one side of the stream and a rarefaction wave on the other. If the sonic path through the tube connecting the two sides has a length that is about half the wavelength of the full sound wave, the compression and rarefaction waves, traveling through the tube in opposite directions, will cross to the opposite sides in the same time. This change in pressure at the respective sides (from compression to rarefaction on one side and from rarefaction to compression on the other) is sufficient to switch the main stream from one wall to the other. The stream will oscillate back and forth as the sound waves travel back and forth.

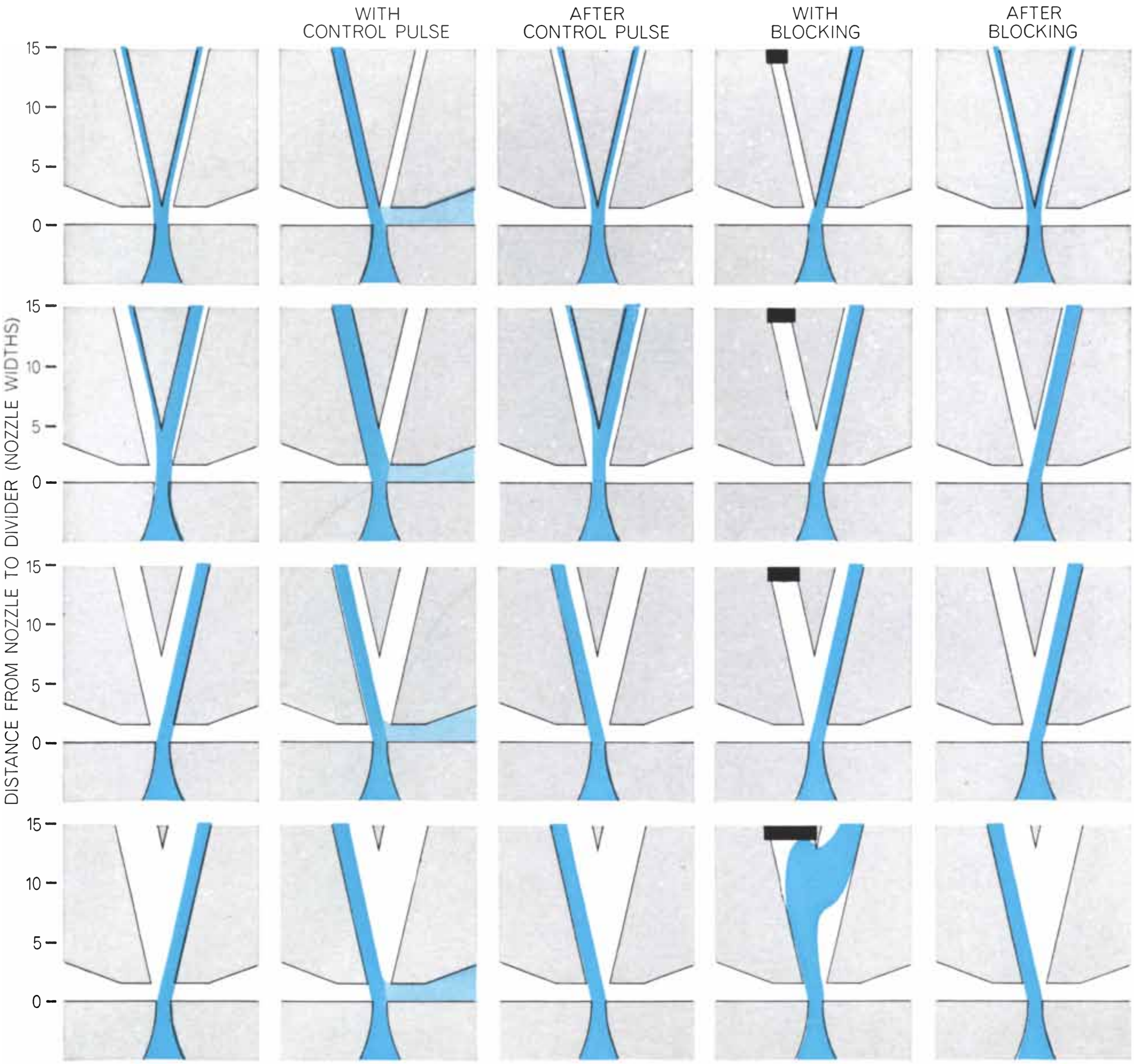
The fluid device can also be designed to act as a logical gate expressing the concept "and" or "or." For the "and" gate the jets are so arranged that jet *A* alone will go to one output, jet *B* alone will go to a different output and the two jets combined will go to a third output that signifies *A* "and" *B* [*see top illustration on page 86*]. For the "or" gate there are two jets, *A* and *B*, on one side of the main stream; either jet *A* or jet *B*, on being activated, will cause the main stream to go to a certain exit port [*see middle illustration on page 86*].

The fluid-control concept lends itself to a great variety of arrangements. The device can be designed, for example, to reset itself, with the main stream always returning to a given exit port in the absence of a deflecting pulse; this can be achieved simply by placing the main-stream nozzle closer to the right wall, say, than to the left wall. By building a network of channels of varying cross section and with varying controls it is possible to create a system that will carry out a series of different operations. And the characteristics of the system can be varied by using various fluids. In most of the computational elements constructed so far the working fluid is air, because it is so readily available and easy to handle.

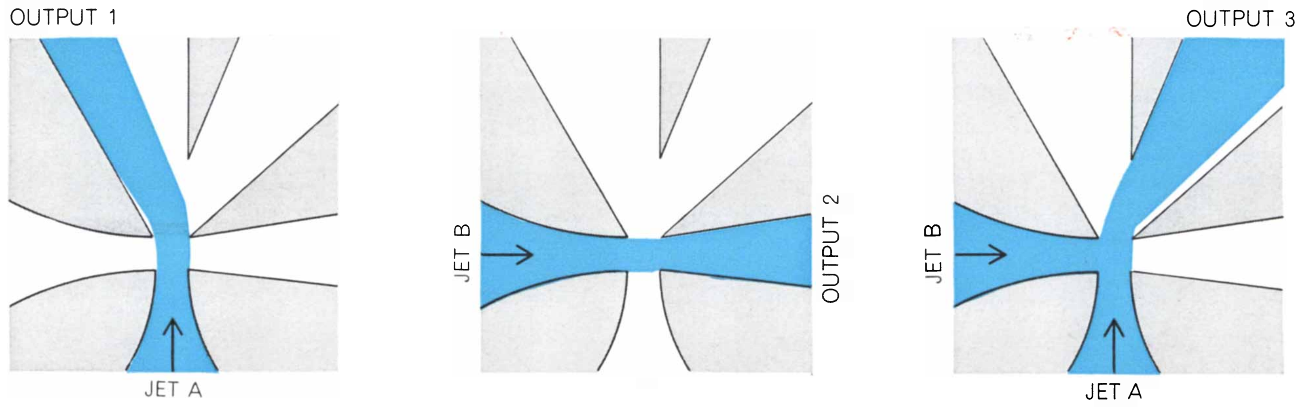
Let us look now at a couple of specific applications of fluid control on which considerable research has been done. One is the steering of rockets in flight. This is managed at present by the use of devices such as jet vanes and swiveled nozzles through which pulses of exhaust are discharged to apply small thrusts correcting the trajectory of the rocket. These devices are far from ideal, because it takes a great deal of force to operate them, their response to commands is fairly slow and they involve moving parts that are subject to being put out of action by the hot exhaust streams. A fluid-control system now under study would avoid those difficulties. The control would be applied to the main exhaust stream itself, that is, the thrust that drives the rocket. A small power stream would be bled from the main exhaust, and this small stream would be used to deflect the main stream when necessary to change the direction of the rocket [*see bottom illustration on page 86*]. The small stream would be controlled by a pair of jets; when the right jet was turned on, it would turn the stream so that it struck the main exhaust from the side, thereby changing the direction of the driving thrust slightly with a resulting change in the trajectory of the rocket's flight.

The idea has been tested in a small land vehicle powered by a turbine engine. By means of a five-stage proportional amplifier weighing less than 10 pounds, an extremely small fluid signal amounting to a flow of less than five thousandths of a pound per minute controlled a jet of 33 pounds per minute that was used to deflect the power stream driving the vehicle.

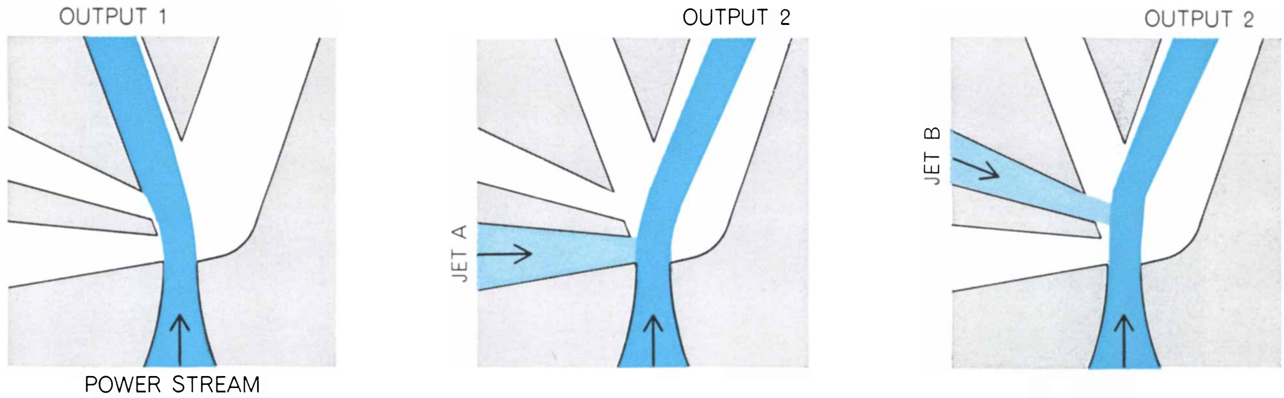
The other application I want to describe is an artificial heart pump developed jointly by workers at the Harry Diamond Laboratories and the Walter Reed Army Institute of Research. This device uses a fluid amplifier of the wall-locking type with air as the working fluid. The stream of high-velocity air emerging from the power nozzle locks onto one wall and then flows on to a chamber containing an artificial ventricle that is made of a flexible plastic and is filled with blood [*see illustration on page 88*]. The rising air pressure in the chamber squeezes the ventricle and



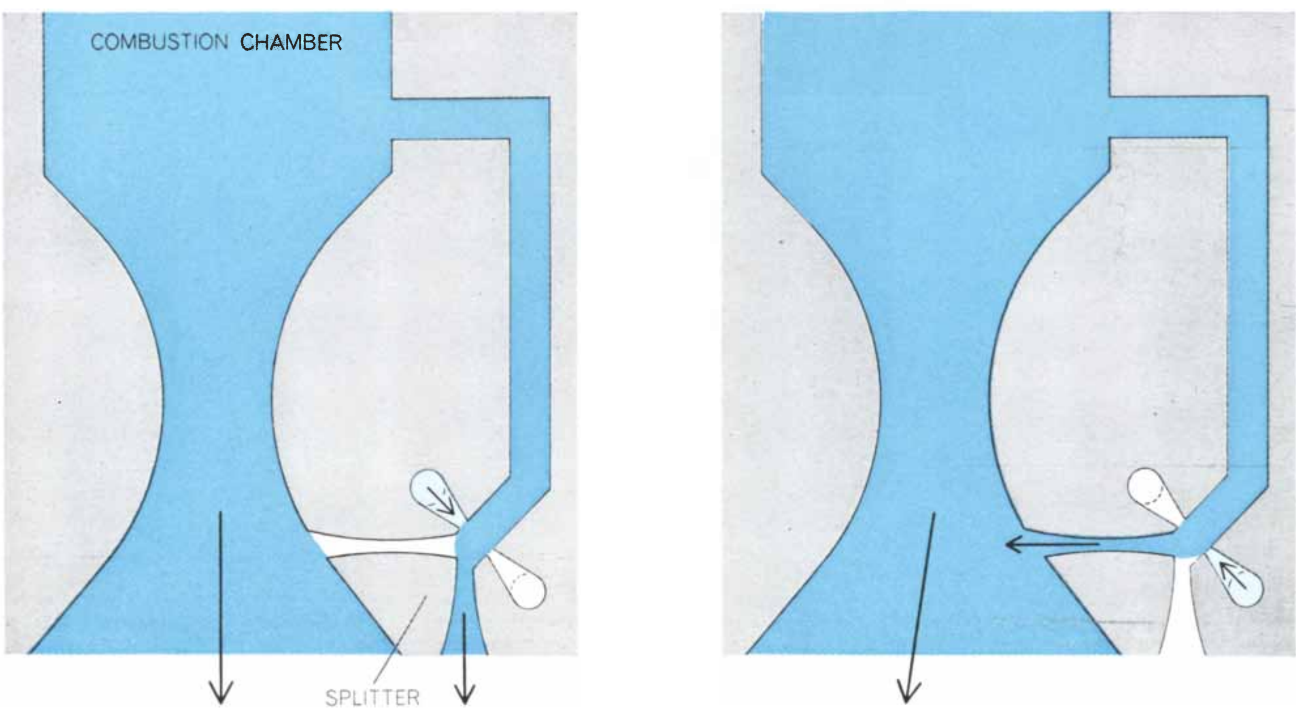
DISTANCE OF SPLITTER from power-stream nozzle in the standard, two-outlet type of fluid switching device has an important effect on the behavior of the stream. When the splitter is very close to the nozzle (*top row*), the stream does not lock spontaneously onto either wall. The stream can be directed into one outlet or the other by a pulse injection from a control jet, but as soon as the control injection stops, the stream resumes its normal behavior of dividing at the splitter and flowing into both outlets. If the splitter is located at a distance amounting to three to five nozzle widths from the nozzle (*second row from top*), most of the stream will begin to flow spontaneously to one outlet. When the splitter is six nozzle widths or more away from the nozzle (*bottom two rows*), the stream will lock onto one wall and flow only to the outlet it has chosen spontaneously or the one to which it is switched. By blocking one of the outlets (*second column from right*) one can divert the stream from the outlet it naturally prefers to the opposite one, but when the block is removed (*column at extreme right*), stream will return spontaneously to preferred outlet.



LOGICAL "AND" GATE can be built using fluid-control components. Jets are so arranged that jet *A* alone will go to one output (*left*), jet *B* will go to a different output (*middle*) and two jets combined will go to a third output (*right*) that signifies *A* "and" *B*.



LOGICAL "OR" GATE contains two control jets, *A* and *B*, on one side of the main power stream. With neither jet on, the stream will go to one output (*left*). Either jet *A* or jet *B*, on being activated, will cause the stream to go to other output (*middle and right*).



ROCKET CAN BE STEERED by the fluid control device depicted here. A small power stream is bled from the main rocket exhaust and used to deflect the main stream when necessary to change the direction of the rocket. The power stream is controlled by a pair of jets. When one jet is on (*left*), the stream simply adds to the main driving thrust of the rocket. When the other jet is on (*right*), it switches the stream so that it strikes the main exhaust from the side, thereby changing the direction of the driving thrust and hence the trajectory of the rocket's flight. Fluid system appears to be more efficient and reliable than other systems currently in use.

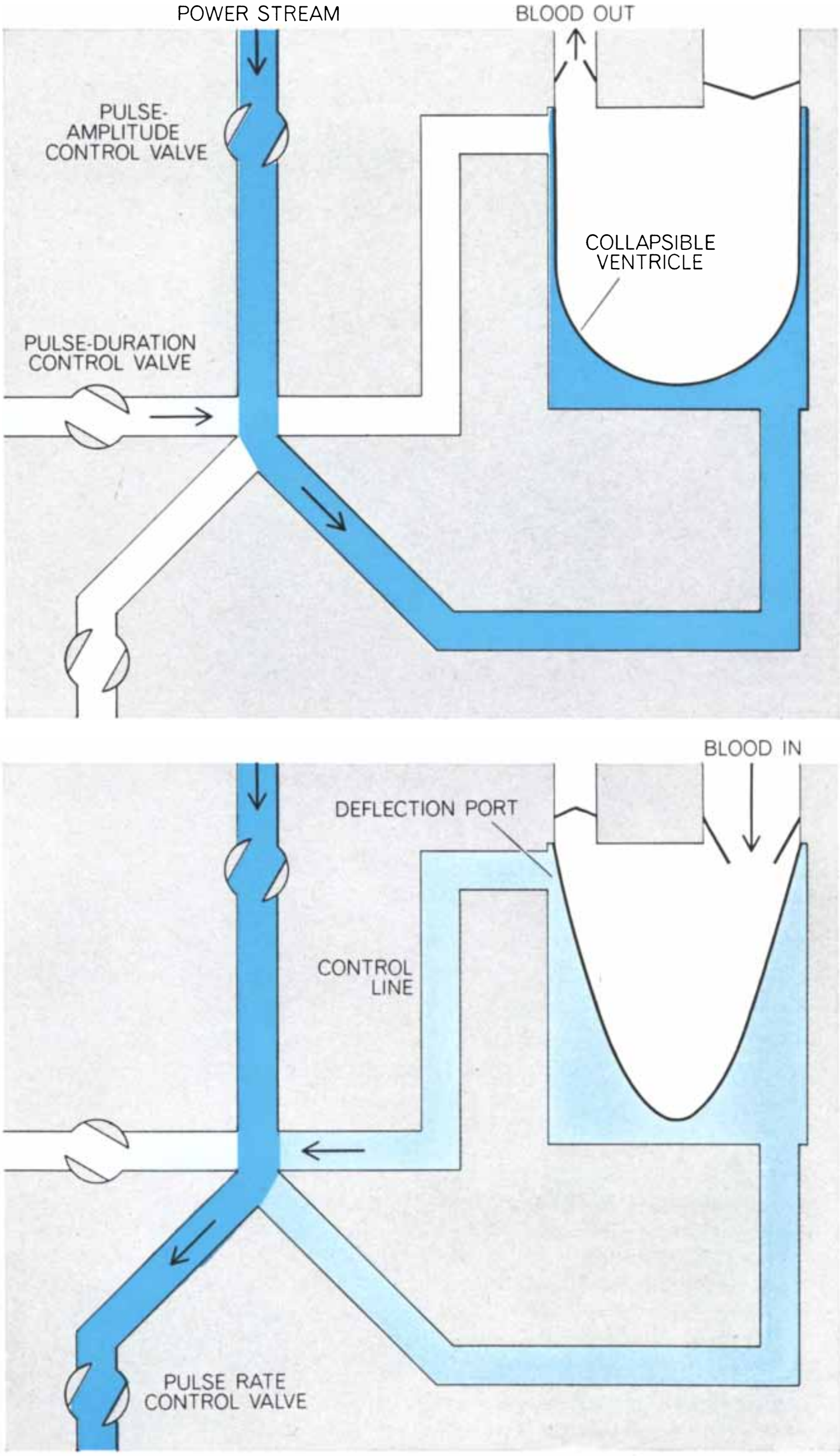
thus forces blood through a valve into the circulatory system of the patient. In effect it acts like the systolic contraction of the heart.

After the ventricle has contracted to a certain volume, the air pressure in the chamber opens a port through which the air then escapes and returns to the place where the power stream is flowing toward the splitter. Hitting the power stream from the side, the returning air causes the stream to switch from the original channel to the opposite channel. This results in a pressure drop in the chamber containing the ventricle; the ventricle therefore begins to expand under the weight of blood that is now able to flow in by gravity through an inlet valve at the top. Meanwhile a control valve on the other side of the main stream in the amplifier is feeding in a certain amount of airflow to prevent the pressure from falling too low. By the time the ventricle has expanded to its full volume this valve admits a flow of air sufficient to switch the main stream back to the original channel, and so the cycle begins again.

The valve admitting air from the side is, of course, the device that controls the duration of the heart pulse. Another valve in the channel on the same side of the splitter controls the rate of the pulse, and the valve that admits the main stream controls the amplitude of the systolic beat. All these controls are adjusted beforehand so that the pump supplies blood at the rate and in the amount the patient requires.

The models built so far are capable of producing blood pressures of up to about 500 millimeters of mercury and blood flows of up to 10 liters per minute. They can maintain pulse rates within a wide range, from as low as 30 to as high as 180 counts per minute. They have proved to be able to adjust their output automatically to changes in the patient's blood-vessel resistance to blood flow. Apparently they cause less destruction of red blood cells than some of the commercial artificial heart pumps now in general use. The chief advantages of the fluid-control pump are its simple, rugged construction, its compactness (it is a small box only a few inches long and weighing only 10 pounds) and its low cost.

The fluid-control concept is only in its infancy—still in the research stage with little practical use made of it so far. One of the problems that must be solved is that of miniaturization of the fluid element so that it will compare in compactness with an electronic or a

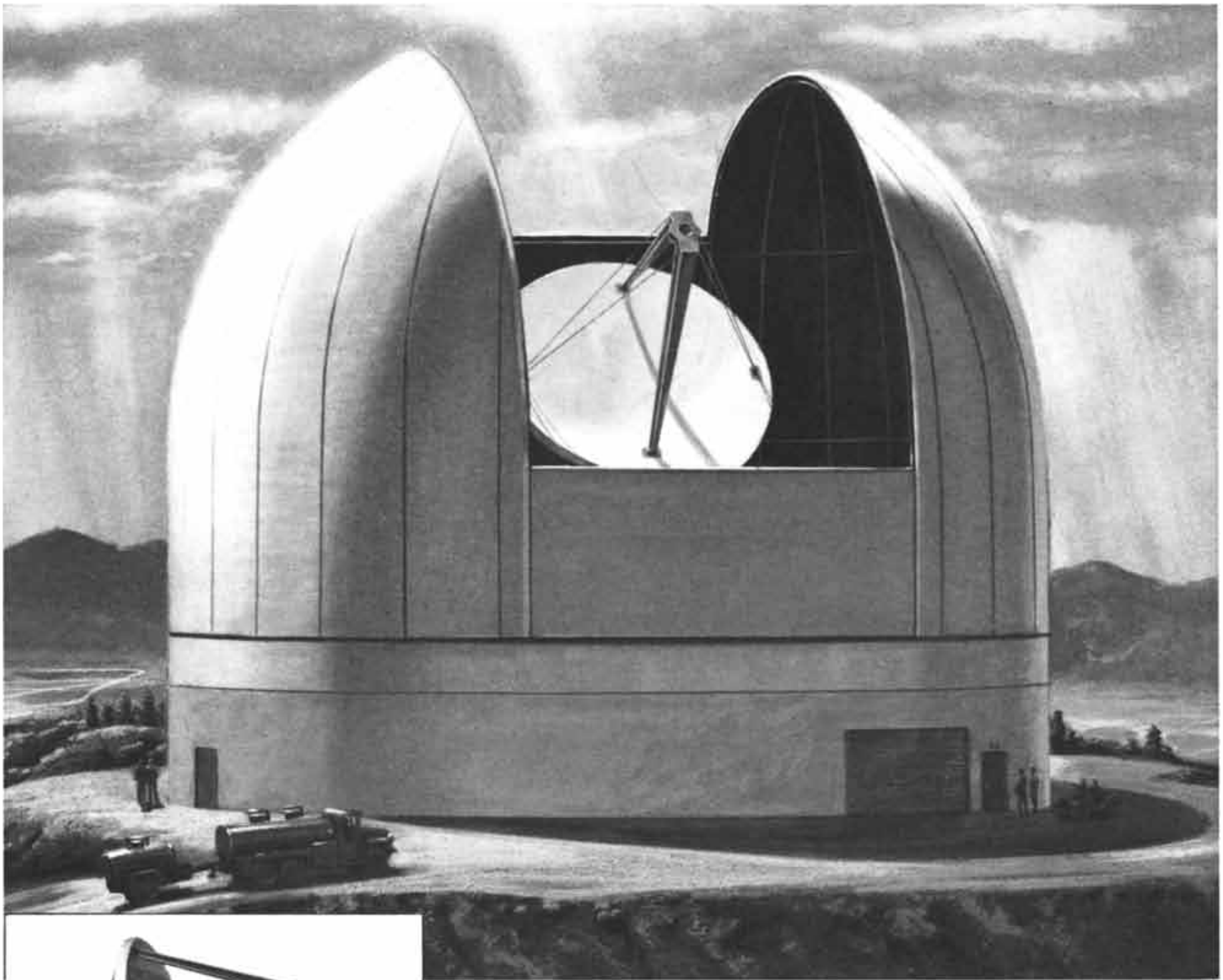


ARTIFICIAL HEART PUMP uses a fluid amplifier of the wall-locking type with air as the working fluid. The power stream of high-velocity air locks onto one wall and then flows on to a chamber containing an artificial ventricle that is filled with blood (*top*). The rising air pressure in the chamber squeezes the ventricle and thus forces blood through a valve into the circulatory system of the patient. After the ventricle has contracted to a certain volume (*bottom*), the air pressure in the chamber opens a port through which the air then escapes and returns to the place where the power stream is flowing toward the splitter. Hitting the power stream from the side, the returning air causes the stream to switch to the opposite channel. This results in a pressure drop in the chamber containing the ventricle; the ventricle therefore begins to expand under the weight of blood that is now able to flow in by gravity through an inlet valve at top. Meanwhile a control valve on the other side of the main stream is feeding in a certain amount of airflow to prevent the pressure from falling too low. By the time the ventricle has expanded to its full volume this valve admits enough air to switch main stream back to original channel, and so the cycle begins again.

mechanical component. The most promising technique for doing this seems to be optical fabrication. This entails photographing the design (in this case the pattern of channels, outlets and so on), reducing the negative, projecting the pattern onto a sheet of material that is sensitive to light and then etching away the exposed portions with chemicals. By timing the duration of the treatment with the solvent the channels can be etched to precisely the desired depth. The material may be a plate of sensitized glass; after the photographic exposure, treatment of the glass with heat will transform the exposed parts of the glass into a crystalline phase that is about 20 times more soluble in dilute hydrofluoric acid than the unaltered glass. There are other materials besides glass that lend themselves to similar optical sensitization and chemical machining.

How reliable are fluid amplifiers compared with their electronic counterparts? A number of comparative tests have been made under various conditions. In the range of what may be called ordinary temperatures—between 150 degrees and minus 50 degrees centigrade—electronic amplifiers give a more reliable performance. But at higher or lower temperatures the fluid device is more reliable; for example, at 250 degrees C. or minus 150 degrees C. its reliability is five times greater than that of an electronic device. When they are compared in various environments of ionizing radiation, the story is much the same: the electronic systems are more reliable at ordinary radiation levels but the fluid systems surpass them under exposure to high radiation levels, such as in or near a nuclear reactor. The fluid systems also stand up much better under vibration—an important factor in a rocket, where the guidance system is subjected to the severe vibration accompanying the rocket's takeoff and acceleration. Strong vibration tends to weaken the solder joints and other connections of an electrical system; it has little or no effect on a fluid amplifier. One test model has come through 3,500 million cycles of high-speed vibration at 260 cycles per second without any detectable impairment of its performance.

Research is going forward toward three main goals: (1) understanding the basic processes that underlie the operation of fluid amplifiers, (2) developing methods of producing them in compact size and in quantity at low cost and (3) finding the applications for which they will be most suitable.



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THE HOPEWELL CULT

A 1,500-year-old rubbish heap unearthed in southern Ohio holds the answers to some key questions about the ancient Indians who lived there and built huge funeral mounds filled with offerings

by Olaf H. Prufer

As Europeans explored North America, they found that many of the continent's river valleys were dotted with ancient earthworks. Scattered from western New York to North Dakota and south to Louisiana and the Florida Keys were uncounted thousands of burial mounds, temple mounds, hilltop ramparts surrounded by ditches, and earthen walls enclosing scores of acres. Some Colonial scholars were so impressed by these works that they thought they must have been built by an unknown civilized people that had been exterminated by the savage Indians. In due course it became clear that the earthworks had been put up by the Indians' own ancestors, and that they belonged not to one culture but to a series of separate cultural traditions spanning a period of 3,000 years.

Perhaps the most striking assemblage of these works is located in southern Ohio in the valleys of the Muskingum, Scioto and Miami rivers. It consists of clusters of large mounds surrounded by earthworks laid out in elaborate geometric patterns. As early as 1786 one such group of mounds at the confluence of the Muskingum and the Ohio (the present site of Marietta, Ohio) was excavated; it was found to be rich in graves and mortuary offerings. It was not until the 1890's, however, that the contents of the Ohio mounds attracted public attention. At that time many of them were excavated to provide an anthropological exhibit for the Chicago world's fair of 1893. One of the richest sites was on the farm of M. C. Hopewell, and the name Hopewell has been assigned to this particular type of mortuary complex ever since.

More recent excavations have shown that the Hopewell complex extends far beyond southern Ohio. Hopewell remains are found in Michigan and Wisconsin and throughout the Mississippi valley; there are Hopewell sites in Illinois that are probably older than any in Ohio. Typical Hopewell artifacts have been unearthed as far west as Minnesota and as far south as Florida. The mounds of southern Ohio are nonetheless the most numerous and the richest in mortuary offerings.

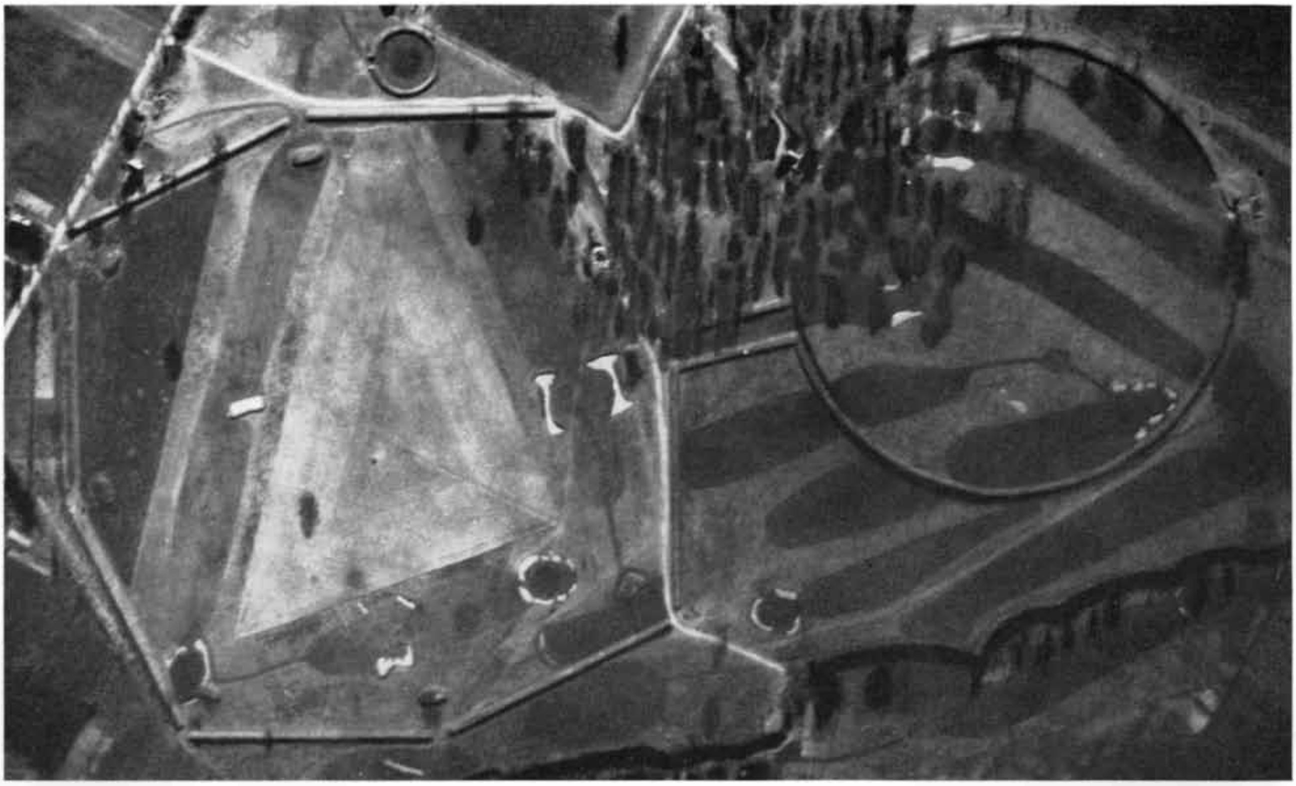
Thanks to carbon-14 dating it is known that the Hopewell complex first materialized in southern Ohio about 100 B.C. and that the last elaborate valley earthwork was constructed about A.D. 550. Until recently, however, there were other questions to which only conjectural answers could be given. Among them were the following: In what kinds of settlements did the people of southern Ohio live during this period? Where were their habitations located? On what foundation did their economy rest? Answers to these questions can now be given, but first it is necessary to say exactly what the Hopewell complex is.

