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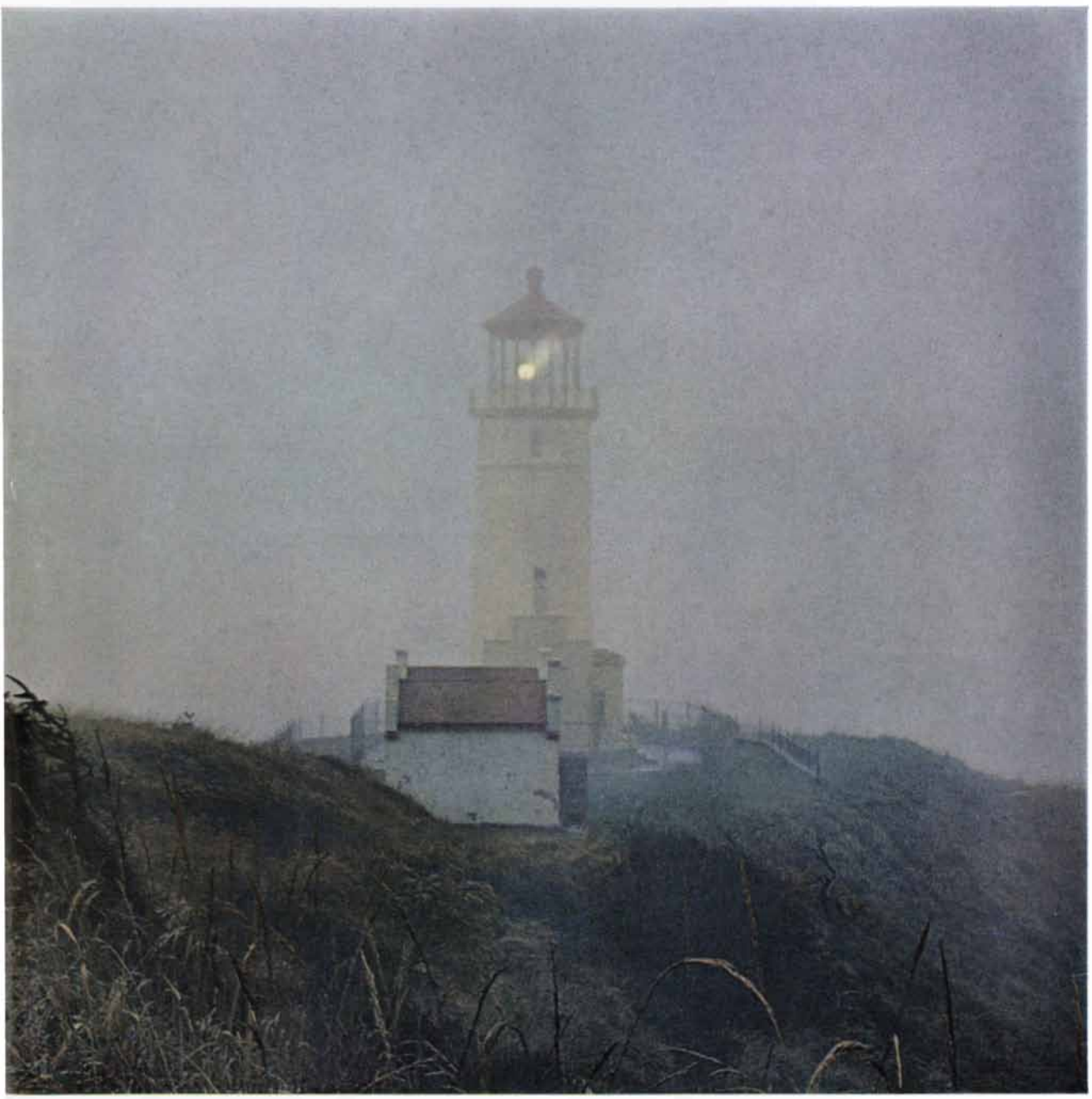

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December 1968

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

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Americans have never in history felt that the sea could be abandoned to others, for the U.S. is far from self-sufficient, importing 66 strategic materials out of 77 needed. Yet 95% of our exports and imports are carried in foreign ships. The inescapable conclusion: our national security demands, 1) that delivery of critical materials to and from our shores should be basically under American control, and 2) that America's shipyards should supply the needed ships, in recognition that reliance on foreign sources for either shipping or ships is fraught with risk.

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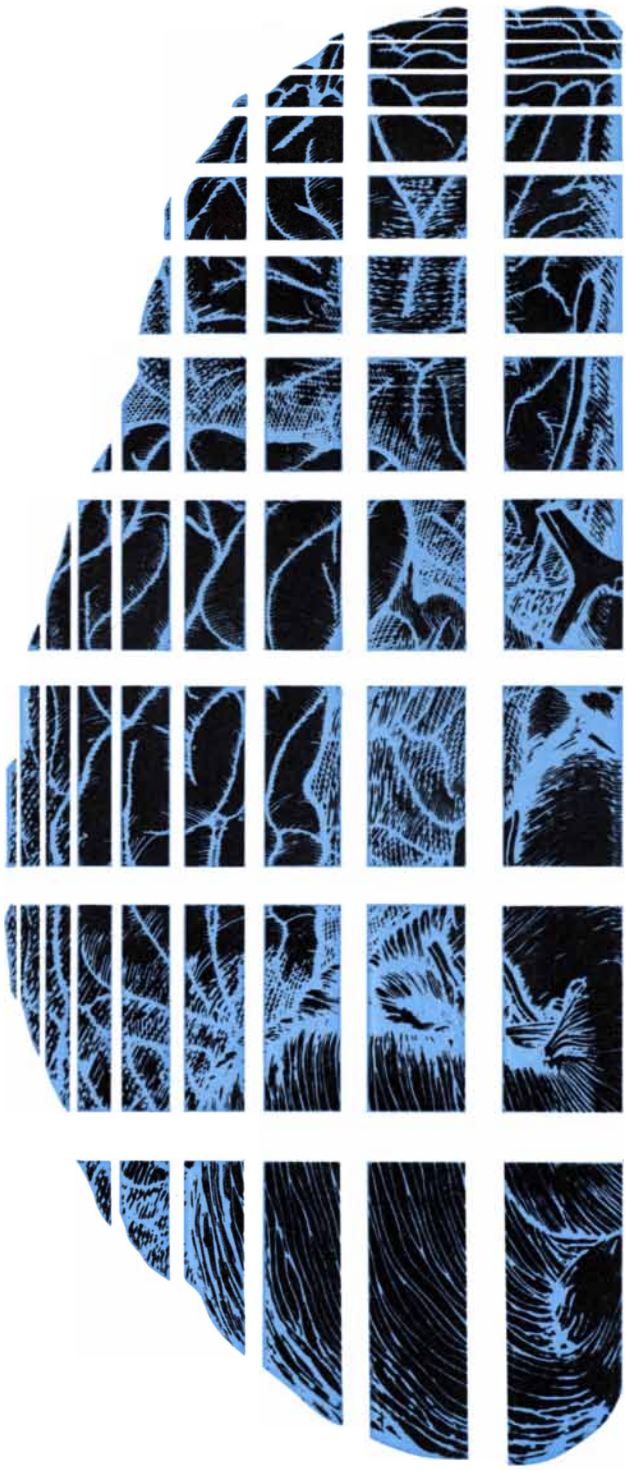

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ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover shows a late-October fog obscuring North Head lighthouse at Long Beach, Wash., near the mouth of the Columbia River. Like most parts of the U.S. Pacific Coast, Long Beach averages 60 days of dense fog a year. The fogs are usually those of the type known as advection fogs (see "Fog," page 74). They develop when moist, warm air is chilled by contact with the cold water of the California Current. Delay of shipping was once the greatest nuisance attributable to fogs. Today, however, they also endanger air and highway travel and, in combination with pollutants in the atmosphere, are a hazard to the health of city dwellers.

THE ILLUSTRATIONS

Cover photograph by John F. Neal

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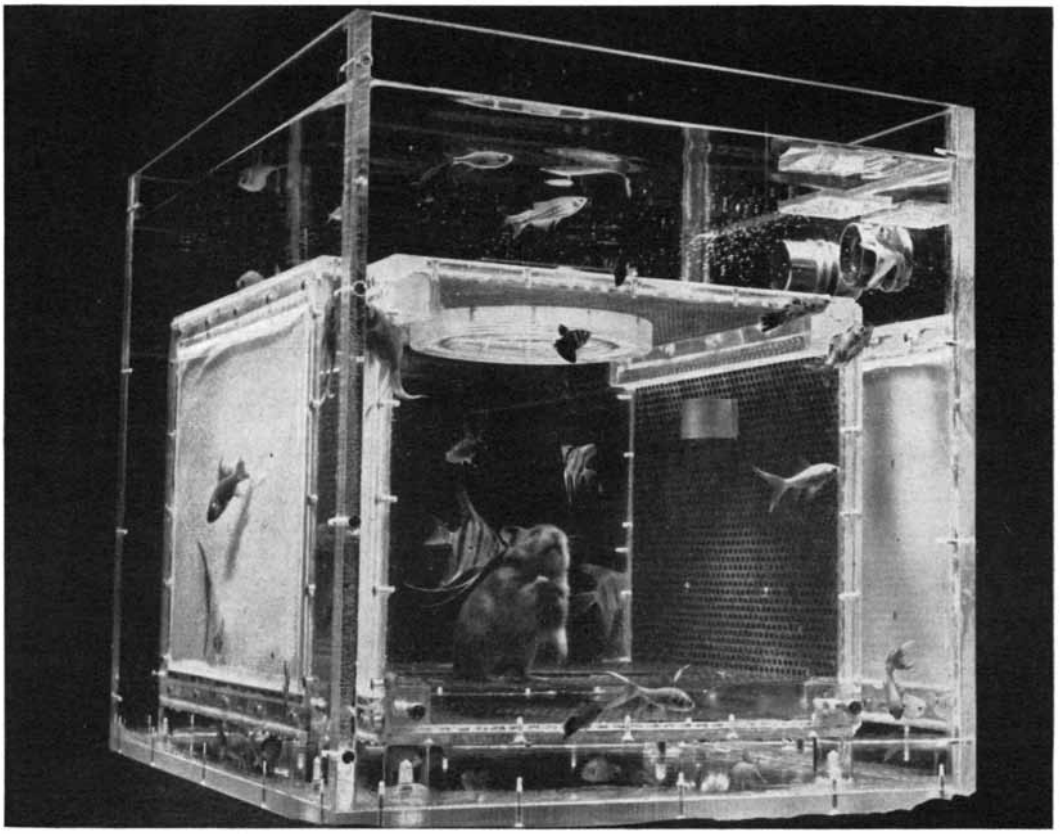
4 years ago, GE demonstrated the most permeable membrane known.

General Electric's original demonstration of keeping an animal alive underwater by extracting oxygen from water and expelling exhaled carbon dioxide through a silicone membrane.



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GENERAL ELECTRIC

LETTERS

Sirs:

I have for some years been a subscriber to *Scientific American*. For the usual reason, satisfaction, I have not previously written to you regarding any of the subject matter. However, I now feel compelled to write regarding your August article "A Study of Ghetto Rioters," by Nathan S. Caplan and Jeffery M. Paige. It does not come up to your usual standards of completeness and correctness of scientific method.

Note (page 15) that the sampling system was stated to be limited to the census tracts where the violence actually took place. Census tracts are supposed to contain only about 4,000 persons and in urban areas may be only a few blocks. Were nearby predominantly Negro (but quiescent) neighborhoods included? We should certainly be told. Especially recall (page 16) that judging from the quoted percentages the rioter group in the two cities together totaled only about 154 persons, and in Detroit alone it must have been only about 48 persons, male and female. With such small samples we are definitely entitled to a discussion of the statistical probabilities of error.

Another point not to be overlooked is this. We are told by the authors (page 16) that respondents were compared with persons arrested for riotous activity on the basis of a number of demographic variables, and that the rioter group more closely resembled the arrested persons than the nonrioters. How well did they compare? What were these variables?

On page 17 we are told that there is a significant relation between schooling and riot activity but (in the same sentence) the authors state that it is the rioters who are better educated. We are all familiar with the usually assumed semantic equivalency of schooling and education but we also know it is often incorrect. How do these groups, rioters and nonrioters together, compare with the inner-city Negro community-at-large in years of schooling and marks attained? If we were told this, we might be able to agree that the whole underclass theory has no merit. However, for all we can tell both groups studied may have been measurably underclass as regards educational level.

The authors give some conclusions that appear unrelated to their data. For example, they state that rioters and nonrioters "do not have a different set of values." How were these values measured? Which questions and answers clearly show this? What values were the same for the groups? One would think that if differences in schooling are measurable, perhaps personal goals and values are different. The next sentence at the end of page 19 seems distinctly misleading. Drs. Caplan and Paige state that "none of these factors sets the rioter off from the rest of the community in a way that justifies considering him a personal failure *or an irresponsible person*." (Italics are mine.) Can we assume they "forgot" to say not irresponsible except that they recognize unlawful measures such as arson, burglary, assault with deadly weapons and malicious vandalism as legitimate tools with which to change the social order?

The last and to me most important question about the article regards the final conclusion, that blocked opportunity is the sole cause of the present riots. The authors make no provision anywhere for any possible alternative theories other than the three studied. Are the Negro's opportunities really entirely blocked or does he perhaps suppose the obstruction to be worse than it is because of what he is told by his leaders? How much of the riotous activity relates to this external in-

Scientific American, December, 1968; Vol. 219, 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.

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Advertising correspondence should be addressed to Allan Wittman, Advertising Manager, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017.

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NAME

NEW ADDRESS

OLD ADDRESS

fluence? The authors ask a very important question that I feel they leave unanswered.

In closing I should like to point out that the importance of this discussion rests in the fact that this study surely played a considerable role in molding the conclusions of the Kerner Commission. Neglecting to mention other possible theories of riot such as agitation should have made the commission members suspicious, but reports received in the public news media would indicate that the commission relied heavily on the correctness of "A Study of Ghetto Rioters." I believe there are clearly serious reasons for doubting the positive conclusions given in view of the limited data.

RALPH D. LAUSA, M.D.

Department of Health
State of Ohio
Columbus, Ohio

Sirs:

In reply to Dr. Lausa we should like to make the following observations.

A detailed description of sampling procedures can be found in the report of the National Advisory Commission on Civil Disorders, footnote 111, pages 171–172 (Bantam edition). As indicated in the *Scientific American* article, our sampling procedure ensured constant and independent probabilities for the selection of each respondent. The size of samples was adequate to test for the reliability of differences between rioter and nonrioter groups. The statistic used was the chi-square. The probability of differences as large as those discussed occurring by chance is less than five in 100 (see page 17 of the article).

A comparison of our data and the data for 13,012 arrestees in 22 cities can be found in footnotes 114–117, pages 172–173 of the Bantam edition of the Kerner Commission report. We show there that rioters were more similar than nonrioters when compared on age and sex. More recently a careful analysis by Robert M. Fogelson and Robert B. Hill of the arrest data for more than 10,000 arrestees shows that the rioters in our study also closely resemble arrestees in region of socialization and occupational level.

Although the two are not identical, certainly the equivalence of schooling and education is more than semantic, particularly for such crude distinctions as between grade school and high school.

Shared values were measured by church attendance and belief in the Protestant ethic, the idea that hard work, rather than luck, leads to success. Both indexes were described on page 19.

Dr. Lausa calls attention to our failure to label the rioter an "irresponsible person." Since this point seems obvious, if not tautological, the only purpose it could serve would be a moral condemnation of riot behavior.

Dr. Lausa asks if opportunities for Negroes are really blocked. We regard this fact as sufficiently well established not to merit further discussion (see, for example, *A Profile of the Negro American,* by Thomas F. Pettigrew, and Chapters 6, 7 and 8 of the Kerner Commission report). Blocked opportunity is not, of course, a new experience for Negroes and consequently is not a sufficient explanation of rioting now. We argued that it is specifically the change in the Negro's image of his own abilities and potential for achievement that has caused barriers passively accepted in the past to be violently rejected today (see the last paragraph on page 21).

Conspiracy and outside-agitator theories of riots have a persistence and popularity that far exceed any empirical evidence available to support them. Our data do not permit a direct test of such theories, but the simple association of H. Rap Brown and Stokely Carmichael and the incident of one or two riots does not constitute evidence of any kind. Routine police actions are the single largest source of precipitating incidents and in fact were the immediate focus of conflict in both Detroit and Newark.

We would urge Dr. Lausa to read the Kerner Commission report rather than to rely on "reports received in the public news media." The analysis reported in "A Study of Ghetto Rioters" is incorporated in a 16-page section (of a 609-page document) and reflects only a small part of the total research activities of the commission. The commissioners had access to independent research concerned with the question of "outside agitators," as Dr. Lausa would have discovered had he read the report. Needless to say, any conclusions reported in our article do not necessarily reflect the views of either the commission and its staff or the editors of *Scientific American.*

NATHAN CAPLAN

University of Michigan
Ann Arbor, Mich.

JEFFERY M. PAIGE

University of California
Berkeley, Calif.

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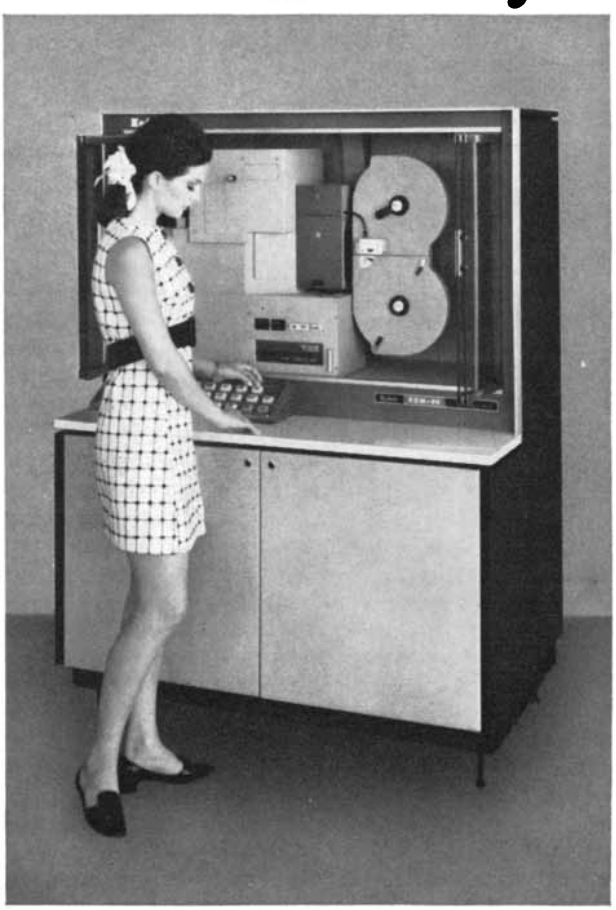

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1918: "An exchange telegraph dispatch from Copenhagen states that during the war Austria-Hungary suffered a total of more than 4,000,000 casualties in killed and wounded, the total number killed being 800,000 men and 17,000 officers. The Socialist *Vorwärts* of Berlin places the total German losses at 6,330,000, of which about 1,600,000 were killed and the fate of 260,000 is unknown. The total number of prisoners is put down as 490,000. An official announcement from London states that the first official figures of 658,665 British killed did not include men reported missing, or who died through accident or sickness, and it gives the total from all causes as a little more than 1,000,000 dead. The American casualties to date total 250,000, of which 36,154 were killed and 17,000 died through disease or causes not classified."

"When the naval section of the Peace Conference settles down to its work, we suggest that one of the first, if not the very first, subjects to be considered should be the placing of a ban upon the construction and use of the submarine. This should be done, first, on the ground that as a lawful weapon of war it has failed of its purpose; second, that as an instrument of piracy and a menace to the freedom and safety of the seas it has proved to be a weapon of frightful potency. Therefore let Civilization put the thing under the ban. That can be done at once and for all time."

"It was announced on November 11th at the annual meeting of the Aero Club of America that Mr. Gianni Caproni, the famous Italian airplane constructor, is planning to build an air cruiser of the heavier-than-air type with a number of motors aggregating 18,000 horse-power. The armistice having lifted the ban on the discussion of coming aeronautic developments, the Transatlantic Flight Committee of the Aero Club of America, of which Mr. Henry A. Wise Wood is chairman, made known the fact that there are several airplanes already being designed, each to be equipped with 5,000 horse-power. Caproni has one such machine, and it was in connection with the discussion of this type that it became known that Caproni has an 18,000-horse-power air cruiser under consideration, which will be capable of carrying a large number of passengers in non-stop flights across the Atlantic."

"To the SCIENTIFIC AMERICAN the year 1919 means much. First of all we are entering an era of peace and intensive industrial effort, following the greatest war of all ages. Reconstruction and reclamation projects on an undreamed of scale are to be inaugurated within the next 12 months. Marvelous inventions are to be disclosed to a curious world. Scientific discovery and research, which have been dormant during the past four years of strife, bloodshed and appalling destruction, are again coming into their own. So the year 1919 is a great year for the SCIENTIFIC AMERICAN, which has ever been the chronicle of worthy achievements since its founding in 1845."

SCIENTIFIC AMERICAN

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"So important a movement as the recent Social Science Congress, held at Birmingham, England, gave us hopes that in the deliberations of the many learned and thinking men sure to be present at such a meeting, something practical and definite might be evolved that would contrast refreshingly with the vague and unsatisfactory proceedings hitherto characteristic of similar movements. We are compelled to say, however, that a careful review of the transactions of this congress has resulted in the disappointment of our hopes. Why is the mockery of applying the name of science to a conglomeration of crude speculative opinions, unsystematized and without the solid basis of fact, persisted in? There was no such thing as social science, in the strict interpretation of the term, apparent in the deliberations of the Congress at Birmingham. Not the slightest reference, so far as we can see, to the natural laws which govern the formation of all society, or even the slightest attempt to show that those laws are violated in its present organization, and if so, how and why. In the place of such a method, which, if there be a *science* of sociology, is certainly possible, we have discussions upon jurisprudence, free trade, international law, neutrality of the English Government during the late rebellion in the United States, change of nationality, etc., etc.—in short, topics as foreign as possible to the subject in hand. We are more than ever impressed with the belief that such meetings will never result in any permanent, or even temporary, alleviation of the current evils of modern society."

"On Saturday, the 28th of November, a trial of velocipedes took place in New York at the armory of the 22d Regiment on 14th Street. Four different makers were represented. Two of the velocipedes were of the French style, high and awkward to mount. The one generally conceded to be the best was an American design, embracing several improvements upon the French machine."

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Most Americans 30,000 feet


Gettysburg Battlefield

The Grand Canyon at dawn...Manhattan at dusk...sunlight on the winding Mississippi.

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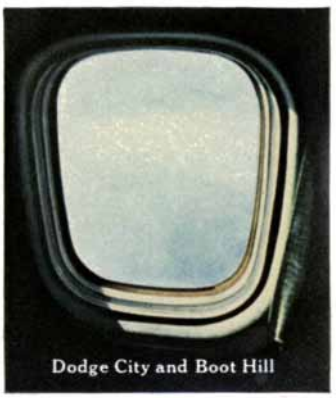
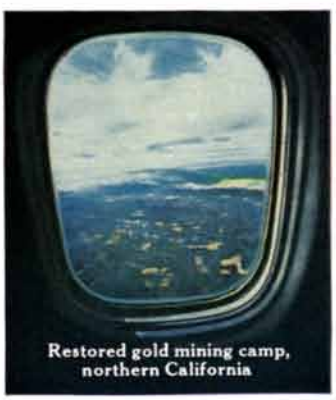

Dodge City and Boot Hill

However, from that same jet, this too is America...

Arkansas...patches of green...Maine...patches of green and blue...California...clouds...South Dakota...patches of brown.

A sight to send any traveler back to his magazine.

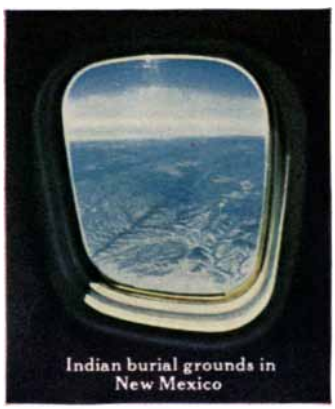
But, whether unmissable or eminently missable, neither of these aerial versions of America has much to do with the land that's down below...


Restored gold mining camp, northern California

Arkansas...back-country fiddling on the second floor of the Court House in Mountain View, songs "older than nobody knows"... Maine...the ferry ride from Boothbay Harbor to Cabbage Island for a clambake, roasting

see America at and 600 mph.

corn warming the cool evening ... California... the happy insanity of the Calaveras frog jumping contest, an annual event since before Mark Twain... South Dakota...the trip on the narrow gauge railroad from Hill City to Oblivion – and back.


Indian burial grounds in New Mexico

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Hertz

A way at the world.