What is known about the Hopewell complex of Ohio has been learned almost exclusively from the nature and contents of burial mounds. In many places these structures are found in groups enclosed by earthworks linked in a pattern of squares, circles, octagons and parallel lines [*see top illustration on page 92*]. The dimensions of some of the enclosures are immense: the largest known Hopewell earthworks in Ohio—the Newark Works in Licking County—covered four square miles. Many of the burial mounds are also large: the central mounds on the Hopewell farm and at the Seip and Harness sites, all of which are in Ross County, range from 160 to 470 feet in length and from 20 to 32 feet in height. Within the mounds are the remains of numerous human bodies, some of them alone and some in groups. If the bodies were simply interred, they rest on earthen platforms surrounded by log cribs; if they were cremated, the bones are found in shallow basins of baked earth.

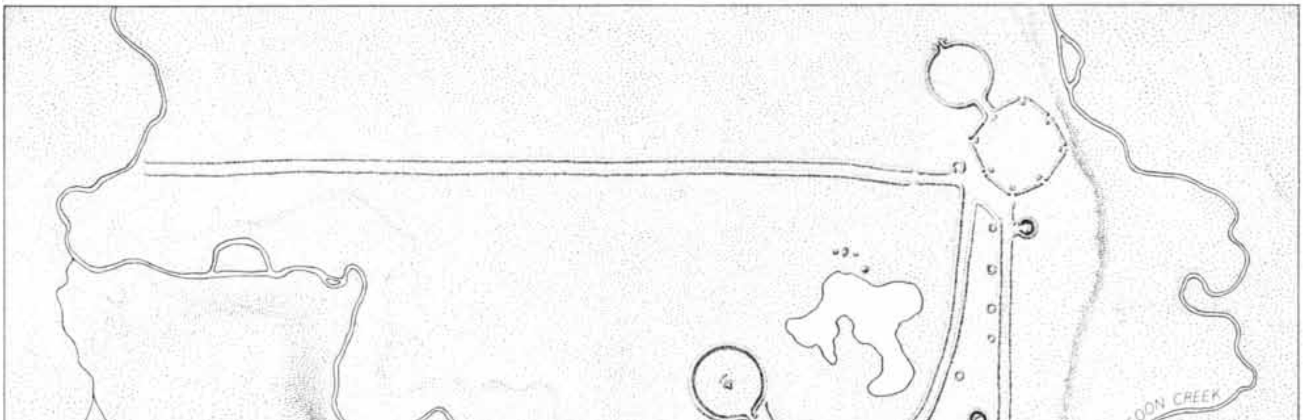
The sequence of events in the construction of a major mound seems to have been as follows. Bare ground was first covered with a layer of sand; then a large wooden structure was raised on this prepared floor. Some of the structures were so extensive that it is doubtful that they had roofs; they were probably stockades open to the sky. Individual graves were prepared inside these enclosures; in many cases the burials were covered with low mounds of earth. When the enclosure was filled with graves, the wooden structure was set afire and burned to the ground. Then the entire burial area was covered with layer on layer of earth and stone, forming the final large mound.

The quantity and quality of the grave goods accompanying the burials indicate that the people of the period devoted a great deal of time and effort to making these articles. A marked preference for exotic raw materials is evident. Mica, frequently cut into geometric or animate shapes, was imported from the mountains of Virginia, North Carolina and Alabama [*see illustration on opposite page*]. Conch shells, used as ceremonial cups, came from the Gulf

SILHOUETTED HAND made from a sheet of mica (*opposite page*) is typical of the elaborate grave offerings found at the Hopewell site near Chillicothe, Ohio. Human, animal and geometric figures of mica are characteristic Hopewell funerary goods; they are particularly abundant in southern Ohio.



OCTAGON AND CIRCLE in this aerial photograph are a portion of the earthworks marking the most extensive known Hopewell construction: the site at Newark, Ohio. Most of the four-square-mile array (*see original plan below*) has now been obliterated by modern building. Only these figures (now part of a golf course) and another circle (used for years as a fairground) have been preserved.



LONG AVENUES bounded by parallel earthen walls constitute the major parts of the Newark site. When first surveyed, the longest parallels (*top*) extended from the paired figures shown in the photograph at top of page to the Licking River, two and a half miles distant. Both circles are quite precise: the fairground circle (*center*) diverges at most 13 feet from a mean diameter of 1,175 feet, and the golf course circle only 4.5 feet from a mean diameter of 1,045 feet. The Newark site has never been systematically excavated.

Coast. Obsidian, exquisitely flaked into large ritual knives, was obtained either from what is now the U.S. Southwest or from the Yellowstone region of the Rocky Mountains. The canine teeth of grizzly bears, frequently inlaid with freshwater pearls, may also have been imported from the Rockies. Copper, artfully hammered into heavy ax blades and into ornaments such as ear spools, breastplates and geometric or animate silhouettes, was obtained from the upper Great Lakes.

Even in their choice of local raw materials the Hopewell craftsmen of Ohio favored the precious and the unusual. Much of their work in stone utilized the colorful varieties of flint available in the Flint Ridge deposits of Licking County. The freshwater pearls came from the shellfish of local rivers, and they were literally heaped into some of the burials. The tombs of the Hopewell site contained an estimated 100,000 pearls; a single deposit at the Turner site in Hamilton County has yielded more than 48,000.

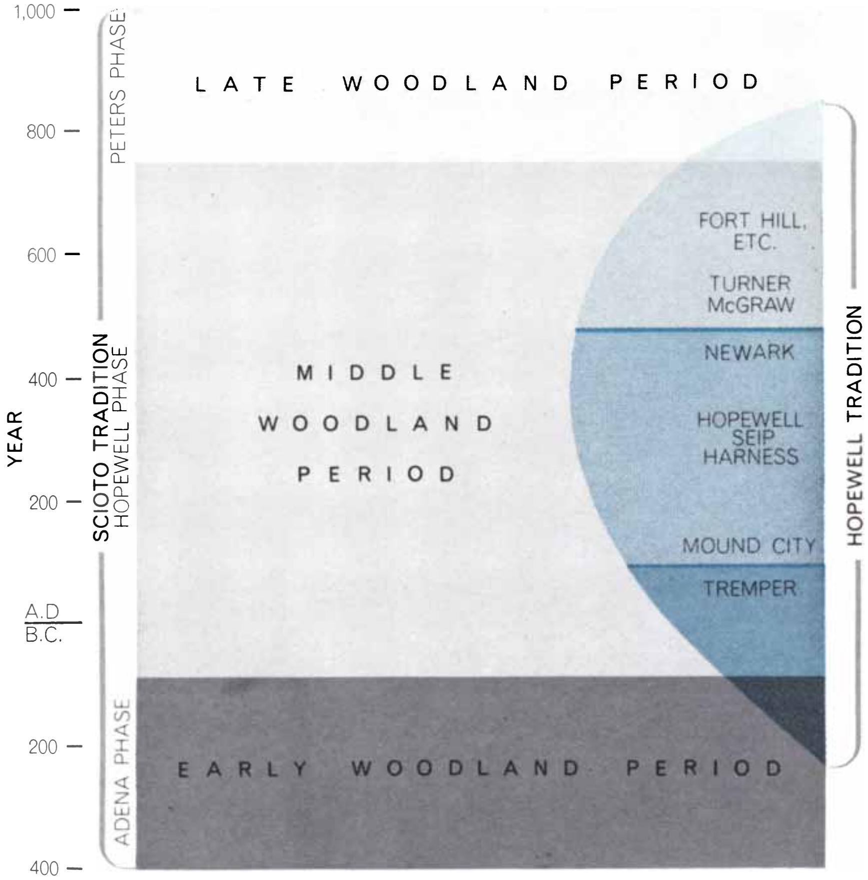
Other typical Hopewell grave furnishings are "platform" pipes [*see lower illustration on page 98*], elaborately engraved bones of animals and men, clay figurines and highly distinctive kinds of decorated pottery. Projectile points of flint show characteristic forms; the flintworkers also struck delicate parallel-sided blades from prepared "cores."

For the most part these characteristic objects of the Hopewell complex are the same wherever they are found. In spite of this fact the Hopewell complex cannot be classed as a "culture" in the anthropological sense of the word, that is, as a distinct society together with its attendant material and spiritual manifestations. On the contrary, the Hopewell complex was only one segment of the cultural totality in each area where it is encountered. A reconstruction of life in eastern North America from 500 B.C. to A.D. 900 reveals the existence of distinct cultural traditions in separate regions, each rooted in its own past. During the Hopewell phase each of these regional traditions was independently influenced by the new and dynamic religious complex. The new funeral customs did not, however, take the place of the local culture; they were simply grafted onto it. Although the word "cult" has some unfortunate connotations in common usage, it is more appropriate to speak of a Hopewell cult than of a Hopewell culture.

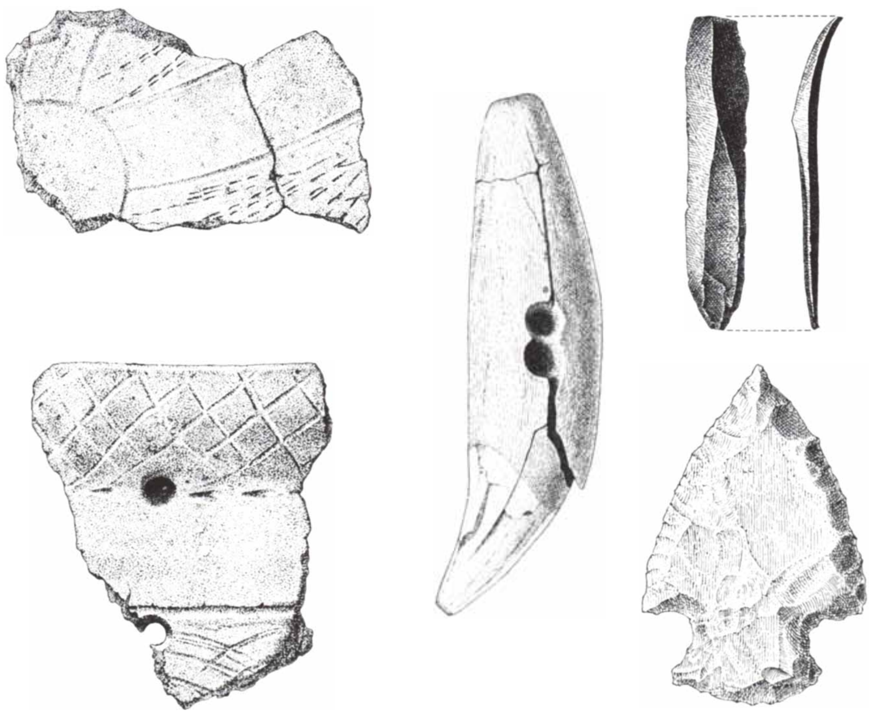
The exact religious concepts that

EARTHWORKS characteristic of the burial cult are found throughout eastern North America. Major Hopewell centers, from the Gulf Coast to the Great Lakes, are named on the map.

SOUTHERN OHIO is the locale of the most abundant and richest Hopewell sites. The majority are found along the Miami, Scioto and Muskingum rivers and range in date from 100 B.C. to A.D. 550. After that no more lowland centers were built; instead hilltops were fortified (*colored dots locate three major examples*). The McGraw site was excavated by the author.



SEQUENCE OF CULTURES in southern Ohio during the rise and decline of the Hopewell funeral complex indicates that a local tradition of Woodland culture, called Scioto, was present in the area before the Hopewell cult appeared and continued both during and after it. The earliest of the Woodland culture periods began about 1200 B.C. in southern Ohio.



IDENTITY OF FARMSTEAD discovered at the McGraw site as the residence of Indians who participated in the burial cult is proved by the presence of characteristic Hopewell tools and ceremonial objects. The fine, parallel-sided flint blade is typically Hopewell, as is the "Snyders" projectile point. The bear canine and the pottery are standard burial finds.

permitted the successful diffusion of the Hopewell cult necessarily remain unknown. Curiously enough, however, the cult's consumption of exotic materials for grave goods may have provided a mechanism for its diffusion. Procurement of raw materials entailed an exchange system of almost continental proportions; many widely separated areas in North America must have been brought into contact as their natural resources were tapped by practitioners of the Hopewell rites.

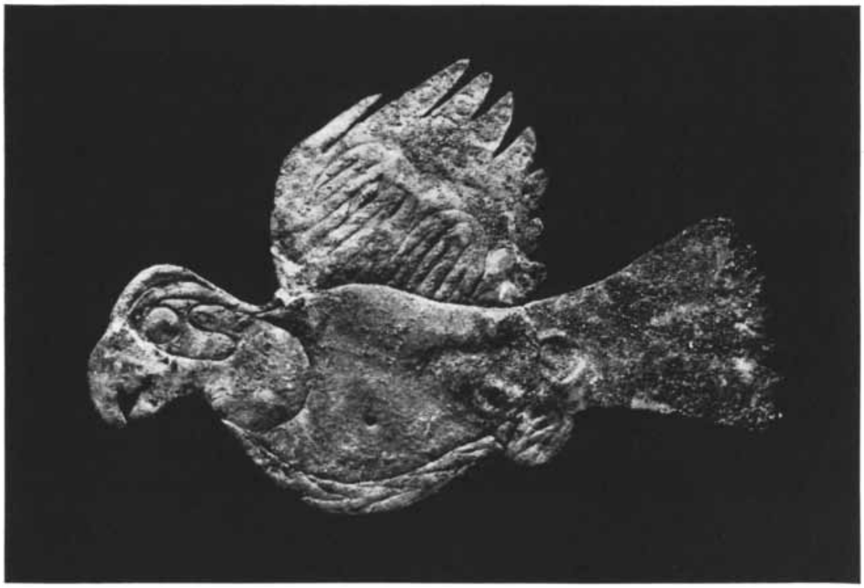
Students of the Hopewell remains in southern Ohio have been disturbed for more than a century by the lack of evidence for any habitation sites linked to the great funerary centers. In other Hopewell areas, notably Illinois, large villages are clearly associated with the local ceremonial sites. Years of patient fieldwork in Ohio had failed to produce anything that could legitimately be called a settlement. The extensive enclosures and their associated clusters of burial mounds contain no evidence of habitation to speak of. The little that has been found seems to mark brief squatters' tenancies, probably associated with the construction of the final mounds or with ceremonies that may have been performed from time to time. Clearly the nature of Hopewell society and its settlement patterns in Ohio were markedly different from those in Illinois.

Still another puzzle was the fact that remains of corn have been found at only two Ohio Hopewell sites—Harness and Turner—and in both cases under doubtful circumstances. It was therefore supposed that the Hopewell phase in Ohio was one of simple hunting and collecting and no agriculture. Whether because of this supposition or because earlier investigators were looking for sizable villages, most of the search for Hopewell habitation sites has been confined to regions near the ceremonial centers, leaving the rich bottomlands along the rivers largely unexplored.

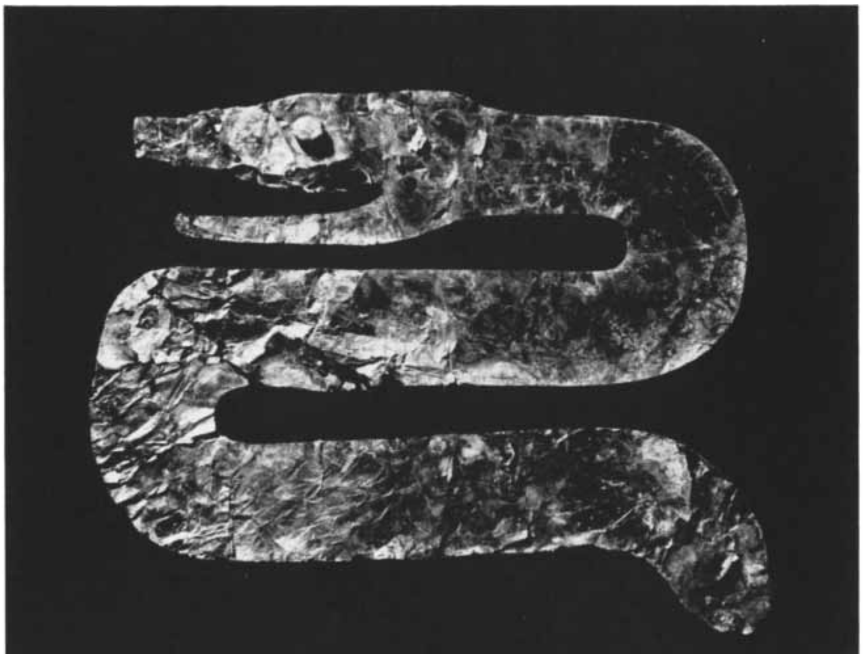
While reflecting on all these factors in 1962 I was struck by a possible parallel between the Ohio Hopewell sites and the classic ceremonial sites of certain areas in Middle America, where the religious center remained vacant except on ritual occasions and the population lived in scattered hamlets surrounding the center. To apply such an assumption to the Ohio Hopewell complex meant granting the people agriculture; it meant, furthermore, that the bottomlands were the very zones in which to look for small farming commu-

nities. Survey work along the floodplain of the middle and lower Scioto River during the past two years has amply demonstrated the validity of this assumption. Our survey teams from the Case Institute of Technology have turned up 37 small sites—the largest of them little more than 100 feet in diameter—marked by thinly scattered objects on the surface. These objects include sherds of cord-marked pottery, chips of flint, fragments of shell and bone and, most important, the fine, parallel-edged bladelets that are among the characteristic artifacts of the Hopewell complex.

It is certain that many such habitation sites are now lost forever under the accumulated silt of river floodplains and that others have been destroyed by river meandering. A perfect example of flood burial in the making is provided by the McGraw site, which is located on bottomland near an ancient meander of the Scioto River two miles south of Chillicothe. Alva McGraw, the owner of the land, brought the site to our attention in 1962. Surface indications were scanty; over an area 10 feet square we found only a few potsherds, some shell fragments, bits of flint and fire-cracked rocks. The site was on a nearly imperceptible rise of land, the remnant of a knoll that had been almost covered by river silts.



BIRD EFFIGY from Mound City combines cutout and repoussé techniques in copper work. The metal was imported from outcroppings at Isle Royale in Lake Superior. Hopewell funeral offerings of copper include rings, ear spools, breastplates and headdresses, many geometric forms, copper-plated wooden objects and large ax blades, evidently cold-forged.



SNAKE EFFIGY from the Turner site is a foot-wide mica silhouette cut from a sheet imported from Virginia or North Carolina. Some Ohio burials were literally blanketed by mica.

Under ordinary circumstances no archaeologist would have been attracted by such an impoverished find. It happened, however, that this site and similar ones on the McGraw farm were soon to be destroyed by road construction. We therefore decided without much enthusiasm to sound the area with a modest trench. Where the trench cut into the ancient knoll we found no remains at depths lower than the plow zone: eight inches below the surface. But where the trench extended beyond the knoll, proceeding down its slope to the adjacent silt-covered low ground, we struck a dense deposit of residential debris, evidently the refuse heap of an ancient farmstead.

This deposit, a foot thick and 95 by 140 feet in extent, was packed with material. There were more than 10,000 pottery fragments, some 6,000 animal bones, nearly 2,000 identifiable mollusk shells, abundant remains of wild plants and both an ear and individual kernels of corn. In fact, this single rubbish heap contained enough material to answer the questions posed at the beginning of this article.

First, in spite of the pattern of organized village life associated with the Hopewell cult 400 miles to the west in Illinois, the people of southern Ohio lived in small, scattered farm dwellings. This does not mean that the population was sparse; indeed, the size and complexity of the ceremonial earthworks in Ohio imply ample manpower. The significant fact is that the two groups shared a religion but lived quite different secular lives. In seeking parallels for this phenomenon one turns to the early, expansionist days of Christianity or of Islam, when a religion was shared by peoples with sharply contrasting cultures.

Second, the Ohio Hopewell people built their dwellings not near ceremonial centers but on the floodplains of the

HUMAN FIGURES representing a kneeling man and a standing woman are modeled in terra-cotta. Unearthed at the Turner site, they were ritually broken, or "killed," before burial.

PLATFORM PIPE from the Mound City site has a bowl carved to represent a toad. Pipes showing birds, fishes, mammals and human figures were also made for Hopewell burials.

rivers, presumably because the bottomland was most suitable for agriculture. As for their economy in general, they raised corn, but a substantial part of their food came from hunting, fishing and collecting. Analysis of the animal bones in the McGraw deposit shows that the commonest source of meat was the white-tailed deer. Other game animals that have been identified in the deposit are the cottontail rabbit and the turkey. River produce was of equal or perhaps greater importance for the larder; we found the bones and shells of a variety of turtles, the bones of nine species of fish and the shells of 25 species of mollusk.

Among the wild-plant foods these people collected were nuts: the deposit contained charred remains of hickory nuts, walnuts and acorns. Other wild plants that have been identified are the hackberry and the wild plum. Apparently corn was the only plant the people cultivated, but the remains make it clear that their knowledge of corn-raising had not been recently acquired. The charred ear of corn from the McGraw site, still bearing a number of kernels, is of a 12-row variety. It appears to be of a type intermediate between the northern flint corn grown in Ohio in late pre-European times and the ancient flint corns and popcorns known from elsewhere in the Western Hemisphere. One of the isolated kernels from the deposit has been identified as belonging to an eight-row or 10-row variety of corn; it possibly represents a full-fledged, although small, member of the northern flint type. These relatively advanced types of corn imply a long period of agricultural activity before the site was first occupied.

The date of the McGraw site's occupation can be estimated both from the style of its artifacts and from carbon-14 determinations; it is roughly A.D. 450. The bulk of the artifacts could have come from any pre-Hopewell site in Ohio; for example, less than 4 percent of the pottery fragments found in the deposit are characteristic of the Hopewell complex. This reinforces the point made earlier: Whenever the influences of the Hopewell cult appear, they are imposed on an already existing culture that for the most part continues in its own ways.

The McGraw site is nevertheless clearly identified as belonging to the Hopewell complex not only by the few Hopewell potsherds but also by other characteristic Hopewell artifacts. Parallel-sided flint bladelets were found in large numbers, and the bulk of the projectile points were of the classic Hopewell type known as "Snyders," after the site of that name in Illinois. The inhabitants of the McGraw farmstead evidently included craftsmen engaged in the production of grave goods for the Hopewell cult: cut and uncut mica was found in abundance. One bear tooth turned up in the midden, with typical countersunk perforations but without any inlay of pearls. There were also two ornaments made of slate that, like the bear-tooth ornament, were unfinished. Perhaps all these objects were discards; this would help to explain their presence in a refuse heap.

The McGraw site therefore casts considerable light on life in southern Ohio

Seven reasons why the S-C 3070 is the best output printer for small and medium sized computers

The S-C 3070 printer uses a unique cathode ray tube to generate characters. Letters, numbers and symbols are formed by extruding electron beams through selected characters etched into a tiny matrix within the cathode ray tube. Characters from the tube are projected through a lens to a paper where they create an electrostatic image. Powdered ink adheres to the latent electrostatic image of the characters and is fused to the paper using heat to form a permanent copy. This electronic and electrostatic system of printing offers these seven advantages to users of small and medium sized computers:

Asynchronous—The printer starts and stops under commands of the computer. When the computer doesn't wish to fill an entire line, the printer proceeds immediately to the next line. Unlike the S-C 3070, synchronous printers must delay until the entire line is filled with characters or blank space before accepting anything more. With the S-C 3070, therefore, you save valuable computer time.

High speed—The printer is capable of producing 500 perfectly formed characters per second in lines containing up to 120 characters. If the lines are completely filled, a minimum of 225 can be produced in one minute. Ordinarily lines are not completely filled, resulting in an average speed of 400 lines per minute. In many printing applications where only a few characters are used in each line, the rate reaches approximately 500 lines per minute.

Reliability and stability—Because of the stability of the electronic circuits and basic design simplicity, reliable unattended operation is provided. Mean-time-between-failures exceeds 500 hours. In a 72-day government-run test, the S-C 3070 was run constantly 24 hours a day, producing 164,000,000 bits of information, without an error. Downtime for routine maintenance during the test was only 1%.

Low maintenance—There are no critical operator adjustments to make, no type to clog, no hammers to readjust, etc. Over 10,000 feet of printed copy can be produced before minor cleaning is required.

Inputs—The S-C 3070 operates on-line with computers or accepts cards, punched paper tape or information from communications terminals. Interface equipment is available to match the unit to the output of virtually any data source. Typical of the small or medium-sized computers with which it may be used are the IBM 1620, Univac M1218 and Burroughs D825.

Low cost—The basic S-C 3070 printer is priced at less than many other computer printers that do not offer all these features. The basic printer is available at a low monthly lease price of $695, including service in major metropolitan areas.

Non-impact printing—The electrostatic printing process results in copy that is highly legible and produces very little noise. Under normal office ambient noise conditions, non-impact printing is so silent it is difficult to tell when the printer is running. Quiet operation creates an improved working environment. The printed copy may be stored on rolls or cut and stacked in sheets.

Write for information—For additional information on the S-C 3070, write to Department E-56, Stromberg-Carlson, P.O. Box 127, San Diego, California 92112.

STROMBERG-CARLSON
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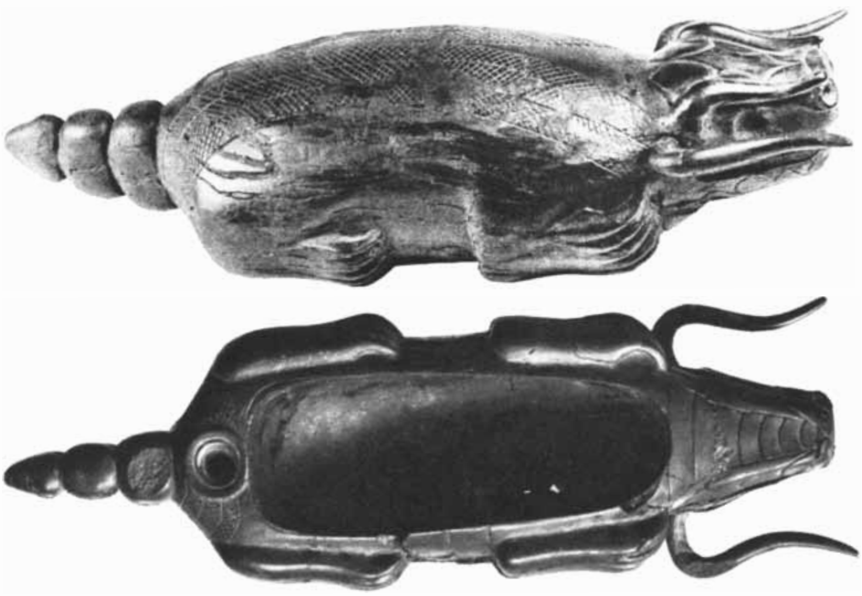
CEREMONIAL BLADES unearthed at the Hopewell site are of obsidian, probably from the Yellowstone area of the Rocky Mountains. The largest (*center*) is 13 inches in length.

during the latter days of the Hopewell phase. Skilled hunters and food-collectors, gifted artisans in a wide range of materials, the people who manufactured the rich grave goods for the ritual burials lived in small scattered farmsteads on the river bottoms.

But were the people who made the grave goods the same as those who were buried in the great Hopewell mounds? Curiously this appears to be unlikely, at least in southern Ohio. To explain why, it is necessary to sketch what is known about the rise and decline of the Hopewell complex against the general background of the various prehistoric cultures in eastern North America.

Of the four successive major culture stages in this part of the New World—Paleo-Indian, Archaic, Woodland and Mississippian—only the third is involved here. In southern Ohio the Woodland stage begins about 1200 B.C. and ends shortly before the arrival of the Europeans. In the entire eastern part of North America, southern Ohio included, the Woodland stage is divided into Early, Middle and Late periods.



MYTHICAL BEAST with four horns and feet with five talons decorates the surface of a narrow stone object 10 inches long. It was found at the Turner site. Its purpose is unknown.

In southern Ohio the people of the Early Woodland period were mound builders long before the Hopewell cult arose. They belonged to the Adena culture (which takes its name from a mound site near Chillicothe). The remains of the Adena people show that they were roundheaded rather than longheaded. They lived without contact with the Hopewell cult until about 100 B.C.; at that time, according to carbon-14 determinations, the Tremper mound of Scioto County was raised. This mound contained some 300 crematory burials. Many of the grave offerings are typical of the Adena culture, but some of them show Hopewell influences.

As skulls from later burials indicate, the arrival of the Hopewell cult in Ohio (presumably from Illinois) was accompanied by the arrival of a new population; these people were longheaded rather than roundheaded. How many immigrants arrived is an open question. The total number of individuals found in Ohio Hopewell mounds—an estimated 1,000—can represent only a fraction of the population of this region during the Middle Woodland period. It seems probable that most of the local inhabitants were the roundheaded Adena folk, many of whom may well have continued to live typical Adena lives untroubled by the neighboring Hopewell cultists. The fact that numerous Adena mounds continued to be built during Hopewell times is strong evidence for this.

To judge from their production of Hopewell ceremonial objects, the residents of the McGraw site would not have been undisturbed Adena folk. It is equally unlikely that they were immigrants from Illinois. It seems more probable that the immigrants were a privileged minority who in some way had come to dominate some of Ohio's Adena people, among whom were the farmers of the McGraw site.

Why did the Hopewell complex ultimately disappear? It may be that one part of the answer is plain to see. From their first arrival in southern Ohio until A.D. 550 these cultists evidently not only felt secure in themselves but also appear to have taken no steps to guard from raiders the treasures buried with their dead. After that time, however, no more ceremonial centers were built in open valleys. Instead it seems that every inaccessible hilltop in southern Ohio was suddenly crowned by earthworks that appear to have served a defensive function.

This does not mean that such sites as

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Our new phosphors used for stamps won't help you find letters in the dark. But they do throw light on a new way to handle mail faster. ■ The United States Post Office Department had a need for a special kind of phosphor as fine as confectioner's sugar, yet able to luminesce brightly under ultraviolet. (Reduction of particle size generally dulls the glow.) Sylvania was able to successfully meet *both* requirements. ■ What is the purpose? To speed the processing of mail. Airmail stamps, now being tested, are coated with a red-glowing phosphor solution. Letters with these stamps are then passed through special electronic equipment—and these machines are able to read the color of the bright glow and sort the mail, automatically! ■ Sorting is only one job our phosphors can do. They can identify documents to fight counterfeiting, illuminate safety and marking devices, "code" pills and capsules—can be used in plastics to make objects glow without electricity. ■ How did we get to be experts in phosphors? Through years of solid experience and leadership, starting with phosphors for lamps and cathode-ray tubes. Sylvania is also a leader in tungsten and molybdenum, special chemicals, and semiconductor materials. We're hard at work on many advanced developments in all of these important areas. We offer our participation in your product developments. Chemical & Metallurgical Division, Sylvania Electric Products Inc., Towanda, Pennsylvania.

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Fort Hill, Fort Ancient and Fort Miami were permanently inhabited strongholds. Quite the contrary; at Fort Hill, for example, a survey of the land surrounding the foot of the hill has revealed several small farmsteads resembling the McGraw site. It is probable that the hilltop earthworks were places of refuge that were occupied only in time of danger. That there were such times is demonstrated by the evidence of fires and massacres at the Fort Hill, Fort Ancient and Fort Miami sites.

What was the nature of the danger? As yet there is no answer, but it is interesting to note that at about this same time the Indian population in more northerly areas first began to protect their villages with stockades. Unrest of some kind appears to have been afoot throughout eastern North America.

This being the case, it is not hard to envision the doom of the Hopewell cult. Whatever its basic religious tenets, the tangible elements of the ceremony were the celebrated grave goods, and the most notable of the goods were produced from imported raw materials. The grave goods were of course cherished for their part in the religious scheme; could the scheme itself be kept alive when the goods were no longer available? I suggest that the Hopewell cult could survive only as long as its trade network remained intact and, further, that the postulated current of unrest in eastern North America during the seventh and eighth centuries A.D. was sufficient to disrupt that network.

Whether or not this caused the collapse of the Hopewell cult, there is no question that it did collapse. By the beginning of the Late Woodland period, about A.D. 750, elaborate burial mounds containing rich funeral offerings were no longer built. For the very reason that Hopewell was only a cult and not an entire culture, however, the distinctive local traditions that had participated in the Hopewell ceremonies now reasserted themselves.

In Ohio this regional tradition is named Scioto [*see top illustration on page 94*]. Because of the alien nature of the Hopewell ceremonial complex, the phase of the Scioto tradition—called Hopewell—during which the funeral centers were built has a dual status. In terms of chronology the Hopewell phase was only one subdivision of the Scioto tradition. At the same time the Hopewell religious cult must be granted the status of a full-fledged tradition in its own right.

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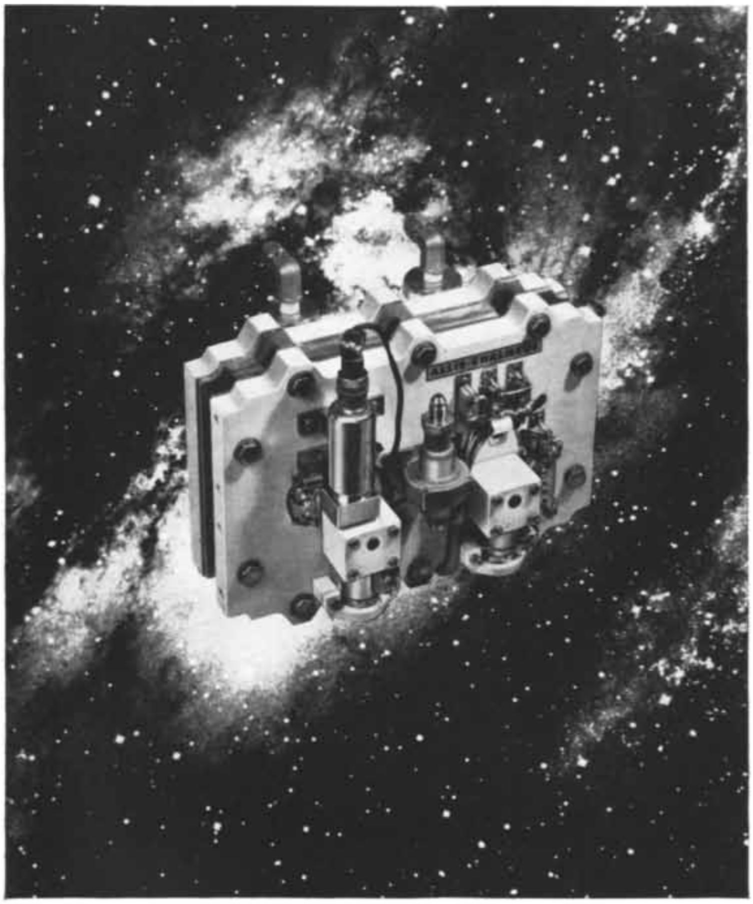

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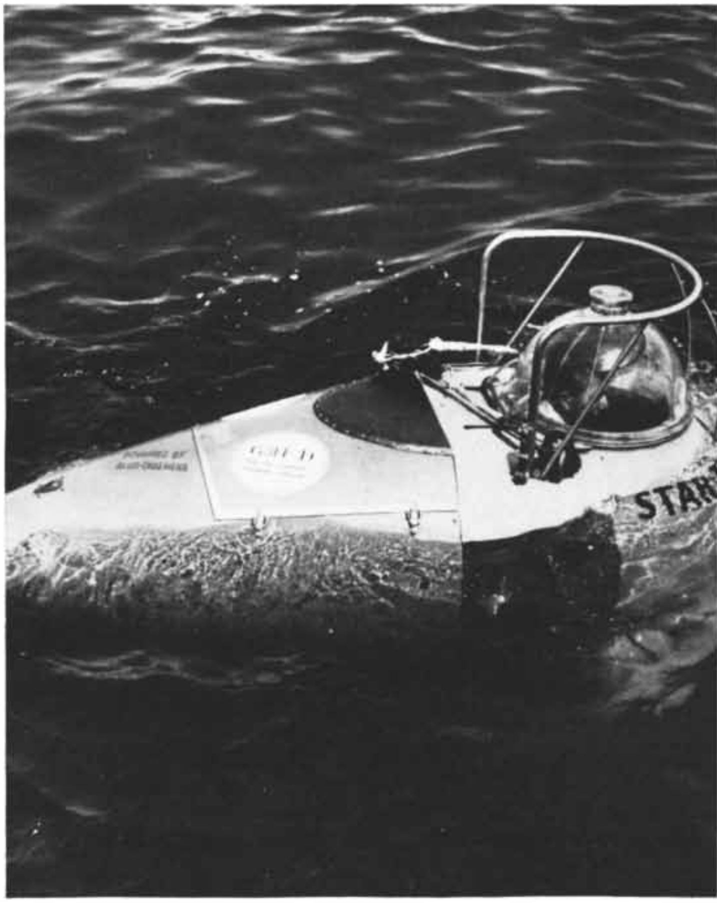

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How Cells Make Antibodies

The process has now been clarified by experiments with single antibody-producing cells grown in culture. These experiments indicate that antibody manufacture is directed by the genes

by G. J. V. Nossal

The human body is capable of producing on demand any one of thousands, possibly millions, of different antibodies, each specifically constructed to attack a specific antigen. How does it manage this complex task? Do the body's cells build antibodies in the same way that they build other proteins, under the direction of specific genes? If so, the cells must contain a very large number of different antibody genes and also an elaborate mechanism primed to switch on the right gene when the body is invaded by a particular antigen, be it a bacterium, a virus or some other foreign protein material.

At the Walter and Eliza Hall Institute of Medical Research in Melbourne we have been investigating these questions by means of special cell cultures. Conceptually the production of antibodies rather resembles a large industrial organization that manufactures a wide range of products in many different factories. The system offers three elements for analysis. First there are the factories themselves: the cells that make antibody. Then there are the products: the antibody molecules. Finally there are the specification-presenting customers, so to speak: the antigen molecules. We shall examine each of these in detail and attempt to show how the system is operated with such remarkable efficiency.

Until a couple of decades ago it was generally believed that antibodies were produced by the large antigen-devouring cells known as macrophages or "scavenger cells." Then in a classic study Astrid Fagraeus of Sweden brought forth evidence suggesting that the actual producers were a family of specialized cells called plasma cells, which show up in considerable numbers at the site of an infection as inflammation gets under way. She found that two days or so after she had injected a vaccine intravenously into an experimental animal "plasmablasts" began to appear in its spleen (a prime source of white cells). These young plasma cells divide rapidly, and after a few days their progeny become more specialized: the nucleus of the cell shrinks and the surrounding cytoplasm expands. The fact that this cytoplasm is rich in ribonucleic acid (RNA), which directs the synthesis of protein, was taken as a strong indication that the plasma cell actively produced protein—that is to say, antibody. Then Albert H. Coons and his co-workers at the Harvard Medical School added weight to this suspicion by showing that plasma cells actually contain antibody.

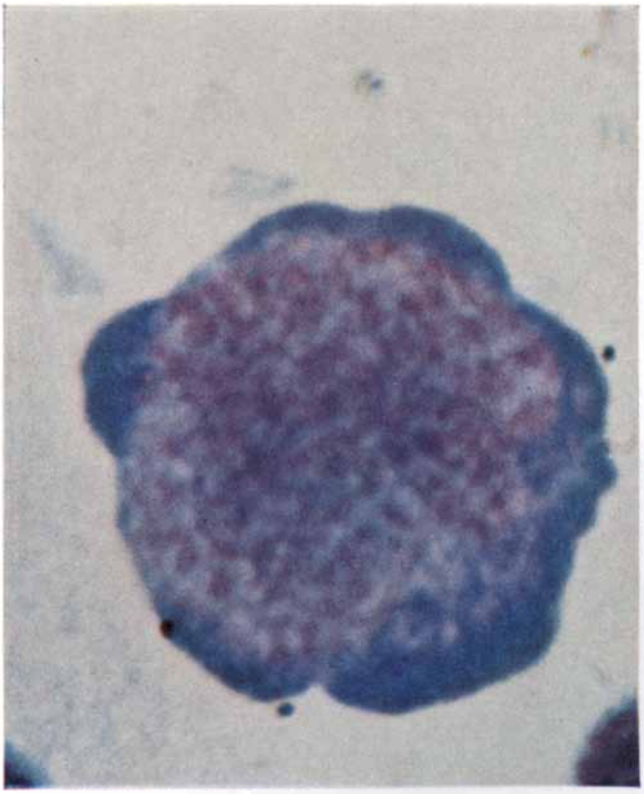
Work in our laboratory has now proved definitely that these cells do indeed manufacture antibody. We have been able to follow the process by culturing single plasma cells in tiny droplets. This procedure has made it possible to measure the production of antibody by living cells and to study the quality, purity and chemical characteristics of the antibody produced.

As the antigen for our first experiments we selected a protein extracted from the flagella, or "flippers," of Salmonella bacteria (which include the human typhoid bacilli). The flagella enable the bacteria to move about. Antiserum to this material (that is, serum containing antibody to its protein) will paralyze the flagella and rapidly immobilize the bacteria. Thus the organisms' reaction provides a ready test for the presence of the specific antibody.

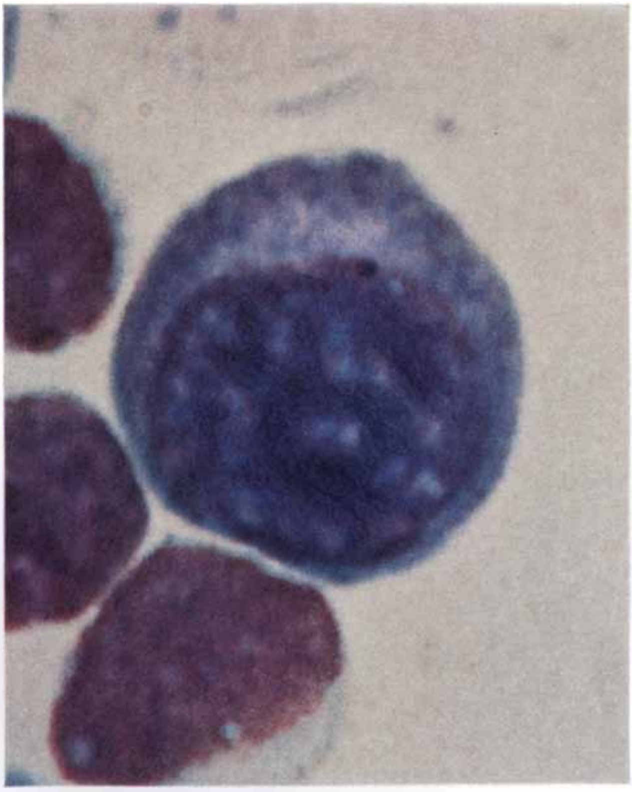
We begin by injecting the flagella protein into a rat. After the rat has had time to react to the foreign protein we remove the lymph nodes draining the site of the injection, tease the tissue apart into its individual cells and place each cell in a microdroplet of tissue-culture liquid, which we deposit as a hanging drop on the underside of a glass cover slip. The drop is covered with a film of paraffin oil to prevent its evaporation. All this is done with a micropipette and a micromanipulator under a phase-contrast microscope. We then incubate the cell in the drop for several hours at 37 degrees C. (the human body temperature). Having thus given the cell time to manufacture antibody, we finally inject three to 10 mobile Salmonella bacteria into the microdrop.

If the bacteria are of the right strain—that is, the same strain as the one from which the flagella protein, or antigen, was extracted—they stop moving promptly, often within a few seconds. On the other hand, bacteria of any other strain will go on swimming about indefinitely. The action is so specific that antibody that rapidly immobilizes *Salmonella typhi* has no effect whatever, even in high concentration, on the closely related *Salmonella paratyphi a.*

The lymph-node cells, for their part, show a similar specialization. Lymphocytes and scavenger cells give no evidence of having formed antibody; they fail to immobilize even the "right" bacteria. Plasma cells, on the other hand, frequently show the effect. In their young, plasmablast stage they produce relatively little antibody, but by the time they have matured they are loading the microdrop around them with so much antibody that the liquid will immobilize bacteria even when it is diluted 1,000 times. The immobilization test affords a measure of the amount of antibody produced by the cell, because the

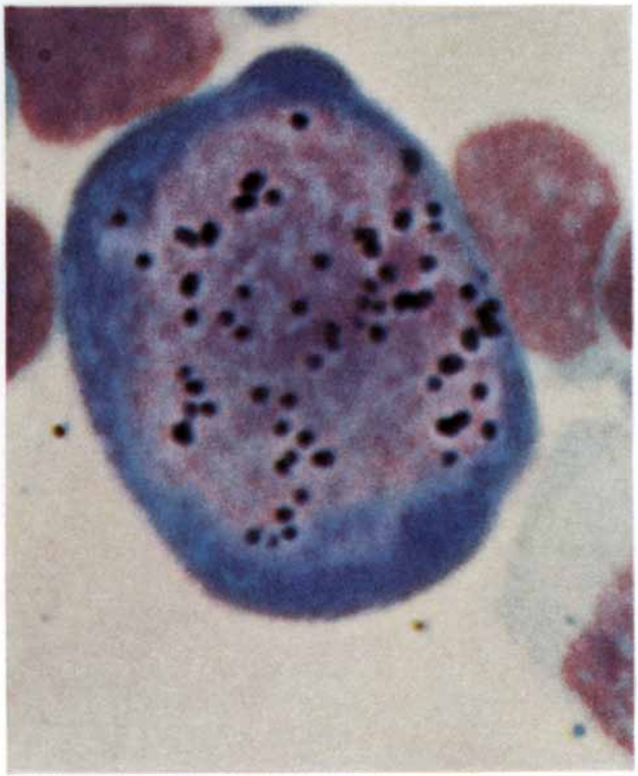


PLASMABLAST, the first type of cell induced by the introduction of an antigen, is shown in culture. The reddish cells that appear in these micrographs are not involved in antibody production.

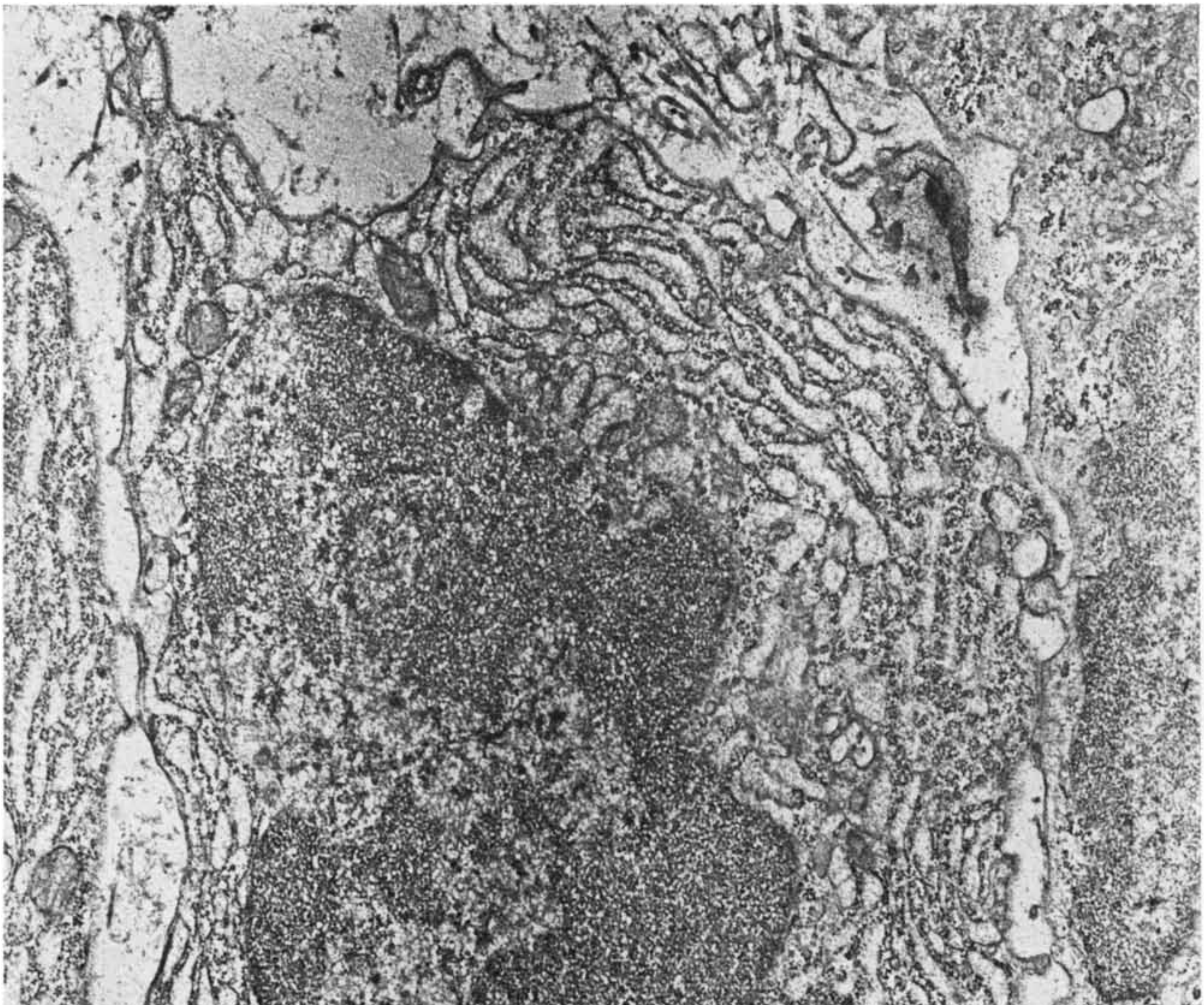


IMMATURE PLASMA CELL is the offspring of the plasmablast. The cytoplasm (*blue outer region of the cell*) has expanded; the nucleus (*red interior*) and overall size of the cell have diminished.

MATURE PLASMA CELL has an even more fully developed cytoplasm. Ribonucleic acid (RNA) located in the cytoplasm directs the synthesis of antibodies, the proteins that act to neutralize antigens.



RADIOAUTOGRAPH of plasmablast shows sites of deoxyribonucleic acid (DNA) synthesis. Precursor of DNA was labeled with radioactive atoms that on decaying made black dots in emulsion.



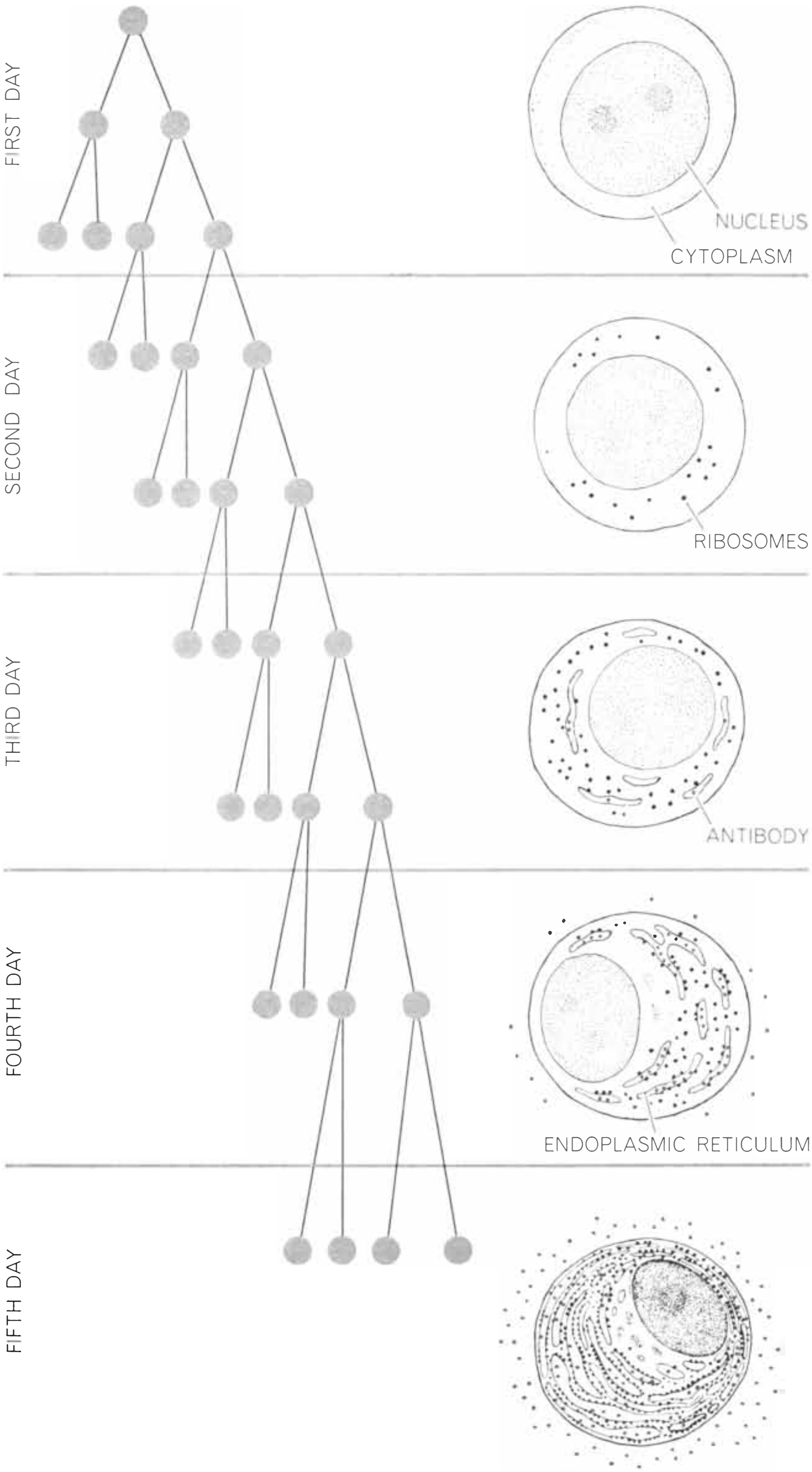
SITES OF ANTIBODY PRODUCTION, the ribosomes, appear as tiny black dots lining channels called the endoplasmic reticulum in this electron micrograph of a plasma cell enlarged some 28,000 diameters. The presence of an antigen has induced development of the endoplasmic reticulum to the point where the eccentrically shaped nucleus has been pushed into one region of the cell. The process by which antibodies, once made, are released from plasma cells is not known. The objects around the edges are other cells.

speed of immobilization depends on the concentration of the antibody. A mere few thousand molecules of antibody are enough to immobilize bacteria in a short time.

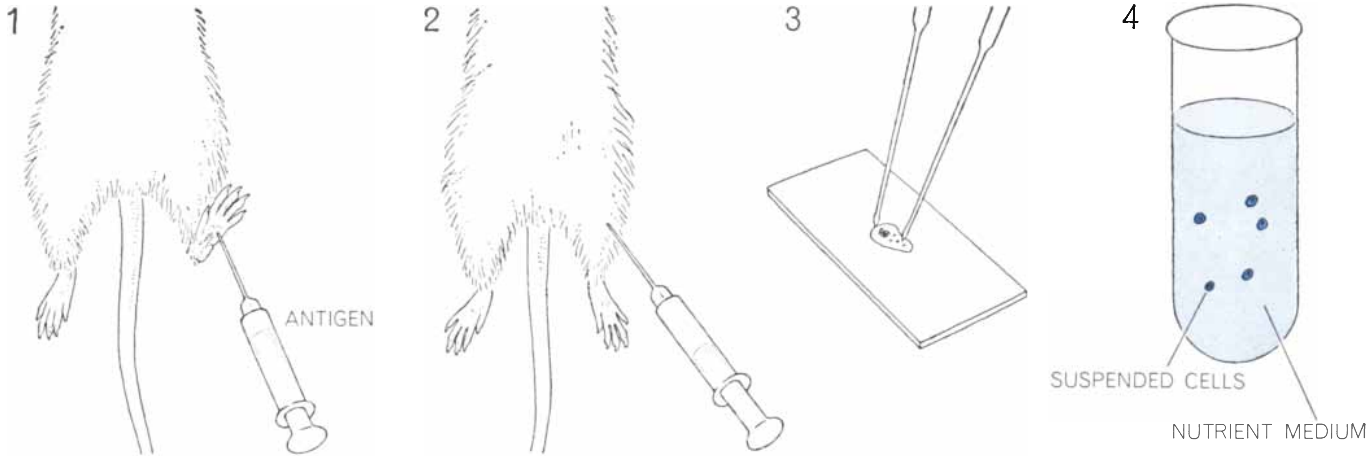
The evolution of the plasma cells again puts one in mind of the development of a large industrial plant. The young, primitive plasmablasts that emerge two or three days after the antigen has been injected represent the tooling-up stage. The plasmablast is a hive of activity; construction is proceeding apace. A few products are being turned out, but most of the energy is going into setting up the machinery and adjusting the assembly line. The mature plasma cell, on the other hand, is like a factory a decade after launching. This is the era of high production, regular dividends and little or no expansion. Nearly all the cell's energy is being put into its one specialized task: turning out a maximum of antibody for export and distribution.

How far does this specialization go? Is a given plasma cell restricted to making a single kind of antibody or can it synthesize more than one kind? We undertook experiments to find out whether or not a cell could produce various antibodies simultaneously. Although theoretical considerations had prepared us to expect fairly strict specialization, we were still somewhat surprised to learn how strict it actually was. With rare exceptions each cell made just one antibody, even when other plasma cells in the lymph nodes were equally busy making other antibodies. In other words, there was a sharp division of labor; the prevailing principle was one cell, one antibody. In about one case in 50 we found a cell making trace amounts of a second antibody, but this may have been accidental—the result, for example, of a tiny, undetectable shred of cytoplasm from another cell clinging to the cell in question.

As happens so frequently in present-day research, another group of workers had quite independently taken up the same investigation we had: the study of antibody production by single cells in microdroplets. A group headed by Melvin Cohn and Edwin S. Lennox that is now at the Salk Institute in La Jolla, Calif., used much the same technique, except that their antigens were virus proteins and the production of antibody was assayed by its neutralization of the virus's infectivity. To our dismay their findings differed in several important respects from our own. They concluded



CLONAL DEVELOPMENT of plasma cells is outlined in this representation of cells at five stages of maturity (*column at right*) and the generations to which they belong (*column at left*). After contact with an antigen the plasmablast takes some 10 hours to divide. The time of division grows successively longer; it is not until the fifth day after contact that mature plasma cells, members of the ninth generation, are producing a great deal of antibody (*colored dots*). Maturity can be seen to entail a shrinking of the nucleus and extension of the cytoplasm as the cell devotes itself to the task of making antibody. The nucleus consequently becomes dense and its two nucleoli (*dark spots in top cell*) seem invisible.



ISOLATING A PLASMA CELL was accomplished in the laboratory of the author as illustrated in this sequence of drawings. An antigen was injected into the footpad of a rat (*Step 1*). Five days later the draining lymph node was removed from the rat's leg (*Step 2*). Cells were teased out of the soft tissue with needles, spun in a centrifuge and suspended in a nutrient medium (*Step 3*). At right (*Step 5*) are a top view and side view of Step 4, in which a cell from the suspension is transferred by means of a

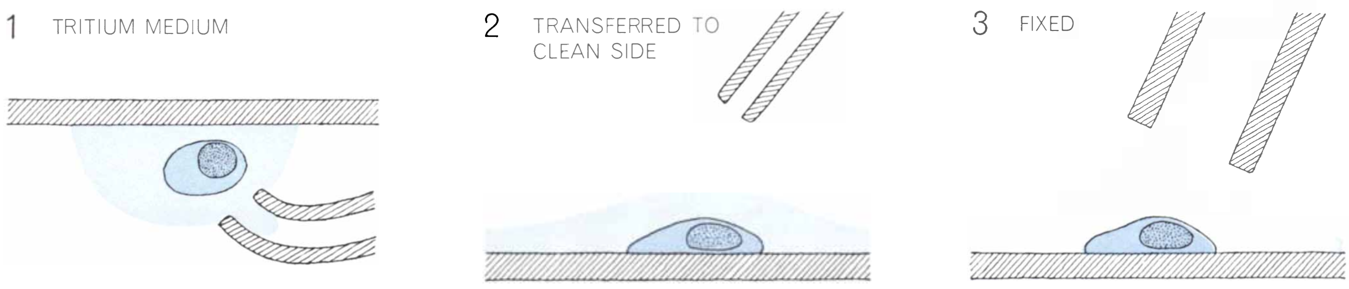
from their experiments that many plasma cells made two different antibodies simultaneously, and also that small lymphocytes, as well as plasma cells, often made antibody. We have been trying to find some reasonable explanation for this difference in results, but so far we have failed to do so. In our hands hundreds of experiments performed by members of our group in various laboratories on three continents have always yielded the same result: one cell, one antibody.

At all events, we begin to see the main outlines of the production picture. As the order for antibody comes in, by way of the arrival of an antigen, the white-cell construction centers (the lymph nodes, spleen or bone marrow as the case may be) commence to turn out the miniature factories that will produce the antibody. These units start as immature plasmablasts and take a little time—a matter of days—to tool up for full production as mature plasma cells. This leads us to the interesting question: What accounts for the great speeding up of antibody production that occurs in a person who has already been exposed to a previous invasion by the same antigen?

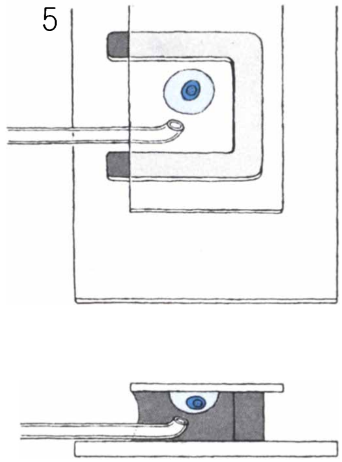
"Immunological memory," as it is called, is by all odds the most remarkable feature of the immune response. A patient who has been vaccinated or has recovered from an infection responds to a second attack by the same antigen with so prompt and massive an outpouring of the appropriate antibody that the infection is stopped in its tracks. How is this stepped-up production accomplished? Do the plasma cells produce more antibody than they did the first time or does the new attack generate a greater number of these cells?

Investigating the question with further experiments, we found that both responses took place: in a reinfection there were more plasma cells and each cell formed more antibody. The multiplication of cells, however, was much more pronounced than the production increase by individual cells. It was as if the first exposure to the antigen had left the animal prepared with precursor cells that were ready to turn into plasma cells of the right kind as soon as the original invader reappeared. We have named these precursors "memory" cells.

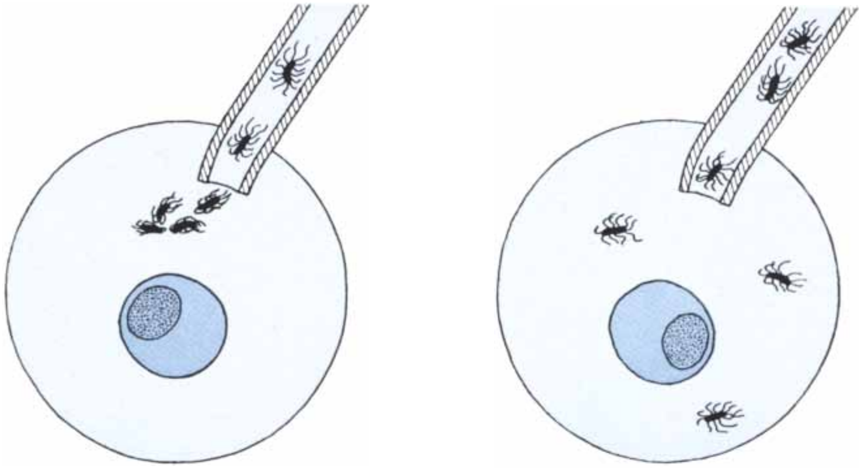
We next looked into another interesting feature of the immune response. It has been known for some time that the specific antibody produced by a mammal changes somewhat as the animal's response progresses. During the early stages of the response the animal produces an antibody molecule with a molecular weight of nearly one million; then it switches to making a lighter version of the same antibody with a molecular weight of only 160,000. The heavy and light versions of the molecule are respectively known as 19*S* and 7*S*; the "*S*" signifies Svedberg units, a measure of the rate of sedimentation of the molecules in a centrifugal field. Using the technique of analyzing antibody production by single cells, we established that the switchover occurred within each individual cell. At first the cell formed only the 19*S* antibody, then for a short period both 19*S* and 7*S*, and finally only 7*S*.