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PHILIPS

THE AUTHORS

RAYMOND P. POWELL ("Economic Growth in the U.S.S.R.") is professor of economics and Henry S. McNeil Professor of Russian Studies at Yale University. After being graduated from the University of California at Berkeley in 1942 he served as a pilot in the U.S. Air Force for three years. In 1952, after two years as an instructor at Princeton University, he obtained his Ph.D. from Berkeley and joined the Yale faculty. Powell writes: "My interest in Soviet economics dates back to Berkeley in the late 1930's, where it emerged somehow out of the combined action of campus radicalism and an enthusiasm for Tolstoi, Dostoevski and all that. I have traveled in the Soviet Union twice, in 1957 and again in 1964. On the latter occasion I spent most of a month researching in the Lenin Library in Moscow, which may be the world's least friendly and most efficient library. Besides my current research interests, which are chiefly Soviet monetary affairs, much of my time is absorbed by the problem of how to teach technical disciplines to people who will never acquire professional competence in them. In particular I am lecturing in an introductory course that tries to convey economics as a challenging intellectual discipline by analyzing Soviet as well as Western organization systems."

J. B. GURDON ("Transplanted Nuclei and Cell Differentiation") is a lecturer at the University of Oxford. He was educated at Eton, where he studied Greek and Latin, and at Christ Church College, Oxford, where he took up biology. Before his graduation in 1960 he was mainly interested in entomology, and his first published paper dealt with the discovery of a species of sawfly new to the British Isles. During graduate work at Oxford he became interested in embryology. Gurdon writes that aside from his work his "main interests include ski-mountaineering and horticulture."

ALAN H. BARRETT ("Radio Signals from Hydroxyl Radicals") is professor of physics at the Massachusetts Institute of Technology. Following graduation from Purdue University in 1950 he did graduate work at Columbia University, where he was awarded his Ph.D. in 1956. His work in radio astronomy began when he accepted a postdoctoral fellowship at the U.S. Naval Research Laboratory, where he worked in 1956 and 1957. He then spent four years in the department of astronomy at the University of Michigan before going to M.I.T. Barrett was codesigner of the microwave radiometer experiment aboard the *Mariner II* spacecraft to Venus. He is one of the codiscoverers of the radio lines of the hydroxyl (OH) radical in the spectrum of the interstellar medium.

J. R. HEIRTZLER ("Sea-Floor Spreading") is director of the Hudson Laboratories of Columbia University. He was educated as a physicist, receiving his Ph.D. from New York University in 1953, but has long made hobbies of geology and astronomy. After obtaining his doctorate he taught in universities, worked as a nuclear physicist in industry and, from 1960 to 1967, was in charge of a group that was engaged in research on geomagnetism at the Lamont Geological Observatory of Columbia University. He writes that "firsthand experience with the oceans during World War II and a love of travel combined to give me a strong interest in marine geophysics."

JOEL N. MYERS ("Fog") is an instructor in meteorology at Pennsylvania State University, where he was graduated in 1961, received a master's degree in 1963 and is now working on his doctorate. He writes: "At the age of seven I became interested in the weather and began keeping a daily record of the local conditions. At the age of 14 I was appointed a cooperative weather observer by the U.S. Weather Bureau." In addition to his teaching he does a daily broadcast on weather that is carried by two educational television stations. He remarks that the program is somewhat unusual "in that it serves the double role of providing an in-depth analysis and forecast of the weather while attempting to educate the viewers about basic meteorological concepts." Myers is interested in applying specialized weather forecasts to industry and has developed a consulting service used by most of the major ski areas in the northeastern U.S. A headline on a newspaper account of his service read, "Slopes' Top Aide an Avid Nonskier."

ALLEN PARDUCCI ("The Relativism of Absolute Judgments") is professor of psychology at the University of California at Los Angeles. He took his bachelor's degree in philosophy at the University of Michigan in 1949 and his Ph.D. in psychology at the University of California at Berkeley in 1954. He taught at the University of Oregon and Swarthmore College before going to U.C.L.A., where he recently received the U.C.L.A. Award for Distinguished Teaching. Parducci notes that he regards experimental psychology "as a source of hypotheses that one tries, never successfully, to test outside the laboratory." As his article suggests, he rates high-speed sailing very favorably on a scale of relative judgments of satisfaction. "I am currently attempting," he writes, "to establish my own distribution for the values experienced while standing on a surfboard propelled by a hand-held sail."

J. GEORGE SOTTER and GARY A. FLANDRO ("Resonant Combustion in Rockets") are respectively an engineering specialist at the AiResearch Manufacturing Company in Los Angeles and assistant professor of mechanical engineering at the University of Utah. Sotter obtained his bachelor's degree at Pennsylvania State University and his Ph.D. from the University of Sheffield in England. Flandro received his bachelor's degree at the University of Utah and his master's degree and doctorate from the California Institute of Technology. Sotter and Flandro, then on opposite sides of the Atlantic Ocean, did parallel work on the formation of vortexes in unstably burning rockets. They began their collaboration several years later after meeting while they were both working at the Jet Propulsion Laboratory.

KATHLEEN LONSDALE ("Human Stones") is a crystallographer who was trained in physics and mathematics (taking her doctorate in science at the University of London in 1928) but later was for many years professor of chemistry at University College London until her retirement this September. She is a Dame Commander of the Order of the British Empire and a Fellow of the Royal Society, to which (in 1945) she was the first woman elected. In 1966 she was president of the International Union of Crystallography and in 1967–1968 she was president of the British Association for the Advancement of Science. In addition to her work on stones she is interested in the geometry of the chemical reactions that take place in the solid state, the place of crystallography in the process of aging, the diffraction effects of thermal vibration and other forms of disorder in crystals, and the structure and properties of diamonds. She also notes: "I have honorary membership in the Sigma Delta Epsilon Fraternity and am a 'Daughter of Mark Twain.' (I don't know *what* the latter implies!)"

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Economic Growth in the U.S.S.R.

Statistics on Soviet output, compiled by economists in the U.S., are analyzed to reveal a remarkably high annual rate of growth. An attempt is made to determine how this high rate was attained

by Raymond P. Powell

For some two decades economists in the U.S. have been working to obtain an objective picture of the growth of the economy of the U.S.S.R. The effort was initiated in the late 1940's by Abram Bergson, then at Columbia University (he is now director of the Russian Research Center at Harvard University), and an associated group of specialists at the Rand Corporation. The study has enlisted a number of other investigators, including staff members of the National Bureau of Economic Research and Government departments and individual scholars working independently. Starting with the aim of acquiring reliable data on the rate of the U.S.S.R.'s economic growth, the study went on to analyze the process by which that growth was attained. The long inquiry has now reached a stage where, with respect to the economy of the U.S.S.R., we have quite a clear picture of what one might call "the other side of the moon."

The problem for Western economists of studying the economy of the U.S.S.R. was indeed akin to a problem in the natural sciences such as observing the surface of Venus or examining the structure of DNA molecules. There was no direct access to the subject. The Soviet government does publish comprehensive statistics on industrial and agricultural production and on other general measures of economic growth. For several reasons, however, it appeared that these indexes could not be accepted at face value. The reports of the Soviet Central Statistical Administration do not supply the detailed data from which the indexes are composed. The methods used in the construction of the indexes often differ from those regarded elsewhere as being acceptable. There were grounds for suspicion that the official indexes were affected by propagandistic bias. And the belief that the official measures did not accurately reflect the actual state of affairs was strengthened by certain implausibilities in their behavior over a period of time.

How could one obtain an independent view of the U.S.S.R.'s economic growth? Clearly it would be necessary to start as close to scratch as possible and attempt to construct our own estimates of Soviet production from basic data. What we needed was detailed information, for the various sectors of the economy, on the quantities of output, prices and the flows of expenditures, which are the ultimate constituents of production indexes. Since it was not possible to go directly to the sources to collect the requisite statistics, the only available approach was to make a thorough search of all the economic publications issued by the U.S.S.R. that might yield the kind of basic data we needed. Fortunately for our studies there was an extensive body of published material. During the early 1930's and in the years since 1956 the U.S.S.R. regularly issued a comprehensive statistical annual rather like the *Statistical Abstract* of the U.S. Considerable data were released in published versions of annual and long-term production plans. We also had access to a substantial part of an unpublished, classified version of the Soviet plan for the year 1941, which had fallen into the hands of the German army during World War II. We were able to collect information on prices from Soviet handbooks that list the official prices at which goods are bought and sold among state enterprises and to the public. A careful combing yielded bits of economic information from the daily newspapers, textbooks, monographs, the monthly journals of industries such as steel and cement and the journals of the State Planning Committee and the Academy of Sciences.

This search in many ways resembled an archaeological dig. The Library of Congress, the Widener Library at Harvard, the Columbia University Library and the New York Public Library constituted tells containing large, unworked accumulations of Soviet publications. Our diggers spent many man-years of eye-wearying, if not backbreaking, labor delving into this material. Almost nothing was known about what useful information might be found or where it might be located. Hence a person searching through the musty stacks of the Library of Congress, coming on a relevant item, could experience the thrill of discovery. The archaeological analogy also applies to the interpretation of the information after it was found. Fitting the pieces of data together depended more on notions

of plausibility than on pure logic or formal statistical reasoning.

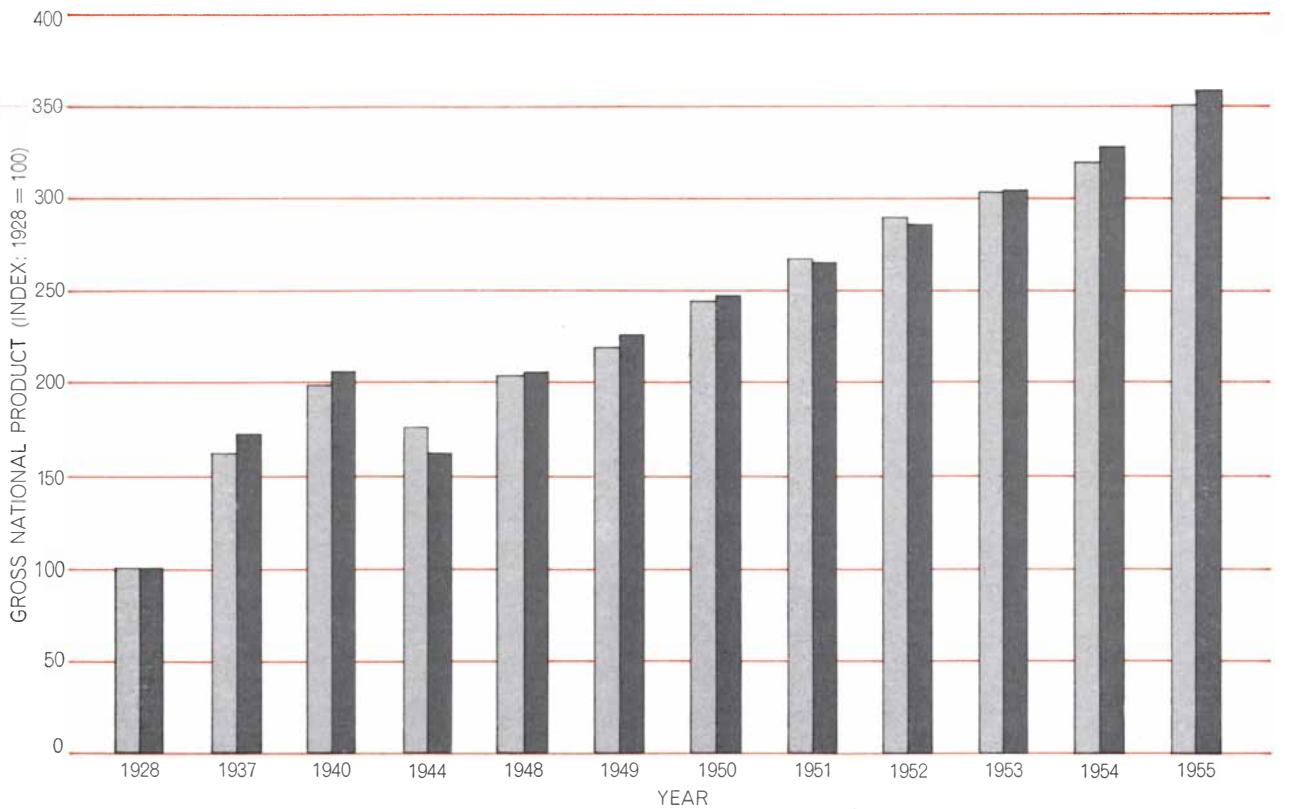
We had begun the search with the premise that at the level of basic data—detailed quantities and prices—the Soviet official information would be more realistic and closer to fact than it would be at the level of summary or generalized measures. Although this assumption proved to be valid in a sense, we found that the elementary information required extensive analysis and corrective interpretation. Definitions varied from time to time and from source to source. For example, in the early 1930's Soviet reports shifted from announcing harvests of grain in terms of "barn yields" (the amount of grain delivered to the barn) to reporting grain production in terms of "biological yields," including grain left in the field. This resulted in a difference in the measured harvest of as much as 40 percent.

Similar shifts or variations in reporting occurred in other sectors of production. Published figures for industrial output sometimes covered only large-scale producers and at other times were extended to include all producers; in the reporting of steel production the definition of "rolled steel" was expanded to include pipes and forgings from ingots; "lumber" production came to include wood that was sawn at building sites; the basis for reporting brick production was changed to include bricks made on collective farms. In the same vein, reported revenues of the national budget sometimes included withdrawals from accumulated deposits in the State Bank. "Working capital" sometimes meant assets and sometimes liabilities. It is clear that occasionally such changes in definitions were made with an intent to mislead, but perhaps more often they were merely the result of carelessness in statistical practice of a kind that is not unknown in Western countries.

The inconsistencies in definitions and accounting practices presented us with a formidable task. In order to arrive at a consistent and accurate picture of the trends in production over a period of time we had to make specific adjustments for the shifts or variations in reporting. This entailed a painstaking search for every fragment of information and every published explanation that might clarify the coverage of each category. In the end the pieces of the puzzle were interpreted, collated and fitted together into coherent statistical series that were thought to be consistent in meaning and coverage. These independently obtained component series were then combined into summary measures for the economy as a whole. Our results portrayed the growth of the economy in the period from 1928 (when the U.S.S.R. had approximately recovered to its pre-World-War-I level and began its forced-draft industrialization) through 1966.

We have been able to subject the validity of our estimates to certain tests. The most convincing test consisted in measuring the growth of the gross national product by two independent methods. The gross national product (G.N.P.) of a country is customarily defined as the aggregate annual production of goods and services, not including what is used up in the production process itself. To evaluate the "real" changes in G.N.P. over a period of years one must, of course, allow for changes in prices; consequently the prices of a single year are usually selected as a basis for comparison. G.N.P. in other years is valued in those prices and is often expressed in terms of an index number, or ratio, related to that year.

G.N.P. in a given year can be measured either from money expenditures for the goods and services produced or from the physical outputs of goods and

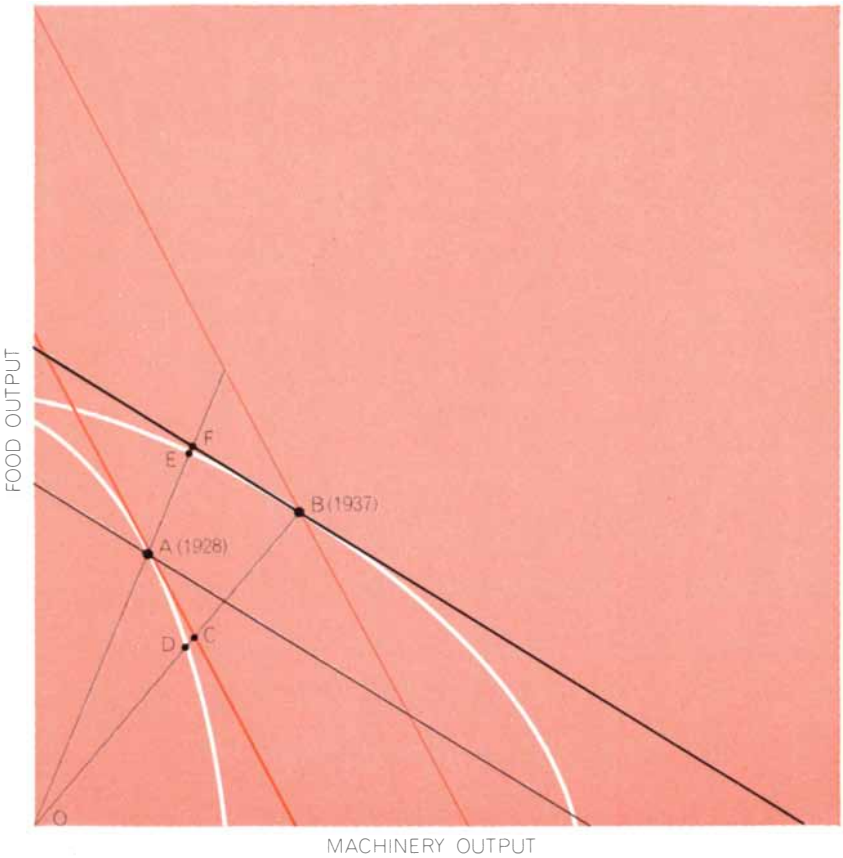


GROSS NATIONAL PRODUCT of the U.S.S.R. was estimated by two different methods, providing a check on statistical techniques. The two sets of estimates, made by the "deflation" method (*light gray*) and "commodity flow" method (*dark gray*) in 1937 prices, were very similar, differing by more than 3 percent only in 1937 and 1944 and yielding almost exactly the same rate of growth.

services. In the first case one adds up each year's money outlays by all persons, businesses and government and, by means of price indexes, translates the resulting total in current prices into a total valued in prices of the base year; this procedure is called "deflation." The other procedure for measuring G.N.P., called the "commodity flow" method, uses a different set of data. The quantities required in this case are physical outputs (tons of steel, yards of cloth and so forth) and man-years of services. For purposes of comparison the physical outputs are converted into money values by assigning prices of the base year to the component products and services.

Inasmuch as the two methods of G.N.P. measurement depend on different kinds of information, they offered a good opportunity to test the consistency of our compilations of statistics on the Soviet economy. If we had correctly interpreted and evaluated the basic data, the computation of the year-by-year G.N.P. record in the U.S.S.R. should tell approximately the same story whether it was done by the deflation method or by the commodity-flow method. Accordingly estimates of G.N.P. prepared by the two methods, covering the period from 1928 through 1955 and using 1937 as the price-weight year, were compared. Bergson had estimated G.N.P. by the deflation method (for the most part); Richard Moorsteen and Abraham Becker of the Rand Corporation and I had made comparable estimates using the commodity-flow method (for the most part).

The results turned out to be reassuringly similar [*see illustration on opposite page*]. For all but two of the individual years the estimated G.N.P. index numbers did not differ by more than 3 percent, and over the 27-year period as a whole the two estimates agreed within a fraction of a percentage point on the average annual growth of G.N.P. The fit of the two estimates was close enough to justify confidence that they were reliable within tolerable margins of error. It is still conceivable that the published data on which we had to rely might have been systematically falsified, but it is hard to believe that the Soviet government would do this when it needed reliable statistics for its own planning and controls, or that it could maintain two sets of records, one for its own use and one for publication. Moreover, we collected the data from many sources, and it is hardly likely that Soviet officials would have anticipated that all this material would be subjected to tests of consistency such as we have applied. Since the results of our estimates do hang together, one can reasonably conclude that the basic information published in the primary Soviet sources is essentially factual. By the same token the check provided by our tests can be taken to indicate that interpretations of the basic data by the U.S. investigators were not significantly colored by a "cold war" bias. There is a further basis for confidence in the fact that the sources and methods used in developing our estimates are fully explained in several shelves of published monographs and memorandums.

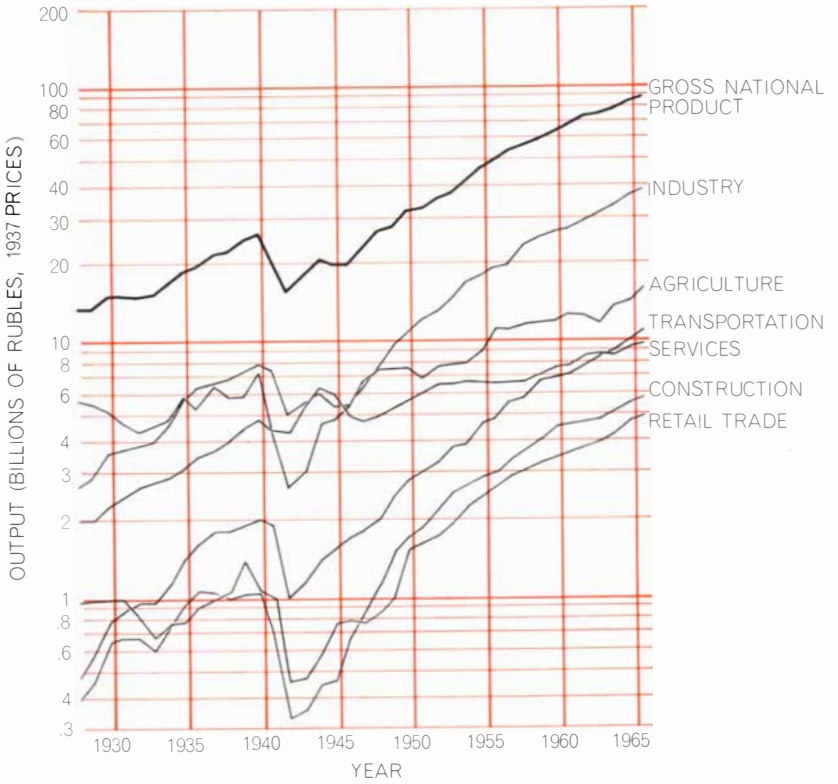


OUTPUT INDEXES in different prices are conceived of as measures of the change in productive capacity for specified mixes of products. Actual outputs of the Soviet economy in 1928 (*A*) and 1937 (*B*), for example, lie on "production-possibility functions" (*white curves*) that represent the economy's ability in that year to produce all possible mixes of food and machinery. Such a function can be approximated by passing through two output points two lines whose slopes represent relative prices in 1928 (*color*) and 1937 (*black*). An index of output weighted with 1928 prices gives, as a measure of 1937 output compared with 1928's, the ratio OB/OC, which approximates the actual increase in capacity for the *1937* product mix, or OB/OD. An index in 1937 prices, on the other hand, gives OF/OA for the ratio of 1937 to 1928 output, approximating the increase for the *1928* mix, OE/OA.

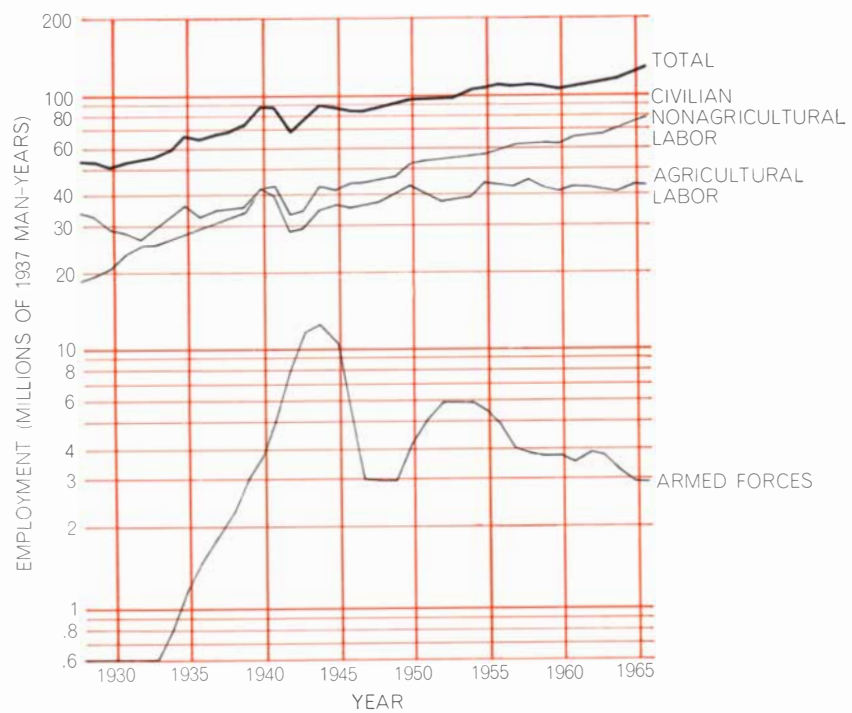
What, then, is our estimate of the U.S.S.R.'s actual growth rate in the period from 1928 through 1966? It must be pointed out at once that arriving at a single true figure for the average annual growth in G.N.P. is not possible, because the estimate will depend on what prices we choose for weights. This requires some explanation.

For illustration let us consider estimates in two different sets of prices of G.N.P. growth in the period from 1928 to 1937, during which time the Soviet government carried out its first two five-year plans and effectively industrialized the economy. Measured in the postindustrialization prices of 1937, G.N.P. over this period grew at a rate of 6.2 percent (in estimates made by Moorsteen, Becker and myself). Measured in the preindustrialization prices of 1928 (in estimates made by Bergson), the growth rate is 11.9 percent, or almost twice as high. What are we to make of this disparity?

The explanation is simple in terms of arithmetic. During the nine-year period the production of machinery grew much more rapidly than the production of food. Consequently measuring the G.N.P. growth rate in terms of 1928 prices, when the price of machinery was relatively high, gives predominant



SOVIET G.N.P. has grown at a high rate, with rapid growth in industry (particularly heavy industry) offset by slow growth in agriculture. Services are a mixture of slowly and rapidly growing components. These figures are in 1937 prices; in 1928 prices growth is about twice as rapid from 1928 to 1937. (On the logarithmic scale used in all these charts constant percentage rates of increase appear as straight lines and parallel lines represent equal rates.)