TRACING PROCESS begins with the introduction of tritium, the radioactive isotope of hydrogen, into the medium in which a plasmablast is suspended beneath the cover slip of a microscope slide. This labeled hydrogen is incorporated into thymidine and eventually appears in a constituent of the cellular DNA: thymine. The cell is transferred by a micropipette to a dry, clean slide (*Step*



micropipette to the glass slip covering the well in a microscope slide. The droplet of nutrient medium containing the cell is suspended in paraffin oil at body temperature.



SPECIFICITY OF AN ANTIBODY was demonstrated by experiment in which an antigen that immobilizes *Salmonella typhi* bacilli was injected into a rat, and antibody-producing cells were isolated. When *Salmonella typhi* were put in contact with cells (*left*), they could not move. *Salmonella paratyphi* bacilli, a related strain, were unaffected (*right*).

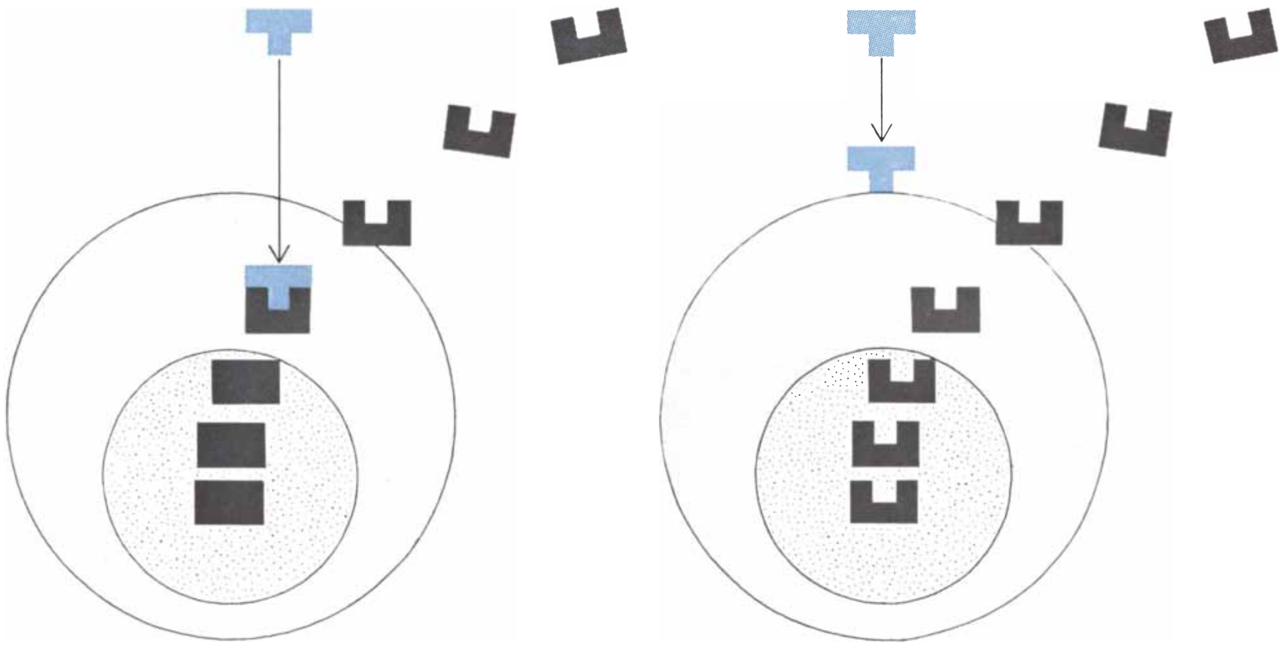
To obtain more information about the workings of these factories it then became necessary to look into the chemical events taking place within them. The problem of finding out what is going on in a single cell of course calls for a technique of exquisite sensitivity. Fortunately such a technique is available. It is autoradiography, the procedure in which a cell is fed a substance labeled with radioactive atoms and the cell then records its metabolic uptake of this substance by its radioactive emissions; these are recorded in a photographic emulsion placed next to the cell [see "Autobiographies of Cells," by Renato Baserga and Walter E. Kisieleski; SCIENTIFIC AMERICAN, August, 1963].

We have used the technique to measure the rates at which our cells synthesize ribonucleic acid (RNA), deoxyribonucleic acid (DNA) and proteins. The radioactive label usually employed is tritium (hydrogen 3). For measurement of the manufacture of DNA, for example, the radioactive hydrogen is incorporated in thymidine, a precursor containing thymine, one of the building blocks of DNA; for similar study of the synthesis of a protein the label is attached to an amino acid. The labeled substance is then added to the microdroplet containing our cell. After a certain measured time the cell is washed, dried on a glass slide, fixed, covered with a layer of photographic emulsion and put away in a dark place—all, of course, with a micromanipulator. Days or weeks later the slide is taken out and the photographic emulsion is developed and fixed in the usual way. This brings out the amount of darkening that has been produced by radioactive emissions from the cell. The radioactivity indicates how much labeled material the cell took up from the culture medium in the time that elapsed before the cell was fixed. Thus one can measure the rate at which the cell synthesized a given product (RNA, DNA or protein) simply by counting the number of darkened grains in the photographic emulsion.

A cell's production of DNA shows how fast cell division is taking place, because the cell doubles its content of this genetic material just before it divides. Measuring DNA synthesis by means of autoradiography, we have found that the young plasmablasts divide about every 10 hours, which is about as fast as any mammalian cell can divide. After the offspring of these cells have reached the stage of full maturity as plasma cells, however, they apparently stop dividing. It appears that, starting with a single plasmablast, there are typically nine successive divisions, producing a "clone," or colony, of cells before division stops. The clone includes not only mature plasma cells but also a number of primitive "memory" cells that are prepared to react vigorously to any future encounter with the same antigen. Very likely these cells are able to organize themselves into "germinal centers."

In the plasmablast stage the cells produce a great deal of RNA and protein—mainly structural proteins and enzymes. The mature plasma cells, on the other hand, switch to synthesizing mainly antibodies: 90 to 95 percent of all the protein they produce is antibody. Curiously the mature plasma cells of rats,

2) and fixed with methanol (*Step 3*). In Step 4 a photographic emulsion is placed on top of the microdroplet containing the cell. During the time the slide is stored in darkness (*Step 5*) rays emitted as tritium decays mark the emulsion. The top view provided in the last step shows the sites at which radioactive substance was used. Such a view indicates where cell synthesized DNA.

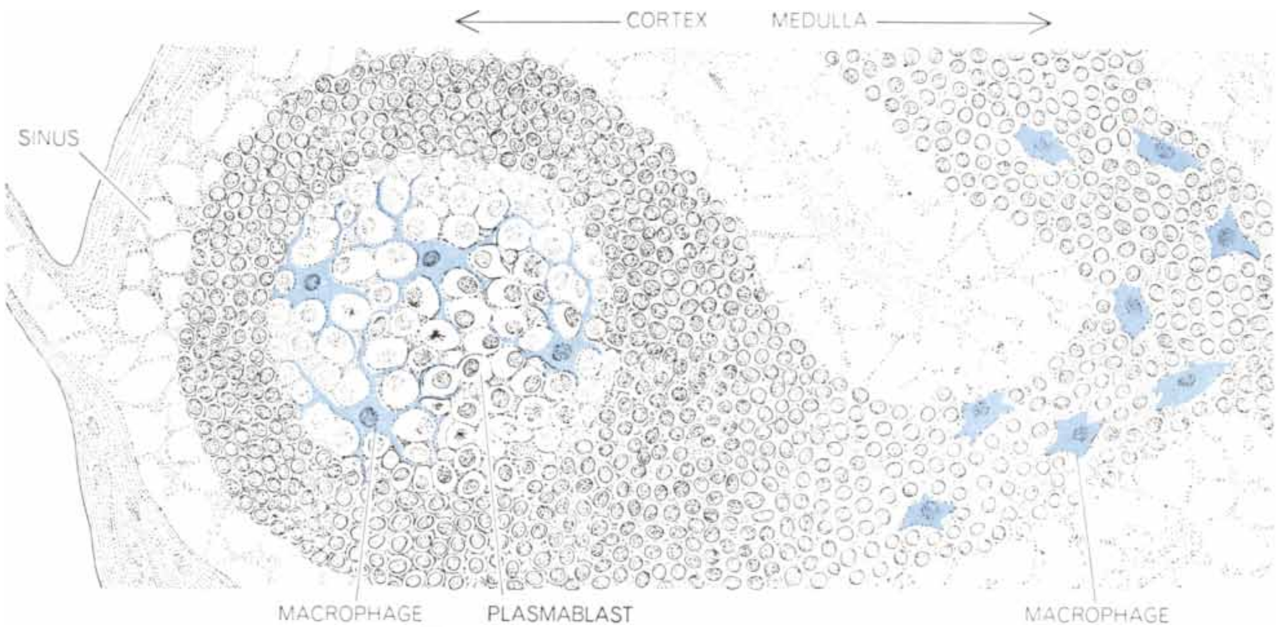


TWO THEORIES OF IMMUNITY are depicted. According to the classical "instructive" hypothesis (*left*) antigen enters a plasma cell and forms a template from which a complementary antibody is produced. The "clonal selection" theory (*right*) suggests that the mere contact of a given antigen and a given plasma cell signals DNA in the cell nucleus to start directing production of antibody.

which we used in our experiments, synthesize very little RNA, although RNA is usually required for protein synthesis. It seems that rats may be somewhat freakish in this respect; recent work has shown that human plasma cells make considerable amounts of RNA. Possibly in rats the cell reads the same RNA blueprints over and over in its manufacture of the antibody molecules.

The development of plasma cells has been studied not only by autoradiography but also by examination of the cells with the electron microscope. We have done little of this work ourselves, but many other groups have pursued intensive microscopic analyses of the cells' anatomy. The electron microscope can magnify the cell 100,000 times and resolve elements within the cell as small as two millionths of a millimeter in diameter.

At this magnification a mature plasma



RESPONSE TO ANTIGEN in a lymph node is illustrated. The colored bodies are macrophages: free-swimming scavenger cells. Macrophages within a follicle, an elevation in the node, extend dendritic arms of cytoplasm that ensnare invading antigen while attracting plasmablasts. The multiplying plasmablasts form a cluster called the germinal center. Macrophages in the medulla, the inner region of the node, may also stimulate reproduction of plasma cells in their vicinity after engulfing (not ensnaring) antigen.

cell looks for all the world like the typical cells of a secretory gland. The cell cytoplasm contains a double membrane marked by an extensive network and studded with little black dots. These dots are the ribosomes—the tiny workshops that synthesize proteins. In many other types of cells ribosomes are strung together like a bead necklace in groups called polysomes. It is believed that the connecting string is "messenger" RNA, which contains the coded information for the construction of proteins, and that the ribosomes read the instructions on the string much as the output device of a business machine reads a punched tape. Certain electron micrographs of plasma cells suggest that perhaps the ribosomes in these cells also are organized into polysomes, but so far we have no conclusive evidence on this point.

A young plasmablast contains many free-floating ribosomes, but it shows no extensive network in its structure. The arrival of an antigen somehow sets in motion a complex series of changes that transforms the potential plasma cell from a relatively unspecialized unit into a highly organized, elaborately specialized system for producing and exporting proteins. The plasmablast begins to synthesize RNA at a high rate, forming messenger molecules and ribosomes in the process. When the factory is equipped for full production, the mature plasma cell not only synthesizes but also in some cases stores large quantities of antibody; occasionally these stores of protein actually become visible as crystals within the cell. How the antibody is released from the cell, or what controls the rate of export, is not known.

It is now high time we looked at the products of these factories: the antibody molecules. Unfortunately this is not at all a simple matter. The products of the plasma cells are about as diverse as the vast array of automobile models put out each year by General Motors. We can nonetheless learn something useful by concentrating our attention on the most common form—the Chevrolet of antibodies. It is the 7S molecule I have already touched on; its full name is 7S gamma globulin.

This molecule, it has recently been discovered, can be disassembled into four parts—four chains that are linked together in the full molecule by covalent sulfur links and hydrogen bonds. They come in two pairs: a pair of heavy chains each of molecular weight 50,000 to 60,000 and a pair of lighter ones of molecular weight 20,000. In each

ANTIGEN CAPTURE by a 7S globulin antibody molecule is illustrated schematically. The antibody has two heavy and two light chains wound in flexible packets and bonded by sulfur atoms (*black bands*). The interaction of a heavy and a light chain at each extreme enables antibody to "open" in a manner conforming to shapes of a wide variety of antigens.

particular 7S antibody the two heavy chains (called *A* chains) are identical with each other and so are the two light ones (called *B*).

Now, it is known that an antibody neutralizes an antigen by somehow attaching itself to the antigen. Where in this four-part structure might we find the active combining site that locks on the antigen? Two different suggestions have emerged. Rodney R. Porter of the Wright-Fleming Institute in London has reported indications that the combining site is in the *A* chain. G. M. Edelman of the Rockefeller Institute, on the other hand, believes on the basis of his experiments that the combining site is shared between the *A* and *B* chains [*see illustration above*].

If Edelman's model is correct, it becomes unnecessary to suppose that the shape of the combining site in each specific antibody is determined by a different single gene, as the Porter scheme would imply. Assuming that this property actually is controlled by genes, a comparatively small number of genes, each specifying a variation of the *A* or *B* chain, would suffice. As few as 1,000 different versions of the *A* chain and 1,000 of the *B* chain could, in various combinations, produce at least a million different configurations to entrap a million different antigens.

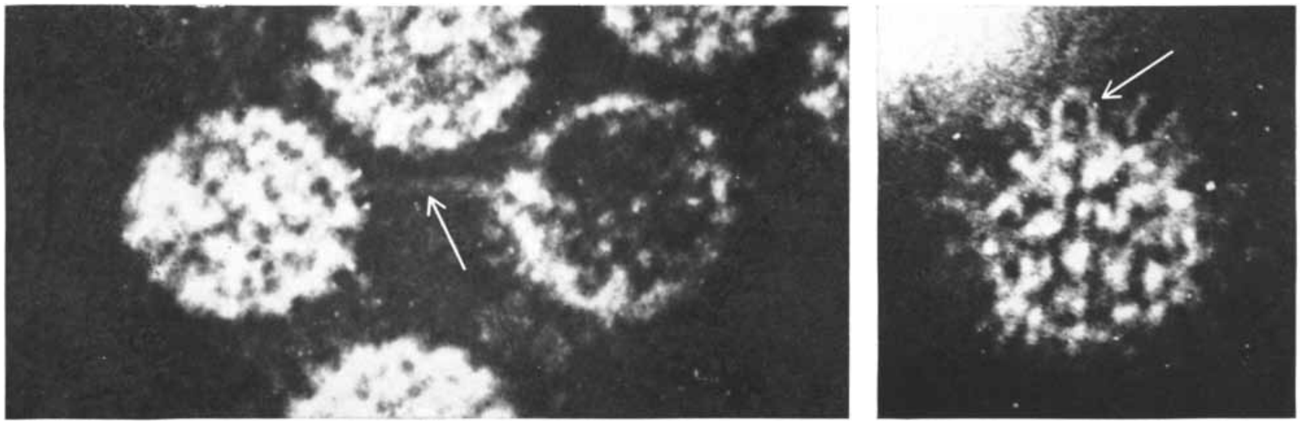
Finally let us examine the antigens themselves. In a sense they can be called the managers of the antibody factories, because they direct what antibodies shall be produced. The arrival of a particular antigen on the scene starts a whole series of specific activities: the proliferation of plasmablasts, the synthesis of RNA and networks by these cells, their progressive differentiation toward mature plasma cells, the synthesis and assembly of *A* and *B* chains into antibody molecules, the creation of "memory cells" and so forth.

Seeking to find out how the antigen triggers all this, Gordon L. Ada and I, together with other workers in our Institute, have recently performed a series of experiments with radioactively labeled antigens. We labeled each antigen molecule with just one atom of radioactive iodine 125, firmly attached to a unit of the amino acid tyrosine in the molecule. At various intervals after the antigen had been injected into a rat we examined sections of the animal's organs by means of autoradiography to see where the antigen had gone. The technique enabled us to trace even single molecules of antigen to their destinations in the body.

We found, in the first place, that the antigen was very efficiently gobbled up by the large scavenger cells, or macrophages. The macrophages deep within the lymph nodes proved to be loaded, as expected, with the antigen. But we also found the antigen trapped in another system that had not been noted previously. In the outer part of the lymph node was a veritable web of fine strands of macrophage cytoplasm. This web captured antigen most actively. Thereafter it soon attracted primitive blast cells, including plasmablasts. These began to multiply and formed round collections of cells we call germinal centers. The exact function of these cells is not clear, but we believe they export both lymphocytes acting as memory cells and antibody-forming cells.

To our surprise we found that little or no antigen made its way into the antibody-producing cells themselves, at least as far as the autoradiographs showed. The plasmablasts occasionally seemed to contain a few molecules of antigen, but in the mature plasma cells there was so little of it that even if the antigen molecules had been broken into tiny pieces, there would not have been enough fragments to provide one for each ribosome or polysome in the cell. All this argued against the hypothesis that antibodies are shaped by contact with the antigen molecule or a fragment of it as the template.

What, then, does launch the plasma-cell system into activity and shape the production of the antibody? The



ANTIBODIES AND ANTIGENS appear in these electron micrographs. In the micrograph at left the antibody molecule (*strand indicated by arrow*) extends between two polyoma virus particles. In the micrograph at right an antibody molecule (*loop indicated by arrow*) attaches both combining sites to one antigen, a wart-virus particle. The micrographs have respective magnifications of 750,000 and 600,000. They were prepared by June Almeida, Bernhard Cinader and Allan Howatson of the University of Toronto.

only current theory that is consistent with all the observed facts is the "clonal selection" theory proposed by Sir Macfarlane Burnet [see "The Mechanism of Immunity," by Sir Macfarlane Burnet; SCIENTIFIC AMERICAN, January, 1961]. The essence of this theory is that the antibody-producing cells need no information from the antigen at all beyond the fact that it is present! The body is equipped with a variety of clones of cells of various capacities. Each group of cells has the potential to react to a particular antigen, and the arrival of that antigen simply triggers the already prepared cells to make the appropriate antibody. As we have seen, the plasmablasts that cluster around the antigen-laden web of the lymph node come into close contact with the antigen. Perhaps mere surface contact with the antigen is sufficient to launch the cells into activity.

Whether the clonal-selection theory is correct, or even partly correct, is still much debated. It seems clear, however, that antibodies are not molded on antigens as templates, and more and more the evidence points to the likelihood that they are constructed according to plans carried by the genes. One can imagine that through the ages the mutagenic processes of nature, working on a vulnerable area, or "hot spot," in the antibody genes (perhaps the two genes controlling the configurations of the *A* and *B* chains), have produced various mutations and thus have given rise to a varied assortment of such genes that persists in the body because of its value in coping with a variety of infections.

In terms of our industrial analogy, it appears that evolution has built an antibody-production system that would make any factory manager wide-eyed with envy. All the manager in this case (the antigen molecule) has to do is to walk up to the right building (an appropriate cell) and knock on the door. The knock sets off feverish activity inside the building: elaborate machines are speedily constructed and the number of workshops multiplies. Soon, without the manager having even crossed the threshold, there begins to come off the assembly line a steady stream of custom-built automobiles designed to suit him exactly. The manager himself did not design the car. Inside the initially empty factory building a very complex computer system (the cell's DNA) saw him coming, remembered all the mistakes and lessons of past ages in coping with his requirements and speedily arranged to greet him with the correct answer.

Quantized Vortex Rings in Superfluid Helium

Vortex rings analogous to smoke rings in air can be produced in liquid helium. They move in strange ways and exhibit discrete quantum effects on a large scale

by F. Reif

The natural world that physicists attempt to understand has two main aspects. On the one hand there is the macroscopic world of objects of the kind we see and feel. On the other there is the microscopic world of atoms and molecules, in which the essential discreteness of nature described by the laws of quantum mechanics is of paramount importance. When matter is of macroscopic dimensions, that is, when it is composed of billions and billions of atoms, the discrete behavior of its constituents is so smeared out that quantum effects are usually undetectable. The situation can be quite different, however, if matter is studied at very low temperatures. The near absence of random thermal motion in matter at these temperatures results in such a high degree of internal order that quantum effects may become manifest even on a macroscopic scale. What follows will describe some recent experiments that have helped to provide striking evidence for the existence of such macroscopic quantum effects in liquid helium.

The experiments were performed with ordinary helium, which consists almost entirely of the isotope helium 4. Gaseous helium liquefies when it is cooled to 4.2 degrees Kelvin (degrees centigrade above absolute zero). When it is cooled still further, to 2.18 degrees Kelvin, it becomes a "superfluid." This fluid has the remarkable property of being able to flow through extremely small holes or channels without encountering frictional resistance [see "Superfluidity," by Eugene M. Lifshitz; Scientific American, June, 1958]. Superfluidity is itself a consequence of the highly ordered state of liquid helium at low temperatures and of the resulting importance of quantum-mechanical effects. The following hypothetical experiment will provide a simple illustration.

Suppose a golf ball is propelled into a liquid with some small initial velocity. Imagine further that we have eliminated gravity or any other external force that might act on the ball. What will happen? In an ordinary liquid such as water the ball would very quickly be brought to rest by the net frictional force resulting from collisions of the ball with individual water molecules. In superfluid helium at a sufficiently low temperature, however, the internal order of the liquid is so great that it is not permissible to consider the effects of individual helium atoms separately. Instead one must regard the liquid as a unified whole, as though its atoms formed a single gigantic molecule in which no atom moves independently of any other; such a molecule could only be described by the laws of quantum mechanics.

If the temperature of the liquid is not close to absolute zero, however, its degree of internal order is not perfect: there exist in the liquid small disturbances that mar its perfection. These deviations from perfect order may consist of local variations in density (compressions or rarefactions) or of tiny eddies that move through the liquid in a random way as if they were particles [see "Superfluidity and 'Quasi-Particles,'" by F. Reif; Scientific American, November, 1960]. Collisions with such disturbances would slow down the golf ball and eventually halt it. The lower the temperature of the liquid, the smaller the number of disturbances in it and consequently the freer the ball's travel through it. At absolute zero, with the liquid reduced to perfect internal order, the ball would encounter no friction whatever and would lose no momentum. It would simply continue to move through the liquid with its initial velocity unchanged, as if it were traveling in a vacuum! To describe the passage of the ball through the perfectly ordered liquid, we may say that the liquid merely deforms gently to let the ball pass, getting out of the way in front of the ball and then closing in behind it.

A few years ago Lothar Meyer and I at the University of Chicago, and independently G. Careri and his co-workers in Italy, performed some experiments that are basically equivalent to the imaginary experiment with the golf ball. Our "ball" was a charged particle of atomic size—essentially a helium ion—whose motion through liquid helium could be studied under various conditions. A plate covered with radioactive polonium and immersed at one end of the vessel containing the liquid provided a source of charged particles by ionizing the helium atoms immediately adjacent to the plate. The rest of the apparatus consisted of one or more grids immersed in the middle of the vessel and a collecting electrode at its other end [*see illustration at bottom left on page 118*]. The ions arriving at this collector gave rise to a small current that could be measured with a sensitive meter.

Even at the lowest temperatures available in our experiments there are a sufficient number of disturbances in the liquid to stop an ion before it has traveled any appreciable distance. When one uses a grid to apply a small electric force to the ion, however, it can be made to drift in the direction of the force with a constant net velocity. This velocity can be determined at various temperatures simply by measuring the time required for the ion to traverse a known distance. Our measurements showed that when the temperature of the liquid helium was lowered from 2 degrees Kelvin to .5 degree, the velocity produced by a given electric field increased approximately 100,000 times. The decreasing number of disturbances, and the increasing degree of order of the liquid, was thus made vividly apparent. Although at .5 degree K. there are still so many disturbances in the liquid that the ion moves only about a ten-thousandth of a centimeter between encounters with them, this distance is already some 10,000 times greater than the distance between neighboring helium atoms in the liquid.

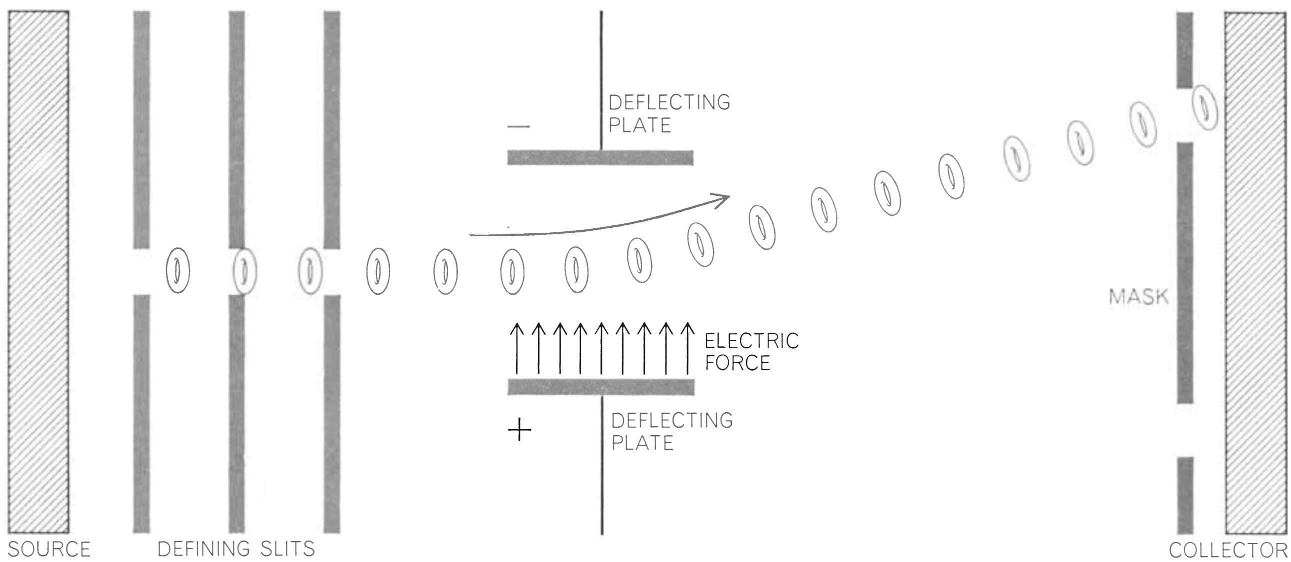
These experiments suggested that it would be most interesting to conduct such investigations under conditions that would minimize the effect of the disturbances on ions moving through the liquid. In collaboration with a graduate student, George W. Rayfield, I therefore undertook at the University of California at Berkeley similar experiments specifically designed to go to lower temperatures and to use stronger electric forces. We soon encountered some highly unexpected effects.

It became apparent that, as the temperature is sufficiently reduced or the electric force is sufficiently increased, the behavior of the charge-carrying entities observed in the experiments changes quite abruptly. There is a marked reduction in the frictional resistance encountered by such a charge-carrier (which might be a single ion or perhaps a more complicated entity consisting of many atoms and carrying a single charge). The situation is most striking at the lowest temperature used in our experiments: .28 degree K. At this point frictional effects are so small that, if a charge-carrier is given an initial push by an electric force, it can travel on for several centimeters without any appreciable loss of energy. Indeed, it can travel on to the collecting electrode even against an opposing electric force, unless that force is made strong enough to overcome the charge-carrier's kinetic energy. In short, the charge-carrier behaves in all respects as if it were moving through a vacuum instead of through the actual liquid.

What exactly is the nature of the charge-carrier that exhibits these surprising properties? To investigate this question we set out to measure the velocity of the charge-carrier's travel. For this purpose the apparatus was modified slightly [*see illustration at bottom right on next page*] so that three grids were immersed in the liquid helium. The energy of a charge-carrier arriving at the first grid was known in terms of the electric force acting on the charge-carrier between the source and the grid. The velocity of a charge-carrier with this energy was then determined by measuring the time it required to travel freely, in the absence of any constant external forces, from the first grid to the third grid. The time could be measured quite accurately by applying to the middle grid a small electrical signal that reversed its direction periodically and thereby acted as a clock.

The velocity measurements revealed two surprising facts. First, the velocity of the charge-carriers is quite low: about 100,000 times lower than one would expect if the charge-carrier were simply a helium ion. The second fact is even more startling. If the energy of the charge-carrier is increased, its velocity decreases; indeed, its velocity is in roughly inverse proportion to its energy. In other words, the greater the force applied to the charge-carrier in the direction in which it moves, the more it is slowed down!

Although these experimental results seemed rather paradoxical, they contained some clues for their interpretation. The very fact that the velocity of the charge-carrier is so low indicates that it is much more massive than a single helium ion and suggests that it must consist of many thousands of atoms forming some well-defined large-scale entity. What kind of object could this entity be? One thought that occurred to us was that it might be a vortex ring, a commonplace example of which is a smoke ring in still air. As everyone who has seen a smoke ring knows, it is a remarkably stable structure. Could it



BEHAVIOR OF VORTEX RINGS in superfluid helium was demonstrated by the experiment depicted in this illustration. The apparatus was immersed in a vessel containing superfluid helium. (Gaseous helium liquefies at 4.2 degrees Kelvin and becomes superfluid at 2.18 degrees K.) The problem was to show that charge-carrying entities originating at the source (*left*) were not singe helium ions but vortex rings bearing a single charge. It was predicted that a pair of electrically charged plates (*center*) would deflect such rings (*color*) four times more than single ions. Openings in the mask in front of the collector plate (*right*) were located in accordance with this prediction. Current collected by the plate confirmed the prediction. Size of the rings is much exaggerated.

be that the body observed in our experiments was simply a vortex ring that bears a charge and moves through the liquid helium in the same way that a smoke ring moves through air? A little thought about the properties of vortex rings in fluids will demonstrate that this is a reasonable conclusion.

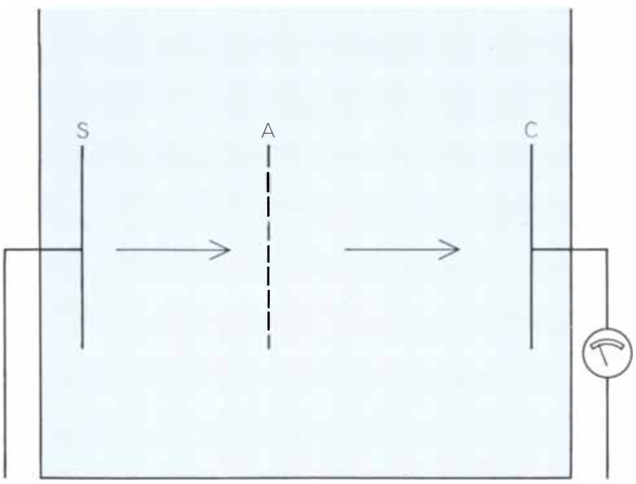
A vortex can exist in any fluid, whether liquid or gas. A simple linear vortex is exemplified by the rotational fluid motion observed in the water above the open drain of a washbasin or in the air masses forming a tornado. Considering such a vortex in ideal terms as consisting of a frictionless fluid, we can describe it by saying that the fluid rotates around a straight hollow axis—the "core" of the vortex—in such a way that the velocity (v) of each portion of the fluid decreases in inverse proportion to its distance (r) from the axis. This relation can be expressed as $v = K/r$; the quantity K, the "strength" of the vortex, is a constant that does not change with time. The magnitude of K depends on how much energy was initially imparted to the rotational motion of the vortex.

The hollow axis of a vortex need not be straight; it can be curved. In particular it can be bent around and joined end to end to form a ring (as in the chemist August Kekulé's celebrated image of a snake grasping its tail, which gave him the idea of the benzene ring). Any vortex ring has this doughnut-shaped structure. The vortex axis follows the circular axis of the doughnut, and the particles of the fluid in the ring revolve around this axis.

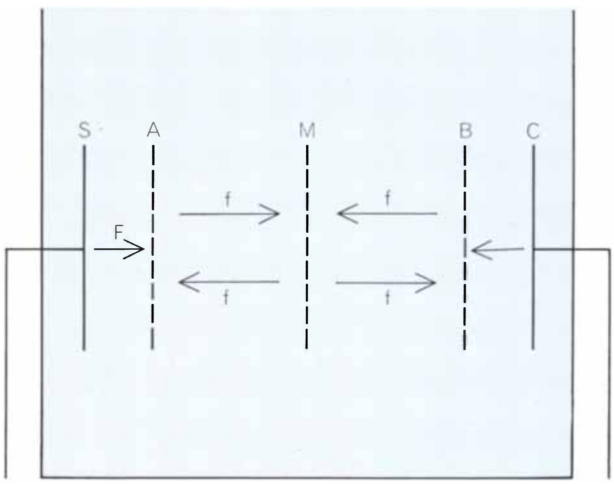
Any vortex axis has associated with it a certain kinetic energy per unit of length by virtue of the motion of the rotating fluid. If one now imagines that the vortex axis is bent in a circle to form a vortex ring, the kinetic energy in the ring is obtained simply by multiplying the energy per unit of length of the axis by the total length of the axis, that is, the circumference of the ring. The energy stored in a vortex ring is thus proportional to its circumference or its diameter.

It is a familiar fact that a smoke ring in still air travels slowly in a direction perpendicular to the plane of the ring. How does this motion of a vortex ring come about and how fast is it? These questions can best be answered if the reader will examine the bottom illustration at right. The illustration shows cross sections at two points on opposite sides of the ring. In one section the rotation of the vortex is counterclockwise as one looks into the picture along the axis of rotation; in the opposite part of the ring, where the axis of rotation points out of the paper, the rotation is clockwise. The nature of the ring can therefore be analyzed approximately as though one were dealing with a pair of straight vortex axes of equal strength (but with their fluid circulating in opposite directions) separated by a distance equal to the diameter of the ring. If only one of the two vortices were present, its axis would be stationary, with the fluid rotating about it. But when both vortices are present, the rotation of the fluid around one vortex extends to the other vortex and influences its motion. The rotation of the fluid in the first vortex causes the fluid in the second vortex to move to the right; as a result the second vortex is swept along to the right. In exactly the same manner the rotation of the fluid in the second vortex causes the fluid in the first vortex to move to the right; as a result the first vortex is also swept along to the right. Under their mutual influence both vortices move to the right with the same velocity. This argument shows why the vortex ring as a whole moves to the right, or in a direction perpendicular to its plane.

These considerations indicate how one can calculate the velocity of the ring as a whole. This velocity must essentially arise from the velocity the fluid rotating around one vortex has at the position of the other vortex that it sweeps along. We have noted, however, that the velocity of rotation of each portion of fluid surrounding a vortex is inversely proportional to its distance from the axis of rotation. In the illustration the two vortices are simply separated by a distance equal to the diameter (D) of the ring. It follows that the rotation of the fluid surrounding one vortex causes the portion of the fluid at the position of the other vortex to have a velocity K/D (K, again, is the strength of the vortex). The pair of vortices, and the ring as a whole, therefore moves in the axial direction essentially with the velocity K/D. This result shows that if the diameter of a vortex ring with a given strength is increased, its velocity



MOTION OF HELIUM IONS through liquid helium (*color*) was studied by immersing in the liquid a source of ions (S), a plate for collecting them (C) and a grid for controlling the motion (A). Charge of the ions was measured by a meter (*right*). Electric forces (*arrows*) were produced by batteries connected to the electrodes.



VELOCITY OF A CHARGE CARRIER was studied with three grids. As a result of force F the carrier enters the region between A and B with a known amount of energy. The time required for the carrier to travel from A to B in the absence of external forces is measured by M, which applies a small alternating force (f).

should decrease in inverse proportion. In other words, the bigger the ring, the more slowly it should move through the fluid.

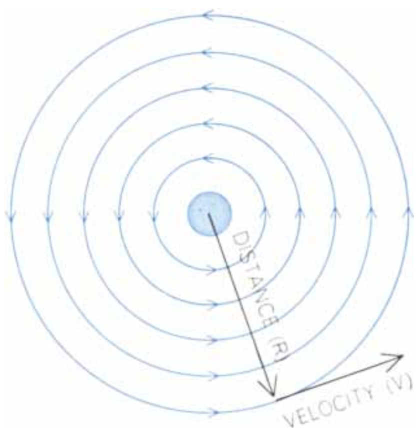
This discussion will have indicated the essential properties of a vortex ring. The ring's energy is directly proportional to its diameter, but its axial velocity is inversely proportional to its diameter. As a result the velocity of the ring decreases in inverse proportion to its energy. If the vortex ring is acted on by an external force, its energy is increased. Then, however, it increases in size and slows down. Indeed, the larger the external force, the slower the motion of the ring through the fluid. All these strange properties are precisely those exhibited by the charge-carriers observed in our experiments. The experimental results can therefore be explained by assuming that the charge-carriers are vortex rings formed of liquid helium.

The predicted properties of vortex rings are so odd that it seems worth verifying that they are indeed exhibited by visible vortex rings in ordinary liquids. A convincing demonstration can be provided with vortex rings consisting of a white liquid injected into a tank of plain water [*see bottom illustration on page 122*]. When the white vortex ring consists of plain water, so that it is subject to no net external forces, it moves through the tank with relatively little change in its velocity and size. A white vortex ring of salt water, however, behaves differently. Since salt water is heavier than plain water, the ring is pushed downward by a net gravitational force greater than buoyancy. In agreement with the prediction, the ring is observed to increase in size as it moves downward with decreasing speed.

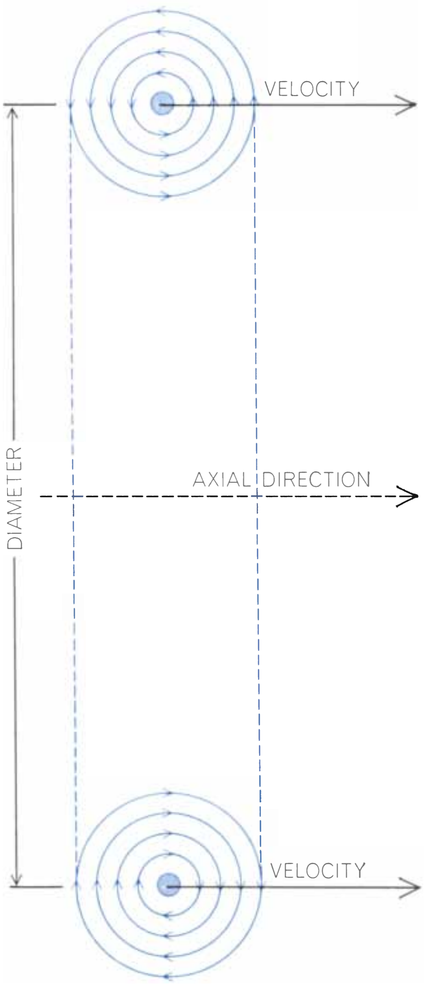
Now let us return to our experiments with charge-carriers in liquid helium. Our measurements, made under a large variety of conditions, showed that there is a unique relation connecting the energy and the corresponding velocity of the observed charge-carriers. If the charge-carriers are vortex rings, as we have been led to conclude, the relation implies that all these vortex rings must have the same strength (K). The actual magnitude of the strength is readily derived from the experimental data. But why should all vortex rings in liquid helium always have this particular strength?

The answer to this question represents the most significant aspect of the experiments: it provides direct evidence that quantum mechanics is profoundly important for describing the behavior of liquid helium. To appreciate this point, let us once again consider the simple case of a long, straight vortex in a fluid. In an ordinary fluid the strength of this vortex can have any value, because on the macroscopic scale and at ordinary temperatures a continuous series of values is permitted. This is not true of liquid helium, where the temperature is so low and the internal order so great that the liquid must be treated as a single molecule. The laws of quantum mechanics must now be directly applicable to the liquid as a whole. As a result the liquid is allowed only certain discrete states of motion. Just as in a hydrogen atom the angular momentum of the electron revolving about the nucleus is allowed only certain values, each of which must be a whole-number multiple of Planck's quantum constant $\hbar$, so the angular momentum of each helium atom in a liquid-helium vortex must be restricted to a value that must be a whole-number multiple of $\hbar$. The angular momentum of a helium atom is given by the formula mvr; that is, it is obtained by multiplying the mass (m) by the velocity (v) and the distance (r) from the axis of rotation. In the vortex, as we have noted, $v = K/r$, so the formula for angular momentum simplifies to the product mK. Since the angular momentum must be an integral multiple of $\hbar$, it follows that K—the strength of the vortex—must be always some whole-number multiple of $\hbar/m$. In short, the strength must be quantized. This conclusion, derived by reasoning from quantum laws, is remarkable because it predicts that Planck's constant $\hbar$, which is usually relevant only to phenomena at the atomic level, in liquid helium applies on the macroscopic scale.

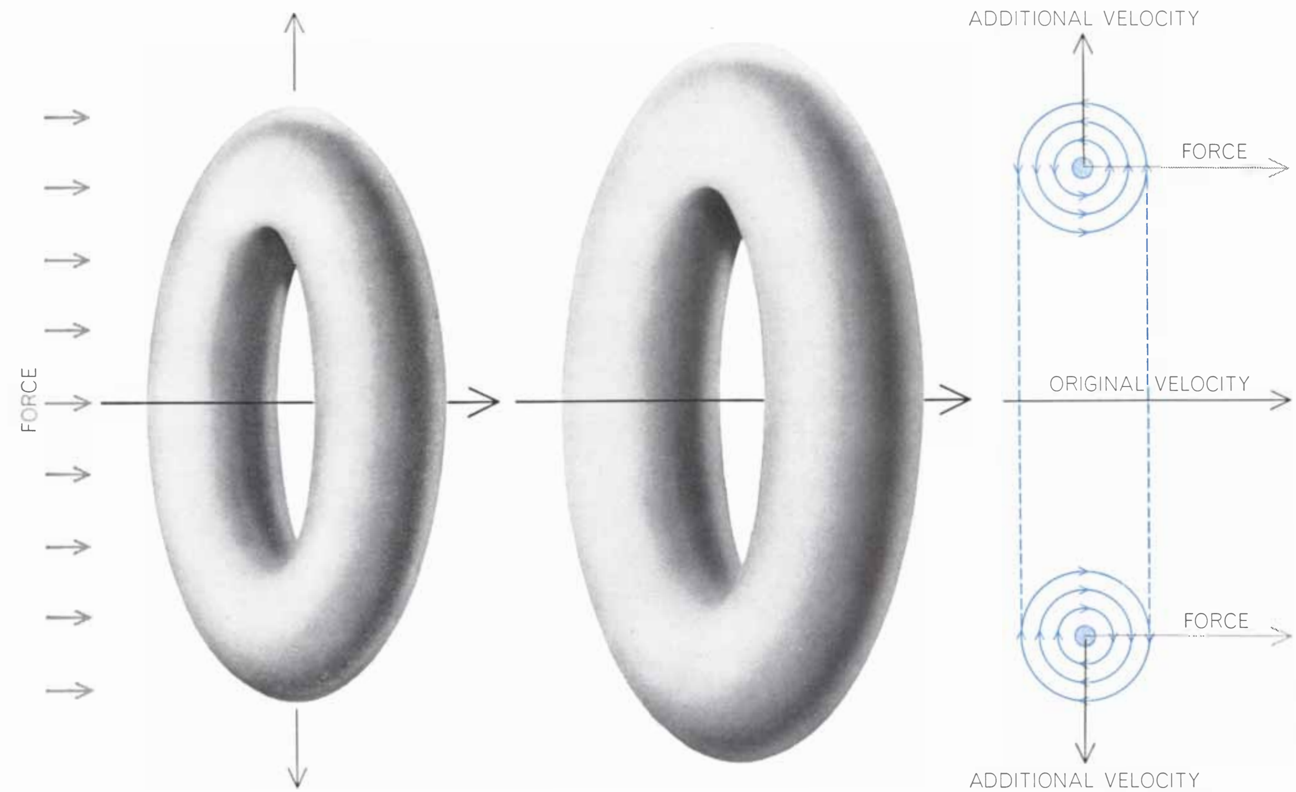
The quantization of strength should be the same if the straight vortex is bent or joined end to end to form a vortex ring. Our experiments on charge-carrying vortex rings in liquid helium, however, have enabled us to deduce a unique value for this strength. The value turns out to be exactly equal (within a margin of experimental error of about 3 percent) to the quantity $\hbar/m$, obtained by dividing Planck's constant by the mass of a helium atom (m). In other words, the strength of the vortex rings as measured in our experiments precisely fulfills the demands of quantum mechanics: it amounts to the smallest possible value, or just one quantum unit $\hbar/m$. (Under our experimental con-



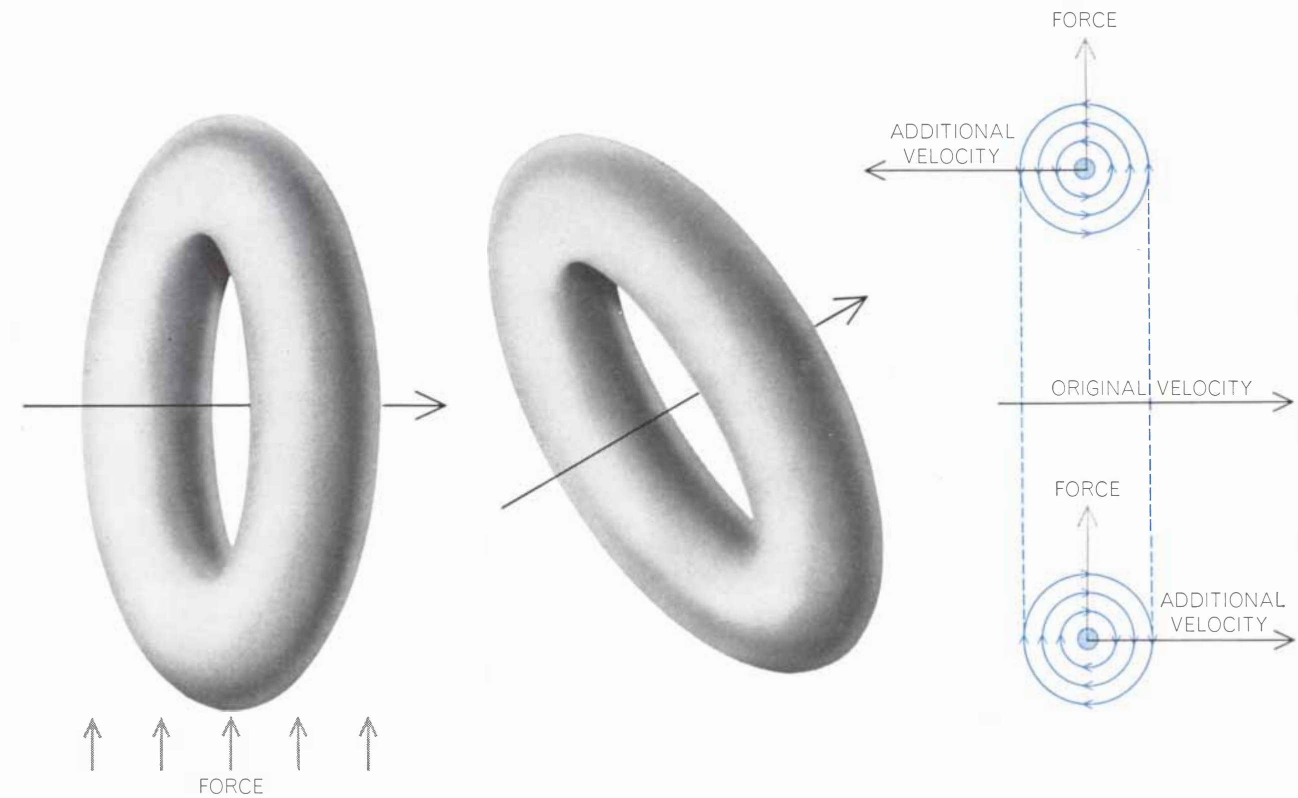
STRAIGHT VORTEX such as that observed in a tornado is shown in cross section. The vortex has a hollow axis around which the fluid rotates in one direction (*curved arrows*). The symbol V denotes the velocity of the fluid at the distance R.



VORTEX RING is essentially a straight vortex closed in a loop. Here the motion of fluid in a ring that is moving to the right is shown in cross section. The representation is schematic; the flow does not have equal strength outward from the axis, nor does it stop abruptly at the vertical broken lines.



EXPANSION OF A VORTEX RING is the result of a force acting at right angles to the plane of the ring. This force, the effect of which is shown in detail by the cross sections and the arrows at right, imparts to the vortices velocities that push them outward.



TILTING OF A VORTEX RING occurs when a force acting parallel to the plane of the ring imparts velocities that push the edges of the ring in opposite directions. Effects of the force on points on opposite sides of the ring are shown at right.

ditions it would be difficult to produce rings with a strength greater by as much as another quantum unit, the smallest possible larger value.)

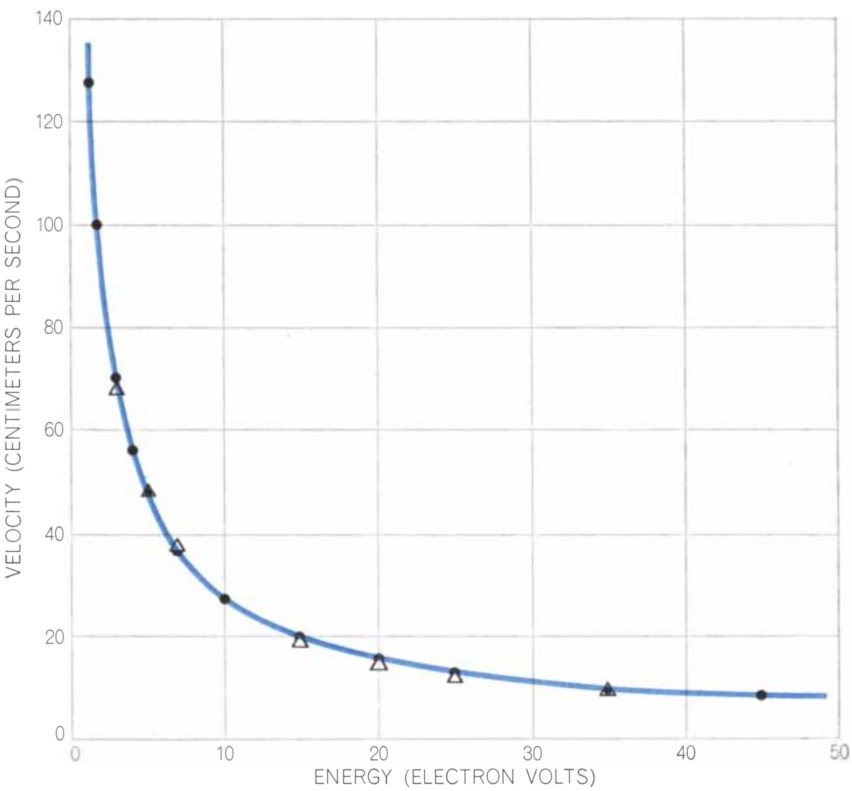
Compared with the theoretical curve showing how velocity should be related to energy in vortex rings of this strength, our experimental measurements fit the curve quite well [*see illustration on this page*]. One feature of the results provides further support for the vortex-ring interpretation. In liquid helium at higher temperatures positive ions behave rather differently from negative ones, but in these experiments it makes no difference whether the charge-carrier has a positive or a negative charge: both types fall on the same curve. This confirms that the charge-carrier is composed of a large number of atoms, so that the nature of the small charged particle carried along by the group as a whole is comparatively unimportant.

A liquid-helium vortex ring with an energy of 50 electron volts is about a ten-thousandth of an inch in diameter, and we have worked with even larger ones. Such a ring can be considered truly macroscopic, since its diameter is about 10,000 times the distance between any two adjacent atoms in the liquid. Our experiments therefore provide good evidence for the manifestation of discrete quantum effects on a macroscopic scale.

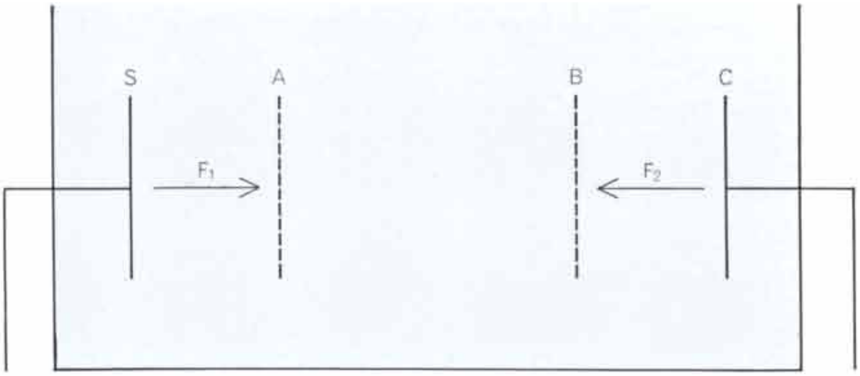
Now that we have gained an insight into the main properties of quantized vortex rings in liquid helium, we can try to answer a number of other questions about them. How, for example, is such a vortex ring originally created? At sufficiently low temperatures, or in the presence of a sufficiently large electric force, a helium ion can be accelerated to a high velocity between encounters with the relatively few disturbances in the liquid. We surmise that the ion can thus acquire enough energy to form around itself, out of the atoms it pushes aside in moving through the liquid, a vortex ring of atomic size. The ion is then likely to be trapped in the hollow core of the ring, endowing the ring with a charge localized along its axis. After this has happened the ring grows in energy and size as a result of the applied electric force.

Is it possible to understand the strange motion of vortex rings under quite general conditions? Consider first a single straight vortex such as the one shown in the top illustration on page 119. If an electric force is applied to the charged vortex axis in a direction to the right, it tends to push the axis into a region where the rotating fluid moves upward; hence the axis is driven upward and the vortex moves upward at right angles to the applied force. The argument can now be applied to the motion of a vortex ring. If an electric force is applied at right angles to the plane of the ring as indicated in the top illustration on the opposite page, it pushes the axes of the two vortices (shown in cross section) into regions where the fluid rotates in such a way that the vortex axes are driven outward. This argument shows why the diameter of the ring increases under these conditions. On the other hand, if the electric force is applied along the plane of the ring itself, as shown in the bottom illustration on the opposite page, it will have the effect of driving the near edge of the ring to the right and the far edge to the left; in other words, it will tilt the ring. We have calculated that, because of this tilting, a vortex ring subjected to an electric force acting at right angles to its original direction of motion would be deflected four times as much as an ordinary charged particle would be. An experiment designed to test this prediction showed that the prediction indeed holds true [*see illustration on page 117*]. The experiment still further confirmed that we are dealing with vortex rings.

Finally, why is it that a vortex ring in liquid helium at low temperatures can move so freely over a large distance with a negligible change of velocity? It is basically because a vortex ring has a large inertia, since it consists of many thousands of atoms, and because it collides with rather few disturbances if the temperature is very low. A simple experimental arrangement enabled us to measure the energy loss of a vortex ring that was allowed to move freely over a fixed distance in the absence of any external force. We found that the energy loss increases rapidly when the number of disturbances in the liquid is increased by raising its temperature. The measurements indicate that a vortex ring with an initial energy of 10 electron volts can travel in liquid helium at .28 degree K. a distance of 55 centimeters before losing half its energy; when the temperature is



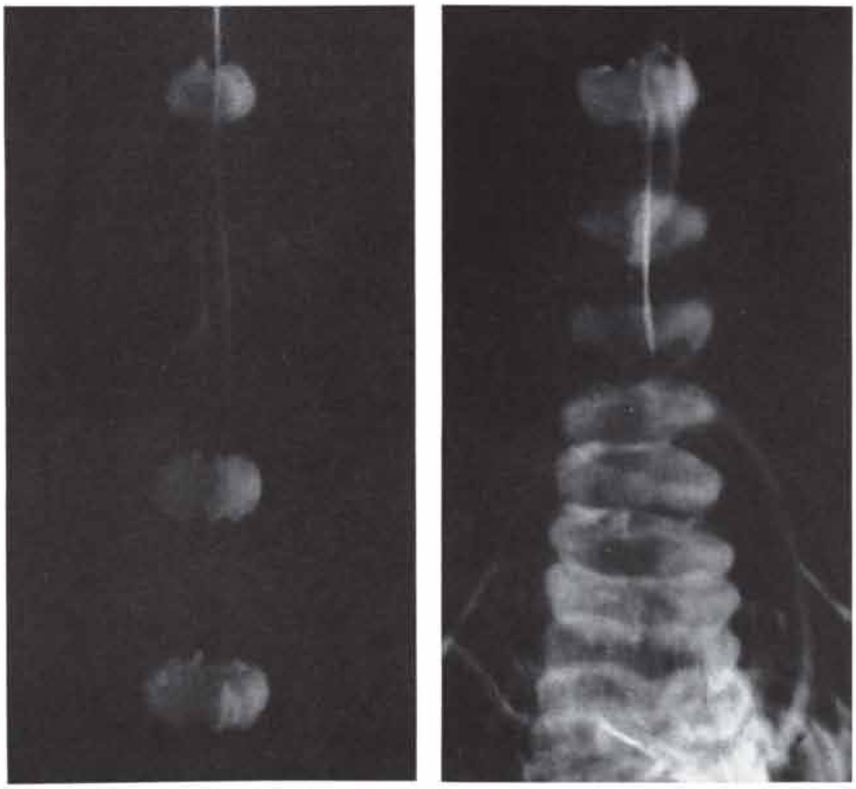
VELOCITY AND ENERGY of a charge-carrier are plotted on this graph. Experimentally observed figures for positive charge-carriers (*dots*) and negative carriers (*triangles*) are plotted on a vertical axis giving the velocity in centimeters per second and a horizontal axis giving the energy in electron volts. The colored curve shows the theoretically predicted relation between the velocity and energy of a vortex ring with a strength equal to one quantum unit (Planck's constant $\hbar$ divided by the mass of one helium atom).



LOSS OF ENERGY BY A VORTEX RING can be measured with a two-grid system. A force (F_1) applied between the source of the vortex rings (*S*) and the first grid (*A*) determines the energy with which the ring enters the region past the grid. A second force (F_2), applied between the second grid (*B*) and the collecting plate (*C*), is adjusted until the ring cannot quite reach the plate. This opposing force is measured; the difference between it and the initial force determines energy lost by the ring in the region between the grids.

raised to .7 degree, it can travel only .1 centimeter before losing the same amount of energy.

The series of experiments described in this article has made possible exceptionally detailed studies of the behavior of vortex rings in a nearly frictionless fluid. Their most significant result, however, is the demonstration that matter on a macroscopic scale can exhibit discrete quantum effects. The finding that vortex rings in liquid helium have a strength that is precisely equal to one quantum unit forms a beautiful bridge between quantum theory and the macroscopic world of ordinary observation.



VORTEX RINGS IN WATER display some of the behavior of vortex rings in liquid helium. In photograph at left a single ring consisting of water colored white moves from top to bottom. With its motion stopped at regular intervals by a flash lamp, it can be seen to increase in size only slightly. Ring at right consists of white salt water, which is of course heavier than white plain water. With its motion stopped at same intervals, it increases in size and slows up as it is pulled down by a net gravitational force greater than buoyancy.

MATHEMATICAL GAMES

On polyiamonds: shapes that are made out of equilateral triangles

by Martin Gardner

In February, Charles Scribner's Sons will publish *Polyominoes,* a book of great interest to many readers of this department. The author is Solomon W. Golomb, a mathematician associated with the California Institute of Technology's Jet Propulsion Laboratory and professor of engineering and mathematics at the University of Southern California. It was in 1953 that Golomb, then a student at Harvard University, coined the term "polyomino" for any flat figure formed by joining unit squares along their edges. Since a "domino" consists of two attached squares, Golomb proposed calling a three-square figure a "tromino," a four-square figure a "tetromino" and so on.

Among puzzle fans the 12 pentominoes—all the different ways of uniting five unit squares—proved the most popular. They were the topic of this department in December, 1957, and again in November, 1960. So intriguing were the combinatorial problems posed by these 12 little shapes that working with them became something of a national pastime. Sets of plastic pentominoes were marketed both in this country and in Britain, and Golomb found himself swamped with suggestions for new problems and requests for more information. Now, to the delight of all pentomino buffs, he has assembled in one profusely illustrated volume everything of interest currently known about the pentominoes and their square-cornered cousins.

This month we consider a triangular cousin. It is mentioned briefly in Golomb's book and there are scattered references to it in a few journals, but most of what is known about this new recreation has been discovered so recently that it appears here for the first time. It is a field with many fundamental problems yet to be solved and a rich supply of patterns and theorems still to be discovered.

Golomb had pointed out as early as 1954, in an article on polyominoes for the *American Mathematical Monthly,* that a recreation similar to polyominoes could be based on pieces formed by joining unit equilateral triangles. A Glasgow mathematician, Thomas H. O'Beirne, writing in the *New Scientist* in 1961, proposed calling such shapes "polyiamonds." Taking his etymological cue from Golomb, O'Beirne reasoned that if a "diamond" consists of two attached triangles, a figure formed by three triangles should be called a "triamond," four triangles a "tetriamond" and so on up through "pentiamond," "hexiamond," "heptiamond" and higher n-iamonds. Obviously there is only one form of diamond and triamond, and the reader can quickly convince himself that there are three tetriamonds and four pentiamonds. (As with polyominoes, mirror reflections of asymmetrical forms are not usually considered different.) The hexiamonds, by a pleasing coincidence with the pentominoes, are exactly 12 in number. There are 25 heptiamonds. Beyond this no accurate counts have been established.

The 12 hexiamonds are shown in the illustration on the opposite page with appropriate names, most of them first proposed by O'Beirne. The reader is invited to copy these 12 shapes on a sheet of cardboard and carefully cut them out. The coloring on the shapes should be ignored. It is best to use cardboard that is the same on both sides, so that asymmetrical pieces can be turned over at will. It is good to have a supply of isometric paper on hand for ease in recording patterns.

It is obvious that any pattern formed by two or more hexiamonds must contain a number of unit triangles that is evenly divisible by 6. We can go further. By coloring the pieces as shown we see that every piece except the last two (sphinx and yacht) are "balanced" in the sense that they contain three triangles of each color. Therefore any figure made by fitting together two or more balanced hexiamonds must itself be balanced. The yacht and sphinx are each unbalanced four to two. If one of these pieces appears in a figure, the figure must be unbalanced by an excess of two triangles. If both pieces are used, the figure must be either balanced (the yacht and sphinx being so placed that they compensate for each other) or unbalanced with an excess of four triangles. This provides a powerful check for eliminating many figures that otherwise might be thought possible.

Consider, for example, the equilateral triangle of order-6 [*top of illustration at top left on page 126*]. It contains 36 unit triangles; it is the only triangle within the range of the 12 hexiamonds that has a number of unit triangles evenly divisible by 6. One could waste many hours vainly trying to construct this triangle with six hexiamonds. If it is colored as shown, however, we find that it contains an excess of six triangles of one color. Since the maximum achievable excess is four, the figure is seen at once to be impossible.