EMPLOYMENT is charted in terms of the 1937 work-year in civilian nonagricultural occupations. The increase in total employment reflects, in addition to population growth, both an increase in the proportion of the population in the work force and changes in hours worked, including a World War II increase and a cutback under Premier Khrushchev in 1958.

weight to the rapid growth of the machinery component over the period and inclines the G.N.P. index upward. The 1937 prices, on the other hand, give less weight to the machinery component, because by 1937 the price of machinery had dropped to a relatively low level, and they place a heavy weight on the slowly growing food component, whose price had become relatively high.

Moorsteen has worked out an explanation of this in economic terms that can be most readily understood by study of the accompanying chart [*see illustration on preceding page*]. In essence the explanation suggests that the difference between the Soviet G.N.P. index in 1928 prices and the index in 1937 prices is a measure of the economy's changed capacity for the production of various product mixes—for example mixes with different proportions of food and machinery. For the 1928–1937 period the difference reflects a great increase in capacity for producing mixes containing a large proportion of machinery and a relatively small increase in capacity for mixes containing a large proportion of food. This radical shift in the Soviet economy's production capabilities helps to explain the nation's exceptionally high economic growth rate over the period 1928–1966, as we shall see. It represents the transformation of the economy from one suited chiefly for the production and processing of agricultural raw materials into one with a large capacity for the production of investment goods, thus opening the way to rapid growth.

Since 1937 the U.S.S.R. has apparently not undergone disproportionate shifts in its production capacities such as occurred during the 1928–1937 period (apart from capacity for large-scale military production, as in World War II). In peacetime years in the post-1937 period the behavior of G.N.P. in the U.S.S.R. shows little sensitivity to price weights; it is much the same whether we measure it in 1937, 1950 or 1958 prices. It seems reasonable, therefore, to use 1937 prices as weights for all of the period following 1937.

Two long-term calculations, then, have been made, one measuring the growth of G.N.P. throughout the entire 1928–1966 period in 1937 prices, the other using 1928 prices for the period up to 1937, and 1937 prices for the period thereafter. The estimate employing 1937 prices throughout can be interpreted as measuring the growth of the economy's capacity to produce the preindustrialization product mix before 1937 and the postindustrialization mix thereafter. This

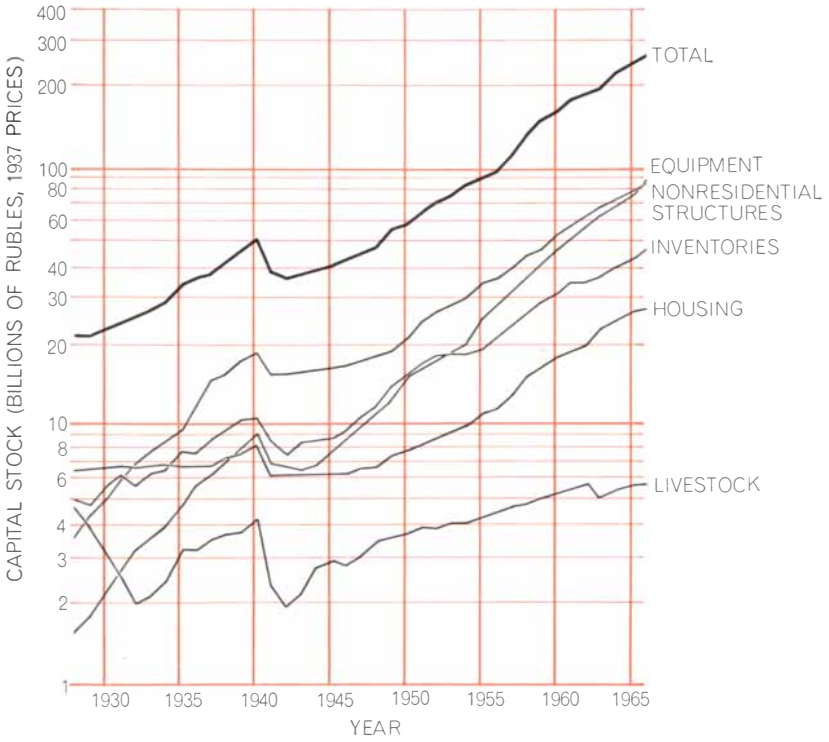
calculation puts the average annual growth rate over the 38-year period at 5.4 percent. The other method can be taken as measuring production capacity for the postindustrialization mix from the beginning. In this computation the growth rate comes out at 6.7 percent.

Both figures are substantially below the U.S.S.R.'s official account of growth during the same period. Its official reports of the increase in national income (which is akin to but not identical with our G.N.P. concept) put the annual growth rate over the period at 9.2 percent. The discrepancy between the official version and our estimates involves a number of possible explanations, but the significant conclusion is that our estimates, although they are lower, imply that the U.S.S.R.'s economic growth has been remarkably rapid.

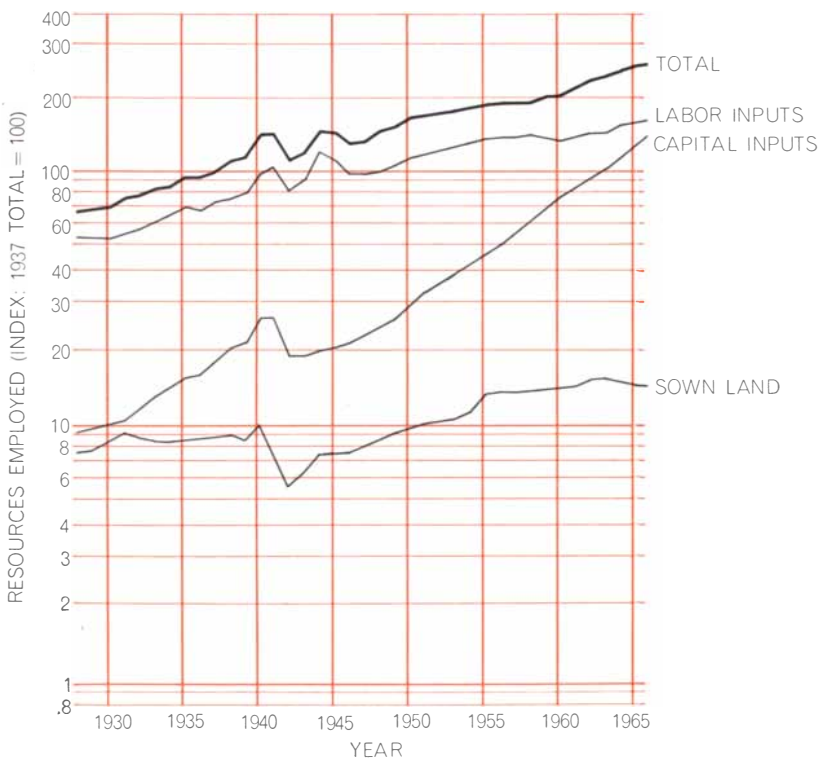
Over the same 38-year period the growth of the U.S. economy has averaged 3.3 percent per year, which is far behind the Soviet rate whether we take 5.4 percent or 6.7 percent as the representative figure for that rate. Even in the years since 1958, when Soviet growth has slowed somewhat and the U.S. economy has recovered from the trough of the 1958 recession, the Soviet economy has outgrown ours, with an annual rate of 6.1 percent to our 4.8 percent. To find rates of sustained growth (apart from episodes such as recoveries from war or depression) in the capitalist world that are comparable to the Soviet record one must go back to historical instances such as the U.S. in the 1870's and 1880's, Australia in the 1860's and 1870's and Japan in the 1920's and 1930's. Even those growth rates were only on the order of 5 or 5.5 percent. Taking into account the fact that the U.S.S.R.'s growth was set back severely by World War II and that its average annual rate for the 38-year period since 1928 nevertheless ranges between 5.4 and 6.7 percent, the Soviet accomplishment appears to be essentially unprecedented.

How did the Russians do it? Economic growth depends generally on two factors: increases in the supply of productive resources (which include labor, capital and natural resources) and improvements in techniques of production or technology. We have no direct measure of the rate of change of Soviet technology over the period in question. We can, however, estimate the increase in resources, and, as we shall see, something about the relative role of technology can be inferred from this information and the behavior of G.N.P.

In terms of man-years (adjusting for



CAPITAL STOCK has grown rapidly, reflecting a large increase in the share of Soviet G.N.P. allotted to investment, or expenditures for new capital. The rise in the stock is even sharper in 1928 prices than in the 1937 prices used here. Equipment has grown faster than 11 percent per year in spite of serious losses in World War II. Data are for end of each year.



TOTAL RESOURCES EMPLOYED are calculated by adding the three components, in 1937 prices, logarithmically: the logarithm of the total equals the weighted sum of the logarithms of components. Labor inputs are weighted for agricultural-industrial differences in quality, component capital inputs according to their service lives at an assumed 8 percent interest rate. Inputs of natural resources are represented by the acreage of sown agricultural land.

changes in the length of the work year over the period studied) labor employed in the Soviet economy grew at an annual rate of 2.2 percent. This was twice the rate of growth of the population, which was held down by a decline in the birth-rate and by losses in the famine of the early 1930's and still larger losses in World War II. The proportion of the population engaged in work was increased, however, by absorption of the considerable urban unemployment and rural underemployment that had existed in 1928, by a rise in the percentage of the population in the employable ages and by a marked increase in the employment of women in all capacities from heavy manual labor to the professions. To the increase in the number of workers we must add an improvement in the quality of the work force that resulted from the government's large expenditures on schools and universities and from the acquisition of skills by peasants who moved from farms to factories. Using the shift from agricultural to nonagricultural work as a rough guide, we estimate the increase in total labor inputs, adjusted for quality changes, at 2.8 percent per year—a notably high rate. It is interesting to note, however, that as late as 1966 more than a third of the Soviet work force was still engaged in agriculture, compared with only about 5 percent in the U.S.

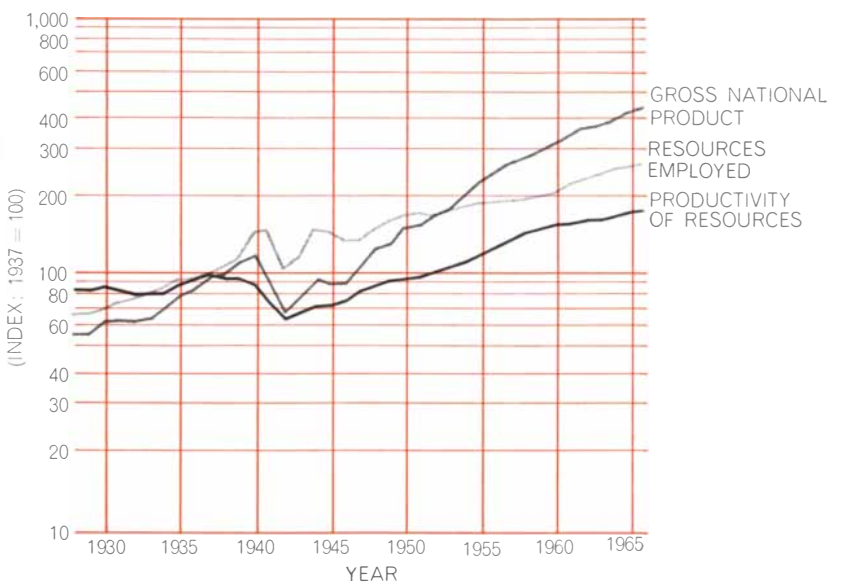
When we look at the growth of the capital stock (which includes equipment, housing, nonresidential construction, inventories and livestock), we find what is doubtless the single most distinctive element of the process by which the U.S.S.R. has attained its growth. Over the 38-year period the capital stock rose at an extraordinary rate, increasing by 6.5 percent per year. Annual expenditures on new capital (gross investment), measured in 1937 prices, accounted for a progressively larger share of G.N.P.; from 8 percent of G.N.P. in 1928, investment rose to 21 percent in 1937, fell off during the war and then resumed its rise until it reached 31 percent of G.N.P. in 1958, at which level it has been stabilized since. In the postwar period in particular the rate of accumulation of capital in the U.S.S.R. has been phenomenal: between 1950 and 1966 the nation's total capital stock quadrupled.

The great increase in the investment share was of course obtained largely at the expense of personal consumption. Statistical calculations indicate that per capita consumption in the U.S.S.R. rose materially over the 38-year period. In large part, however, this was because of a reduced number of dependents per worker and the shift of workers from farms to higher-paying urban employment. For these reasons a better measure of the fruits derived by the population from the industrialization of the economy may be provided by the trend in real wages in the principal sectors of the economy. A careful study by Janet Chapman of the University of Pittsburgh indicates that the real wages of urban workers in the U.S.S.R. declined after 1928 and did not regain the 1928 level until about 1958. Farm workers' earnings probably followed a similar course. Hence it appears that the ordinary Soviet worker has begun only within recent years to reap benefits in terms of his personal consumption from the rapid growth of the economy as a whole.

The third factor to be considered is the increase in the use of natural resources. The U.S.S.R.'s exploitation of resources such as coal, oil, iron ore and timber has no doubt increased enormously over the past four decades, but we have no acceptable way of estimating the increase. The only natural-resource input we can measure with any accuracy is that of land. In the 38-year period the U.S.S.R. increased the area of sown agricultural land by more than 80 percent, or at the rate of about 1.6 percent per year. Major additions came from the nation's gains of territory in 1939–1940 and from Premier Khrushchev's program of plowing up the "virgin lands" in the 1950's.

What was the combined contribution of the three kinds of resources—labor, capital and land—to the growth in G.N.P.? In principle we can approximate this by adding the three together with weights equal to their respective earnings in the weight year. We are confronted, however, with the difficulty that in this socialist state interest has not been paid on capital (at least until the past year or two) and rent is not paid on land. As a basis for estimating the earnings that should be assigned to capital we have chosen two alternative figures as low and high limits for the interest rate; the low figure, based on the rate of yield in advanced Western countries, is 8 percent and the upper figure is 20 percent. For the rental earnings to be assigned to agricultural land we have used a figure of 40 percent of the total wages paid to farm labor, which is the proportion paid in rent on farmland in the U.S.

We can then calculate that in terms of 1937 prices the combined growth of all resources over the 38-year period was 3.5 percent per year if we assume an 8 percent interest rate on capital, or 4.3 percent per year if we use a 20 percent interest rate. Comparing this range (3.5 and 4.3 percent) with the range of our two estimates of the growth of G.N.P. (5.4 to 6.7 percent), we find that the growth of resources would appear to account for somewhere between one-half



PRODUCTIVITY OF TOTAL RESOURCES is calculated by dividing G.N.P. by total resources employed. It reflects, among other things, technological change. With alternative prices and interest rates (1937 prices and an 8 percent rate are used here) the rate of increase in productivity ranges from .3 to 3.1 percent. As suggested by the chart, increased productivity appears to have contributed less to growth of G.N.P. than the increase in resources.

APARTMENT AND OFFICE BUILDINGS are under construction along Kalinin Avenue in Moscow. Nonresidential construction has been a fast-growing component of the Soviet economy since 1928 but housing was largely disregarded until after World War II.

and four-fifths of the G.N.P. growth. If we measure resources in 1928 prices for the period before 1937 and in 1937 prices for the period thereafter, the alternative growth rates for total resources are 3.9 and 5.1 percent (depending on which interest rate we use), and in that case the apparent contribution of resources to the growth in G.N.P. is between three-fifths and nine-tenths.

This admittedly crude estimate of the size of the contribution that increased resources have made to the U.S.S.R.'s economic growth represents probably the most important lesson that can be drawn from our data on the Soviet experience. Allowing for the various uncertainties in the data and in our inferences, the estimate still suggests that more than half and perhaps upward of three-quarters of Soviet growth has been achieved by the essentially mechanical and ruthless process of forcing out of the economy ever greater supplies of productive resources.

Dividing G.N.P. by an index of total resources, we can obtain an index of the overall productivity of the Soviet economy per unit of resources [*see illustration on opposite page*]. The results indicate that productivity has increased at the rate of somewhere between .3 and 3.1 percent per year over the 38-year period. Somewhat similar calculations show that in the long run the annual increase of productivity in the U.S. has been on the order of 1.5 to 2 percent. Estimates of present levels of productivity in the U.S. and the U.S.S.R. indicate that the productivity of resources in the U.S.S.R. remains far below that in the U.S. Such productivity calculations as these reflect, among other things, the level or the rate of change of technology.

As a late starter in the move to industrialization the U.S.S.R. had the advantage of being able to borrow advanced techniques already developed elsewhere. It sent men to the West for training, brought in Western technicians, mined the Western technical literature and imported prototype machines and even entire factories. Under these circumstances it is somewhat puzzling that the rate of increase of productivity and its present level are not higher. It may be that for an underdeveloped country the difficulties of borrowing advanced techniques and adapting them to the country's own needs and resources are greater than is commonly supposed. It also appears possible that the Soviet authorities may have handled the borrowing badly, by concentrating excessively on a few industries (and on military and space projects), permitting themselves such irrational commitments as Lysenkoism in agriculture and creating obstacles to the introduction of new techniques at the operating level. Indeed, in view of all the problems and difficulties one might conclude that the rate of increase in the productivity of resources in the Soviet economy has been surprisingly high.

This is so particularly because the Soviet economy is known to be highly inefficient, in the sense that it has consistently fallen short of its production possibilities. Inefficiency, however, is not necessarily incompatible with rapid growth as long as the degree of inefficiency does not rise markedly over a period of time. Furthermore, by reducing its inefficiencies such an economy can produce spurts of extraordinary growth. The U.S.S.R.'s rapid rise in productivity in the late 1950's, for example, may well have been due in part to the fact that the economy was recovering from the extraordinarily low level of efficiency at which Stalin had left it. It is significant that Premier Kosygin declared that improvement of efficiency was the objective of the economic reforms he initiated in 1965, and that improved efficiency was meant to reverse the slowdown of recent years in Soviet economic growth.

It will be understood that these observations on the sources of Soviet growth are highly tentative, as are most explanatory hypotheses in economics. While a reworking of the estimates of Soviet growth rates is unlikely unless large quantities of new data are released, analysis of the Soviet growth process has only begun, and new or revised explanations of it are bound to be put forward.

Transplanted Nuclei and Cell Differentiation

The nucleus of a cell from a frog's intestine is transplanted into a frog's egg and gives rise to a normal frog. Such experiments aid the study of how genes are controlled during embryonic development

by J. B. Gurdon

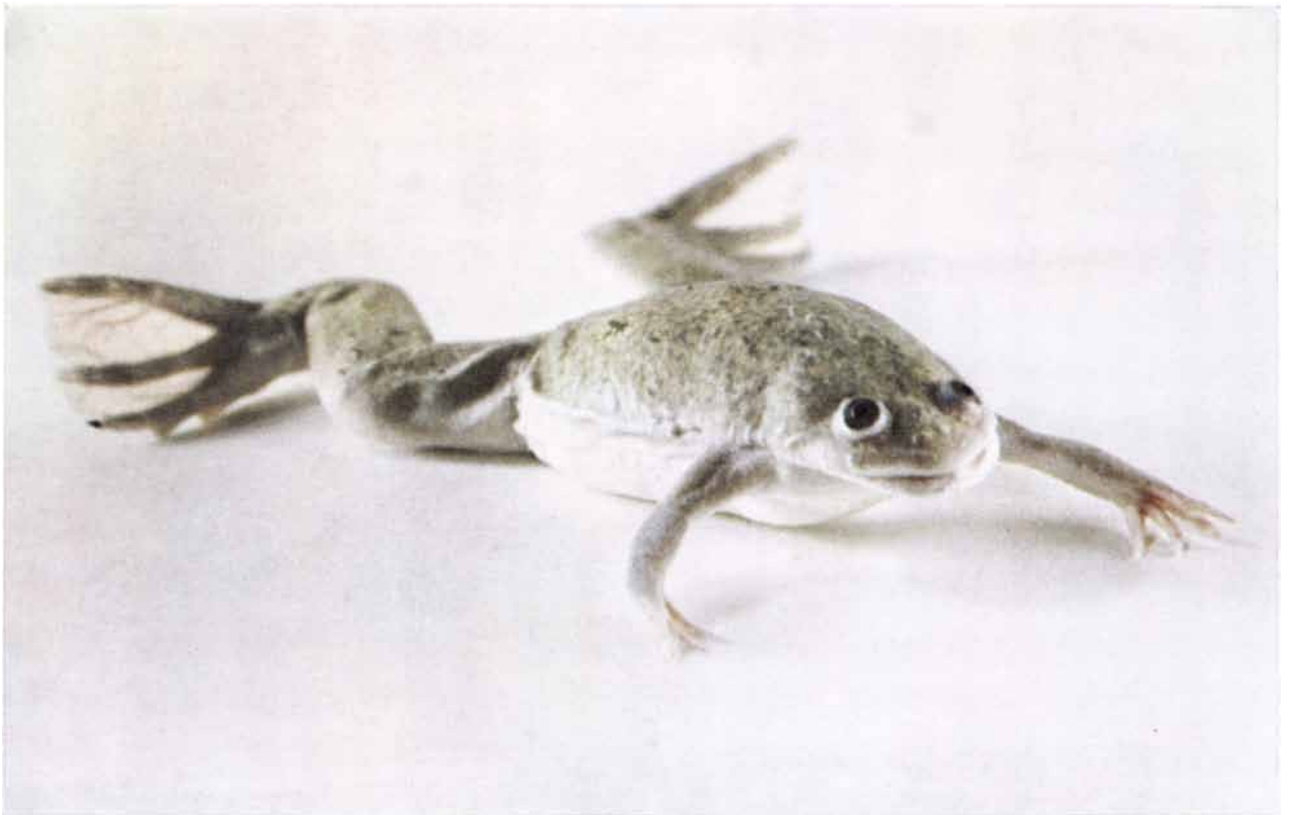
The means by which cells first come to differ from one another during animal development has interested humans for nearly 2,000 years, and it still constitutes one of the major unsolved problems of biology. Much of the experimental work designed to investigate the problem has been done with amphibians such as frogs and salamanders because their eggs and embryos are comparatively large and are remarkably resistant to microsurgery. As with most animal eggs, the early events of amphibian development are largely independent of the environment, and the processes leading to cell differentiation must involve a redistribution and interaction of constituents already present in the fertilized egg.

Several different kinds of experiment have revealed the dependence of cell differentiation on the activity of the genes in the cell's nucleus. This is clearly shown by the nonsurvival of hybrid embryos produced by fertilizing the egg of one species (after removal of the egg's nucleus) with the sperm of another species. Such hybrids typically die before they reach the gastrula stage, the point in embryonic development at which major cell differences first become obvious. Yet the hybrids differ from nonhybrid embryos only by the substitution of some of the nuclear genes. If gene activity were not required for gastrulation and further development, the hybrids should survive as well as nonhybrids. The importance of the egg's non-nuclear material—the cytoplasm—in early development is apparent in the consistent relation that is seen to exist between certain regions in the cytoplasm of a fertilized egg and certain kinds or directions of cell differentiation. It is also evident in the effect of egg cytoplasm on the behavior of chromosomes [see "How Cells Specialize," by Michail Fischberg and Antonie W. Blackler; SCIENTIFIC AMERICAN, September, 1961]. Such facts have justified the belief that the early events in cell differentiation depend on an interaction between the nucleus and the cytoplasm.

Nuclear transplantation is a technique that has enormously facilitated the analysis of these interactions between nucleus and cytoplasm. It allows the nucleus from one of several different cell types to be combined with egg cytoplasm in such a way that normal embryonic development can take place. Until this technique was developed the only kind of nucleus that could be made to penetrate an egg was the nucleus of a sperm cell, and this was obviously of limited use for an analysis of those interactions between nucleus and cytoplasm that lead to the majority of cell differences in an individual.