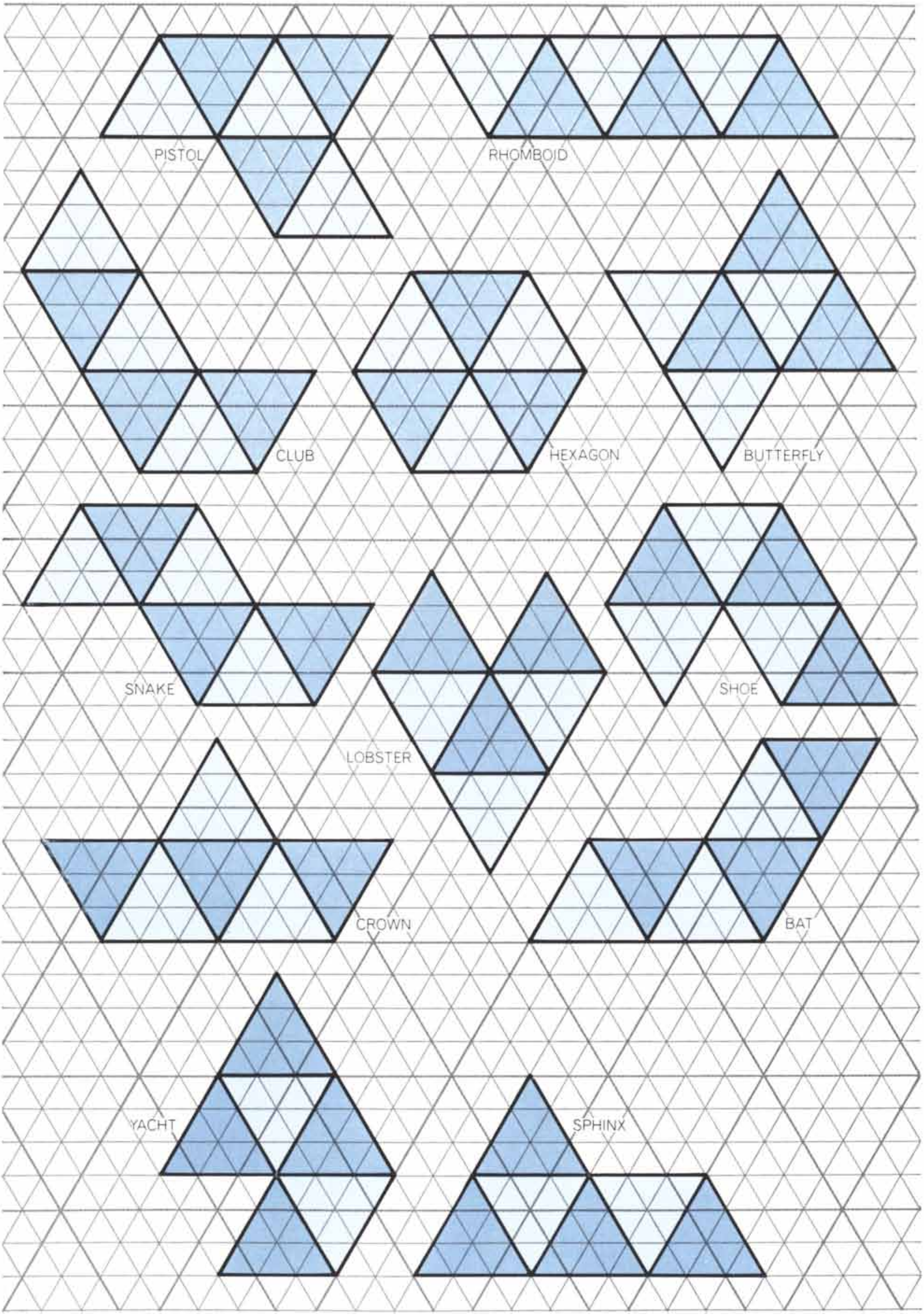
Attention turns naturally to the parallelograms. Only the 3×3 and 6×6 diamonds (rhombi) contain the proper number of triangles. The smaller diamond is easily found to be impossible, but the 6×6 has scores of known solutions. One solution, by Maurice J. Povah of Blackburn, England, is shown at the top of the illustration at bottom right on page 126. It is interesting on two counts: all pieces except the hexagon touch the border, and a line divides the pattern into congruent halves. The halves can, of course, be fitted together in other ways to make bilaterally symmetrical figures.

Among the rhomboids (parallelograms with oblique angles and unequal adjacent sides) these facts are known:

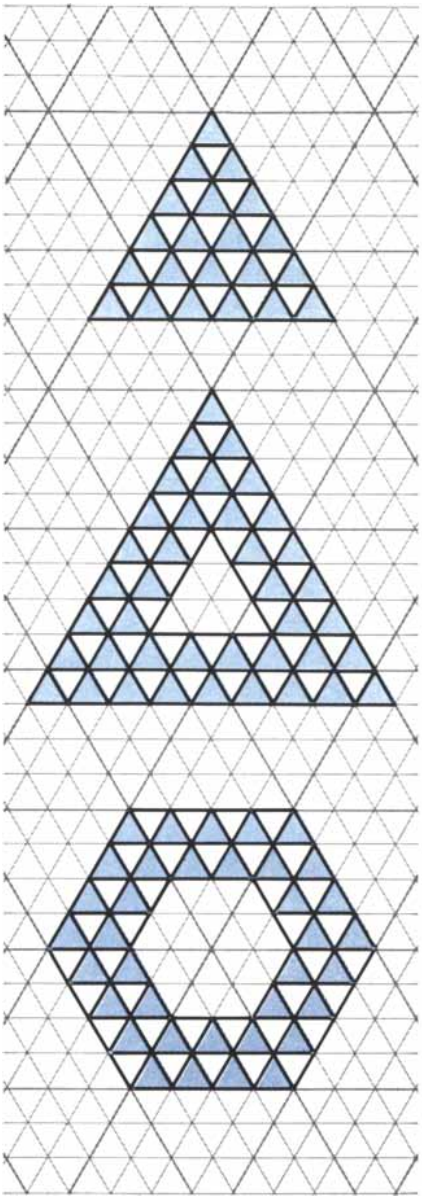
1. If one side is 2, the other side must be a multiple of 3. The 2×3 is impossible. The 2×6 has one solution (ignoring independent reflections of the two halves), shown in the illustration at bottom left on page 126. It is easy to prove that only these four pieces are usable in any rhomboid with a side of 2. The rhomboidal piece leaves a space alongside it that cannot be filled, and each of the other pieces divides the figure into two areas, both of which contain an odd number of unit triangles. Since an odd number cannot be a multiple of 6, no other rhomboid with a side of 2 is possible.

2. If one side is 3, the rhomboid will contain a multiple of six triangles. The 3×3 is impossible. The 3×4, 5, 6, 7, 8, 9 and 10 are all possible, each with many solutions.

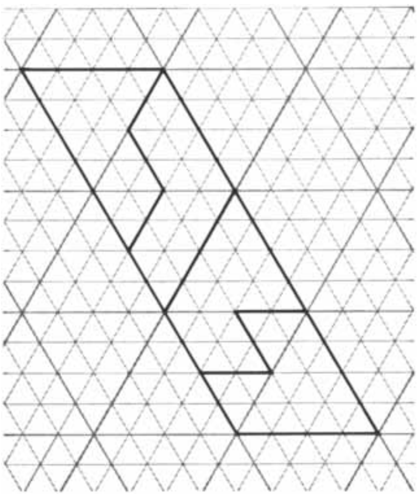
The 3×11 is possible, but it is so



The 12 hexiamonds



Three "impossible" hexiamond patterns



The only possible rhomboid with a side of 2

difficult to achieve that I leave this as an advanced exercise for the reader. In all known solutions (one will be given in this department next month) the bat is the piece left out. It is not known if there is a solution with some other piece omitted.

The 3 × 12, which calls for all 12 hexiamonds, is the outstanding unsolved problem in the field. No solution has been found, nor has an impossibility proof been devised. Can any reader cast light on this problem?

3. If one side is 4, the other must be a multiple of 3. The 4 × 3 (mentioned earlier as 3 × 4) is possible. So is the 4 × 6. The 4 × 9, which uses all 12 pieces, has many solutions, one of which is shown in the illustration at bottom right. The shaded sections can be reflected to give three other solutions.

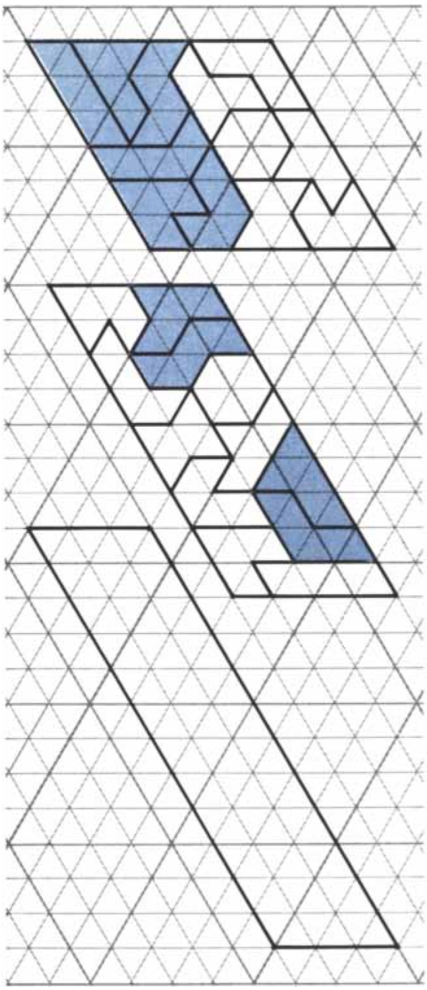
4. If one side is 5, the only rhomboid with a suitable number of triangles is the 5 × 6. There are many solutions.

Charles H. Lewis of Roslyn, N.Y., was the first to propose ring-shaped figures such as the two at the bottom of the illustration at the left. It is easy to show that the triangular ring is impossible by coloring it and observing that it is unbalanced by six triangles. The hexagonal ring is balanced, but a simple impossibility proof was discovered by Meredith G. Williams of Washington, D.C. The hexagon can go in only two positions, all others being derived by rotating or reflecting the figure. In either position it is impossible to add the lobster without dividing the remaining field into two regions, neither of which has an area that is a multiple of 6.

Many patterns with threefold symmetry have been constructed. Hexagons of order-2 and order-3 exist, as is evident from the order-3 hexagon found by Adrian Struyk of Paterson, N.J. [*see "a" in illustration on opposite page*]. Struyk also found several ways to make the trefoil shape shown in *b* in the illustration. This arrangement permits the moving of one hexagon to make a straight chain of three joined hexagons. In *c* Struyk has bisected the trefoil into congruent halves, and in *d* he has produced a pattern that can be folded around a regular octahedron. The illustration on page 128 features a variety of striking hexiamond patterns, of bilateral and threefold symmetry, discovered by Povah. Note that the figure at top right contains a solution to the problem of forming three congruent shapes using all 12 pieces.

The duplication problem—forming twice-as-high replicas of each hexiamond by using four pieces—is easily solved for each figure. As Lewis has pointed out, the two halves of the 6 × 2 rhomboid [*see illustration at bottom left*] can be fitted together in various ways to duplicate all hexiamonds except the pistol, crown and lobster. The triplication problem—forming larger replicas with nine pieces—cannot be solved for the sphinx and yacht, which are unbalanced by six triangles. The other pieces are balanced, and triplications have been found for all except the butterfly. The butterfly is believed to be impossible, although no proof has been formulated.

In the bottom illustration on page 130 is Povah's solution to what is called the "three twins" problem. In the top illustration on the same page is shown a six-pointed star that has an eight-piece solution that is believed to be unique. It is not difficult, and solving it is an excellent introduction to the pleasures of hexiamondry. Here is a hint: Neither the snake, the hexagon nor the crown can contribute to the star's perimeter. The



Parallelograms involving all 12 hexiamonds star's only known solution will be given next month.

Last month's problems, involving limits, are answered as follows:

If Achilles runs seven times faster than the tortoise, which has a head start of 100 yards, the total distance Achilles travels, before overtaking the tortoise, is the limit of the series

$$100 + \frac{100}{7} + \frac{100}{7 \cdot 7} + \frac{100}{7 \cdot 7 \cdot 7} + \ldots$$

Each term is seven times the next term. Using the trick explained last month, we let x equal the series, then multiply each side by 7:

$$7x = 700 + \frac{100}{7} + \frac{100}{7 \cdot 7} + \ldots$$

The series, after 7, is the original series. Therefore $7x = 700 + x$, or $6x = 700$, and $x = 116\frac{2}{3}$, the number of yards Achilles travels.

The bouncing ball comes to rest after traveling a distance equal to the first foot that it falls, plus the sum of $2/3 + 2/9 + 2/27 + \ldots$. The same procedure is applied (multiplying by the constant factor of 3) to obtain a limit of one foot for the series. Thus the total distance traveled by the ball, before it comes to rest after an infinite number of bounces, is $1 + 1$, or two feet.

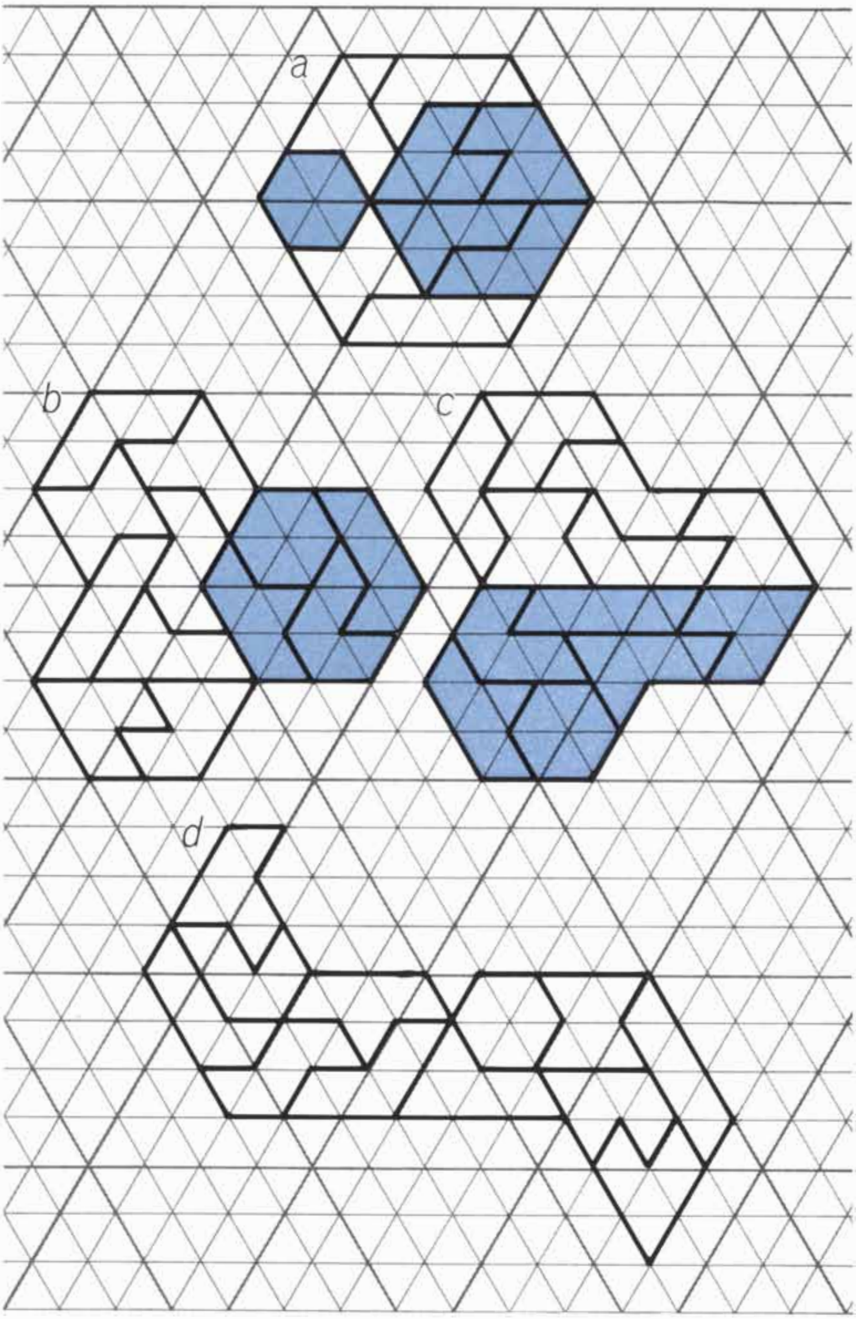
The Hungarian problem of the colored squares calls for the limit of the following series:

$$\frac{1}{9} + \frac{8}{9^2} + \frac{8^2}{9^3} + \frac{8^3}{9^4} + \ldots$$

This is also a geometric progression, with each term 9/8 of the next one. As before, we can use the algebraic trick explained last month, or—what amounts to the same thing—use the following formula for the sum of a converging series in geometric progression:

$$\frac{rx}{x-1},$$

where r is the ratio of adjacent terms (in this case 9/8) and x is the largest term of the series (in this case 1/9). The limit is 1. Therefore as the number of coloring operations increases without bound, the colored area of the unit square approaches the area of 1. In other words, the limit is a fully covered square. Of course this could be achieved in practice only if a coloring procedure could be devised in which the time required for each step would decrease in a converging series. The problem was taken from *Hungarian Problem Book I*, translated by Elvira Rapaport, in the Random House New Mathematical Library.



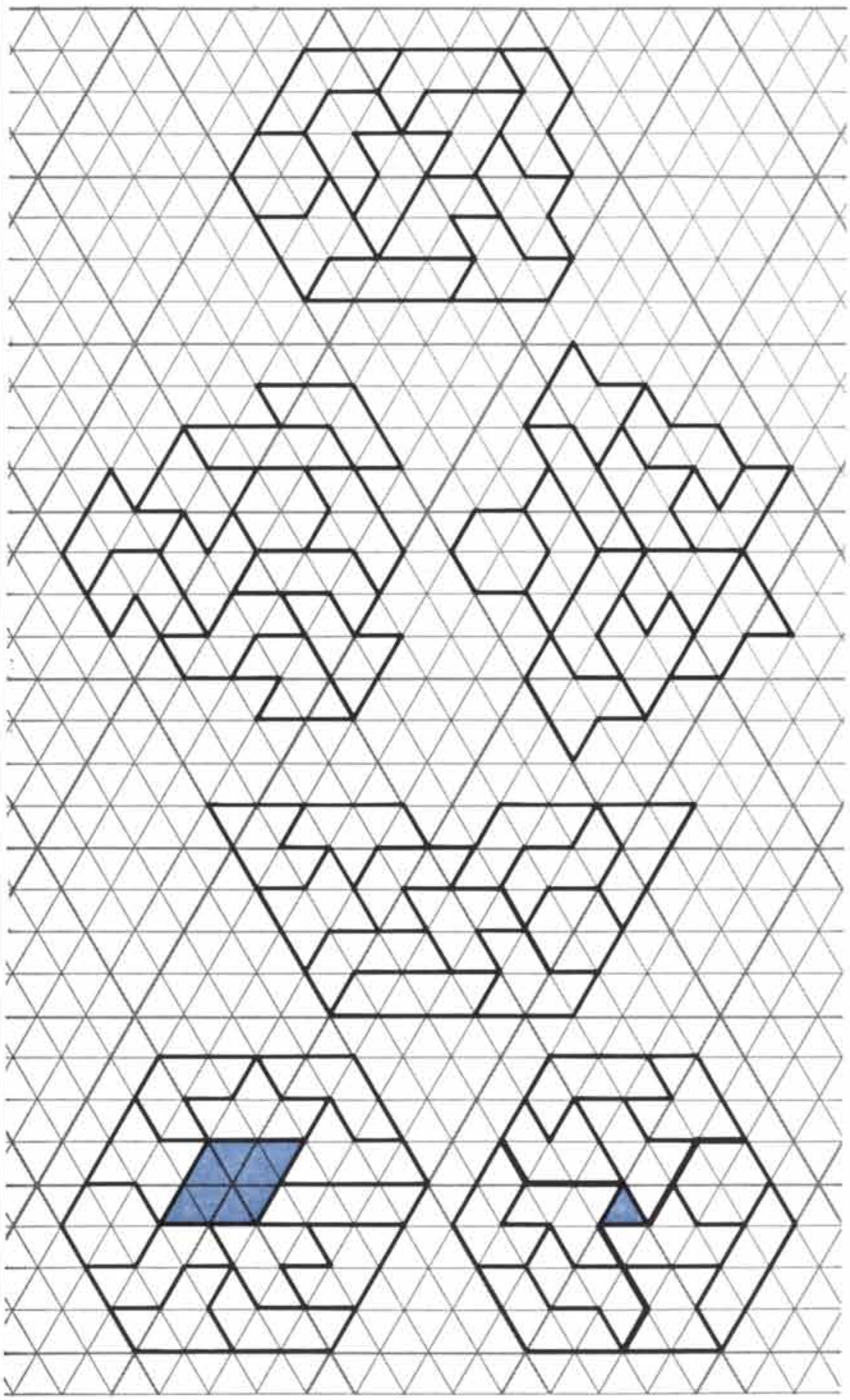
Hexiamond patterns made by Adrian Struyk. Bottom pattern covers a regular octahedron

A number of readers responded to the request for pangrams. Walter G. Leight of the Franklin Institute's Center for Naval Analysis sent *Cozy sphinx waves quart jug of bad milk* (32 letters), *Blowsy red vixens fight a quick jump* (30) and *Quick jigs for waltz vex bad nymph* (28). The last is an improvement over a similar pangram given in September because it eliminates the name "Bud." Proper nouns, abbreviations, initials and so on are considered blots on pangrams.

John G. Fletcher of Pleasanton, Calif., sent the best 26-letter pangram, which he says is due to the mathematician Claude E. Shannon: *Squdgy fez, blank jimp crwth vox!* A crwth is a stringed instrument of Welsh origin. "Jimp" is a Scottish word for "thin," "slender," "delicate." ("I see thee dancing on the green, thy waist sae jimp,/Thy limbs sae clean," wrote Robert Burns.) The sentence is spoken by a man of the Near

East to his short, squat fez as he pulls it down over his ears to blank out the thin, delicate voice (notes) of a crwth being played nearby. Vic Reid, Jr., of New York City reports that while Caesar's legions were encamped one night by a northern lake, they were approached by 15 mermaids who tried vainly to persuade the men to dance with them on the water. A war correspondent cabled 26 letters to his Roman editor: *XV quick nymphs beg fjord waltz.*

Several readers called attention to other answers to the quiz about eight curious words. *Absconded* can, of course, be substituted for *absconder.* Dmitri Borgmann writes that in addition to *typewriter* the following 10-letter words can also be typed on the top row of letter keys: *proprietor, pep-*



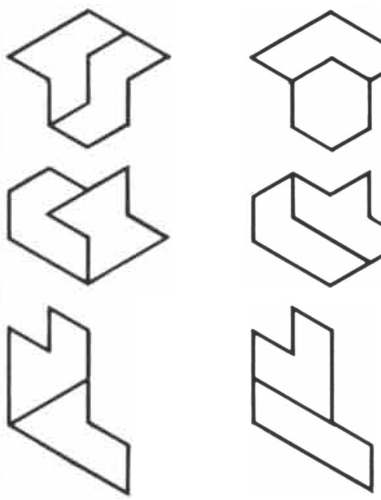
Symmetrical hexiamond patterns made by Maurice J. Povah

perwort, pepperroot and *protopteri*. Others (from W. H. Shepherd of Manchester, England): *perpetuity, repertoire, perruquier, pewterwort* and *pirouetter*. Borgmann goes on to say that *gymnopedia, limnophile* and *somnopathy* are other 10-letter words with *mnop* in the same spot as in *gymnoplast* (although he prefers the sentence *I am no prude*), and *pareciously* and *materiously* are alternates for *facetiously* in having the vowels and *y* in alphabetical order.

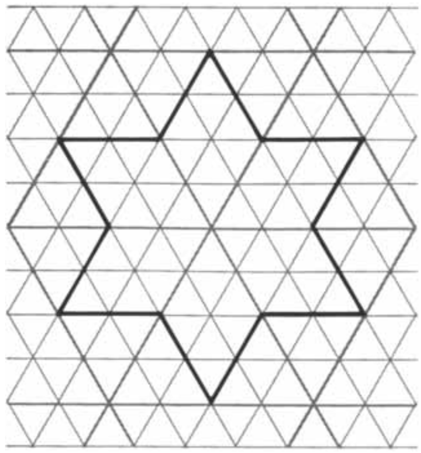
Stuart G. Schaeffer found another, more timely solution to the "cares—caress" riddle, which he expressed in what he calls "shaggy doggerel":

A century and more ago
Clairvoyant Englishmen did know
That in the twentieth century
Tranquillity would shattered be,
And so suggested bitter noise
Be changed to sweet and silent joys
By adding modest and conceitless
"S" to make the Beatles beatless.

The virtuosity of readers in finding anagrams on the full names of the two presidential candidates makes it impossible to do justice to the hundreds of ingenious anagrams received. Curiously each candidate's name involves a similar difficulty: taking care of the five *N*'s in Lyndon Baines Johnson and the five *R*'s in Barry Morris Goldwater. Dmitri Borgmann's best for Johnson is *No ninny, he's on job, lads.* Essentially the same anagram was submitted by Arthur Schulman, James H. Cochrane and Raphael M. Robinson. *Hands on only nine jobs* was independently devised by Mrs. H. A. Morss, Jr., and Mr.



Solution to the "three twins" problem



Star to be made with eight pieces

and Mrs. Bruce D. Hainsworth; virtually the same phrase also came from Mrs. E. M. Cutler and many others. The best anti-Johnson anagram is from Walter I. Cole, Jr.: *None sin? Sly hand on job.* I should add that Cole also sent the following anti-Goldwater anagram: *My star error—a glib word.*

The best anagram favorable to Goldwater—*Smart, bold, grey warrior*—was submitted by David Rabby, who also balanced it with a favorable Johnson anagram. Most Goldwater anagrams stressed a fear that his policies would provoke war. *Morbid story—larger war* was discovered by both Mrs. Cutler and L. E. Card. Among 39 clever anagrams contributed by Mr. and Mrs. Gerald Dantzic are *Wary world's rarer bigot; Orders big "moral war" try!* Other anagrams of similar import: *Sorry brew, Mr. Gladiator!* (Mrs. Coburn A. Buxton), *Bald, raw, gory terrorism* (Arthur Schulman), *Sly orator bred grim war* (James H. Cochrane), *Grab rest, moldy warrior* (Alan Wachtel, Phil Leslie). John de Cuevas sent *A great world! By mirrors?* Mr. and Mrs. Bruce D. Hainsworth: *Red Star big moral worry.* Raphael Robinson, a well-known mathematician, imagined the following message signed with Barry's first initial: *Glory! I storm rearward. B.* To which Robinson added the following prayer for a Goldwaterloo: *Lord, bar grim worst year!*

A short note from Dr. Matrix explains his cryptic number, 13212, reported in October, which he said concealed the name of the next president of the United States. The number is partitioned 13-21-2, then taken in reverse order. The second, 21st and 13th letters from the *end* of the Pledge of Allegiance to the Flag are L. B. J.

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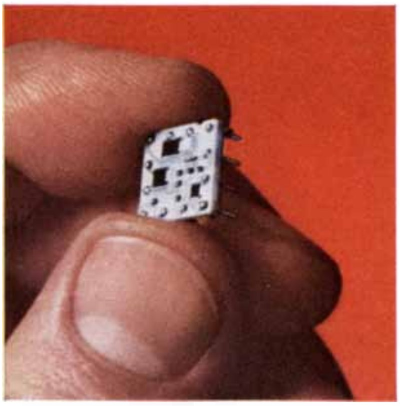

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THE AMATEUR SCIENTIST

Mainly on simulating gravitational fields with droplets of water on a soap bubble

Conducted by C. L. Stong

Still another charming experiment has been inspired by the kitchen sink: a dynamic model of the gravitational field. The field is represented by a soap film stretched across a loop of wire, and orbiting bodies are represented by drops of soap solution that glide over the film. The weight of the drops distorts the film much as the presence of massive bodies in space distorts the gravitational field. For this reason the new model demonstrates not only the relative motion of gravitating bodies but also the perturbations that arise as a consequence of their interaction. Gregory Yob of Carmichael, Calif., was able to develop the experiment as a result of happenstance.

"Recently, while washing the dishes," he writes, "I lifted a water glass upside down from the pan and noticed that a film of soapy water had formed across the mouth of the glass. As I watched the film some water from my wet hand ran down the side of the glass and onto the film, distorting it into a funnel-like shape. When I shook the glass, several droplets that hung from the film went into orbit, much like the movement of the planets around the sun. The orbits were somewhat erratic and did not last very long because I could not hold the film level or keep it still. As soon as the dishes were finished I made a rigid support for the film.

"My first attempt was a crude ring, made from the wire of a coat hanger clamped in a vise. To form the film I lifted a pan of soapy water under the ring so that the wire was submerged and then I lowered the pan gently. I put water droplets on the film with a medicine dropper. A drop launched near the edge would spiral toward the center and finally come to rest. I could control the shape of the spiral by moving the dropper tangentially when releasing the drop. I could easily simulate the orbit of a single body, as conventionally demonstrated by gravitational models that consist of a suitably curved surface of plastic or stretched rubber on which a rolling sphere represents the orbiting body [see "The Amateur Scientist," SCIENTIFIC AMERICAN, October, 1958]. With a little practice I soon learned how to simulate a number of other gravitational effects, including the orbits of several bodies about each other, tidal effects, the formation of stars and the reentry of a missile or a satellite into the earth's atmosphere. All are demonstrations that cannot be made with the solid models.

"To measure these phenomena I made another apparatus that consisted of a ring assembly to hold the film, a stand, a pan of soap solution and some leveling wedges [*see top illustration on opposite page*]. With this apparatus I measured the static properties of the film, such as its shape, rate of evaporation and surface tension.

"For the ring I used about 60 centimeters of three-millimeter copper-coated steel welding rod bent into circular form 20 centimeters in diameter. The ring should be reasonably circular, but it does not have to be perfect. (A substitute material for the ring, if one is desired, should be nonporous and at least three millimeters thick, otherwise it will not hold a film long enough for experiments.)

"The ends of the wire ring were soldered together in the form of a butt joint. A supporting crossarm was made from a 30-centimeter piece of the same kind of rod. This stiffened the ring and also served as a base line for measuring the shape of the film. The ends of the crossarm were bent down at right angles to make brackets about three centimeters long and were soldered to the ring. This arrangement provided a convenient space between the crossarm and the film. The ends of the crossarm were attached to the ring at points remote from the butt joint so that the joint would not be damaged by the heat of subsequent soldering. Half of the crossarm was calibrated for length by a series of file notches at one-centimeter intervals from the center of the ring [*see bottom illustration on opposite page*].

"To attach the ring and crossarm to the stand I soldered two 25-centimeter rods vertically to the unmarked side of the crossarm, one at the edge and the other about two centimeters from the center point. The ring assembly was painted black and the file marks white. The vertical rods were pushed into close-fitting holes drilled in a wooden stand shaped like a C. The stand rested on three wedges. The pan of soap solution was placed on the base.

"My soap solution consisted of one part of Liquid Lux detergent and 19 parts of tap water. Other detergents tended to produce a viscous area in the center of the films that impeded the free travel of the droplets. The pan was placed about 20 centimeters below the ring and the solution was some three centimeters deep.

"To make a film the pan is gently raised until the ring is immersed, then slowly lowered until the film separates from the solution. I found that if the crossarm was immersed in the solution, a second film would form that distorted the main film. When the crossarm is not immersed, the single film will last about three minutes in still air.

"As an initial experiment I timed the average life of a film with a stopwatch. The film bends downward slightly under its own weight, causing the liquid to flow toward the center. After about one minute enough liquid has drained so that the edges of the film take on the characteristic interference colors of a soap bubble. During the second minute the edges turn black and the coloring extends almost to the middle of the film. By the end of the third minute the color has reached the center. The film is easily broken at this stage and is almost useless for experimentation. Films usually break during the fourth minute.

"To measure evaporation from the film I made a distortion gauge: a small copper wire coated with black enamel that was scratched at one-millimeter intervals. One end was wrapped around the crossarm near the center so that the remainder extended down into the film. The point at which the film made contact with the wire was recorded at 10-second intervals until the film broke. The evaporation rate appeared to be constant, as I expected, because the area of the film remains constant during its lifetime.