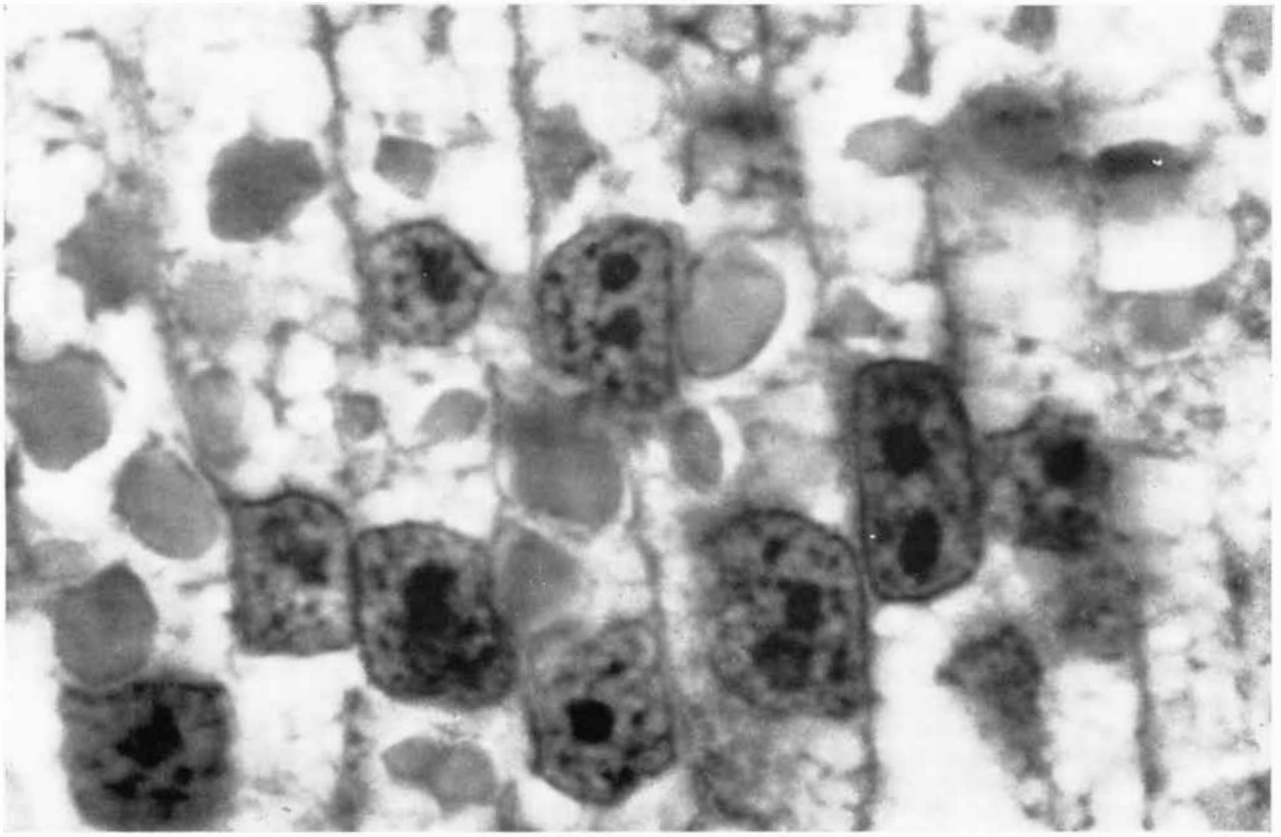
The technique was first applied to the question primarily responsible for its development. The question is whether or not the progressive specialization of cells during development is accompanied by the loss of genes no longer required in each cell type. For example, does an intestine-cell nucleus retain the genes needed for the synthesis of hemoglobin, the protein characteristic of red blood cells, and a nerve-cell nucleus the genes needed for making myosin, a protein characteristic of muscle cells? If unwanted genes are lost, the possibility exists that it is the progressive loss of different genes that itself determines the specialization of cells, as August Weismann originally proposed in 1892. The clearest alternative is that all genes are retained in all cells and that the genes are inactive in those cells in which they are not required. Before describing the nuclear-transplant experiments that distinguish between these two possibilities, we must outline the methods used to transplant living cell nuclei into eggs.

The aim of a nuclear-transplant experiment is to insert the nucleus of a specialized cell into an unfertilized egg whose nucleus has been removed. Ingenious attempts in this direction were made many years ago by constricting an egg just after fertilization and then letting one of the early-division nuclei that appeared in the nucleated half of the egg enter the non-nucleated half. This method, however, is applicable only to the nuclei of early embryos whose cells are not normally regarded as being specialized. The first real success in transplanting living cell nuclei into animal eggs was achieved in 1952 by Robert W. Briggs and Thomas J. King, both of whom were working at the Institute for Cancer Research in Philadelphia. Their method, which has been generally adopted in subsequent work, involves three steps [*see illustration on page 27*]. Owing to the fortunate circumstance that the unfertilized egg of an amphibian has its nucleus (in the form of chromosomes) located just under the surface of the egg at a point visible through the microscope, it is not difficult to obtain an egg with no nucleus. This can be done by removing the region of the egg that contains chromosomes with a needle or by killing the nuclear material with ultraviolet radiation. The second step is to dissociate a tissue into separate cells,

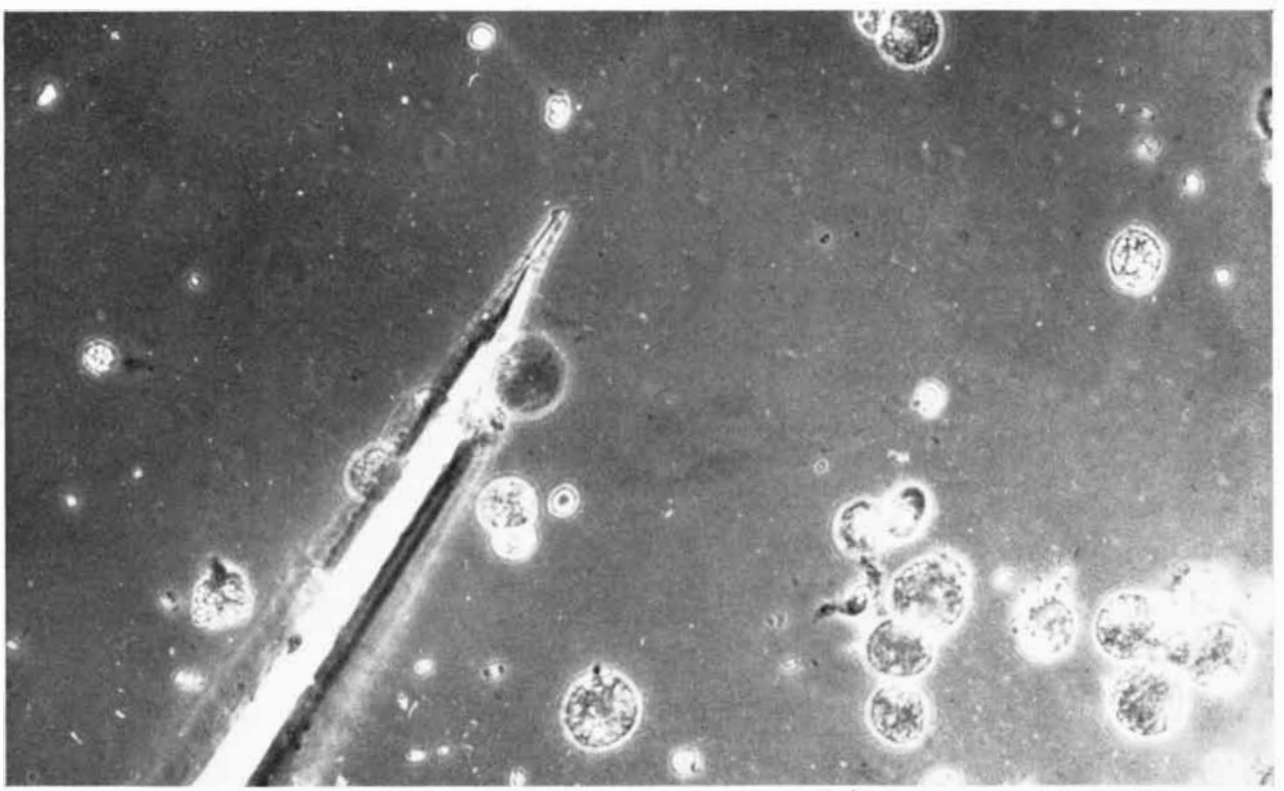


NORMAL FROG was raised in the author's laboratory at the University of Oxford from an egg that had been fertilized in the usual way by a sperm. The frogs used in the experiments described in this article were the South African clawed species *Xenopus laevis*.

TRANSPLANT FROG was raised from an egg cell from which the nucleus had been removed and into which the nucleus of an intestine cell had been transplanted. The frog is normal in all respects, indicating that intestine-cell nucleus has full range of genes.



DONOR CELLS used in the author's transplant experiments were taken from the epithelial layer of intestine. The micrograph shows the cells' characteristic columnar shape, central nucleus and yolk contents. Cells will be dissociated in preparation for transplant.



SINGLE NUCLEI from intestine epithelium cells are obtained for transplanting by sucking the whole cell into a micropipette (*left*). Smaller in diameter than the cell, the pipette breaks the cell wall; only the nucleus and a coating of cytoplasm enter the host egg.

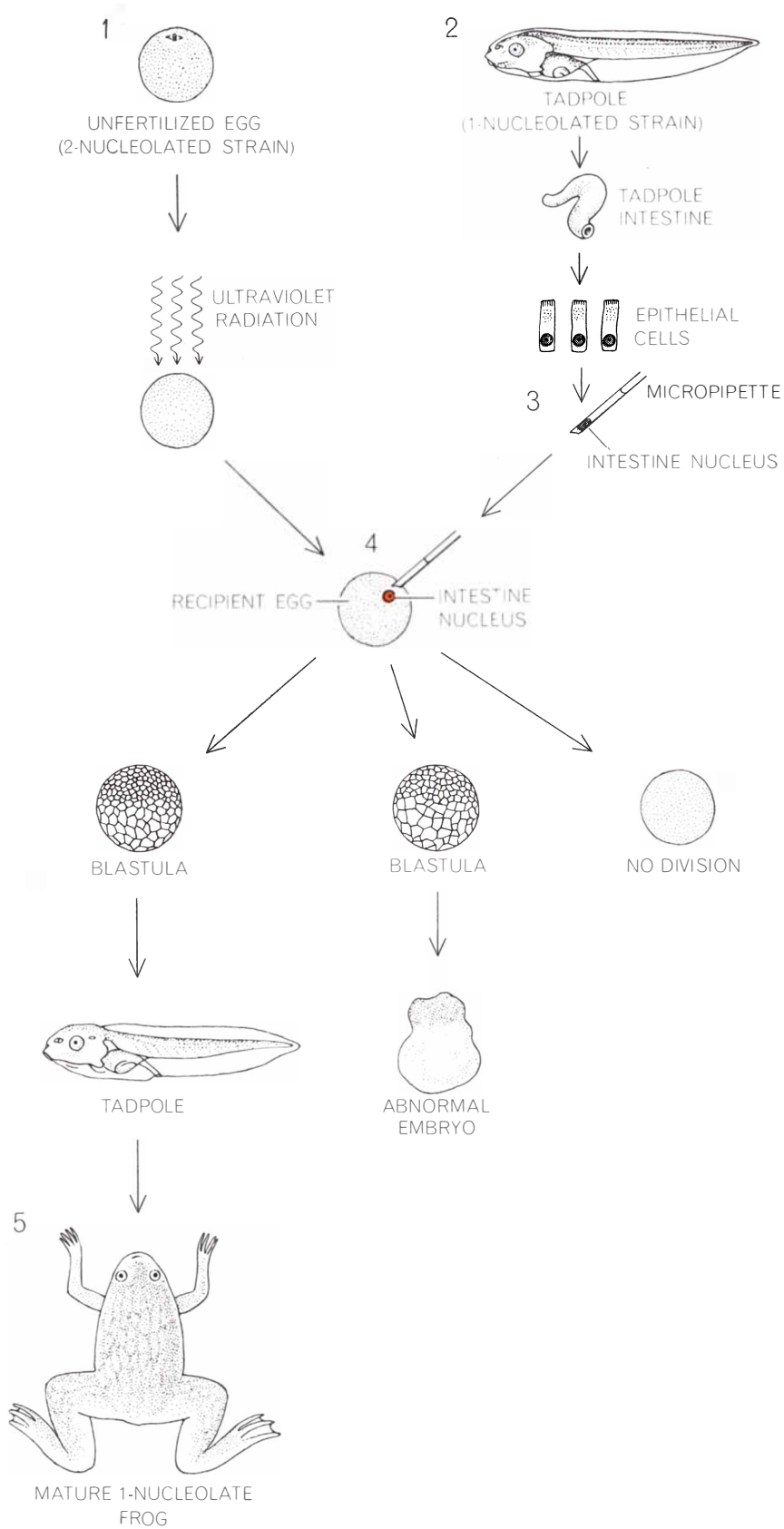
each of which can be used to provide a donor nucleus for transplantation. The cells separate from one another in a medium lacking calcium and magnesium ions, which are removed from the embryo more quickly by adding to the medium a chelating substance such as Versene.

The third and most difficult stage in the procedure involves the insertion of the donor-cell nucleus into the enucleated egg. Briggs and King found that this can be done by sucking an isolated cell into a micropipette that is small enough to break the cell wall but large enough to leave the nucleus still surrounded by cytoplasm. This compromise is required because the nucleus in an unbroken cell does not make the necessary response to egg cytoplasm, and conversely a bare nucleus without surrounding cytoplasm is readily damaged by exposure to any artificial medium. The broken cell with its cytoplasm-protected nucleus is injected into the recipient egg. The amount of donor-cell cytoplasm injected is very small and does not have any effect.

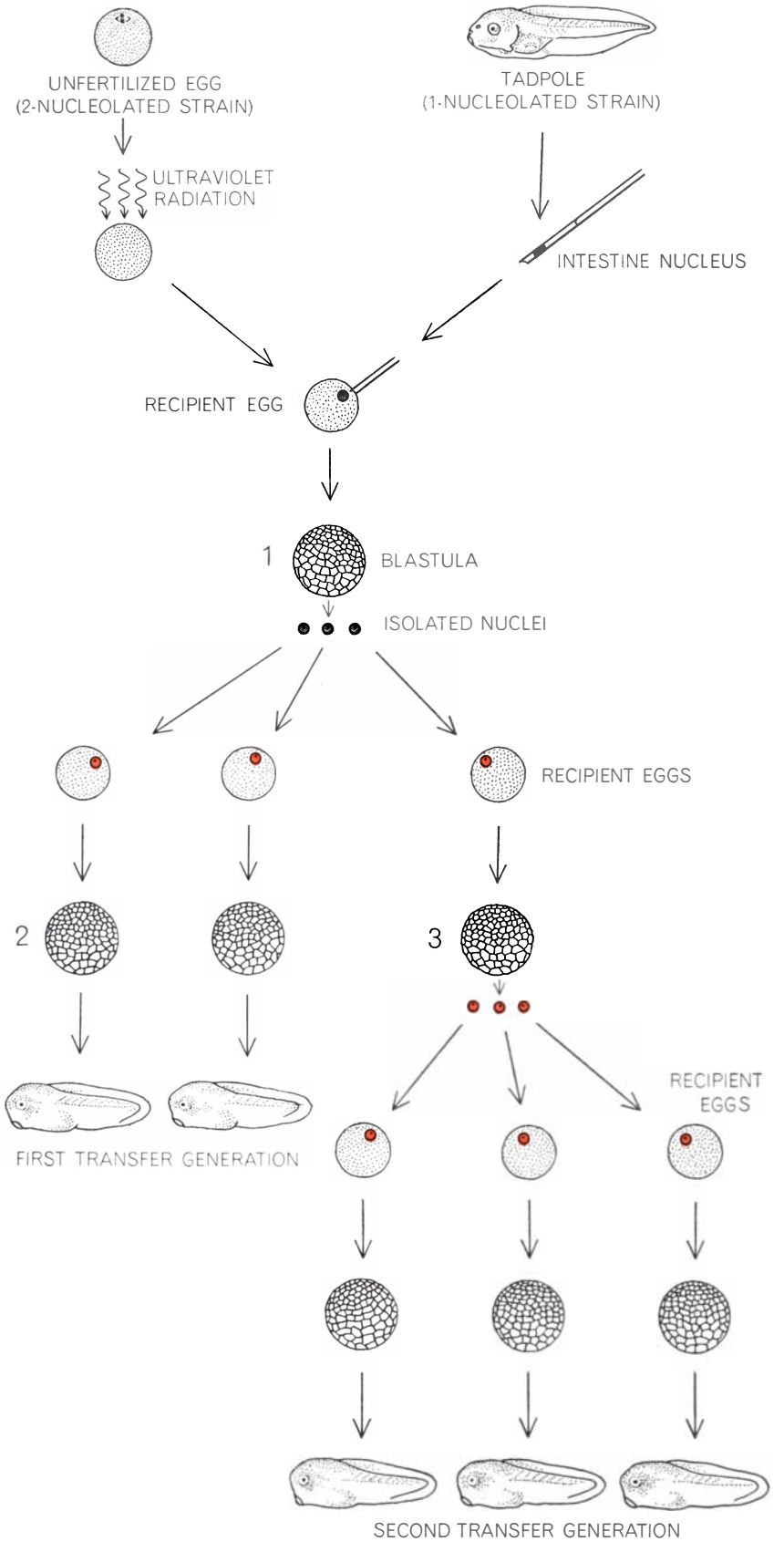
A useful extension of the basic nuclear-transplant technique is called serial nuclear transplantation. It involves the same procedure as the one just described except that instead of the donor nuclei being taken from the cells of an embryo or larva reared from a fertilized egg, they are taken from a young embryo that is itself the result of a nuclear-transplant experiment. The effect is the same as in the vegetative propagation of plants, namely the production of a clone: a population consisting of many individuals all having an identical set of genes in their nuclei.

One other feature of nuclear-transplant experiments is of the greatest importance for their interpretation. It is the use of a nuclear marker whereby the division products of a transplanted nucleus can be distinguished from those of the host egg nucleus. A nuclear marker is virtually indispensable where attention is to be paid to the development of a very small percentage of eggs that have received transplanted nuclei, since one cannot otherwise be sure that an occasional error in enucleation by hand or by ultraviolet irradiation has not occurred. Only by the presence of a marker in the nuclei of a transplant embryo does one have proof of its origin.

A nuclear marker must be replicated and therefore be genetic. One of the most useful for nuclear transplantation is found in a mutant line of the South African clawed frog *Xenopus laevis*, discovered at the University of Oxford by Mi-



TRANSPLANT PROCEDURE starts with preparation of a frog's unfertilized egg (*1*) for receipt of a cell nucleus by destroying its own nucleus through exposure to ultraviolet radiation. Next, intestine is taken from a tadpole that has begun to feed (*2*) and cells are taken from its epithelial layer. A single epithelial cell is then drawn into a micropipette; the cell walls break (*3*), leaving the nucleus free. The intestine-cell nucleus is transplanted into the prepared egg (*4*), which is allowed to develop. In some 1 percent of transplants the egg develops into a frog that has one nucleolus in its nucleus instead of the usual two (*5*).



SERIAL TRANSPLANTS, which follow the same first steps as the transplant illustrated on the preceding page, make use of embryos that have not developed normally. At the blastula stage (*1*) the abnormal embryo's cells are dissociated. The cells' genetically identical nuclei are then transplanted into enucleate eggs, giving rise to a clone: a population comprised of genetically identical individuals (*2*). The procedure can be continued indefinitely (*3*).

chail Fischberg. The nuclei of most normal frog cells contain two of the bodies called nucleoli; the nuclei of cells carrying the mutation never have more than one. This mutation is almost ideal as a nuclear marker because a sample of cells taken from any tissue at any developmental stage beyond the blastula (the hollow sphere from which the gastrula arises) can be readily classified as being mutant or not.

We can now return to the question of whether or not genes are lost in the course of normal cell differentiation. Nuclear-transfer experiments are performed to answer this question on the assumption that if the combination of egg cytoplasm with a transplanted nucleus can develop into a normal embryo possessing all cell types, then the transplanted nucleus cannot have lost the genes essential for pathways of cell differentiation other than its own. For example, if a normal embryo containing a specialized cell type such as blood cells can be obtained by transplanting an intestine-cell nucleus into an enucleated egg, then the genes responsible for the synthesis of hemoglobin cannot have been lost from the intestine-cell nucleus in the course of cell differentiation. The only assumption here is that a gene, once lost, cannot be regained in the course of a few cell generations. It happens that the best evidence for the retention of genes in fully differentiated cells comes from two series of experiments carried out at Oxford on eggs of the frog *Xenopus*.

The fully differentiated cells used for these experiments were taken from the epithelial layer of the intestine of mutant tadpoles that had begun to feed. Intestine epithelium cells have a "brush border," a structure that is present only in cells specialized for absorption and that is assumed to have arisen as a result of the activity of certain intestine-cell genes. Not all the cells of the intestine are epithelial, but when the epithelial cells are dissociated, they can be distinguished from the other cell types by their large content of yolk, by the ease with which they dissociate in a medium that contains Versene and sometimes by their retention of the brush border.

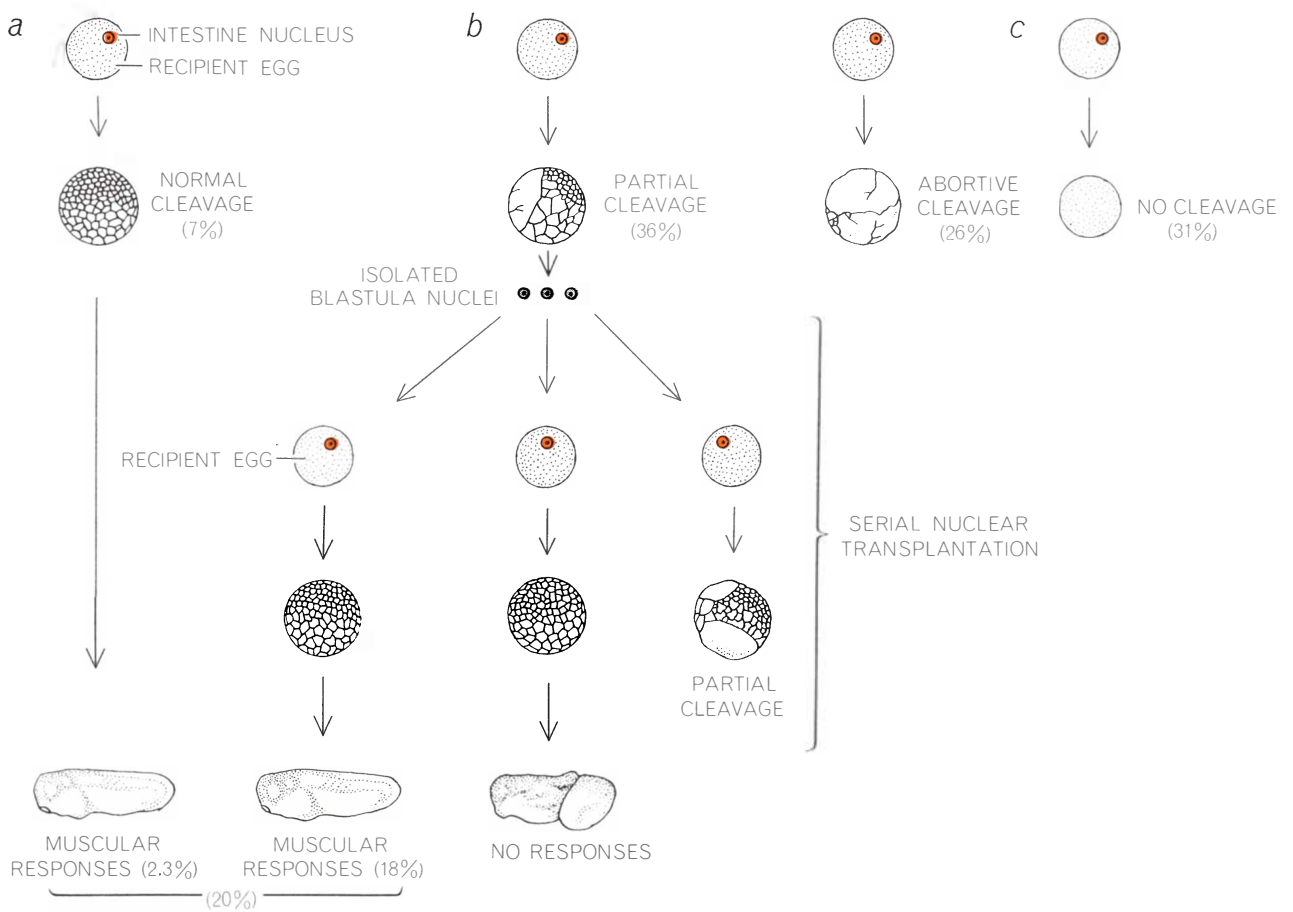
The first experiments with intestine-cell nuclei were designed to show that at least *some* of these nuclei possess *all* the genes necessary for the differentiation of all cell types, and therefore that some of the transplant embryos derived from intestine nuclei could be reared into normal adult frogs. Both male and female adult frogs, fertile and normal in

every respect, have in fact been obtained from transplanted intestine nuclei [*see bottom illustration on page 25*]. Although only about 1.5 percent of the eggs with transplanted intestine nuclei developed into adult frogs, all of these frogs carried the mutant nuclear marker in their cells; their existence therefore proves that at least some intestine cells possess as many different kinds of nuclear genes as are present in a fertilized egg.

Subsequent experiments with intestine nuclei were designed to show that *many* of these nuclei have retained genes required for the differentiation of at least *some* quite different cell types. In these experiments the criterion for gene retention was the differentiation of functional muscle and nerve cells by nuclei whose mitotic ancestors had already promoted the differentiation of intestine cells. Functional muscle and nerve cells are present in any nuclear-transplant embryo that shows the small twitching movements, or muscular responses, characteristic of developing tadpoles just before they swim. Out of several hundred intestine nuclear transfers, about 2.5 percent of the injected eggs developed as far as the muscular-response stage or further. The reason why the remainder did not reach this stage is not necessarily because that proportion of intestine nuclei lack the necessary genes. In some cases it is known to be the inability of certain recipient eggs to withstand injection; in others it is the incomplete replication of some of the transplanted nuclei or their daughter nuclei during cleavage. In either case a nuclear-transplant embryo should contain some cells with normal nuclei as well as some abnormal cells responsible for the early death of the embryo.

Serial nuclear transplantation offered a means of overcoming both difficulties. A sample of nuclear-transplant embryos whose development was so abnormal they would have died before reaching the muscular-response stage provided nuclei for serial-transplant clones. In 70 percent of the serial-transplant clones some of the embryos developed as far as the muscular-response stage or beyond it. By adding the proportion of nuclei shown by first transplants to be able to support muscular-response differentiation to the proportion shown by serial transplantation to possess this capacity, we can conclude that at least 20 percent of the intestine epithelium cells must have retained the genes necessary for muscle-cell and nerve-cell differentiation [*see illustration below*].

There is no reason to believe that muscle-cell or nerve-cell genes have been lost or permanently inactivated in the remaining 80 percent of transplanted intestine nuclei. There are many reasons why it might not have been possible to demonstrate their presence. For example, about 50 percent of all the eggs that received intestine nuclei failed to divide even once. When a sample of these eggs was sectioned, they were found to contain either no nucleus at all or else a nucleus that was still inside an intact intestine cell. In the first instance the nucleus presumably stuck to the injection pipette and was never deposited in the egg; in



NERVE AND MUSCLE TISSUE develop in nuclear-transplant embryos in some 20 percent of cases, showing that many nuclei of differentiated cells still possess the genes necessary for other kinds of function. The criterion of success is development of an embryo to the point at which small twitching motions are observed; this occurred in more than 2 percent of first transplants (*a*) and in 18 percent of serial transplants (*b*). Many eggs that failed to develop (*c*) contained either no transplant nuclei or still unruptured cells.

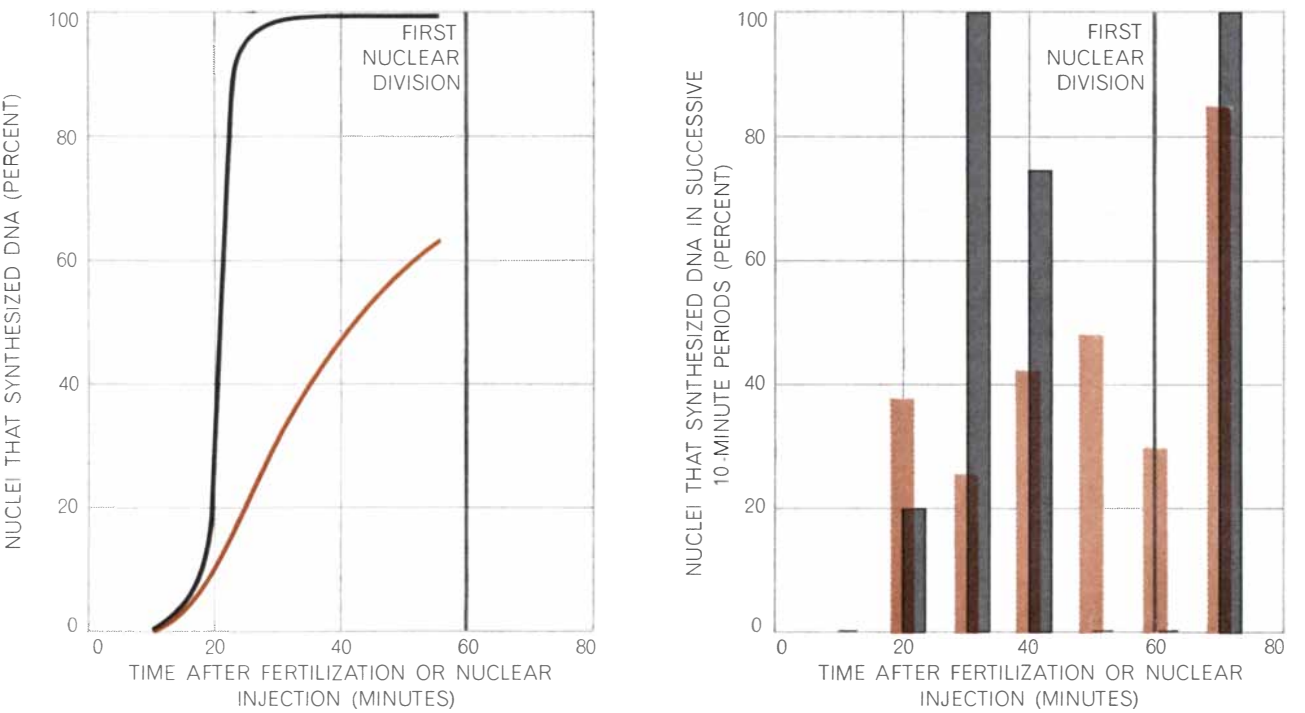
the second, the donor cell was never broken so as to liberate its nucleus, a technical error that is easy to make with very small cells. In both cases the developmental capacity of the intestine nuclei was not tested, and the recipient eggs that failed to divide should not be counted in the results.

It is clear from these experiments that the loss or permanent inactivation of genes does not necessarily accompany the normal differentiation of animal cells. This conclusion is not inconsistent with a recent finding: the "amplification" of the genes responsible for synthesizing the ribonucleic acid (RNA) of the subcellular particles called ribosomes. This phenomenon was demonstrated in amphibian oöcytes, the cells that give rise to mature eggs. The nuclear-transfer experiments just described do not exclude such amplification, which simply alters the number of copies of one kind of gene in a nucleus. Instead they show that specialized cells always have at least one copy of every different gene.

The inability of some transplanted nuclei to support normal development has attracted considerable interest because it is always found that the proportion of nuclei showing a restricted developmental capacity increases as the cells from which they are taken become differentiated. Furthermore, serial nuclear-transplant experiments conducted by Briggs and King (and subsequently by others) have shown that all the embryos in a clone derived from one original nuclear transplant often suffer from the same abnormality, whereas the embryos in a clone derived from another original transplant may suffer from a different abnormality. Some of the abnormalities of nuclear-transplant embryos can therefore be attributed to nuclear changes that can be inherited.

The discovery that these changes arise as a result of nuclear transplantation, and not in the course of normal cell differentiation, was an important one. This was first established by Marie A. DiBerardino of the Institute for Cancer Research, who made a detailed analysis of the number and shape of chromosomes in nuclear-transplant embryos. Abnormal embryos were usually found to suffer from chromosome abnormalities that were not present in the donor embryos, a finding that at once explains why the factors causing many of the developmental abnormalities of nuclear-transplant embryos are inherited. The fact that chromosome abnormalities arise after nuclear transplantation does not necessarily mean that they are of no interest; there could be a connection between the kind of chromosome abnormality encountered and the cell type of the donor nucleus concerned. In spite of an intensive search, however, no such relationship has yet been found.

The origin of these chromosome abnormalities is probably to be understood as an incompatibility between the very slow rate of division of differentiating cells—only one division every two days or more—and the rapid rate of division in an egg, which starts to divide (and causes any injected nucleus to try to divide) about an hour after injection. Unless an injected nucleus can complete the replication of its chromosomes within this brief period, they will be torn apart and broken at division. This concept is supported by the observation, made at Oxford in collaboration with my colleagues C. F. Graham and K. Arms, that many transplanted nuclei continue to synthesize the genetic material DNA right up to the time of the first nuclear division, whereas sperm and egg nuclei always complete this synthesis well be-

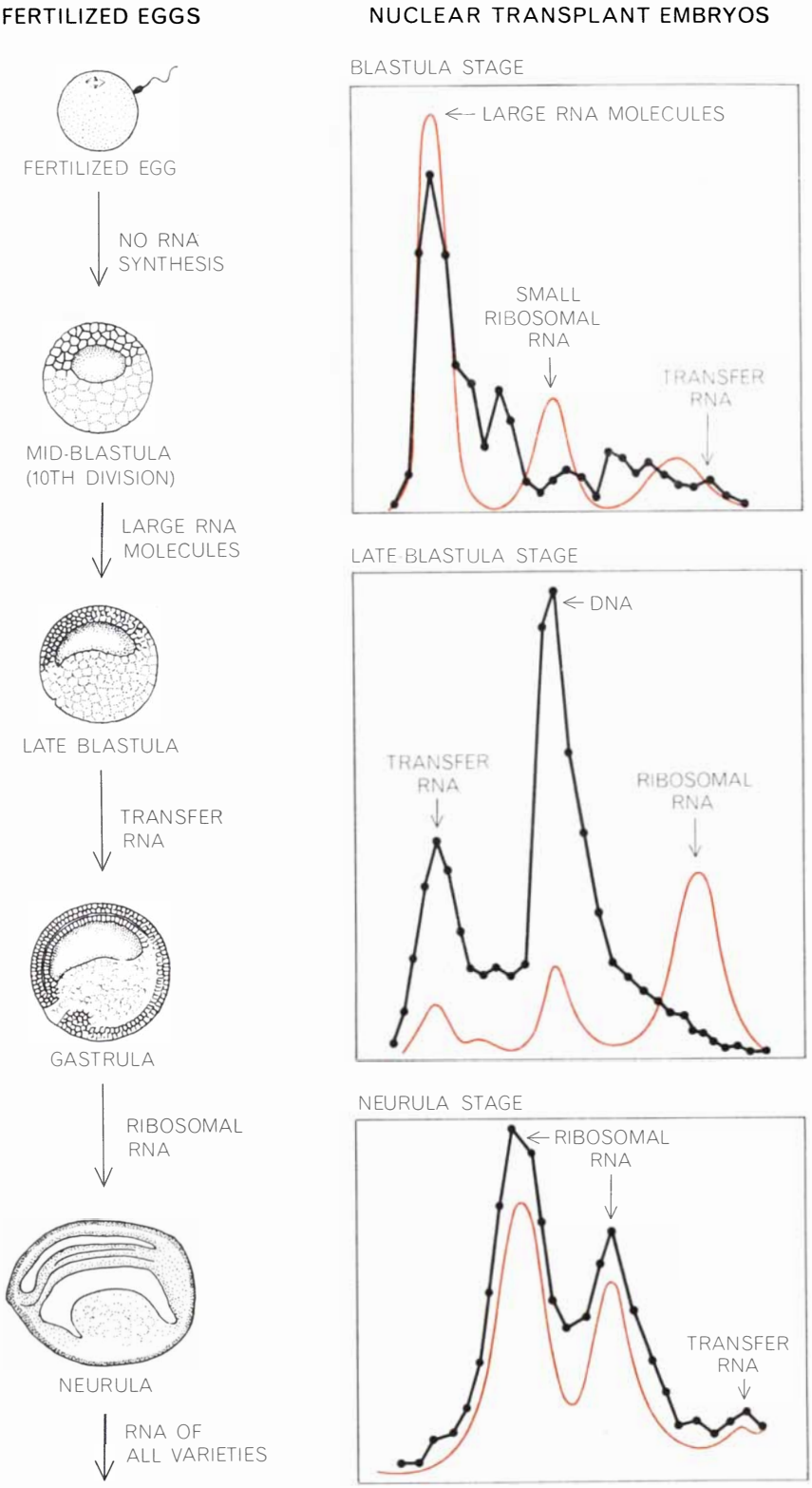


RATE OF REPLICATION of the chromosomes in a transplanted nucleus is slower than the rate in the nucleus of a normally fertilized egg, as is seen when DNA synthesis by each is compared (*left*). All egg nuclei had synthesized DNA within 30 minutes after fertilization (*black curve*), whereas some 30 percent of transplanted brain nuclei (*color*) had failed to do so by the time the first mitotic division of the nucleus took place. When the synthesis of DNA was assessed at 10-minute intervals (*right*), the nuclei of fertilized eggs (*black*) were found to have ceased synthesis, an indication of completed chromosome replication, before time for mitotic division. Some 30 percent of transplanted gastrula nuclei, however, were still making DNA (*color*). Failure of transplant nuclei to complete replication before division results in damage to the chromosomes as they are torn apart, producing abnormalities.

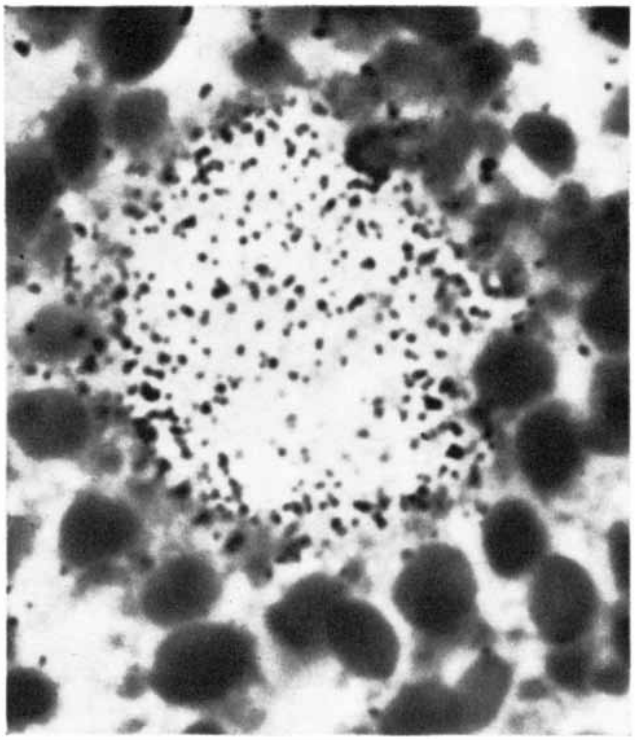
fore division. Presumably molecules associated with the DNA of specialized cells prevent the chromosomes of such cells from undergoing replication as rapidly as those of sperm nuclei, thereby leading to the chromosome abnormalities commonly observed in nuclear-transplant embryos.

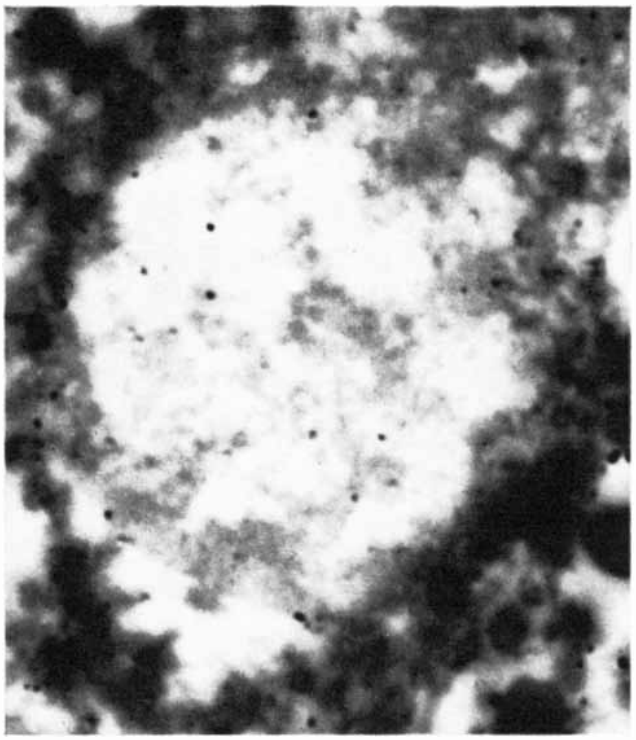
Having concluded that the specialization of cells involves the differential activity of genes present in all cells, rather than the selective elimination of unwanted genes, we can now consider how genes are activated or repressed during early embryonic development. Nuclear transplantation has been used to demonstrate that the signals to which genes or chromosomes respond are normal constituents of cell cytoplasm. This information has come from experiments in which the nucleus of a cell carrying out one kind of activity is combined with the enucleated cytoplasm of a cell whose nucleus would normally be active in quite another way. One of two results is to be expected: either the transplanted nucleus should continue its previous activity or it should change function so as to conform to that of the host cell to whose cytoplasm it has been exposed. For the purposes of these experiments changes in nuclear activity have to be recognized by the appearance of direct gene products and not by the much less direct criterion of the normality of nuclear-transplant embryo development. Many of these experiments have been carried out in collaboration with Donald D. Brown of the Carnegie Institution of Washington or with another of my Oxford colleagues, H. R. Woodland.

The first experiments were designed to find out if the different functions performed by any one gene—the synthesis of DNA, the synthesis of RNA and chromosome condensation in preparation for cell division—are determined by cytoplasmic constituents. Three kinds of host cell were used: unfertilized but activated eggs whose nucleus would normally synthesize DNA but no RNA; growing oöcytes in which the nucleus synthesized RNA but not DNA, and oöcytes maturing into eggs, in which situation the nucleus consists of condensed chromosomes arranged in the "spindle" of cell division, and synthesizes neither RNA nor DNA. Two kinds of test nuclei were used: nuclei from adult brain tissue, which synthesize RNA but almost never synthesize DNA or divide, and nuclei from embryonic tissue at the mid-blastula stage of development; mid-blastula nuclei do not synthesize RNA but

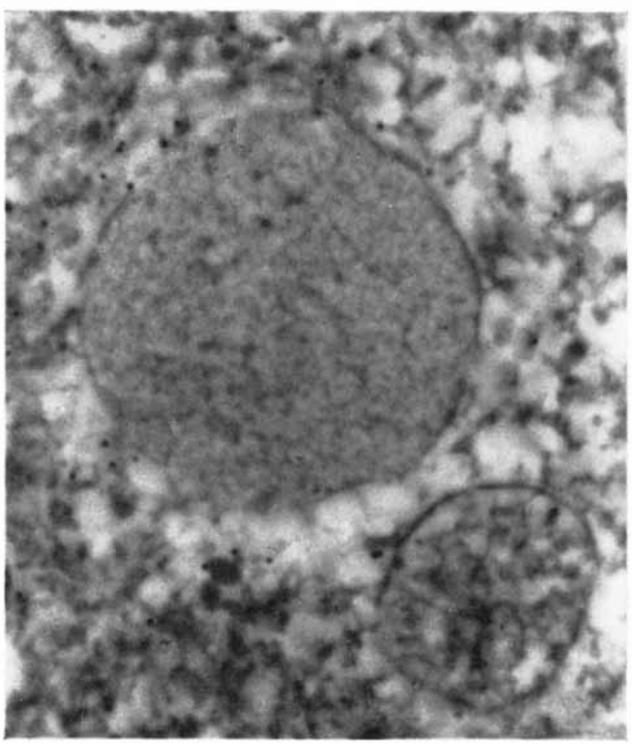


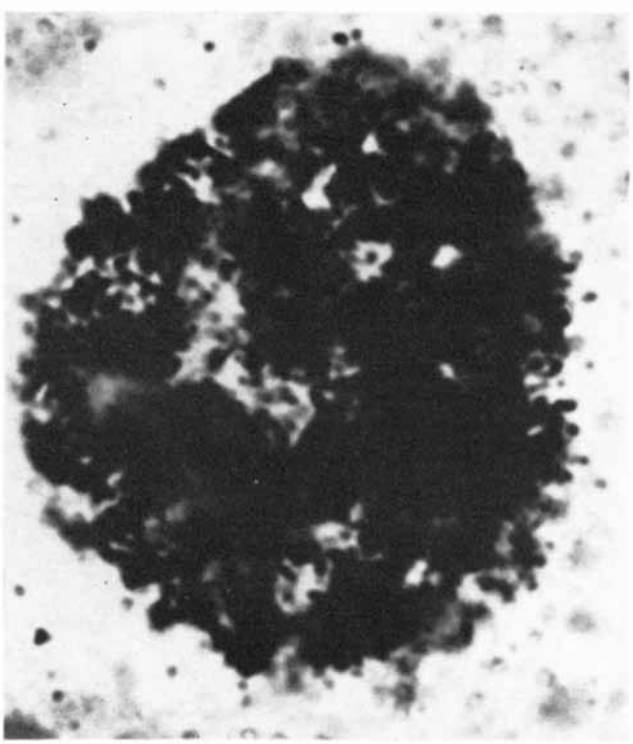
CYTOPLASMIC CONTROL of the activities of genes is demonstrated in a nuclear-transplant experiment. As a normal embryo develops (*left*), early growth stages are marked by the nuclear synthesis of different varieties of RNA. The nucleus of a cell from an embryo at the neurula stage, which synthesizes all varieties of RNA, is transplanted into an egg. At first the transplanted nucleus halts RNA synthesis. On reaching the blastula stage (*top right*) the nucleus starts to synthesize large RNA molecules. In this graph and the other ones the black curve indicates the extent to which radioactive precursors of various nucleic acids are incorporated. The quantity of preexisting nucleic acids is in red. At the late-blastula stage (*middle right*) transfer RNA, but not ribosomal RNA, is synthesized. By the neurula stage (*bottom right*) nucleic acid synthesis has gone on to include the making of ribosomal RNA.





CHANGE IN ACTIVITY of a transplanted nucleus to conform to the normal activity of the host cell's missing nucleus is shown in two photomicrographs. Nuclei from embryos at the mid-blastula stage of development, which synthesize DNA but not RNA, have been injected into an oöcyte (*left*) and an egg (*right*). Oöcytes, the cells that grow into eggs, synthesize RNA but not DNA; eggs do the opposite. A substance that is a precursor of RNA, labeled with a radioactive isotope, was injected simultaneously. The many black dots, formed by the radioactive precursor, show that the substance was incorporated in newly synthesized RNA in the oöcyte, a factor in the host cell's cytoplasm having altered the injected nuclei's activity. The nuclei in the egg, however, make no RNA.



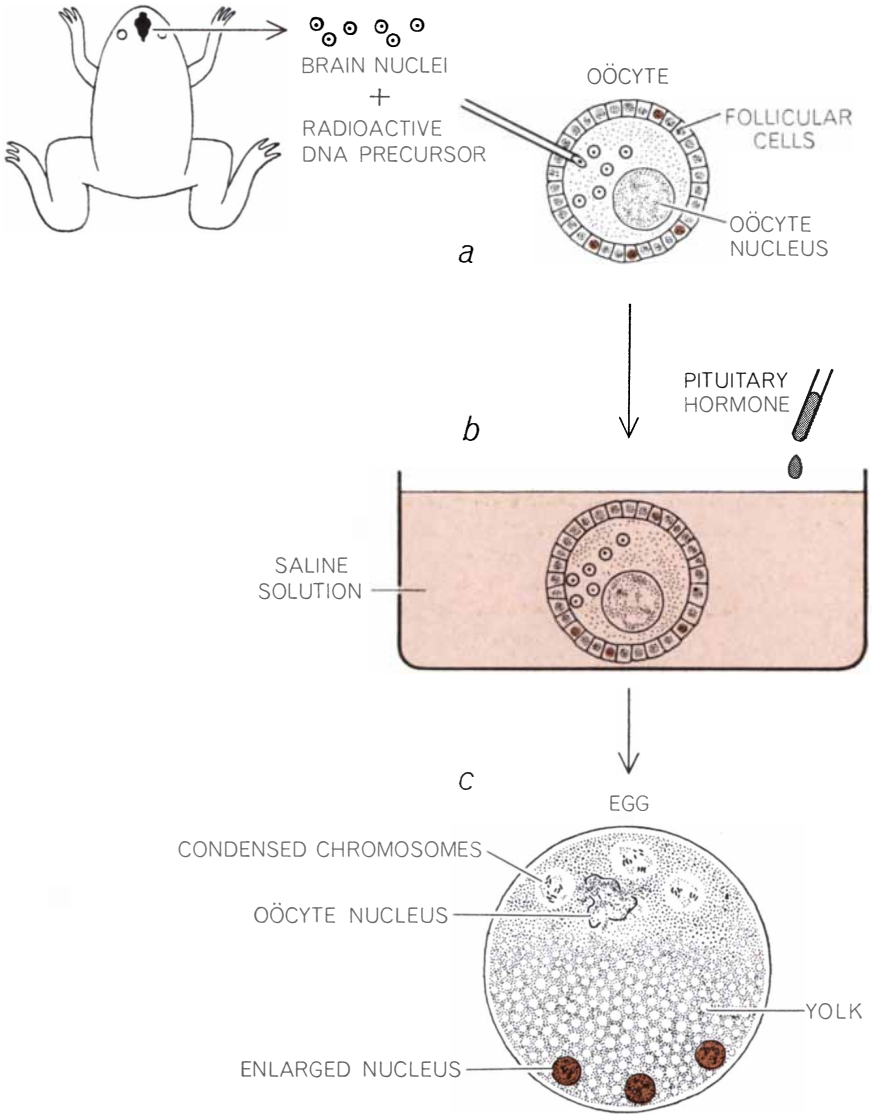


REVERSE RESULTS are shown in two other photomicrographs. The nuclei to be injected are from frog brain cells; they synthesize RNA but almost never DNA. The radioactively labeled precursor is one that is taken up only in DNA synthesis. In the oöcyte (*left*), where the synthesis of RNA is progressing, the nucleus contains no radioactive DNA. The intense radioactivity in the egg (*right*) shows that the injected brain nuclei have switched from RNA to DNA synthesis in response to a factor in the host cell's cytoplasm.

synthesize DNA and divide about every 20 minutes. For technical reasons it was desirable to inject each host cell with many nuclei, even though this can prevent the subsequent division of the injected cell. The results were clear: In all respects tested the transplanted nuclei changed their function within one or two hours so as to conform to the function characteristic of the normal host-cell nucleus [*see illustrations on opposite page*]. Mid-blastula nuclei injected into growing oöcytes stopped synthesizing DNA and dividing and entered a continuous phase of RNA synthesis that lasted for as long as the injected oöcytes survived in culture (about three days). Adult brain nuclei injected into eggs stopped RNA synthesis and began DNA synthesis. When the same nuclei were injected into maturing oöcytes, they synthesized neither RNA nor DNA but were rapidly converted into groups of chromosomes on spindles.