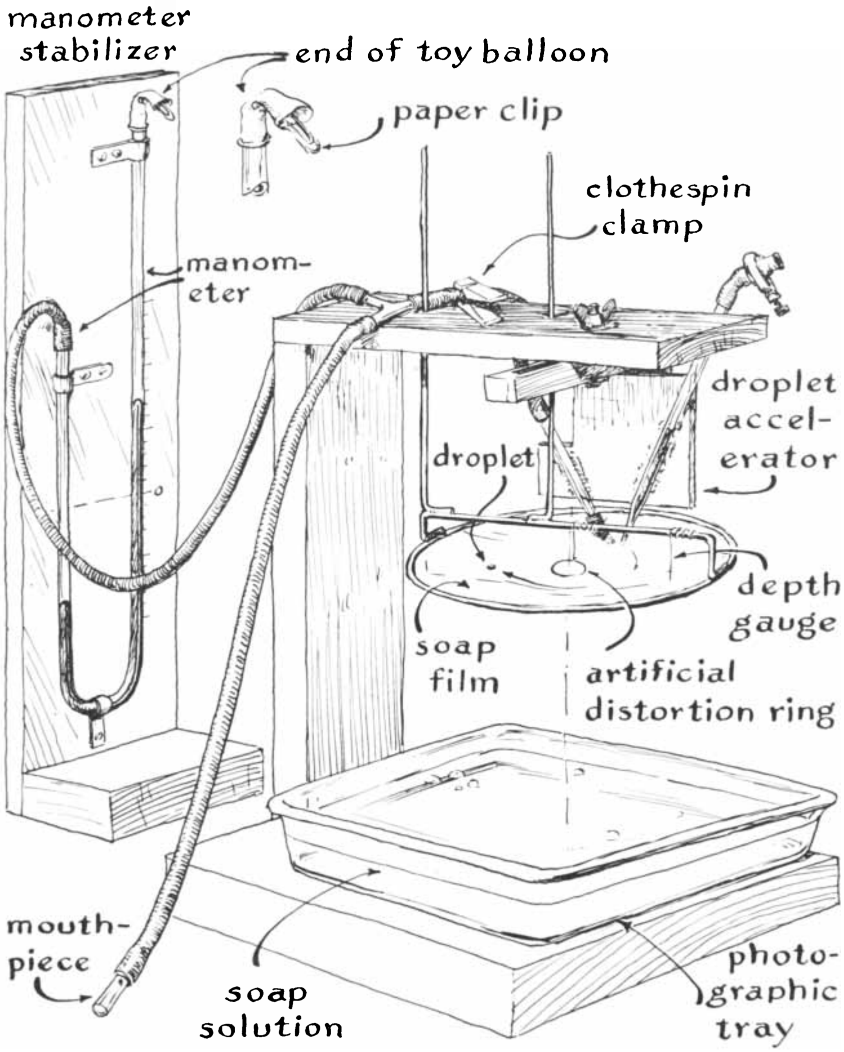
"I found the shape of the film by sliding the measuring wire along the crossarm and observing the point of intersection between the film and the wire at one-centimeter distances. The unloaded film appeared to be roughly spherical. Determination of its true shape would require a more precise method of measurement.

"To find the approximate shape of the film when it was loaded by a droplet I first centered the droplet in the ring by adjusting the wedges to level the stand and then measured the film shape as before. A graph of these measurements resembled the inverse-square, funnel-shaped curve used in the solid simulators. Attempts to measure shape when the film was loaded with two drops failed. One drop or the other would fall off, so I settled for synthetic loading. I achieved that by attaching to the crossarm a small ring of the same wire used for the distortion gauge. The ring could be placed in contact with the top side of the film at any desired position on the vertical axis and would thus distort the film any desired amount.

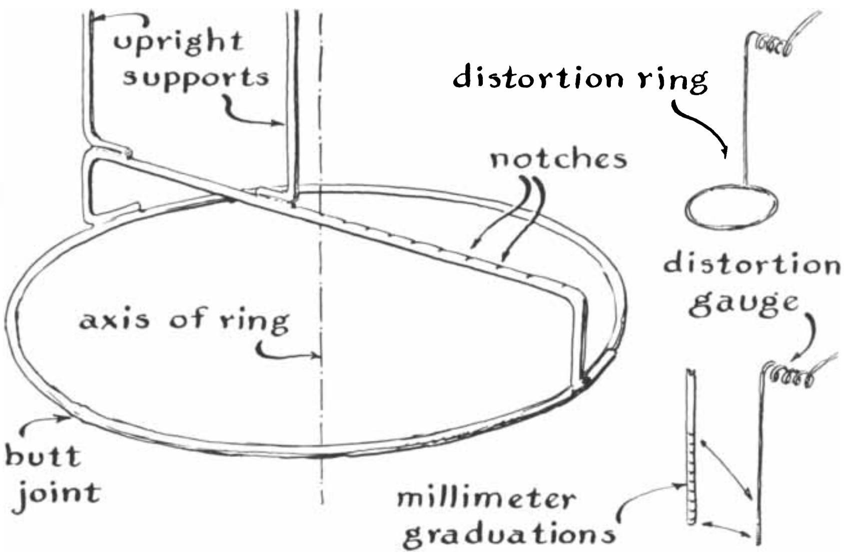
"The weight of a droplet was measured by determining the number of drops required to make a gram of liquid. The medicine dropper I used released drops of about .024 gram. I measured the surface tension of the soap solution by using a balanced rod and finding the force required to lift it clear of the solution. The method indicated a surface tension of .03 gram per centimeter, about half that of pure water.

"After making these static measurements I began experimenting with the orbits of drops and with tidal effects. To investigate the velocity of the drops I needed an accelerator for shooting drops onto the film at controlled speed and direction. My first two attempts to make an accelerator—one with a pendulum and one with a film placed at an angle to the main film—were unsatisfactory.

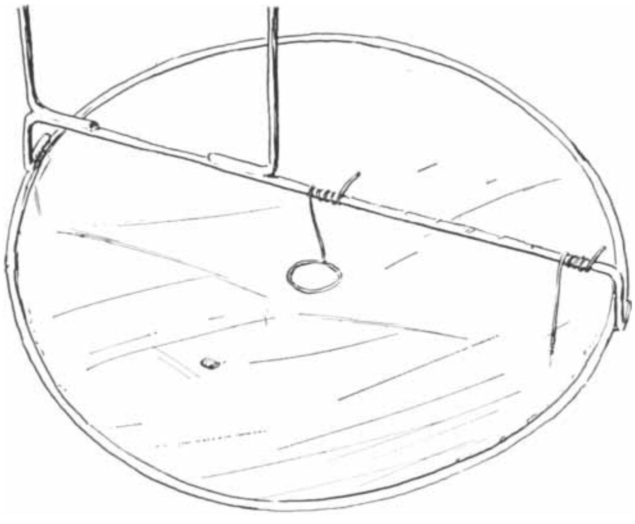
"The final model consists of a pipette



Apparatus for the soap-film experiments



Details of wire loop supporting soap film

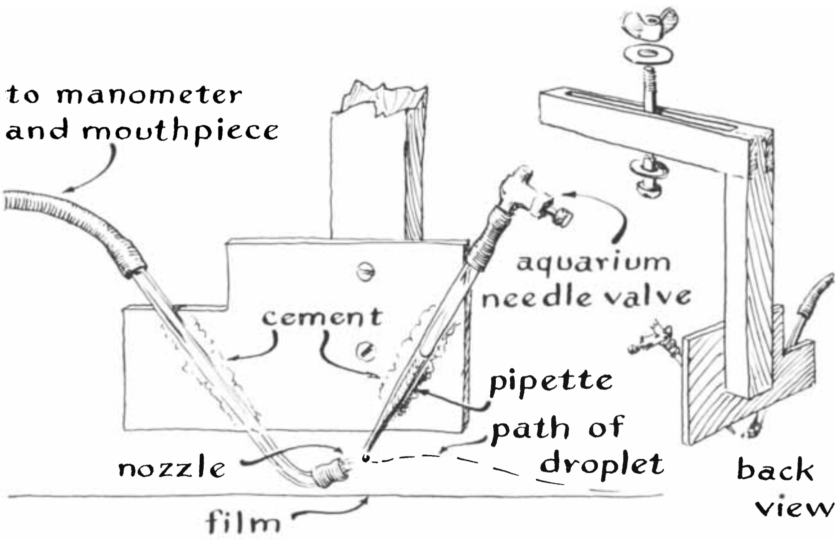


Arrangement of small ring for distorting soap film

that injects a drop into a jet of air that acts as the accelerator. It works beautifully. The air jet is formed by a glass nozzle that makes approximately a right angle with the glass tubing from which it was formed. The diameter of the nozzle is about three millimeters. An adjustable rubber sleeve near the opening of the nozzle helps to preserve the streamline flow of the jet. A rubber tube connects the nozzle to a glass Y joint. A clothespin on the rubber tube serves as a pinch clamp for regulating the flow of air. From one arm of the joint a rubber tube is connected to a mouthpiece; the tube from the other goes to a water manometer. Oscillations of the water column in the manometer are suppressed by a check valve. The valve consists of the neck of a toy balloon and a paper clip. One end of the rubber tube is slipped over the open arm of the manometer and the free end of the tube is weighted by the paper clip.

"When the clothespin and the rubber sleeve of the nozzle are properly adjusted, droplets released by the pipette can be accelerated smoothly. A needle valve at the top of the pipette controls the rate at which drops are released [*see illustration below*].

"To calibrate the accelerator I placed the nozzle 19.6 centimeters above the soap solution. That is the distance at which drops require .2 second to fall to the pan. The horizontal distance traveled by the drop at various pressures, as indicated by the manometer, was then measured. By multiplying the horizontal distance by 5 I found the velocity of the drops in centimeters per second. Velocity was then plotted against the manometer pressure. By referring to the graph I could launch a drop onto the film at any desired velocity.



Equipment for accelerating a drop of water

"Having calibrated the apparatus, I observed the orbit of a drop around a stationary body by launching a drop around the distorting ring. After several elliptical orbits the drop spiraled in to collide with the ring, simulating the orbital decay of a satellite around a massive body.

"My second experiment was to observe the orbital decay of two drops of equal mass. First I put one drop in the center of the film and then launched the other around it. In this case I found that I could shoot the drop more easily by hand than with the accelerator. The orbiting drop first spirals toward the stationary drop. As the spiral decreases the center drop begins to spiral outward until both drops orbit around a common center, separated by some three centimeters. When drag decelerates the system until the objects are spaced about one centimeter apart, both drops become radially elongated, simulating tidal action. The model is imperfect in one major respect: the velocity of the bodies decreases as they spiral inward instead of increasing as in the case of celestial objects. When the tidal bulges finally make contact, the more massive drop of two that are unequal in size usually absorbs the smaller one. By coloring one drop with ink and waiting until both drops coalesce one can see that the central body spins violently on its axis. This phenomenon suggests the conservation of angular momentum. The entire sequence normally takes six or seven seconds. The use of an immiscible fluid such as cooking oil for the drops reduces friction and provides a longer show, but the tides and the capture of the drops are not as easily seen. When I used composite drops of both oil and water, the tides would simulate those of the earth (the oil) and the oceans (the water). To photograph the bodies in the various stages of orbital decay the drops were colored with ink and flash exposures were made against a white background.

"I found that I could provide a droplet with an 'atmosphere' by tapping the main ring with my finger until the droplet broke into several small parts. At one stage, before the fluid coalesces, the surrounding area contains some of the drop's liquid, simulating the atmosphere. A small drop, when added to the film as a satellite, orbits normally until it hits the atmosphere. It then falls directly toward the center drop, as observed in the case of a reentering missile. Even some curls of turbulence are evident.

"Another interesting phenomenon is the simulation of the formation of a star or a planet. This is demonstrated by spraying fine droplets of solution onto a fresh film with a toothbrush and letting them coalesce into a drop; the spray represents the interstellar gas cloud and the drop the star.

"The apparatus can doubtless be modified for demonstrating still other interesting effects. For example, a curved universe could be simulated by using a saddle-shaped ring for negative curvature or by deflecting the film by an upward current of air to form a positive curvature. Another possibility is to show the effects of gravity on light by vibrating the film and allowing the waves to travel through the droplets. I have not had time so far to explore fully all the potentialities of the model. The experiments that have been made, however, certainly support an observation once made by the British physicist C. V. Boys: 'There is more in a common soap bubble than those who have only played with them generally imagine.' "

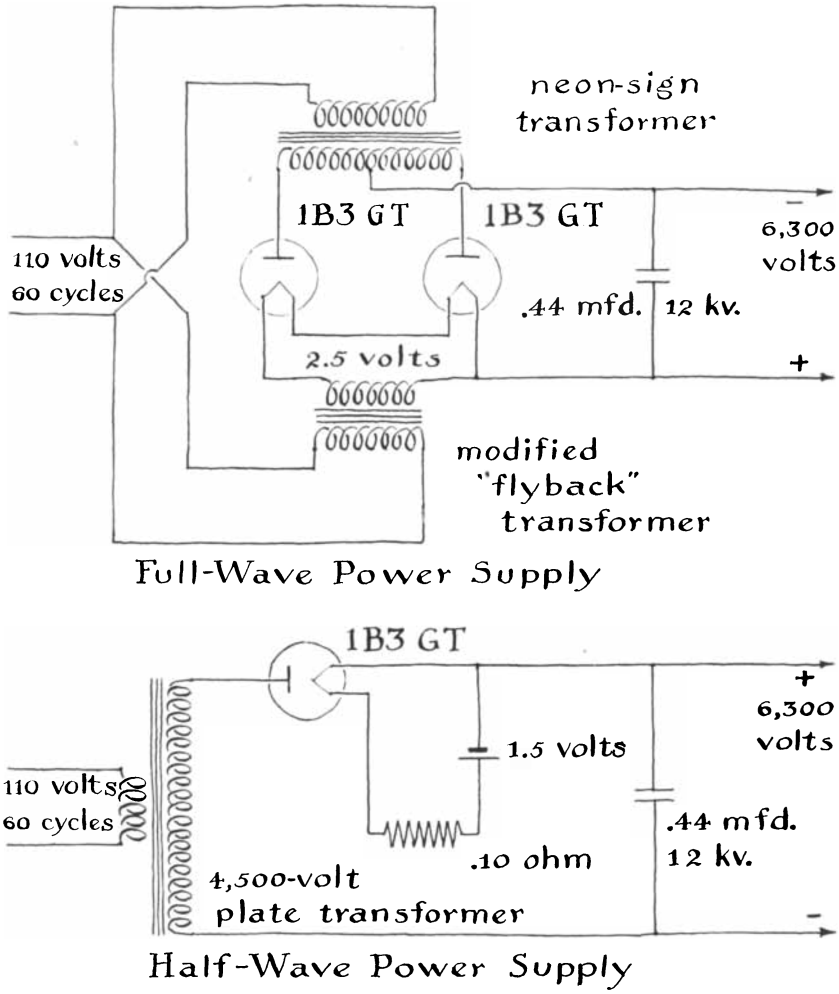
While experimenting with Leyden jars in 1777 the German physicist Georg Christoph Lichtenberg observed that an electric discharge between a pointed electrode and a conductive plate covered with fine powder would scatter the powder into strange and beautiful patterns that differed characteristically, depending on the polarity of the point and the conductive plate. The patterns subsequently became known as Lichtenberg figures. Elric W. Saaski of Iron River, Wis., has built a modern apparatus for investigating the figures and recording them by color photography. The apparatus shows the phenomenon in greater detail than Lichtenberg's.

"My apparatus," writes Saaski, "resembles the Klydonograph more than it does the arrangement used by Lichtenberg. Essentially the Klydonograph consists of a photographic emulsion sandwiched between two electrodes: a small brass disk that rests on a somewhat larger one. The small disk is connected to the power line; the larger one, to the ground. I substituted a water surface for Lichtenberg's powder and for the photographic emulsion of the Klydonograph. The fluidity of the medium and its ability to hold ions in solution are convenient for controlled experimentation. When I made the accompanying photographs, I connected one side of the capacitor to a metal pan 12 centimeters in diameter; the pan contained water to a depth of one centimeter. Then I moved a pointed discharge electrode, which was connected to the other terminal of the capacitor, toward the water until a spark jumped, discharging the capacitor and creating the Lichtenberg figure on the surface.

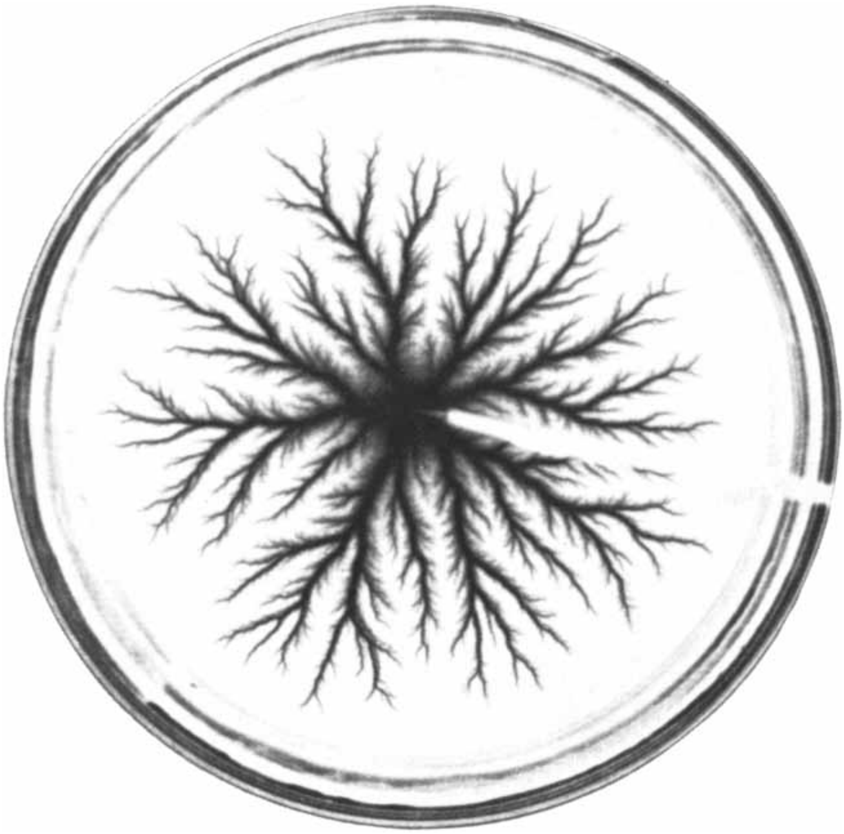
"To produce the direct-current surges for my experiments I used a power supply that consisted of a transformer, a rectifier and a capacitor. The high potential is derived from a 9,000-volt, center-tapped neon-sign transformer that supplies a constant current of 18 milliamperes. This output is converted to direct current by a pair of 1B3 GT high-voltage diodes in a full-wave rectifier circuit. The rectifier was built on a plastic sheet six inches wide and eight inches long, supported on six half-inch porcelain legs. The full-wave circuit was of conventional design, with the current for the filaments supplied by a "flyback" transformer I had rebuilt to function as a step-down transformer on 110 volts a.c. The rectifier does not have to be this elaborate, however. One 1B3 GT tube can be used in a half-wave circuit, with the current supplied by a common 'D' cell if necessary [*see illustration below*]. The maximum output of the full-wave rectifier is 40 milliamperes at 6,300 volts (peak voltage). I was somewhat apprehensive about the ability of the 1B3 GT tubes to take the current surges as the capacitor was charged because the tubes are designed for a maximum load of one milliampere, but my fears proved groundless.

"The rectified current is stored in a capacitor, the modern counterpart of Lichtenberg's Leyden jar. In principle a capacitor is merely two conducting plates separated by some type of insulator. When the two plates are connected to a source of direct current, an excess of electrons accumulates on one plate, with a corresponding deficiency on the other. The charging voltage must not exceed the dielectric strength of the insulating material between the conductors or the insulator will be punctured.

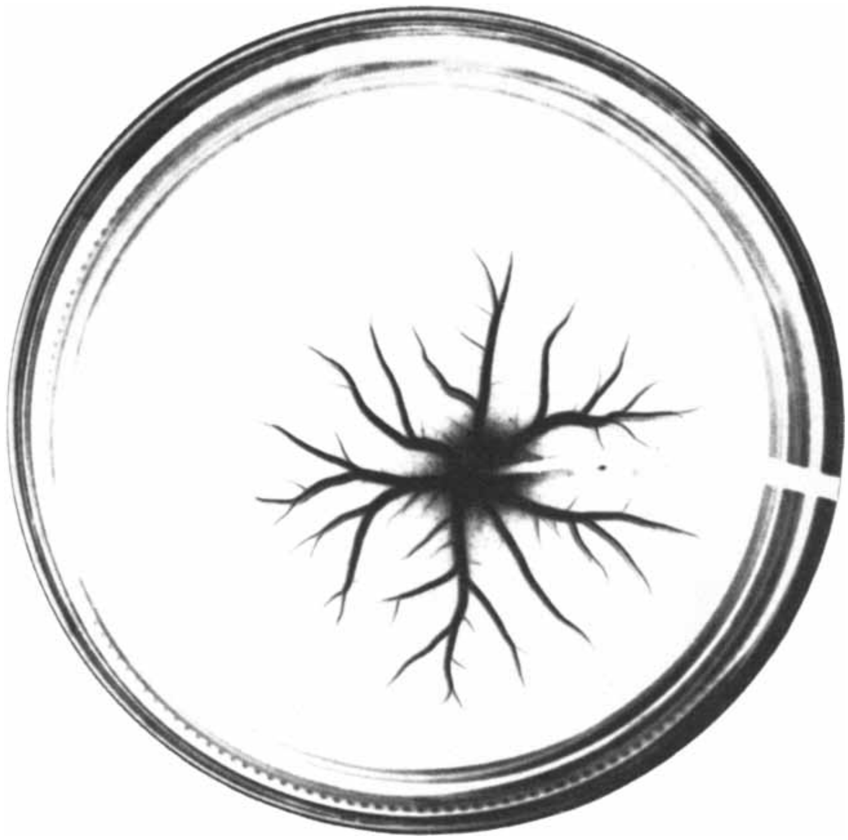
"When the charged capacitor is dis-



Schematic diagrams of high-voltage rectifier circuit



A positive Lichtenberg discharge



A negative Lichtenberg discharge

connected from the source of current and a circuit is completed from one plate to the other, electrons flow until the difference in potential is equalized. By stacking a number of insulated plates and connecting alternate plates it is possible to increase the capacity of the unit to store energy. Capacitors of the size needed for this experiment are priced at $100 and up, depending on the construction. I made one for less than $10. The unit consists of 80 five-inch-square sheets of aluminum foil sandwiched between 79 six-inch-square sheets of Mylar plastic film .003 inch thick. Mylar film has a breakdown strength of approximately 4,000 volts per thousandth of an inch thickness. Unfortunately the dielectric strength of substances does not increase in direct proportion to thickness. My capacitor operates at six kilovolts. For safety's sake I use Mylar film .003 inch thick, rated at 12 kilovolts breakdown. Polyethylene plastic can also be employed. The rated breakdown voltage of this material, however, is only one kilovolt per thousandth of an inch thickness. Both plastics can be ordered through most hardware stores and mail-order houses in the forms used for protecting machinery from the weather.

"Since aluminum generally cannot be bonded to other metals, I found it best to cut each capacitor plate and its external lead from a single piece of foil. Plates cut five inches square with a lead one inch wide and five inches long utilize the 12-inch width of a roll of aluminum foil without waste. Alternatively plates can be cut 10 inches on a side with a lead two inches wide. This saves time and yields a more efficient capacitor because the leakage of charge from the larger plate is 50 percent less than for an equal area consisting of smaller plates.

"The size of the available container must also be considered when one is choosing the dimensions of the plates. My assembly was potted in a sheet-metal box six and a half inches wide, two inches deep and eight inches high. It is lined with plastic sheeting. The negative plates are clamped to the metal box; the positive series, to an insulated terminal on top. After the assembly was completed the container was filled with transformer oil, an insulating fluid bought from our local power company. Mineral oil or any nonreactive liquid can be used, but transformer oil is effective and cheap. Although a capacitor will work in air, the intense electric field between the plates produces ozone. Gradually the ozone weakens the dielec-

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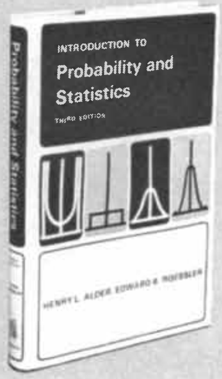

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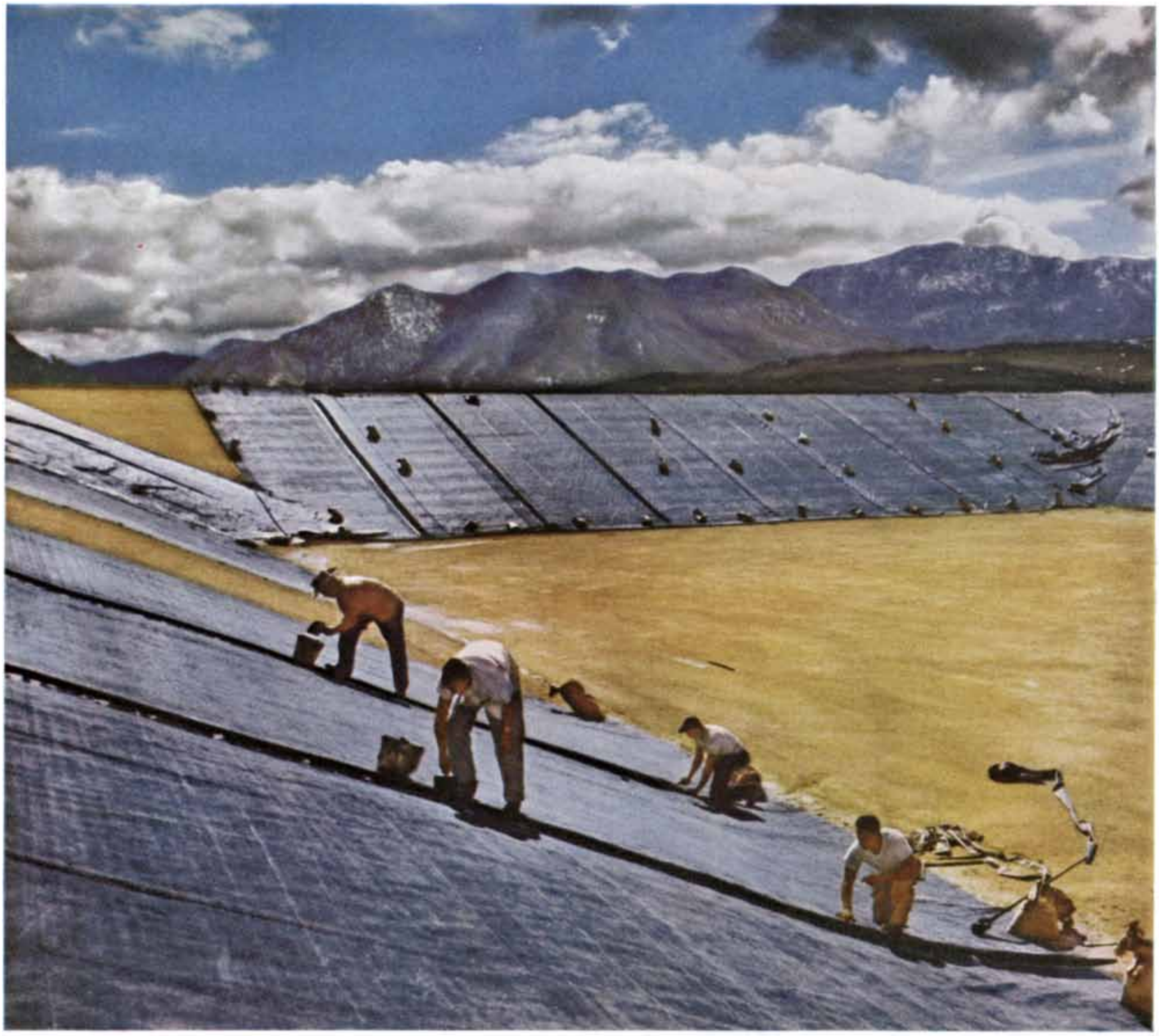

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tric, causing the material to rupture.

"The capacitance of the unit, approximately .44 microfarad, was determined by the formula $C = 2.24 \times 10^{-7} KA/d(n - 1)$, where C is the capacitance in microfarads, K is the dielectric constant, A is the area of one side of one plate in square inches, d is the thickness of one dielectric sheet in inches and n is the number of plates. The dielectric constant of polyethylene is 2.4, that of Mylar about 3.

"The energy capacity of the unit, 8.8 joules, was found by the formula $J = CE^2/2$, where the energy capacity in joules equals one-half the product of the capacitance in microfarads and the charging potential in kilovolts squared. One joule is equivalent to one watt-second, or 1/746 horsepower.

"To record the discharges, a 35-millimeter camera equipped with a closeup lens was placed on a platform 12½ inches above the pan. The room was totally darkened. The camera shutter was opened. The capacitor was then discharged. The Lichtenberg figures literally take their own picture without need for elaborate shutter synchronization. The correct opening of the camera diaphragm was determined by trial.

"The flash is readily seen in the darkened room; serpentine arms extend from a white core as a dull reddish flame that dwindles off into tapering fingers of light blue. Positive and negative discharges are easily distinguished. The former is larger and more detailed than the relatively small and thick-limbed negative discharge. The positive discharge has been likened to the drainage basin of a mountain valley.

"Occasionally the spark jumps to the side of the pan. This effect has been ascribed to anomalies in the distribution of ions at the surface of the water and to the position of the discharge electrode. The spark appears to be a branch of the Lichtenberg figure, one that usurps the available energy, thus preventing the growth of the complete figure. The process by which the branch becomes the main current-carrier is not evident in ordinary photographs because the brilliance of the discharge obliterates the previous activity. Analysis of this phenomenon by high-speed photography would be an extremely interesting but rather elaborate project. I have, however, investigated one peculiarity of these discharges without extensive equipment. The distance a spark travels across water can be increased sharply by adding ions to the water in the form of a salt. A limit is reached when the concentration approaches approximately 150 ions per million water molecules. The maximum discharge distance is about 11 times greater than that of air and three times greater than that of distilled water. At a concentration of only 60 ions per million water molecules the discharge distance is still 90 percent of the maximum distance. Below this concentration it drops rapidly."

STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION (Act of October 23, 1962; Section 4369, Title 39, United States Code). *1.* Date of filing: October 1, 1964. *2.* Title of publication: Scientific American. *3.* Frequency of issue: monthly. *4.* Location of known office of publication: 415 Madison Avenue, New York, N.Y. 10017. *5.* Location of the headquarters or general business offices of the publishers: 415 Madison Avenue, New York, N.Y. 10017. *6.* Names and addresses of publisher, editor and managing editor: Publisher, Gerard Piel, 415 Madison Avenue, New York, N.Y. 10017. Editor, Dennis Flanagan, 415 Madison Avenue, New York, N.Y. 10017. Managing Editor, none. *7.* Owner: Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Atwell & Co. (for Edwin H. Baker Pratt), 45–47 Wall Street, New York, N.Y. 10005; Janet Rosenwald Becker, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Cudd & Co. (for John Crisona, Successor Trustee u/a 10/15/51 F.B.O. Robert L. Rosenwald), c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Dengel & Co. (for Elinor Gottlieb Manucci), c/o Fiduciary Trust Company, 1 Wall Street, New York, N.Y. 10005; Richard E. Deutsch, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Bayard Ewing, 15 Westminster Street, Providence, R.I. 02903; Sidney R. Garfield, M.D., 1924 Broadway, Oakland, Calif. 94612; Nathan W. Levin, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Frasier W. McCann, 10 Rockefeller Plaza, New York, N.Y. 10020; Piel & Co., c/o Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Barbara K. Rosenwald, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Julius Rosenwald II, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Lessing J. Rosenwald, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Rowe & Co. (for Rhode Island Charities Trust), c/o Industrial National Bank of Rhode Island, Trust Department, 100 Westminster Street, Providence, R.I. 02901; Stanley Schaefer, 418 Yerba Santa Avenue, Los Altos, Calif. 94022; I. M. Scott, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Joan Rosenwald Scott, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Harry Snellenburg, Jr., c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Helen Rosenwald Snellenburg, c/o The Chase Manhattan Bank, P.O. Box 1508, Church Street Station, New York, N.Y. 10008; Sydney S. Spivack, Far Hills, N.J.; John Hay Whitney, 110 West 51 Street, New York, N.Y. 10019. *8.* Known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages or other securities: none. *9.* Paragraphs 7 and 8 include, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, also the statements in the two paragraphs show the affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner. Names and addresses of individuals who are stockholders of a corporation which itself is a stockholder or holder of bonds, mortgages or other securities of the publishing corporation have been included in paragraphs 7 and 8 when the interests of such individuals are equivalent to 1 percent or more of the total amount of the stock or securities of the publishing corporation. *10. A.* Total number of copies printed (net press run): average number of copies each issue during preceding 12 months, 411,196; single issue nearest to filing date, 448,795. *B.* Paid circulation: *1.* To term subscribers by mail, carrier delivery or by other means: average number of copies each issue during preceding 12 months, 301,041; single issue nearest to filing date, 307,250. *2.* Sales through agents, news dealers or otherwise: average number of copies each issue during preceding 12 months, 75,896; single issue nearest to filing date, 88,416. *C.* Free distribution (including samples) by mail, carrier delivery or by other means: average number of copies each issue during preceding 12 months, 10,987; single issue nearest to filing date, 32,500. *D.* Total number of copies distributed: average number of copies each issue during preceding 12 months, 387,924; single issue nearest to filing date, 428,166. I certify that the statements made by me above are correct and complete. Donald H. Miller, Jr., Vice-President and General Manager.