The next set of experiments was designed to find out if cytoplasmic components can repress or activate genes, that is, if they can select which genes in a nucleus will be active at any one time. Advantage was taken of the natural dissociation that exists in the time of synthesis of different classes of RNA during the early embryonic development of *Xenopus*. The work of several investigators has established the following sequence of events in *Xenopus* embryos. For the first 10 divisions after fertilization no nuclear RNA synthesis can be detected. Just after this—at the mid-late-blastula stage—the cells synthesize large RNA molecules, which are believed not to include ribosomal RNA but which are likely to include "messenger" RNA. Toward the end of the blastula stage "transfer" RNA synthesis is first detected; this is followed a few hours later, during the formation of the gastrula, by the synthesis of ribosomal RNA.

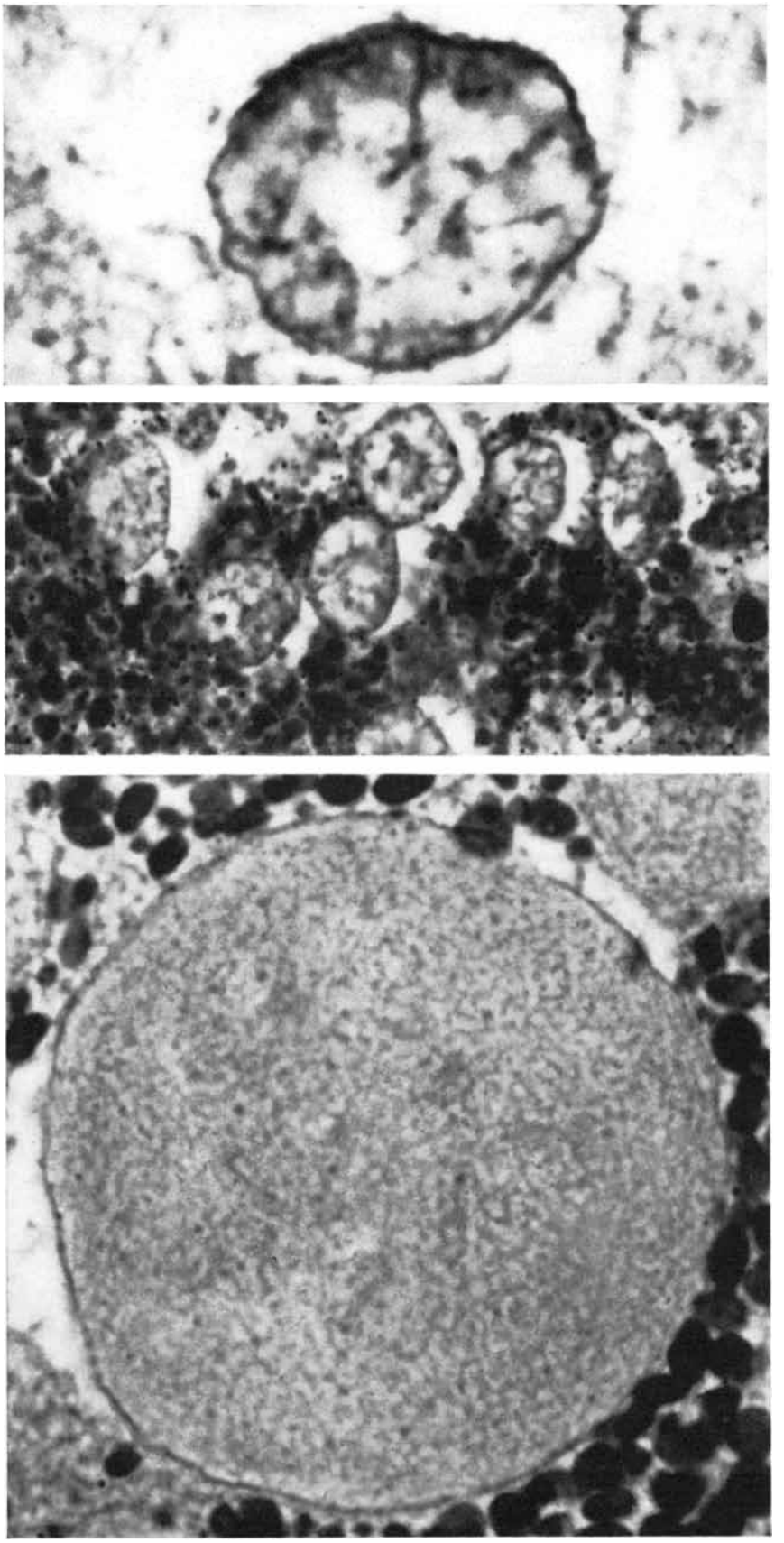
The extent to which these events are under cytoplasmic control has been investigated by transplanting into enucleated eggs single nuclei from embryonic tissue at the neurula stage of development, the one that follows the gastrula stage. As the nuclear-transplant embryos develop, RNA precursor substances that have been labeled with radioactive atoms (for example uridine triphosphate labeled with tritium, the radioactive form of hydrogen) are used to determine the classes of RNA being synthesized at each stage. Autoradiography has shown that a neurula nucleus, which synthesizes each main kind of RNA, stops all detectable RNA synthesis, that is, it no longer incorporates labeled RNA precursors, within an hour of transplantation into egg cytoplasm. Furthermore, chromatography and other kinds of analysis show that, when the transplant embryos are reared through the blastula and gastrula stages, they synthesize heterogeneous RNA, transfer RNA and ribosomal RNA in turn and in the same sequence as do embryos reared from fertilized eggs.



INDUCING FACTOR in egg cytoplasm that alters the activity of the nucleus was found to be absent at the oöcyte level of egg-cell development; when brain nuclei and labeled DNA precursor were injected into oöcytes (*a*), the nuclei did not synthesize DNA. After the oöcyte was brought to maturity (*b*), however, the inducing factor made its appearance (*c*). Brain nuclei near the oöcyte's ruptured nucleus underwent chromosomal condensation like that of the oöcyte nucleus. Brain nuclei in the yolky region began to synthesize DNA.

Taken together, these experiments have shown that changes in the type of gene product (for example the synthesis of RNA or DNA), as well as changes in the selection of genes that are active (for example the synthesis of different types of RNA), can be experimentally induced. Since a high proportion of transplanted neurula nuclei support entirely normal development, the results show that egg cytoplasm must contain constituents responsible for independently controlling the activity of different classes of genes in normal living nuclei.

We can now consider what is perhaps the most interesting question of all: What is the mechanism by which cytoplasmic components bring about changes in gene activity? Of the various changes in chromosome and gene activity that can be experimentally induced in transplanted nuclei, special attention has been devoted to the induction of DNA synthesis by egg cytoplasm. It is



BLASTULA NUCLEI swell up following their injection into an egg (*top*) or into an oöcyte (*bottom*). Within the oöcyte the enlargement may be as much as 200 times. The center micrograph shows blastula nuclei of normal dimensions; the bottom micrograph, a nucleus 48 hours after injection. Genetic material in the nucleus is dispersed during swelling.

easier to analyze than other changes, and it seems likely to exemplify certain general principles of cytoplasmic regulation in early embryonic development.

The origin of the cytoplasmic condition that induces DNA synthesis has been investigated by injecting adult brain nuclei, together with a radioactive labeling substance, into growing and maturing oöcytes. The inducing factor appears just after an increase in the level of pituitary hormone has caused an oöcyte to mature into an egg, an event that is accompanied by intensive RNA and protein synthesis [*see illustration on preceding page*].

Concerning the identity of the inducing factor, the first candidate to be considered was simply the presence of an adequate supply of DNA precursor substances. Woodland, however, has injected growing oöcytes with 10 times the amount of all four common DNA precursors believed to be present in the mature egg. One of the precursors, thymidine triphosphate, had been labeled with tritium. In spite of the availability of these precursors, the brain nuclei did not incorporate the labeled thymidine into DNA. Although this experiment requires further analysis before DNA precursors can be excluded as inducers of DNA synthesis, it encourages a search in other directions.

The next candidate to be considered was DNA polymerase, an enzyme that promotes the incorporation of precursor substances into new DNA in a way that is specified by the composition of the preexisting "template" DNA. DNA polymerase activity in living cells has been tested by introducing purified DNA and tritium-labeled thymidine into eggs. In collaboration with Max Birnstiel of the University of Edinburgh we have established that the injected DNA serves as a template for synthesis of the same kind of DNA. When DNA and labeled thymidine are introduced into oöcytes, no DNA replication can be detected. This means that the cytoplasmic factor inducing DNA synthesis in eggs includes DNA polymerase or something that activates this enzyme. It is doubtful, however, that this is the *only* constituent of the inducer. If it were, the injection of egg cytoplasm (which contains DNA polymerase) into oöcytes might be expected to induce DNA synthesis, a result that is not in fact obtained. This experiment, in which purified DNA is replicated in the cytoplasm of unfertilized eggs, also serves to demonstrate that constituents of injected brain nuclei other than their DNA are not required in

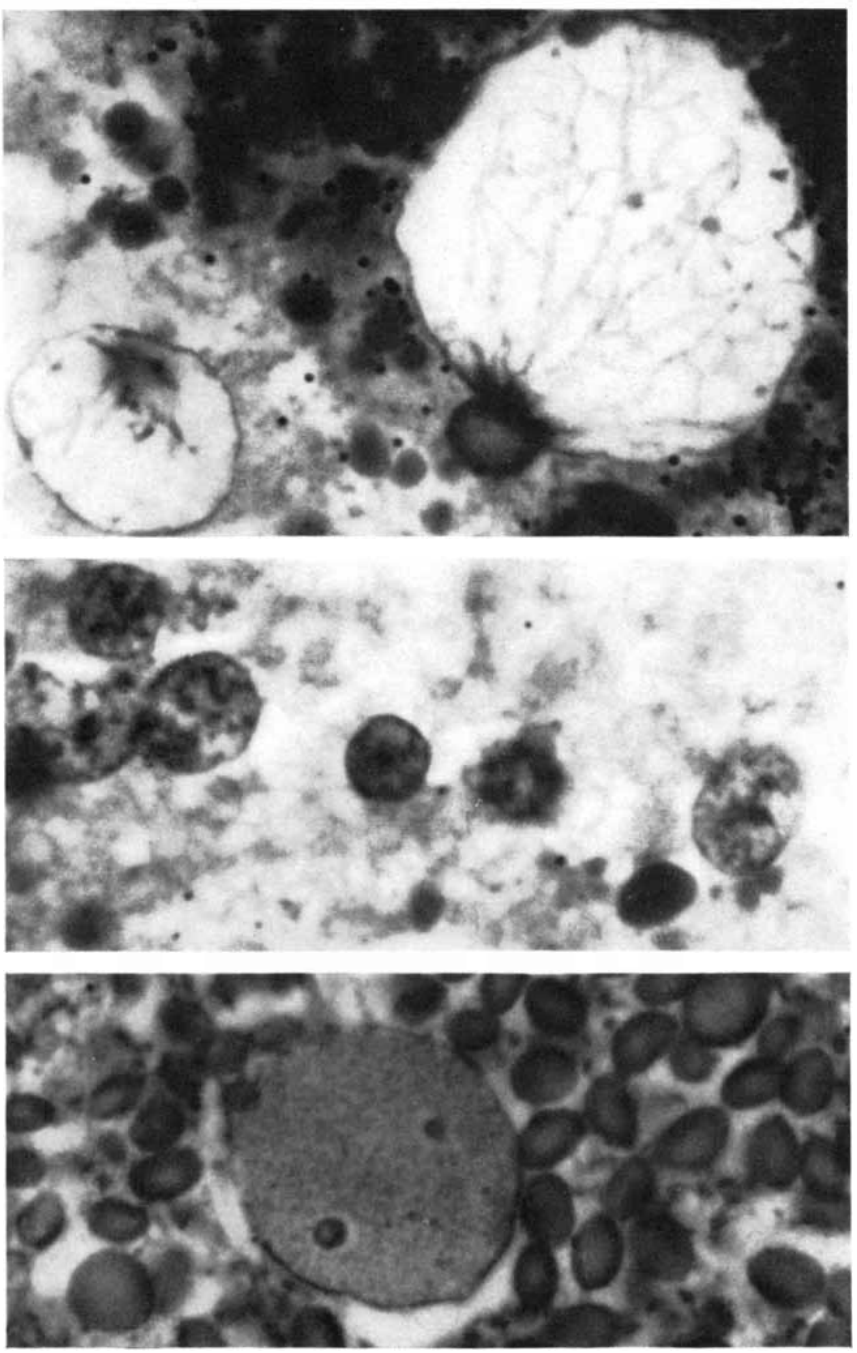
order to initiate the particular reaction being discussed here.

The last aspect of this reaction on which some information is available concerns the mechanism by which the inducing factors in the cytoplasm interact with the DNA in the nucleus. It was noticed several years ago by Stephen Subtelny, now at Rice University (and subsequently by others), that transplanted nuclei increase in volume soon after they have been injected into eggs. A pronounced swelling is also observed in nuclei injected into oöcytes; the swelling is therefore not directly related to a particular type of nuclear response. During this nuclear enlargement chromatin (which contains the genetic material in the nucleus) becomes dispersed and, as Arms has demonstrated, cytoplasmic protein also enters the swelling nuclei. While working at Oxford, Robert W. Merriam of the State University of New York at Stony Brook found a close temporal relation between the passage of cytoplasmic protein into enlarging nuclei and the initiation of DNA synthesis. The interpretation of these events currently favored by those of us involved in the experiments is that the nuclear swelling and chromatin dispersion facilitate the association of cytoplasmic regulatory molecules with chromosomal genes, thereby leading to a change in gene activity of a kind determined by the nature of the molecules that enter the nucleus.

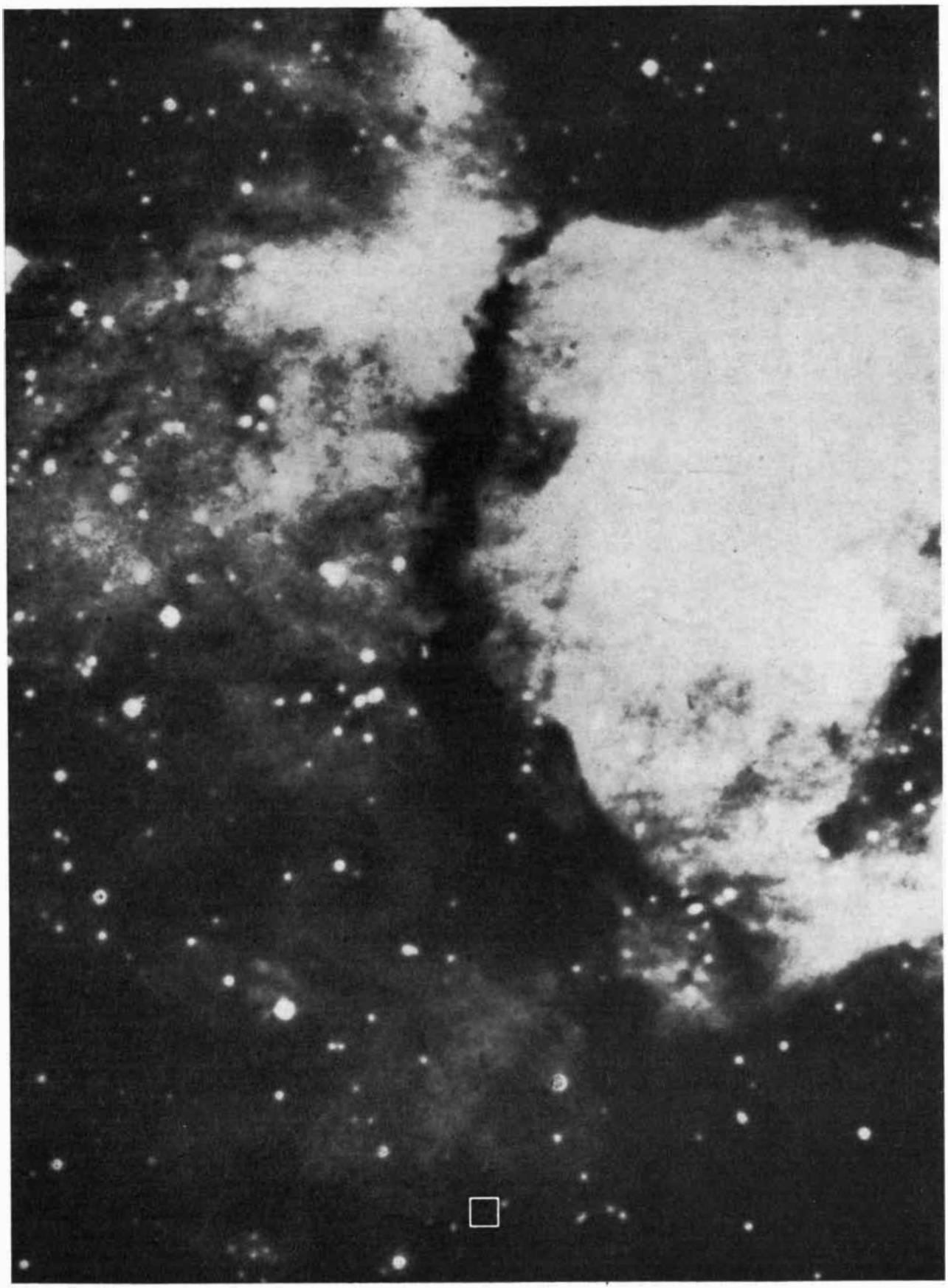
The experiments described here have established two general conclusions. First, nuclear genes are not necessarily lost or permanently inactivated in the course of cell differentiation. Second, major changes in chromosome function as well as in different kinds of gene activity can be experimentally induced by normal constituents of living cell cytoplasm. The same type of experiment is now proving useful in attempts to determine the identity of the cytoplasmic components and their mode of action.

We have had to restrict our attention to what can be described as sequential changes in gene activity, that is, differences between one developmental stage and the next. These may be compared with regional variations in nuclear activity, that is, differences between one part of an embryo and another at the same developmental stage. The latter are hard to study biochemically because of the difficulty in obtaining enough material. There is no obvious reason, however, why the processes leading to the two types of differentiation should be fundamentally different.

Experiments analogous to those described here have been conducted with bacteria infected with viruses, with nuclear transplantation in protozoans and with fusion in mammalian cells. Each kind of material is well suited for certain problems; nuclear transplantation utilizing amphibian eggs and cell nuclei is especially suited to the analysis of processes that lead to the first major differences between cells. Only after these differences have been established by constituents of egg cytoplasm are cells able to respond differentially to the important agents that guide development, such as inducer substances and hormones. Finally, the technique of nuclear transplantation may be used to introduce cell components other than the nucleus into the cytoplasm of different living cells; this is likely to be of great value for the more detailed analysis of early development and cell differentiation.



BRAIN NUCLEI also swell up when injected into an egg (*top*) or an oöcyte (*bottom*), but they do not enlarge as much as blastula nuclei. The center micrograph shows brain nuclei of normal dimensions. During enlargement, dispersal of genetic material and entry of cytoplasmic protein into the nucleus facilitate contact of cytoplasmic regulators with the genes.



RADIO EMISSION FROM HYDROXYL RADICALS was discovered in the course of a study of the absorption by interstellar OH clouds of a small part of the strong radio background radiation emanating from "H II regions" (regions of ionized hydrogen atoms surrounding hot stars). In this photograph of the H II region designated *W*3, made with 48-inch Schmidt telescope on Palomar Mountain, the OH-emitting region is outlined by the small white square. An enlarged map of OH region is on opposite page.

RADIO SIGNALS FROM HYDROXYL RADICALS

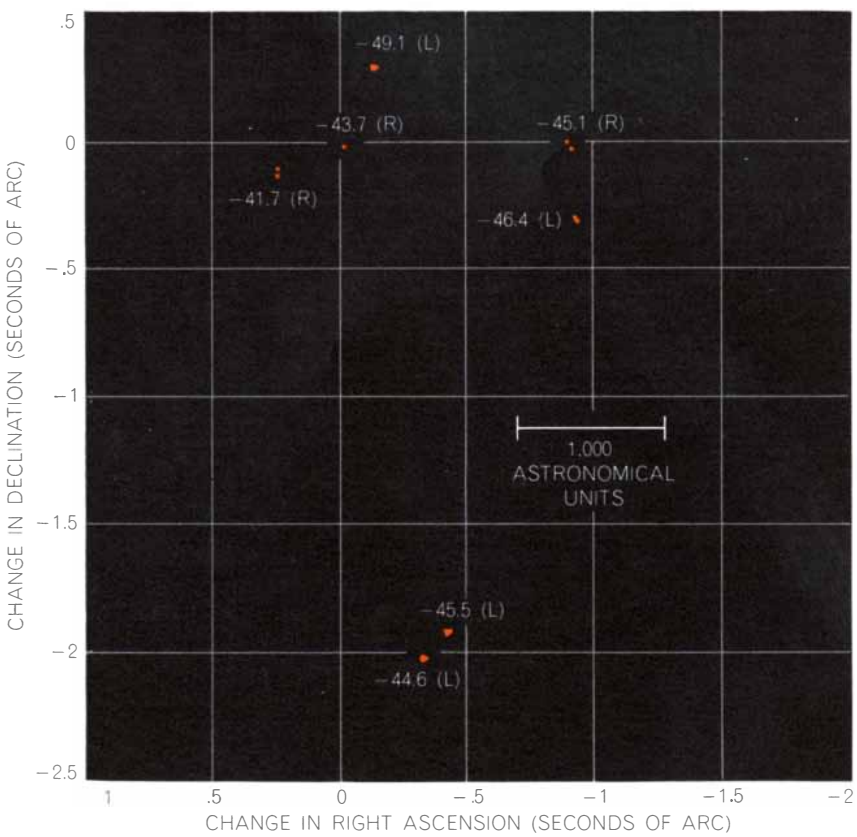
Intense emission signals from space at microwave frequencies characteristic of hydroxyl (OH) radicals may be generated by a kind of maser action in the gaseous envelopes of very young stars

by Alan H. Barrett

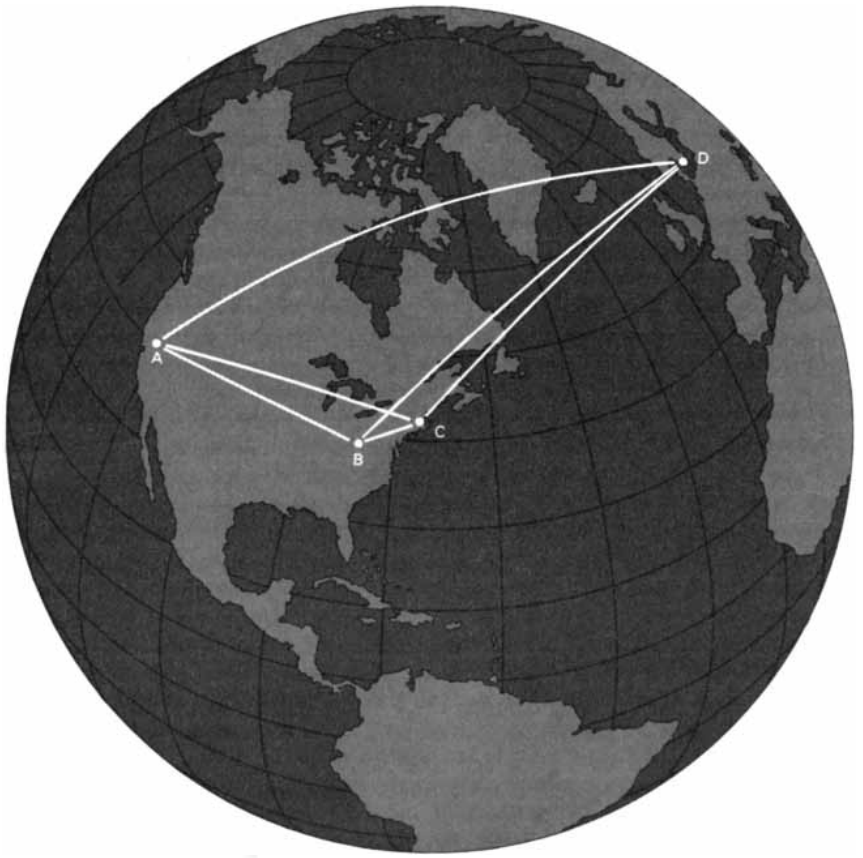
It has become almost axiomatic in astronomy that any search for a particular celestial phenomenon will lead to wholly unanticipated results. The search for hydroxyl (OH) radicals in interstellar space has been no exception. A number of years ago, when radio astronomers began to monitor the specific radio wavelengths that should be either produced or absorbed by oxygen and hydrogen atoms when coupled in the form of OH radicals, they expected absorption to be weak and emission weaker still. Even if OH radicals were detected, no one was sure how important or useful the knowledge might be. Observers knew, however, that the discovery almost 20 years ago of radio emission from un-ionized hydrogen atoms in interstellar space had made it possible for the first time to map the structure of the entire galaxy.

It is now just over five years since OH radicals were detected in interstellar space by a team of radio astronomers from the Massachusetts Institute of Technology. The team consisted of Sander Weinreb, M. Littleton Meeks, Joseph C. Henry and myself. The crucial evidence came when we aimed the 84-foot radio telescope of the M.I.T. Lincoln Laboratory on Millstone Hill in Massachusetts toward a certain strong radio source in our galaxy and detected a very small absorption of radio energy at the precise frequency where OH radicals are known to absorb. The emission of radio waves from OH radicals was finally detected about two years later, in the latter half of 1965, but the characteristics of the emission were so peculiar that there was serious doubt whether the source was in fact OH and not some other atomic or molecular species. Indeed, the early discussions of the observation referred half-jocularly to an unknown emitter dubbed "mysterium." Since then the mystery has been cleared up, only to be replaced by new ones. For example, some of the sources of OH emission, far from being weak, are so intense that no one quite knows how to account for them. The emission from these sources seems to represent the first evidence that nature employs the principle of radio-signal amplification used in the electronic device known as a maser.