BOOKS

A Christmas survey of new books about science for younger readers

by James R. Newman

Every December this department undertakes to review a selection of books for younger readers about science and related matters such as technology and medicine. Herewith the current crop.

Physical Sciences

Discovering the Universe, by Bernard and Joyce Lovell. Harper & Row, Publishers ($3.95). Sir Bernard Lovell, director of the Jodrell Bank radio observatory of the University of Manchester, found that after the U.S.S.R. had launched its first Sputnik many visitors came to see the installation and asked to have explained what its great 250-foot radio telescope did and how it worked. He and Lady Lovell have now put their answers into a splendid book. It tells of the exploration of the universe by optical as well as radio telescopes, what this has revealed about its structure, about stars and galaxies and the solar system and about the specific aims of the continuing investigations to learn more. A clearer, more masterful survey of the subject is hard to imagine. Supported by photographs and diagrams, this is a choice example of the popularization of science that is suited equally to adolescents and grown-ups.

Experiments in Topology, by Stephen Barr. Thomas Y. Crowell Company ($3.50). The world is a queer place, and space, although it seems to be bland, is even queerer; this is why topology rather than Euclidean geometry is its master tailor. In the pages of this book one can learn some of the fundamental theorems of topology and garner information about such strangenesses as the Möbius strip, the Klein bottle, the punctured torus, the Königsberg bridges, knots, sets, limit points, Betti numbers, Euler's theorem and Jordan's. This account is ingenious but not easy. It is for adolescents and anyone with mathematical tastes and spatial imagination. Many diagrams.

Accelerators of Charged Particles, by B. S. Ratner. The Macmillan Company ($3.50). A sound description by a Soviet physicist of the basic principles of accelerators and the nuclear reactions to which they give rise. Little mathematics is used, and it is at an elementary level; no prior knowledge of physics is expected. For older teenagers.

Asterisks: A Book of Astronomical Footnotes, by James S. Pickering. Dodd, Mead & Company ($4). This book, which consists of about 130 radio scripts by the assistant astronomer at the Hayden Planetarium, presents capsules of information on such topics as Baily's beads, the gibbous moon, the nearest star, tidal friction, the conquest of space, water on the moon and the names of the planets. For adolescents.

The Story of the Earth's Magnetic Field, by Germaine Beiser. E. P. Dutton & Co. ($3.50). An untrammeled account of magnetism from the first compass (probably invented by the Chinese) and the discoveries of William Gilbert to present knowledge about such matters as cosmic rays, changes in the earth's magnetic field and the Van Allen belt. For readers of 12 and older.

Sun, Moon and Stars, by W. T. Skilling and R. S. Richardson. McGraw-Hill Book Company ($5.95). A revised and enlarged edition of an attractive, well-illustrated book on basic astronomy. It discusses systematically the solar system, the stars and the methods and instruments of astronomy. For teenagers and adults.

A Short History of the Universe, by Arthur S. Gregor. The Macmillan Company ($4.50). This survey of the birth, evolution and nature of stars and planets caters more to the needs of younger readers than do the Lovells or Skilling and Richardson. It is written with appealing freshness by a man who obviously both loves the subject and loves to teach it. A youngster of 11 or 12 may well get a healthy bite from the astronomy bug if he runs through these pages. Photographs and diagrams.

The Second Book of Experiments, by Leonard de Vries. The Macmillan Company ($3.95). Easy experiments that contribute to one's understanding of such matters as centrifugal force, jet propulsion, inertia, steam power, soap bubbles, capillarity, the Doppler effect, airplane flight, sound reflections, sunspots, Foucault's pendulum, snowfall and evaporation. For children and parents who are not all thumbs.

Playing with Infinity, by Rózsa Péter. Atheneum ($1.65). A paperback reprint of a first-class introduction to some of the ideas of higher mathematics, from transfinite numbers to Gödel's proof. There is no index, which is inexcusable, but the book is worth the trouble. For adolescents and grown-ups.

The Number of Things, by Evans G. Valens. E. P. Dutton & Co. ($4.95). A grab bag of this and that, the principle of selection being things and phenomena that can be described with numbers. Included are chapters on the Pythagorean theorem, the golden section, gnomons, the shape of numbers, geometric and golden means, doubled cubes, vibrating strings, harmony and harmonics, mathematics and astronomy. For readers of 14 and older.

Light: Our Bridge to the Stars, by John Rublowsky. Basic Books, Inc., Publishers ($4.50). The steps by which our knowledge of the nature of light has been acquired, spanning the contributions of investigators from Galileo, Descartes, Newton and Roemer to Maxwell, Einstein and Bohr. Simply written and well told. For adolescents.

Quick and Easy Math, by Isaac Asimov. Houghton Mifflin Company

($3). Tricks, stratagems and other devices probably used as often by old wives and grocery clerks as by astronomers and physicists. The book is designed, if not to make computation a breeze, at least to eliminate some of its tears. For readers of 12 and older.

MEASURING THE UNIVERSE, by Henry Brinton. Roy Publishers, Inc. ($3.95). The story of how man from ancient times has improved his methods and invented instruments for measuring time, the dimensions of the universe and its furniture. The topics include calendars, the size of celestial bodies, their distance from us, gravitation, inertia, planetary orbits, the weight of the earth, the velocity of light, the nature and composition of light, relativistic effects, the temperature of the sun and stars, the Doppler shift and so on. Photographs and diagrams. For adolescents.

OUR WORK IN SPACE, by Willy Ley. The Macmillan Company ($3.95). A brief account of U.S. rocket and satellite programs, with emphasis on the constructive objectives and potentialities of the work. Ley also explains simply and directly what constitutes an orbit and how different kinds of orbital flight can be achieved. Photographs and diagrams. For readers of high school age.

LIGHT AND SIGHT, by Charles Gramet. Abelard-Schuman ($3.75). How we see and the many instruments that have been invented—from the simple hand lens to large telescopes and the electron microscope—to help us to see better, farther and faster. For readers of 12 and older.

THE SUN, by Franklyn M. Branley. Thomas Y. Crowell Company ($3.95). An uncluttered, readable introduction to the physics and astronomy of the sun. Helpful illustrations. For young teenagers.

MAGNET, by E. G. Valens. The World Publishing Company ($3). The basic principles of magnets and magnetic fields, with descriptions of simple experiments supported by excellent photographs by Berenice Abbott. For readers of 10 and up.

Biological Sciences

ANIMAL ANCESTORS, by Sonia Cole and M. Maitland Howard. E. P. Dutton & Co. ($3.50). It may please some men to boast that they are descended from William the Conqueror or even Charlemagne, but the realization that the ancestor common to all of us is a little tree shrew helps to restore perspective and the proper feeling of brotherhood. The forebear of the elephant is the tiny rock hyrax (the "coney" of the Bible); not only the pig but also the hippopotamus belongs to the classification swine; although the steed of an Arabian chief might not like to hear it, the rhinoceros belongs to the same family as the horse; dogs can be traced back to late Eocene times, when their ancestors were small tree dwellers with large brains and long legs (a good example is *Cynodictis*, which resembled the modern civet and was therefore an ancestor of both the dog and the cat). This book is filled with such entrancing information and is also well illustrated. Recommended for anyone 12 and older.

FISHES AND THEIR WAYS, by Clarence J. Hylander. The Macmillan Company ($4.95). The Atlantic salmon was prized by the Romans as a delicacy (the name comes from the Latin *salio*, meaning "leap"); the Dolly Varden trout is disliked by fishermen because it feeds on the eggs and the young of other trout; the Atlantic bluefish is a ferocious killer, often called the wolf of the sea because it can kill 1,000 other fish in a day; the grunt is called a grunt because it grunts by grinding its teeth together; the beau gregory is a six-inch damselfish that makes its home in an empty conch shell, which it defends against all intruders. Many facts of this kind, together with more humdrum material, are to be found in this book about fishes that inhabit American streams, lakes and ocean waters. Photographs and drawings. For readers of 11 or 12 and up.

THE LIVING BATTERY, by E. E. Suckling. The Macmillan Company ($4.50). All living creatures generate electricity, and it plays an important part in the operation of nerves, muscles, heart, brain and other organs. In a few species of fish the currents are strong enough to administer a powerful shock, but in all other living creatures they are weak and require sensitive instruments for their detection. The interpretation of the readings of these instruments has led to a greatly increased understanding of the functioning of both sick and healthy organisms. This interesting story is well told in Suckling's book, which is addressed to high school students and grown-ups.

THE REPRODUCTION OF LIFE, by Robert L. Lehrman. Basic Books, Inc., Publishers ($4.95). An exceptionally lucid introduction to the story of how living organisms reproduce themselves. It begins with chapters on the origin and continuity of life, considers the evolution of sex, the nature and function of hormones, the processes of reproduction in human life, and then, in somewhat greater detail, the cellular, subcellular and chemical activities that are the foundation of the reproduction of organisms. Each topic is treated imaginatively and with intelligent anticipation of the questions the nonspecialist will ask. Effective illustrations. For teenagers and grown-ups. Recommended.

ADVENTURES WITH FRESHWATER ANIMALS, by Richard Headstrom. J. B. Lippincott Company ($4.25). A description of the kind of animals that can be found in lakes, streams and even puddles, with directions for simple experiments to bring out structure, function and other biological data. Well handled, with many illustrations by the author. For readers of nine or 10 and up.

WALT DISNEY: WONDERS OF THE ANIMAL WORLD. Golden Press ($4.95). Having all the flamboyant characteristics of any Disney production, this full-color picture book about various animals—from the platypus, the cock of the rock, the Alpine newt, the caiman, the anteater, the douroucouli, the capybara and the booby to the jaguarundi, the owl and the wild ox—will go down very well with youngsters, even those who cannot read.

MEET THE MAMMALS, by C. H. Keeling. Franklin Watts, Inc. ($3.95). An affably written, pleasantly discursive, informed book about various species of mammal, with the main emphasis on those that are treated as pets. The author and his wife own a private zoo in England, and they run it primarily as an educational service. For readers of 12 and up.

CHEMISTRY OF LIFE, by Katherine B. Hoffman. McGraw-Hill Book Company ($2.50). This book in the "Vistas of Science" series, which offers much for relatively little, is a compact, easily understandable introduction to biochemistry. Illustrations. For readers of 12 and older.

THE LORE OF LIVING PLANTS, by Johannes van Overbeek. McGraw-Hill Book Company ($2.50). A sound, ably written, knowledgeable introduction to photosynthesis, plant nutrition and other plant processes. Attractively priced and fully illustrated. For young adolescents.

Animals, Inc., by Roy Pinney. Doubleday & Company, Inc. ($2.95). About hunters who in the Frank Buck tradition collect specimens for zoos and for that curious band of oddballs who insist on acquiring such pets as ocelots, boa constrictors, harpy eagles, storks, monkeys, cheetahs, barn owls and so on. Photographs. For readers up to 14.

Wonder World of Microbes, by Madeleine P. Grant. McGraw-Hill Book Company ($3.50). This second edition of Dr. Grant's pleasant book includes new material on our knowledge of viruses and nucleic acids. For readers of 12 and up.

You and Your Cells, by Leo Schneider. Harcourt, Brace & World, Inc. ($3.75). An introduction to cell biology, from the amoeba to ACTH. For readers of 12 and up.

The Stuff of Life, by June Clare. Roy Publishers, Inc. ($2.95). How heredity works, including the latest information on the genetic code, told clearly and succinctly for sophisticated adolescents and grown-ups. Photographs and diagrams. A good book.

Watchers, Pursuers and Masqueraders, by Edith Raskin. McGraw-Hill Book Company ($3.50). About the vision of animals: mammals, birds, reptiles, amphibians, insects, spiders and aquatic animals. For readers of 12 and older.

Social Sciences

The Diversity of Man, by Robin Clarke. Roy Publishers, Inc. ($2.95). A very attractive little book that discusses the elements of physical anthropology and biology that are connected with the differences and similarities of people. Knowledgeable, concise and effectively illustrated. For adolescents. Recommended.

The Story of Money, by A. H. Quiggin. Roy Publishers, Inc. ($3.75). The fascinating story of the evolution of money, its descent into many forms from beads and cowries through spades, knives, rings and salt blocks to tin hats, huge stones, grass mats, tea bricks, shoes, five-pound notes and dimes. Ably told by a foremost authority, whose survey of primitive money was noted in these columns a number of years ago

(1949). Fully illustrated. Recommended for ages 12 and up.

Junior Bible Archaeology, by H. V. Morsley. Roy Publishers, Inc. ($3.50). A revised edition of a description of archaeological findings that cast light on the people, places and events of the Bible. For young adolescents.

Technology

The History of Flight, by the editors of *American Heritage* and others. Golden Press ($3.95). A skillful abridgment for young readers of the *American Heritage History of Flight,* from Ki-kung-shi, who was said to have invented a flying chariot nearly 4,000 years ago, and Leonardo da Vinci to military jets. Many paintings, photographs and prints, some in color. For readers of 12 and up.

This Is Automation, by S. Carl Hirsch. The Viking Press ($3.75). A sprinkling of facts about automation that manages, effortlessly enough, to give little information anyone will remember. Harmless for readers of 10 to 12 or so.

Printing Works Like This, by John A. Spellman. Roy Publishers, Inc. ($2.95). Brief explanations of letterpress printing, lithography, screen-process printing, textile printing and bookbinding. Many illustrations, not all of which are helpful. For readers of high school age.

Books: From Papyrus to Paperback, by Esther S. Harley and John Hampden. Roy Publishers, Inc. ($3.95). About Egyptian scrolls, books in ancient Greece and Rome, medieval manuscripts, the invention of printing, the rise of the book trade, the design and making of modern books. Good illustrations. For adolescents.

The Story of the Laser, by John M. Carroll. E. P. Dutton & Co. ($3.95). A routine but satisfactory explanation of what a laser is and does. Photographs. For readers of 12 and up.

Medicine

Veterinarians and Their Patients, by Charles Paul May. Thomas Nelson & Sons ($3.50). How to feed a runt pig, take care of a beagle's toothache, bandage a cow's foot, rescue a duiker from drowning, feed a small gazelle, administer an antibiotic to a whale, transplant corneal tissue to a blind bat ray (the operation being performed in a tank 25 feet below the surface), soothe the frazzled nerves of a neurotic cat, deliver a puppy by Caesarean section, train a Labrador retriever to be a guard dog, educate dogs to help the blind, apply cosmetics to an elephant's eye (to prevent the skin from cracking), quarantine a giraffe, vaccinate almost anything with four legs, treat dog allergies, induce good temper in a donkey by singing to it and train chimpanzees to explore space so that they can prepare the way for their less amiable relatives to land on the moon. An inconsequential but amusing little book that most youngsters would enjoy. Photographs. For readers of 11 or so and up.

Man against Disease, by Geoffrey Lapage. Abelard-Schuman ($3.75). Brief accounts of the work of such men as Jenner, Koch, Pasteur, von Behring, Metchnikov, Kitazato, Ehrlich, Lister, Reed, Domagk, Fleming, Chain and others who gained great victories in man's struggle against disease. Photographs. For readers of 12 and up.

Biography

Carl Friedrich Gauss, by William L. Schaaf. Franklin Watts, Inc. ($2.95). Considering Gauss's incomparable contributions to mathematics—he is rightly considered the last of the great universalists, the subject now being much too broad and too complex to be encompassed by a single person—it is strange that no good biography of him has appeared. The closest approach is the chapter in Eric Temple Bell's *Men of Mathematics,* called "The Prince of Mathematicians." This book is therefore doubly welcome, not only because it gives an admirably succinct account of Gauss's advances in number theory, algebra, statistics, geometry, spherical trigonometry, astronomy, magnetism and other fields but also because it presents the material so that an adolescent can grasp its meaning and appreciate its profundity and beauty. It is safe to assume that very few readers of Schaaf's book, if they have any mathematical aptitude, will not be stimulated to learn more and probe deeper into Gauss's brilliant inventions and discoveries. Highly recommended.

Benjamin Rush: Physician, Patriot, Founding Father, by Sarah R. Riedman and Clarence C. Green. Abelard-Schuman ($4.50). Based mainly on *The Autobiography of Benjamin Rush* and *The Letters of Benjamin Rush* (published in 1948 and 1952 respectively and noted in these columns), this short biography for young teen-agers describes the life of an uncommonly gifted man who made contributions to medicine, particularly in emancipating it from cruel and bizarre practices in the treatment of mental as well as physical illness. Illustrations.

ALESSANDRO VOLTA AND THE ELECTRIC BATTERY, by Bern Dibner. Franklin Watts, Inc. ($2.95). An exceptionally well-illustrated and well-written biography of the great Italian electrician who, among other things, improved the electroscope, gave the correct explanation of Galvani's frog-leg phenomenon (the contact of dissimilar metals) and made the first electric pile, a source of constant-flow electricity to which Benjamin Franklin gave the name "battery." For young teen-agers.

PIONEER ASTRONOMERS, by Navin Sullivan. Atheneum ($3.75). Sketches of the life and work of astronomers from Copernicus and Kepler to Shapley, Hertzsprung and Hubble. For readers of 12 and over.

OUT OF SILENCE INTO SOUND, by Roger Burlingame. The Macmillan Company ($2.95). A competent brief biography of Alexander Graham Bell, who not only perfected the telephone but also devoted a good part of his life to the task of bringing sound to the deaf. Photographs and other illustrations. For readers of 11 or 12 and up.

JULES VERNE, by Franz Born. Prentice-Hall, Inc. ($3.25). A short biography of the extraordinary Frenchman who predicted so many of the spectacular technological triumphs of our time, among them space flight and the exploration of the globe by submarine. For ages 10 and up.

ANTOINE LAVOISIER, by Rebecca B. Marcus. Franklin Watts, Inc. ($2.95). An attractively illustrated, straightforward biography of the famous 18th-century French chemist. For young adolescents.

THE RADAR MAN, by John Rowland. Roy Publishers, Inc. ($3.50). An unpretentious biography of Sir Robert Watson-Watt. For teen-agers.

THE MANY WORLDS OF BENJAMIN FRANKLIN, by Frank R. Donovan and the editors of *American Heritage*.

Harper & Row, Publishers ($3.95). A colorfully illustrated biography in the American Heritage Junior Library touching on all this marvelous man's activities, from his electrical researches and literary labors to his career as a politician and diplomat. For readers of 10 and up.

General

To the Top of the World, by Pauline K. Angell. Rand McNally & Company ($4.50). Ice, Ships and Men, by John Euller. Abelard-Schuman ($3.75). Two readable books on the perennially engrossing subject of Arctic exploration. Mrs. Angell, writing for ages 12 and up, tells the story of Robert E. Peary and his Negro assistant Matthew Henson, whose several journeys to the Arctic culminated in their march to the Pole in 1909. It is a well-written, exciting tale that does not try to make Peary more lovable than he was. Euller's book, addressed to a somewhat younger audience—although teen-agers will also enjoy it—consists of various episodes in the conquest of the Arctic. Both volumes have photographs, maps and other illustrations.

Exploring under the Sea, by J. Gordon Cook. Abelard-Schuman ($3.75). This interesting book is concerned not so much with what can be found under the sea—there has been a surfeit of such introductions—but with the methods and equipment used in underwater exploration from the earliest diver's dress to modern rigid suits, the bathysphere, the submarine and the *Aluminaut*, a kind of underwater house in which explorers can live for weeks without coming to the surface. Good illustrations. For readers of 12 and up.

Face of North America, by Peter Farb. Harper & Row, Publishers ($3.95). A young reader's abridged edition of an attractive description of the North American continent: the geological changes it has experienced, the character of its ocean boundaries, its inland waters, mountains, forests and deserts, and man's imprint on the land. Many good illustrations, including photographs. For ages 12 and up.

Where in the World? by Philip S. Egan. Rand McNally & Company ($3.95). An assortment of 159 questions and answers about the planet earth. Examples: How old is the earth? How did oil get into the ground? What is a seiche? Where was the land of Mu? Does a ship weigh more or less in the moonlight? Is it true that North and South America were once joined to Europe and Africa? Illustrations. For ages about 10 to 13.

Exploits in Africa, edited by John Bayliss. New York Graphic Society ($3.50). Selections, some of them very good, from writings about African animals and African exploits, including true stories by Gerald Durrell, John Gunther, Alan Moorehead and others. For ages 12 to 16.

Africa, by Rhoda Hoff. Henry Z. Walck, Inc. ($3.75). Effective excerpts from the writings of African explorers, colonists, historians, traders and natives, beginning with Herodotus and including such contrasting figures as Anthony Trollope, Strabo, Alexandre Dumas, Henry Stanley, Mary Kingsley, Winston Churchill, Albert Schweitzer, Jan Smuts, Richard Harding Davis, Theodore Roosevelt, Abdel Gamal Nasser, Father Lobo and Kwame Nkrumah. An attractive book. For readers of 12 and up.

This Thirsty World, by Alfred Lewis. McGraw-Hill Book Company ($3.50). A primer of important facts about the world's water resources: their extent, how underground sources of clean water can be replenished, the reclamation of waste water, means of producing artificial rainwater, the desalting of ocean water, the conservation of supplies by dams and aqueducts, the various schemes for bringing water from regions where it is superfluous to those where it is needed. Photographs. For age 12 and up.

Introducing Science, by Alan Isaacs. Basic Books, Inc., Publishers ($4.95). An exclusively descriptive survey of modern science—physics, astronomy, chemistry, living matter—omitting experiment, measurement and mathematics. This does not sound promising but in fact works out well, largely by reason of Isaacs' skill in sticking to essentials and not losing his way. Some of the sections, particularly the one on chemistry, are a little too dry and recitative, but on the whole this is a sound, instructive abstract, accessible to older adolescents and grown-ups. The illustrations are meager.

Marco Polo's Adventures in China, by Milton Rugoff and the editors of *Horizon* magazine. Harper & Row, Publishers ($3.95). The story of what was perhaps the most fascinating adventure in the history of travel: Marco Polo's journey with his father and uncle to the court of Kublai Khan in China between the years 1271 and 1295. Marco's feat changed the history of Europe and opened to the West the incomparable riches and superior civilization of China. First-rate illustrations of every kind, many in color. For readers 12 and up.

THE ERIE CANAL, by Ralph K. Andrist and the editors of *American Heritage*. Harper & Row, Publishers ($3.95). A pleasant history of the narrow man-made waterway, begun in 1817, that on completion ran through the state of New York from Albany to Buffalo, thus opening a new way to the West. The 363-mile Erie Canal was a bold and, as it seemed at the time, preposterous idea, yet it was a highly effective traffic artery, linking the Great Lakes to the seas of the world for more than half a century until the railroads replaced it and much of the old canal was relocated, widened and deepened and incorporated into the New York State Barge Canal system. In addition to the story of the Erie the book tells of many of the other canals, most of them zany creations that were built during the period of the canal craze the success of the Erie had engendered. Some of these systems were patchworks that required dozens of rail sections to join the waterways and included the use of steamboats, cable cars, horse-drawn vehicles and other carriers to complete the journey. A most enjoyable, copiously illustrated volume, with photographs, old prints and many reproductions in color. Highly recommended for readers 10 and older.

ALL ABOUT AVIATION, by Robert D. Loomis. ALL ABOUT BIOLOGY, by Bernard Glemser. ALL ABOUT FIRE, by Raymond Holden. Random House ($1.95 each). Three new books in this sprightly series addressed to ages about 10 to 13. Loomis skips around in the aviation world, describing flight on a commercial airliner, telling what it feels like to pilot a small plane, giving some of the rudiments of the science of flight and so on. The Glemser book is a short outline of biology from the beginning of life to the structure and function of the human body. Fire as man's friend and as man's enemy from prehistoric times until today is Holden's subject. He discusses fire in myth and magic, primitive ways of making fire, fire fighting, a number of disastrous fires on land and water, fire from the sun. Good photographs in each volume.

INDEX OF ADVERTISERS

DECEMBER 1964

ANNUAL INDEX

The following index lists all the authors and articles that appeared in SCIENTIFIC AMERICAN *during 1964. Also indexed are "Mathematical Games," "The Amateur Scientist" and the principal book review in each issue.*

AUTHORS

ARTICLES

MATHEMATICAL GAMES

THE AMATEUR SCIENTIST

BOOKS

BIBLIOGRAPHY

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

EXPERIMENTS IN HURRICANE MODIFICATION

A CLOUD SEEDING EXPERIMENT ON HURRICANE ESTHER, 1961. R. H. Simpson, M. R. Ahrens and R. D. Decker in *National Hurricane Project, Report No. 60.* U.S. Department of Commerce, Weather Bureau, 1963.

AN EXPERIMENT IN HURRICANE MODIFICATION: PRELIMINARY RESULTS. R. H. Simpson and J. S. Malkus in *Science,* Vol. 142, No. 3591, page 498; October, 1963.

NOTE ON THE POTENTIALITIES OF CUMULONIMBUS AND HURRICANE SEEDING EXPERIMENTS. Joanne S. Malkus and Robert H. Simpson in *Journal of Applied Meteorology,* Vol. 3, No. 4, pages 470–475; August, 1964.

ON THE ORIGIN AND POSSIBLE MODIFICATION OF HURRICANES. Herbert Riehl in *Science,* Vol. 141, No. 3585, pages 1001–1010; September, 1963.

THE GEOLOGY OF THE MOON

INTERPLANETARY CORRELATION OF GEOLOGIC TIME. Eugene M. Shoemaker, Robert J. Hackman and Richard E. Eggleton in *Advances in the Astronautical Sciences, Vol. VIII.* Plenum Press, 1962.

INTERPRETATION OF LUNAR CRATERS. Eugene M. Shoemaker in *Physics and Astronomy of the Moon,* edited by Zdeněk Kopal. Academic Press, 1962.

STRATIGRAPHIC BASIS FOR A LUNAR TIME SCALE. Eugene M. Shoemaker and Robert J. Hackman in *The Moon: Proceedings of Symposium No. 14 of the International Astronomical Union,* edited by Zdeněk Kopal and Z. K. Mikhailov. Academic Press, 1962.

THREE-PIGMENT COLOR VISION

THE EYE. Edited by Hugh Davson. Academic Press, 1962.

IN SITU MICROSPECTROPHOTOMETRIC STUDIES ON THE PIGMENTS OF SINGLE RETINAL RODS. Paul A. Liebman in *Biophysical Journal,* Vol. 2, No. 2, Part 1, pages 161–178; March, 1962.

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA, Vol. 53, No. 1; January, 1963.

RETINAL MECHANISMS OF COLOR VISION. E. F. MacNichol, Jr., in *Vision Research,* Vol. 4, No. 1/2, pages 119–133; June, 1964.

PROTEIN-DIGESTING ENZYMES

ACTIVE CENTER OF CARBOXYPEPTIDASE A. Bert L. Vallee in *Federation Proceedings of American Societies for Experimental Biology,* Vol. 23, No. 1, Part 1, pages 8–17; January–February, 1964.

CORRELATION OF STRUCTURE AND FUNCTION IN ENZYME ACTION. D. E. Koshland, Jr., in *Science,* Vol. 142, No. 3599, pages 1533–1541; December, 1963.

MECHANISM OF ZYMOGEN ACTIVATION. Hans Neurath in *Federation Proceedings of American Societies for Experimental Biology,* Vol. 23, No. 1, Part 1, pages 1–7; January–February, 1964.

TRYPSINOGEN AND CHYMOTRYPSINOGEN AS HOMOLOGOUS PROTEINS. Kenneth A. Walsh and Hans Neurath in *Proceedings of the National Academy of Sciences,* Vol. 52, No. 4, pages 884–889; October, 1964.

FLUID CONTROL DEVICES

FLUID AMPLIFIER HANDBOOK. Diamond Ordnance Fuze Laboratories, Ordnance Corps, Department of the Army, 1962–1963.

FLUID JET CONTROL DEVICES. Edited by Forbes T. Brown. The American Society of Mechanical Engineers, 1962.

PROCEEDINGS OF THE FLUID AMPLIFICATION SYMPOSIUM. Diamond Ordnance Fuze Laboratories, Ordnance Corps, Department of the Army, 1962.

THE HOPEWELL CULT

EXPLORATION OF THE MOUND CITY GROUP. William C. Mills in *Ohio Archaeological and Historical Quarterly,* Vol. 31, No. 4, pages 423–584; October, 1922.

EXPLORATIONS OF THE SEIP GROUP OF PRE-HISTORIC EARTHWORKS. Henry C. Shetrone and Emerson F. Greenman in *Ohio Archaeological and Historical Quarterly,* Vol. 40, No. 3, pages 349–509; July, 1931.

HOW CELLS MAKE ANTIBODIES

ELABORATION OF ANTIBODIES BY SINGLE

CELLS. G. J. V. Nossal and O. Mäkelä in *Annual Review of Microbiology*, Vol. 16, pages 53–74; 1962.

SINGLE CELL STUDIES ON 19S ANTIBODY PRODUCTION. G. J. V. Nossal, A. Szenberg, G. L. Ada and Caroline M. Austin in *The Journal of Experimental Medicine*, Vol. 119, No. 3, pages 485–502; March, 1964.

STRUCTURE AND SPECIFICITY OF GUINEA PIG 7S ANTIBODIES. G. M. Edelman, B. Benacerraf and Z. Ovary in *The Journal of Experimental Medicine*, Vol. 118, No. 2, pages 229–244; August, 1963.

QUANTIZED VORTEX RINGS IN SUPERFLUID HELIUM

APPLICATION OF QUANTUM MECHANICS TO LIQUID HELIUM. Richard P. Feynman in *Progress in Low Temperature Physics, Vol. I*, edited by C. J. Gorter. Interscience Publishers, 1955.

EVIDENCE FOR THE CREATION AND MOTION OF QUANTIZED VORTEX RINGS IN SUPERFLUID HELIUM. G. W. Rayfield and F. Reif in *Physical Review Letters*, Vol. 11, No. 7, pages 305–310; October, 1963.

QUANTIZED VORTEX RINGS IN SUPERFLUID HELIUM. G. W. Rayfield and F. Reif in *The Physical Review*, in press.

SUPERFLUID PHYSICS. Cecil T. Lane. McGraw-Hill Book Company, Inc., 1962.

MATHEMATICAL GAMES

MAESTRO PUZZLES. J. E. Reeve and J. A. Tyrrell in *The Mathematical Gazette*, Vol. 45, No. 352, pages 97–99; May, 1961.

PENTOMINOES AND HEXIAMONDS. T. H. O'Beirne in *New Scientist*, Vol. 12, No. 259, pages 316–317; November, 1961.

SOME HEXIAMOND SOLUTIONS: AND AN INTRODUCTION TO A SET OF 25 REMARKABLE POINTS. T. H. O'Beirne in *New Scientist*, Vol. 12, No. 260, pages 379–380; November, 1961.

THIRTY-SIX TRIANGLES MAKE SIX HEXIAMONDS MAKE ONE TRIANGLE. T. H. O'Beirne in *New Scientist*, Vol. 12, No. 265, pages 706–707; December, 1961.

THE AMATEUR SCIENTIST

THE LIGHTNING BOOK. Peter E. Viemeister. Doubleday & Company, Inc., 1961.

SOAP-BUBBLES. C. V. Boys. Dover Publications, Inc., 1959.

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