The OH radical is actually a diatomic molecule composed of one atom of oxygen and one atom of hydrogen. It is called a radical because it is a funda-



RADIO MAP of the OH-emitting region in *W*3 was compiled from data obtained with a gigantic radio interferometer consisting of four widely separated radio telescopes (*see illustration on next page*). The data revealed that what had previously been thought to be a single source of OH emission in *W*3 is in fact a number of closely spaced sources. The best estimate of the size of the smallest OH emission source in *W*3 is .005 second of arc. The number associated with each source is its radial velocity in kilometers per second; a minus sign means that the source is approaching the earth. The letter in parentheses indicates whether the radio emission from the source is circularly polarized to the right (*R*) or the left (*L*). One astronomical unit is equal to the mean radius of the earth's orbit.



RADIO INTERFEROMETER used to obtain the radio map of *W3* on the preceding page consists of radio telescopes located in California (*A*), West Virginia (*B*), Massachusetts (*C*) and Sweden (*D*). The maximum separation (California to Sweden) was about 43 million radio wavelengths. The technique is called very-long-baseline, or VLB, interferometry.

mental constituent of many compounds, the most obvious being water; however, the OH unit is also a physically stable molecule in its own right. Because of electric and magnetic interactions between the electrons of the two atoms and also between the electrons and the atomic nuclei, the "ground" state, or lowest energy state, of OH allows the emission or absorption of electromagnetic radiation at four closely spaced microwave frequencies [*see illustrations on pages 40 and 41*]. The frequencies of emission or absorption are 1,612, 1,665, 1,667 and 1,720 megahertz (million cycles per second). The wavelengths of the radiation corresponding to these frequencies are all approximately 18 centimeters, or slightly over seven inches. Because emission or absorption can take place only over one or more narrow ranges of frequency, one refers to the emission or absorption as occurring in spectral lines.

According to the quantum-mechanical picture of the interactions of an OH radical with radio waves, not all the allowed transitions between the various energy levels will respond equally. For example, it is nine times more probable that radio waves will be emitted at a frequency of 1,667 megahertz by a cloud of OH radicals than that they will be emitted at a frequency of 1,612 or 1,720 megahertz, whereas radio waves at a frequency of 1,665 megahertz should be five times more probable than those at 1,612 or 1,720 megahertz. Thus radio astronomers were originally prepared for, and indeed were looking for, OH emission lines from galactic gas clouds at the frequencies of 1,612, 1,665, 1,667 and 1,720 megahertz in the intensity ratios of 1 : 5 : 9 : 1 respectively. In the event that a cloud was found that contained a very large amount of OH, the intensity ratios of the spectral lines could conceivably all approach unity, but that was not expected to be the general case.

After our discovery of OH absorption in 1963, teams of radio astronomers at several institutions began an intensive search for OH emission. These institutions included M.I.T., Harvard University, the University of California at Berkeley, the Bell Telephone Laboratories and the Commonwealth Scientific and Industrial Research Organization in Sydney, Australia. The various teams tuned their receivers to the spectral line at 1,667 megahertz because this was the frequency where OH was expected to emit the strongest radio waves —stronger than the 1,665-megahertz line by the ratio of 9 : 5, and stronger than either the 1,612- or 1,720-megahertz lines by the ratio of 9 : 1. The searches usually concentrated on those directions in space where the abundance of atomic hydrogen was high, as determined by separate radio observations. The assumption was that if atomic hydrogen was abundant in a particular direction, then OH radicals might also be expected to be abundant in that direction. In the beginning, however, no one had any success; all the results were negative.

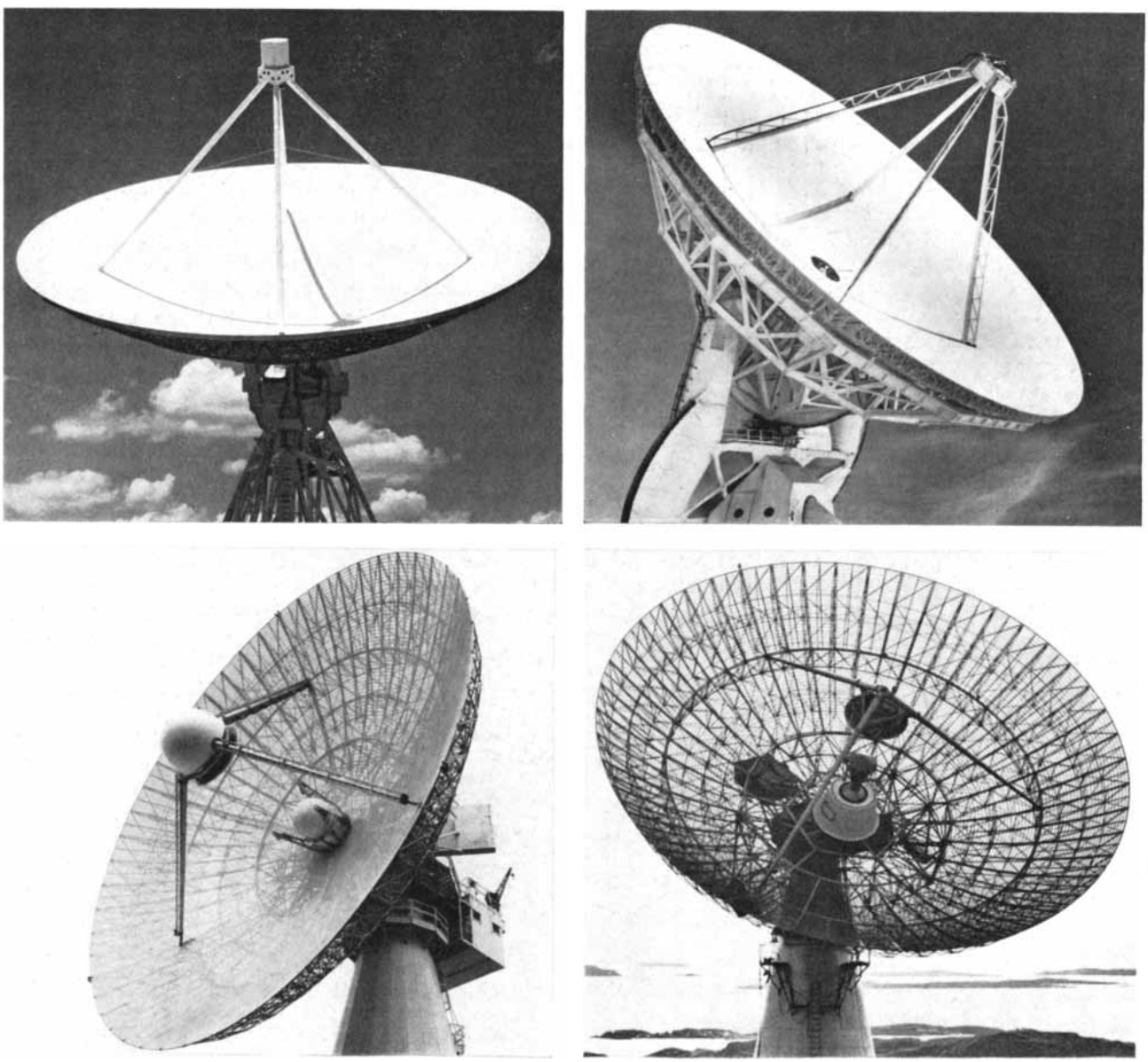
This is not to say that all radio studies of interstellar OH were unproductive. Most groups, while searching for OH emission lines, were also studying the OH absorption lines. These studies are carried out by measuring the total emission from galactic radio sources and trying to detect the small absorptions at the resonant frequencies of OH due to the intervening interstellar gas—the same technique we used to make the initial discovery of interstellar OH. The radio sources themselves were not expected to contain any appreciable OH because these sources are composed largely of highly turbulent, hot, ionized material in which large quantities of un-ionized molecules are not generally found. Nonetheless, it was the absorption studies that eventually led to the discovery of OH emission in a way that was quite unexpected.

As it happened, the groups at Berkeley and Harvard were studying OH absorption by using the "H II regions" as their background sources. These sources are regions of ionized hydrogen atoms surrounding hot stars; they are moderately strong radio emitters, and they all lie in the plane of the galaxy. The initial radio studies of these sources were made by Gart Westerhout of the University of Maryland; in consequence many of them are now designated by the letter *W* followed by a number indicating the listing of the source in Westerhout's catalogue, for example *W3* or *W49*.

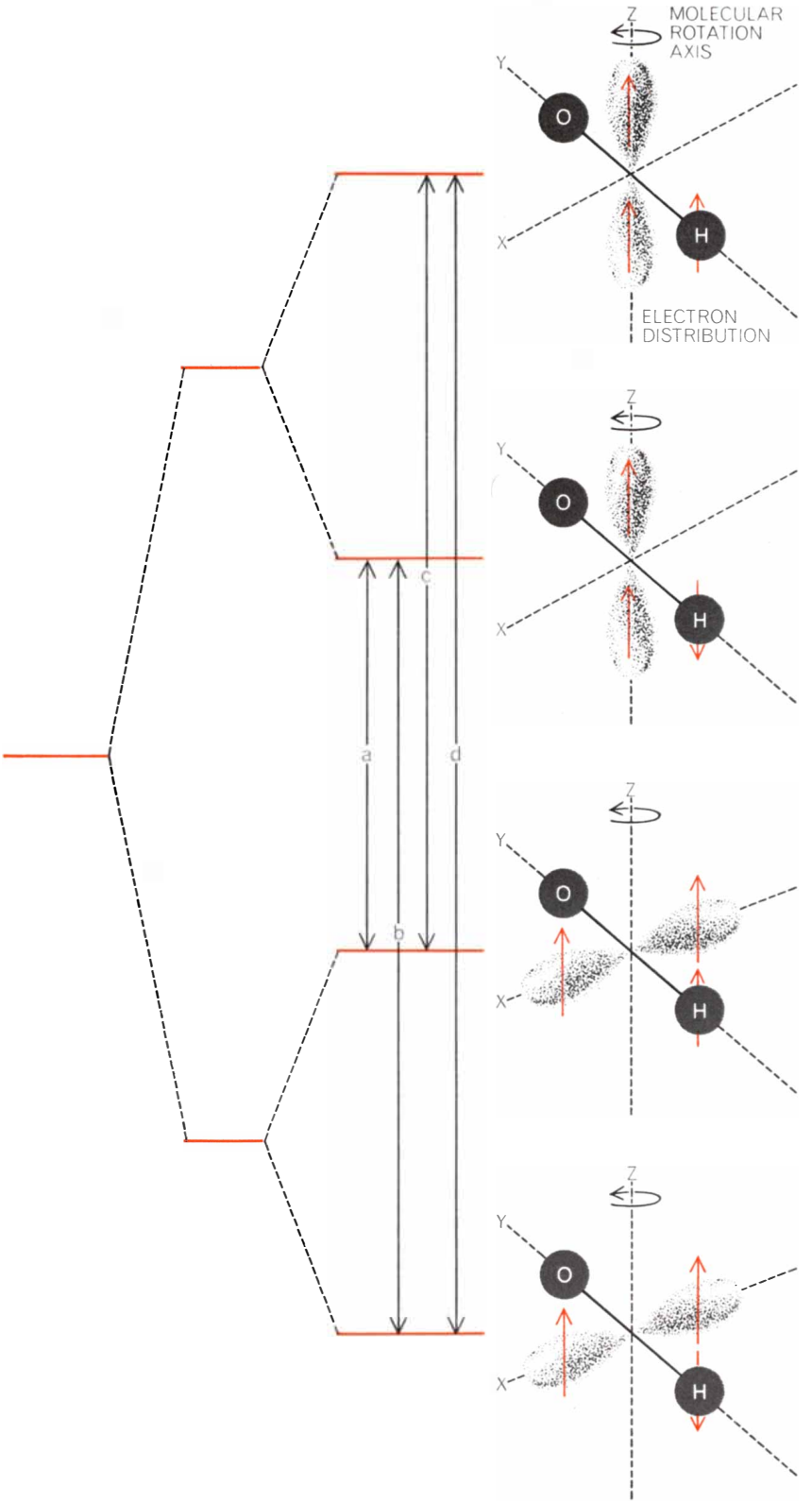
Almost simultaneously the Berkeley astronomers (Harold F. Weaver, David R. W. Williams, Nannielou H. Dieter and William T. Lum) and the Harvard astronomers (Ellen Gundermann, A. Edward Lilley and Samuel J. Goldstein) detected radio emissions at the OH frequencies of 1,665 and 1,667 megahertz

from the radio source *W*49. The properties of the signals, however, did not conform at all with the expected properties. The intensity of the 1,667-megahertz emission was about 100 times greater than the upper limit that had been set previously when looking in other directions within the galaxy. Even more startling, the peak emission at 1,665 megahertz was approximately three times stronger than that at 1,667 megahertz, rather than only five-ninths as strong, the ratio expected. Another peculiar anomaly was that the radial velocity of the material emitting at 1,665 megahertz was not the same as the radial velocity of the material emitting at 1,667 megahertz. This was established by noting slight shifts in the frequencies of the maximum emissions from their predicted values. These observational facts were so at variance with the preconceived ideas concerning the OH radio emission that the Berkeley group for a time believed not only that OH emission was being detected but also that another constituent of the interstellar medium was radiating at 1,665 megahertz, thereby confusing the interpretation of the OH spectra. Because the other constituent was unidentified, it was given the name mysterium pending its identification.

Following the announcement of the discovery of OH radio emission, the results of a number of other studies were quickly published, all of which confirmed the odd character of the OH emission that had been noted by the Berkeley and Harvard radio astronomers. Since the same peculiar traits that had been noted in *W*49 showed up in other sources as well, but not preferentially at 1,665 megahertz, it was soon concluded that all the radio emission could be attributed to OH, and the concept of a blend with an unidentified molecule was abandoned. The observations yielded new and surprising details of the OH



INDIVIDUAL ANTENNAS in the VLB interferometer used to study OH emission from various interstellar sources are shown in the photographs on this page. At top left is the 85-foot antenna at Hat Creek, Calif., operated by the University of California at Berkeley. At top right is the 140-foot antenna at Green Bank, W.Va., operated by the National Radio Astronomy Observatory. At bottom left is the 84-foot Millstone antenna at Tyngsboro, Mass., operated by the Lincoln Laboratory of the Massachusetts Institute of Technology. At bottom right is the 85-foot antenna at Onsala, Sweden, operated by the Chalmers University of Technology.



"GROUND" STATE, or lowest energy state, of the hydroxyl molecule is divided into four closely spaced sublevels. The first division results from the interaction of the unpaired electron (*stippled "cloud"*) with the rotation of the diatomic OH molecule. Two general conditions are possible: either the electron distribution is along the axis of the molecular motion (*top division*) or it is in the plane of the rotation (*bottom division*). The two resulting energy states are further subdivided by the fact that one nucleus of the molecule (*in this case the hydrogen nucleus*) can have its magnetic moment either aligned with or opposed to the molecule's internal magnetic moment (*colored arrows*). A transition between an upper and a lower sublevel is accompanied by the emission or absorption of a quantum of energy at a characteristic microwave frequency. Letters denote allowed transitions.

emission, and many of these details still confound observers and theoreticians alike. Earlier expectations about the intensity and the spatial distribution of the galactic OH emission, based on inferences from the earlier radio studies of un-ionized atomic hydrogen, had to be completely abandoned.

As mentioned above, the intense OH emission was discovered in the course of a study of OH absorption as viewed against the strong radio background radiation of H II regions. It was soon apparent that the regions of OH emission were not generally distributed throughout the galactic plane but instead were intimately associated with H II regions and were extremely small in angular size. In other words, the picture was emerging that some H II regions, approximately 30 to 50 percent, contained small clouds of OH molecules that were somehow able to emit intense radio energy at the proper OH frequencies but not in the expected intensity ratios. Moreover, the intensity spectrum at one OH frequency bore no resemblance to the spectrum at another frequency, even though both appeared to originate from the same source.

Shortly after the announcement of the discovery of OH emission, another puzzling characteristic of the OH radiation was detected. At the Haystack Microwave Research Facility of the M.I.T. Lincoln Laboratory, Weinreb, Meeks, Joseph C. Carter and Alan E. E. Rogers discovered that the emission from the source *W3* was strongly polarized in a linear direction. Subsequent observations by Rogers, using the 140-foot radio telescope of the National Radio Astronomy Observatory at Green Bank, W.Va., and by Robert D. Davies, G. de Jager and Gerrit L. Verschuur, using the 250-foot radio telescope at Jodrell Bank in England, showed that the OH emission from a large fraction of the other H II regions was strongly polarized in a circular direction, the percentage of polarization approaching 100 percent. The polarization of the radiation implied that something about the emitting source or the propagation medium through which it traveled was imparting a preferential polarization direction to the radiation.

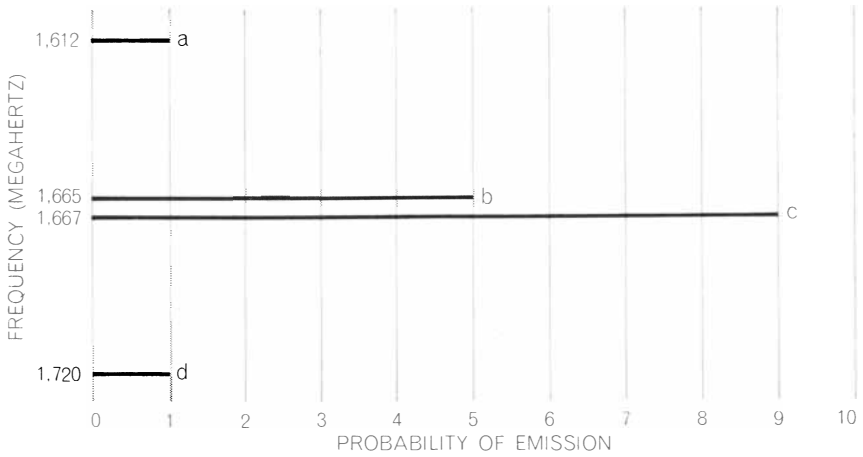
This was the first discovery of polarized spectral-line emission from the interstellar medium, and it gave rise to immediate speculation as to its cause. Many people guessed that a magnetic field was responsible for the observed polarization, but attempts to construct quantitative models that would agree with the observations have not met with success.

Although in some cases magnetic-field strengths some 1,000 times the estimated general interstellar magnetic field seem to be required, this cannot be taken as a serious objection because the OH emission is known to be from localized regions and these could have magnetic fields quite different from the general interstellar field. At present it still seems as if a magnetic field must be invoked to generate the polarization, but the mechanism is by no means clear.

All the observations described up to this point were made using single radio telescopes with angular resolutions of some tens of minutes of arc. This meant that an upper limit of between five and 10 minutes of arc could be established for the angular sizes of the OH-emitting clouds. Even this crude upper limit provided some insight into the unusual nature of the OH-emission process and clearly pointed to the need for more precise measurements. The intensity of the received OH signals was characteristic of a temperature between 100 and 200 degrees Kelvin (that is, well below zero Celsius), but it was known that this received radiation was severely diluted because the width of the beam intercepted by the radio telescope was several times larger than the angular size of the emitting object. Therefore the effective radiating temperature of the source had to be at least 1,000 or 2,000 degrees K. and perhaps very much more. It was important to establish the angular size of the emitting clouds in order to determine just how intense the emission really was at the source. A number of groups of radio astronomers began to attack this problem without realizing that they would be pioneering a new technique before they had a definite answer.

Radio telescopes are known for their poor resolving power, or ability to determine small angular sizes, but if they are used in pairs, the ability of radio telescopes to establish angular sizes is vastly improved. Moreover, as the distance between the two telescopes is increased they are capable of determining smaller sizes. Such systems, which are known as radio interferometers, have been widely used to study the structure of radio sources, but they had not yet been applied to the OH lines. The first attack on the problem came from groups at M.I.T. and the California Institute of Technology, each of which used a pair of telescopes spaced approximately 3,800 wavelengths (.7 kilometer) apart.

These observations began to give a hint of what lay ahead. Neither group was able to establish an angular size for the OH clouds, but both groups agreed that the size of the source was less than 20 seconds of arc and that what was thought to be one source, for example in *W*3, was in fact several sources very closely spaced in the sky. These results implied that the effective radiating temperature of the OH molecules was in excess of one million degrees! We still did not have, however, an answer to the question of the angular size of the OH-emitting clouds.



EXPECTED PROBABILITIES of emission or absorption at the four microwave frequencies corresponding to the allowed energy-level transitions in the ground state of the OH molecule are represented in this bar chart. Based on laboratory measurements and theoretical considerations whole-step transitions (*b*, *c*) are considered more probable than semistep (*a*) or superstep (*d*) ones. Observations show, however, that the expected intensity ratios of 1 : 5 : 9 : 1 (for lines *a*, *b*, *c* and *d* respectively) do not hold in the case of interstellar OH.

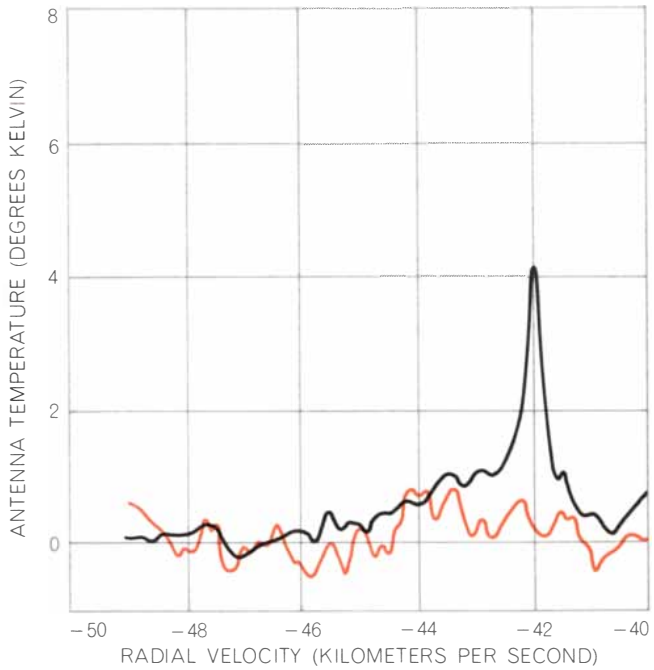
To determine smaller angular sizes required a greater separation of the antennas; the distances needed far exceeded the dimensions of any single observatory. Therefore Harvard and M.I.T. conducted a joint experiment, using antennas separated by 74,000 wavelengths (13 kilometers). Simultaneously groups at Jodrell Bank and Malvern in England began operations with an antenna spacing almost 10 times larger: 700,000 wavelengths (127 kilometers). Both groups obtained similar results, but the English observatories could provide considerably better information about angular sizes because of the greater separation of their telescopes.

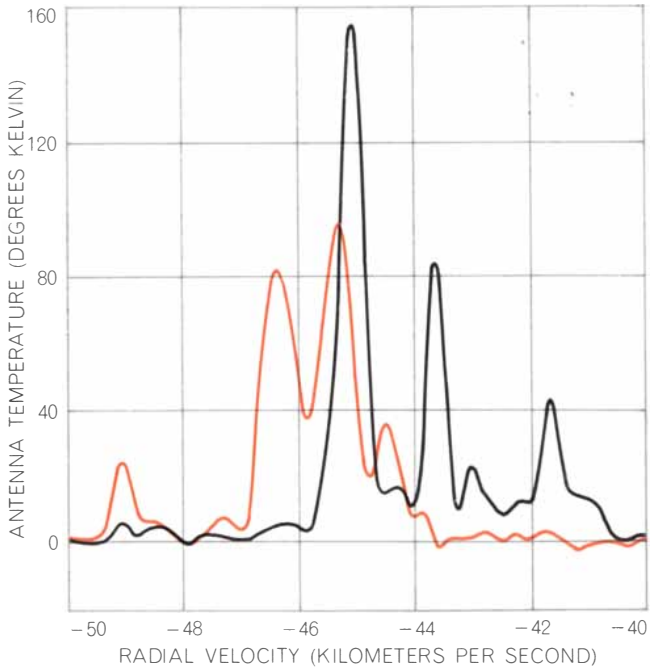
The most surprising result of the observations was that the OH-emitting clouds were smaller than .1 second of arc—and nobody yet knew how much smaller. Since the distance to the source *W*3 was thought to be approximately 1,700 parsecs (5,500 light-years), the observations implied that the OH clouds were smaller in diameter than the solar system as defined by Pluto's orbit.

The observations also revealed further detail on the substructure of the sources. The individual sources in *W*3, for example, were found to be less than .1 second of arc in angular diameter each, and they appeared to be separated by one or two seconds of arc. Each source, or OH cloud, also seemed to have a characteristic radial velocity and polarization. There did not seem to be an obvious correlation between clouds. With such small angular sizes it was possible to conclude that the effective radiating temperature of the OH had to be at least some 10^{11} degrees K. Clearly temperatures of this magnitude have a very limited physical meaning.

To proceed any further required using two radio telescopes separated by at least 250 kilometers in order to obtain an improvement in resolution greater than a factor of two. This called for an advance in technology. At the antenna spacings employed to this point it was practicable to operate the receivers of the telescopes using a common oscillator or clock to preserve phase coherence. This made it possible to tell if the crest of a given radio wave reached one antenna before the other and, if so, to determine precisely the interval between the two arrival times. At much larger antenna spacings it was necessary to equip each radio telescope with its own stable oscillator (such as a hydrogen or rubidium maser) to provide a phase reference. The data from each observatory were then recorded on magnetic tape for later processing in a digital electronic computer. Simultaneous data recording was ensured by using a common nationally broadcast timing signal.

This form of very-long-baseline inter-





INTENSITY SPECTRA of the OH emission sources in *W*3 at the four allowed microwave frequencies reveal a number of peculiar properties. First, although the sources emit at the proper OH frequencies, they do not do so in the expected intensity ratios. Second, slight shifts in the frequencies of the maximum emissions from their predicted values indicate that the radial velocity of the material emitting at one frequency is often not the same as the radial velocity of the material emitting at any of the other frequencies.

ferometry of the OH sources was pioneered by the M.I.T. group, largely through the efforts of Bernard F. Burke, James M. Moran, Jr., and Rogers, using at first the 120-foot Haystack antenna of the Lincoln Laboratory in conjunction with the 140-foot National Radio Astronomy Observatory antenna in Green Bank. The antenna spacing in this case was 845 kilometers. Although the observations were successful, they failed to establish the size of the OH emission sources in *W*3; they did show, however, that the sources were smaller than .02 second of arc. Even though this result represented a significant advance for radio astronomy, still larger baselines were required, and so the assistance of other observatories was requested.

The angular size of the smallest OH emission sources in *W*3 was finally established by means of a gigantic radio interferometer consisting of radio telescopes in Massachusetts, West Virginia, California and Onsala, Sweden [*see illustration on page 38*]. The maximum separation (between California and Sweden) was about 43 million wavelengths (7,720 kilometers). If this approach had not been successful, it is probable that the answer would have had to wait for the advent of extraterrestrial radio interferometers involving earth-orbiting satellites or lunar observatories. With the help of David D. Cudaback of Berkeley and O. Rydbeck and B. Hansson of the Chalmers University of Technology in Sweden, it was finally established that the angular size of the smallest OH emission source in the *W*3 complex is .005 second of arc. This might correspond to an actual linear dimension of approximately the diameter of the orbit of Mars, but such a conclusion is dangerous until more is known about the actual process of emission. One could now conclude that the effective radiating temperatures of the source were on the order of 10^{13} degrees K.

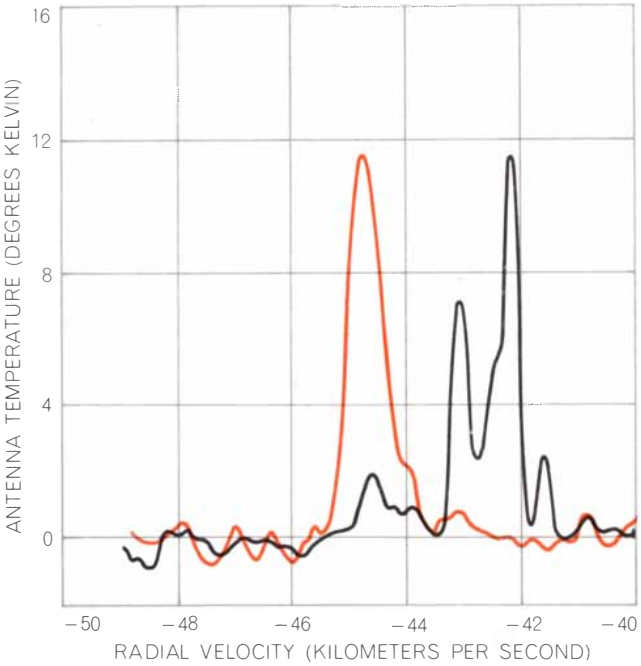
The technique of using very widely spaced antennas to form an interferometer capable of obtaining angular resolutions on the order of a hundredth of a second of arc is a new one to radio astronomy; it will undoubtedly prove to be a powerful tool for many other types of investigation. Subsequent observations will reveal whether the OH emission clouds are moving with respect to one another or are moving together as a group. Several years may have to elapse, however, before any significant motion can be established.

Shortly after announcing their detection of OH emission, the Berkeley workers discovered that the intensity of the OH emission varied with time in at least two of the sources. They found that both the 1,667- and 1,665-megahertz lines originating in two different H II regions varied in amplitude by as much as a factor of five to 10 over a time span of three months from July to October, 1965, and that changes of lesser amplitude took place over periods of only a few days. Observations of this kind are difficult to make with certainty, because many instrumental effects could occur that would give the same apparent result. Consequently the discovery was treated with a good deal of skepticism by the astronomical community.

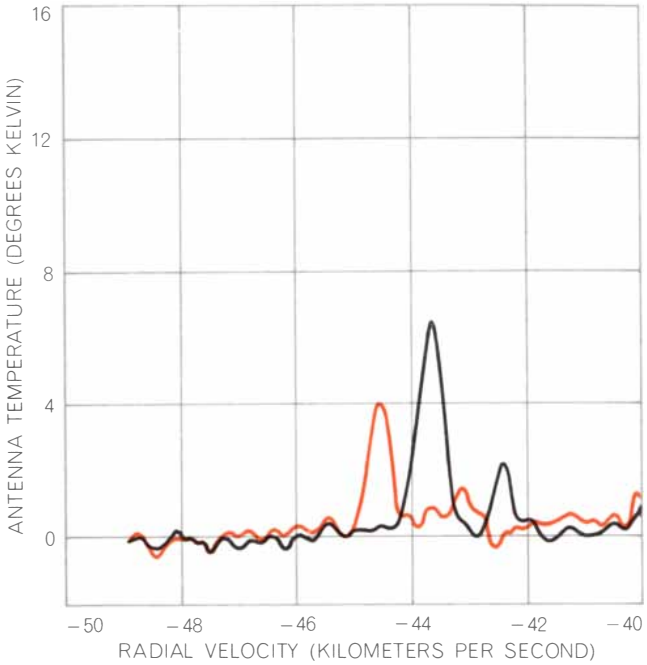
Since then, however, the time variations have been observed by other groups. There is now no doubt about the reality of the effect. The variations appear to be random, and different features of the intensity spectrum for a particular frequency are uncorrelated with one another. This behavior fits nicely with the picture derived from the very-long-baseline interferometry, since the results of these observations have shown that each feature originates from its own OH cloud, and hence its variations could be uncorrelated with any other.

The strong intensity of the OH emission signals suggested other experiments that could be performed. One of these involved the search for OH emission lines originating at energy levels higher than the ground state. Ordinarily it would be fruitless to look for these higher states because under the physical conditions normally prevailing in interstellar space radicals such as OH would exist predominantly in the lowest state of excitation.

The observations have shown, however, that the excitation of OH is anoma-



Third, the OH emission is in many cases very strongly polarized in a circular direction. Black curves show the intensity spectra for radio waves with a left circular polarization. Colored curves show the spectra for radio waves with a right circular polarization.



The frequencies represented by the four graphs are 1,612 megahertz (*left*), 1,665 megahertz (*second from left*), 1,667 megahertz (*second from right*) and 1,720 megahertz (*right*). Relative intensity is indicated in each case in terms of antenna temperature in degrees Kelvin.

lous indeed; therefore one could not state categorically that the other lines of OH would be undetectable. Subsequently Benjamin Zuckerman, Patrick Palmer, Hayes Penfield and Lilley at Harvard were able to detect an OH line near 4,765 megahertz from two H II regions. As in previous studies, the line does not conform to the theoretical intensity ratios, because another line, thought to be stronger, could not be detected. Further studies of these lines should throw light on the process that is exciting, or populating, these higher OH energy levels.

Another experiment suggested by the strong OH emission signals was a test to see if OH could be detected from the nearby galaxies. Both Morton S. Roberts at the National Radio Astronomy Observatory and V. Radhakrishnan at Sydney, observing in the Northern Hemisphere and Southern Hemisphere respectively, tried to detect OH from nearby galaxies. Neither observer was successful. Radhakrishnan concluded that OH emission sources as strong as *W3* were not present in the large Magellanic Cloud.

It was obvious from the beginning that existing astrophysical theories were wholly inadequate to explain the intensity and quality of the observed OH emission from interstellar space. Some mechanism hitherto unknown under astrophysical conditions must be invoked to explain how a radio-emitting source can behave as if it had the extraordinary temperature of 10^{13} degrees K. The intensity of radiation virtually dictates some exotic form of amplification, such as occurs in the maser. To achieve maser-type amplification the populations of the energy levels defining the OH radio lines would have to be inverted so that more OH molecules were in a higher energy state than in a lower energy state. If a radio wave of the proper frequency were to pass through such an inverted population, it would stimulate transitions from the upper state to the lower state. In tumbling to the lower state the excited molecules would add their energy to the radio wave, thereby amplifying it.

Such a process could generate the intense signals that are observed, but the real question now becomes: What is the nature of the process by which the populations become inverted? Since the OH emission is associated with H II regions, which are known to be sources of intense ultraviolet radiation, it is not surprising that ultraviolet processes were initially invoked as a mechanism for inverting the OH population. Later other inversion agencies and mechanisms were considered: infrared as well as microwave radiation, charged particles, the interaction of OH with interstellar dust grains and chemical processes possibly associated with the formation of OH in the interstellar medium. Current interest seems to be focused on two population-inverting processes: one, suggested by I. S. Shklovskii of the Shternberg State Astronomical Institute in Moscow and modified and developed in detail by Marvin M. Litvak of the Lincoln Laboratory, involves infrared radiation; the other, suggested by Philip M. Solomon of Columbia University, is a purely chemical process. Both mechanisms have their supporters and neither can claim general acceptance. Each attempts to explain, in astrophysical terms, the required population inversion, but neither theory has yet accounted for the large degree of polarization that is observed.

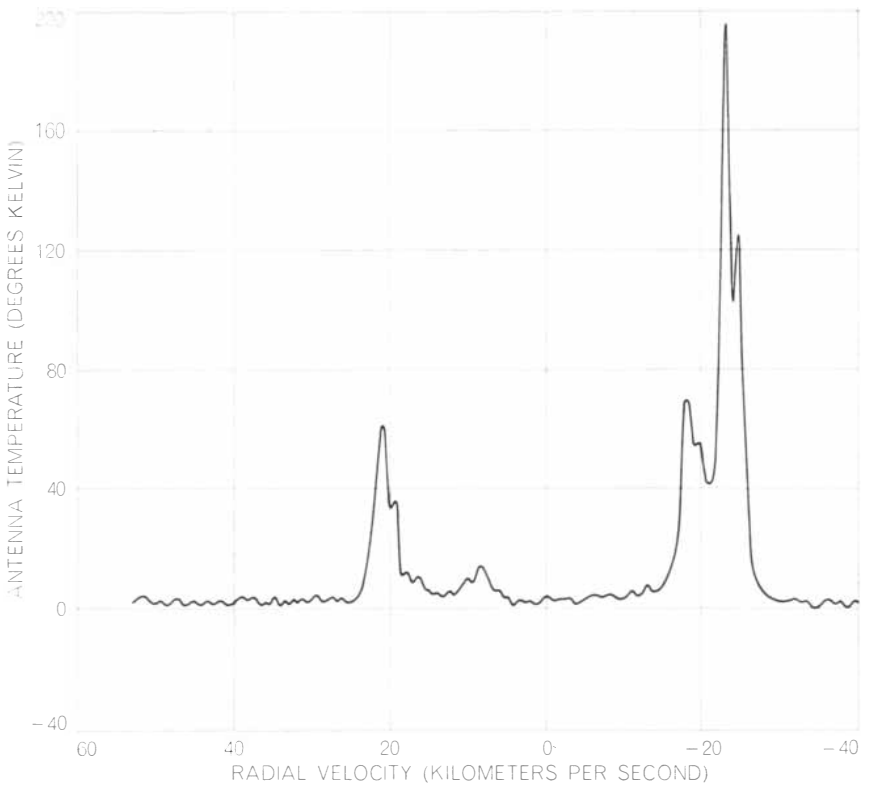
As the results of the very-long-baseline interferometry were unfolding, Shklovskii made the suggestion that the regions of OH emission might be protostars, or stars in the process of being formed. He points out that the size of the OH sources agrees with theoretical estimates of the size of a protostar in the early stages of gravitational contraction. The OH sources, moreover, seem to be confined to H II regions, where it is thought stellar formation is actually going on at present. This idea gained considerable support when Eric E. Becklin and Gerry Neugebauer of Cal Tech discovered a point-source of infrared radiation embedded in the Orion nebula, and Ernst Raimond and Baldur Eliasson, also of Cal Tech, showed that the OH source in Orion was coincident with the infrared source [see "The Infrared Sky," by

G. Neugebauer and Robert B. Leighton; SCIENTIFIC AMERICAN, August].

Neugebauer, Robert B. Leighton and their associates at Cal Tech have made a survey of the sky and have discovered many "infrared stars." None of the 20 infrared stars whose positions have been published are associated with H II regions, but one wondered whether they might be OH emitters that had gone undetected because only H II regions had been carefully studied for OH emission. The answer to that question was obtained in July, 1968, by William J. Wilson and me, using the 140-foot radio telescope at Green Bank; we detected OH emission from four of the 20 stars but were unable to detect emission from the other 16. One of the stars, designated NML Cygnus, emits radio lines more intense than any previously detected on the earth [*see illustration below*]. The emission is most intense at 1,612 megahertz and is wholly undetectable at 1,720 megahertz, the two frequencies that were once thought to be emitted equally. The radiation at 1,612 megahertz is strong and unpolarized. At 1,665 megahertz it is some 30 times weaker but circularly polarized. At 1,667 megahertz it is weaker by another factor of eight. Emission has not been detected at 1,720 megahertz, but if it exists, it is at least 400 times weaker than it is at 1,612 megahertz.

The emission of the Cygnus source at 1,612 megahertz exceeds any spectral line yet detected, but this may simply be a result of its being very close to the earth. Further measurements, using the techniques of very-long-baseline interferometry, will be required to establish its intrinsic radiation intensity. At infrared wavelengths the star is among the brightest in the sky. Moreover, its infrared intensity is constant with time, unlike the intensity of most other infrared stars. The spectrum of the star suggests that its surface temperature is between 800 and 1,000 degrees K.

Inasmuch as OH emission has been associated with infrared stars, one might conclude that this observation supports the mechanism of population inversion by infrared radiation. Alternatively, conditions in the infrared stars may favor chemical inversion. If they are indeed very young stars in the process of formation, they may consist of a dense cloud, or group of clouds, that is condensing under its own gravitational contraction. Since the temperature is not high enough to ionize all the matter present, large numbers of un-ionized atoms and molecules can be expected [see "The Youngest Stars," by George H. Herbig; SCIENTIFIC AMERICAN, August, 1967]. Conditions may be favorable, therefore, for the formation of OH from oxygen and hydrogen atoms and likewise favorable for the population inversion this chemical process can produce. If it turns out that we are observing protostars or very young stars, then radio astronomy will have made a substantial contribution to stellar cosmogony, that is, to the study of the formation of stars.



OH EMISSION FROM INFRARED STAR designated NML Cygnus was found to be very intense at a frequency of 1,612 megahertz; the intensity spectrum at this frequency is shown here. The emission of the Cygnus source at 1,612 megahertz is more intense than any radio line previously detected, but this may simply be a result of its being close to the earth.

Many questions remain: What is the real correlation between infrared stars and OH radio emission? Why are some stars strong infrared emitters and yet not OH radio emitters? Does the OH radio emission vary with time? And if it does, what relation do the variations bear to the infrared variations? If the infrared stars are young stars, perhaps even protostars, when in the course of their evolution do they begin, and when do they cease, to emit OH radiation? How do the OH emitters associated with infrared stars differ from the OH emitters associated with H II regions?

Neugebauer and his associates have observed about 5,000 stars at infrared wavelengths, of which perhaps 500 can fairly be classified as infrared stars, and so the radio astronomer has his work cut out for him. This is a sufficient number so that some meaningful statistics can be developed, as is not the case for emitters in H II regions, which number only about 20. This is an important point because many advances in astronomy are based on statistical arguments, and the chances to apply these arguments to the results of galactic radio astronomy are few.

Radio-astronomical observations have not been closely coupled with stellar observations in the past. Exceptions have been the rather sparse observations of radio emission from flare stars and, more recently, the observations of pulsating radio emission from sources that may yet be visually identified with stars. The recent discovery of OH emission from infrared stars, however, clearly couples radio emission (albeit a special type of emission) with observations of stars at infrared and visual wavelengths. It is beginning to appear as though Shklovskii was correct when he wrote in 1967: "Radio astronomy has entirely unexpectedly provided a powerful method that makes it possible to place stellar cosmogony on a stable observational basis."

In hope of doing each other some good

Big accelerator in the sky

We take on no R&D contracts for photographic materials. Not that we see anything wrong in them. It's just that we prefer a riskier course. Nevertheless, since we do have on hand a fair amount of talent for performing R&D on photo materials, it would be inappropriate arbitrarily to withhold that talent from the service of mankind. When presented with what seems like a worthy challenge, the talent goes to work, and we take our chances on an eventual payout through cash on the barrelhead for merchandise received, even when prospective demand seems unlikely to attain the breadth expected, let us say, by a successful marketer of dog food.

Project HAPPE (High Altitude Particle Physics Experiment) seems like a worthy challenge and a bargain besides. If Prof. Luis W. Alvarez' idea works out, mankind will be able to pursue fundamental truth to the 5000-GeV level or better and leave an extra gigabuck or two for causes that more of mankind are capable of appreciating.

Professor Alvarez and a crew of 60 at the Space Sciences Laboratory of the University of California at Berkeley want to hitch up the cosmos for use as an accelerator. It's back to balloons, with support from NASA. Up where energetic cosmic primaries abound, one carries a cubic meter of 10-kilogauss magnetic field. The present state of the art of superconductivity permits it to be airborne. Before 1947 such field strength hadn't even been attained with superconductors on the ground; but it isn't much for deflecting the 70 GeV-and-up particles to which a Cerenkov counter sensitizes the device.

Because cut-price particles come unlabeled, the deflections give the energy information necessary to do physics with them. Since the deflections are small, to measure them takes high precision in locating the tracks before and after the magnetic field. That is why we have been called upon to coat 200μ of nuclear-track emulsion on both sides of plates 36 inches in diameter—a formidable undertaking for us and worse for the HAPPE crew to try themselves. Good ways to pack for shipment were not immediately obvious either. They have been worked out. Two plates are needed to ride above the magnet and two below. One side of each plate has "optically flat" pins sticking up through the emulsion to permit monitoring the exact location of the plates relative to each other during a 10-hour flight. After processing, positions of the tracks are measured relative to the pins by a marvelous laser-controlled readout machine. For tracks qualified by the Cerenkov counter and located by spark chamber, the machine knows within about one square millimeter where to look. Its microscope objective oscillates vertically through 200μ faster than the critical flicker frequency to obliterate from consideration all silver grains not part of a track straight through the emulsion. The point at which the track intersects the glass becomes a data point good to 1μ. Repeat for the seven other emulsion layers.

There will be no charge for the first big plate delivered, despite the man-years of work we have put into it. Let's just see if the product catches on.

How to order a persuasive movie

At luncheons, dinner meetings, after-dinner meetings, and Sunday morning brunches mankind strives for a proper mix of fact and opinion. Potential audiences abound for a movie you may wish to offer.

Audiences need not always be large. Movies-without-box-office have been known to do a magnificent job with an audience of two persons when they are the right persons. The job is to present a point of view nonverbally. Words are not the only honest way to communicate. It's all waste, however, unless the nature of the audiences, the methods of gathering them, and an exact, crisp, circumscribed objective are all clear in the sponsors' minds from the word "go." Both fact (e.g., "this bad weed grows among this crop") and opinion (e.g., "investment in high-energy physics is good for society") can with skill be made strongly persuasive in movie form.

We are in a position to explain all that precedes the word "go" and how to find the requisite skill and how to deal with those who have it. There is the matter of money. One of the skills highly developed among the 800 or so nontheatrical film producers in the U.S. and Canada is wise timing of the answer to a question usually asked too early in the discussion by the inexperienced prospective client: How much will it cost?

Say we:

> The objective that is too generalized can get expensive. The reason is that writers, artists, photographers, and anyone else who must create something out of a generalization tend to substitute technique for substance. And technique is what can get very expensive in motion picture production.

You can get the booklet that talks like that from R. D. Poey, Department 640, Eastman Kodak Company, Rochester, N.Y. 14650. Its title: "Movies Move People."

Rolls-Royce unlimited.

A whole new kind of flying?
It's one of the strangest spectacles in aviation. A fully armed eight-ton jet fighter plane, apparently quite conventional, takes off straight up, like a helicopter—then, without a moment's hesitation, sweeps into forward flight, faster than a helicopter, up to the speed of sound and beyond.

It's the Hawker Siddeley Harrier, the world's only fully operational Vertical/Short-Take-Off-and-Landing jet fighter.

The Harrier can take off from the middle of a forest or the deck of a destroyer, perform with the gusto of all but the fastest conventional jets, and land again in its own length.

Secret of the Harrier's performance is its Rolls-Royce Bristol Pegasus vectored-thrust engine. This engine has four rotating nozzles that direct the engine's thrust. They're pointed downward on takeoff, so the Harrier literally rises on a column of its own jet exhaust.

Once airborne, the pilot rotates the nozzles rearward, and the Harrier moves smoothly into forward flight. Pilots say it's no more difficult to fly than a conventional jet. Far safer, too, in crosswinds or on slippery runways; the only possible plane on bombed-out runways.

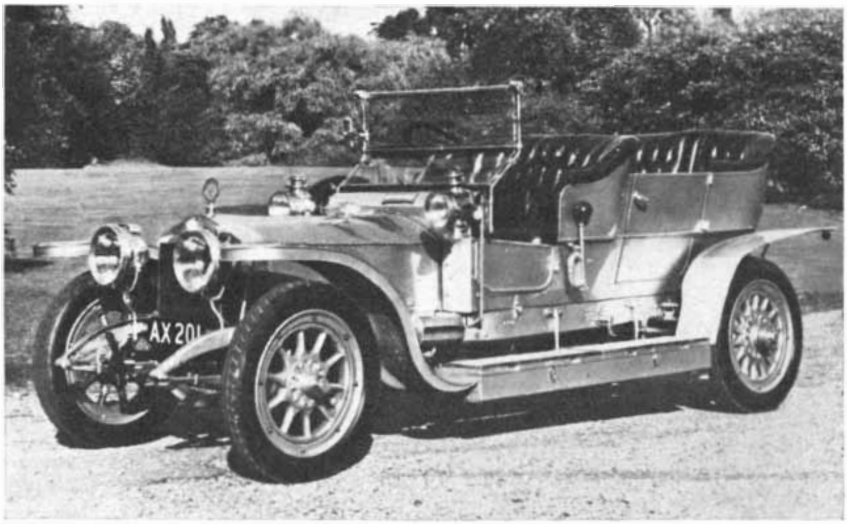
And think of the future for V/STOL aircraft in civil aviation! Airliners with the versatility of helicopters and the flight speed of conventional jets. Airliners that need less than a city block to land and take off in, instead of miles of runways. Little wonder that Rolls-Royce has been deeply involved in V/STOL aircraft since 1953, when their "Flying Bedstead" became the first successful vertical takeoff jet flying machine.

Those wonderful Anglo-American planes. When Rolls-Royce pools its talents with American firms, great things happen. Case in point is the versatile A-7D, an attack-fighter-bomber that can support ground forces, destroy tactical targets in battle areas, deliver large ordnance loads, take off from carriers, fly long range, or loiter over target areas.

Its TF-41 engine was developed and is being manufactured jointly by the Allison Division of General Motors at Indianapolis, and the Aero Engine Division of Rolls-Royce Ltd. at Derby, England. The airframe is being manufactured by the Vought Aeronautics Division of LTV Aerospace Corporation at Dallas. The A-7D made its maiden flight with the TF-41 engine on September 26, 1968.

The P-51 Mustang of World War II was another product of combined talents. This famous American fighter had a Rolls-Royce Merlin engine (the engine that powered the Battle-of-Britain Spitfires) built under license by Packard in the U. S. In addition to a spectacular record during the 1940's, Mustangs also earned laurels in the Korean conflict.

A Florida firm now rebuilds Mustangs, with 20-year-old war surplus Packard/Merlin engines fresh from their crates, for customers in the U. S. and several foreign countries. ▽



It's officially beautiful. ▷
Industrial designers believe that utility is no excuse for gratuitous ugliness. Rolls-Royce agrees. When they designed this Sentinel locomotive they got rid of the toadlike appearance of most switch engines. The design won the 1968 Capital Goods Award from Britain's Council of Industrial Design. The Sentinel was displayed at an exhibition at Birmingham, England—on the lawn, because it was too big to fit inside the building. Rolls-Royce also built the locomotive's diesel engine and automatic transmission. To an engineer, they're beautiful too.

△ **Design by light-pencil.**
This Rolls-Royce engineer is writing with an electronic light-pencil, feeding stress requirements for a turbine disc into a screen connected to Rolls-Royce's complex of 39 computers. The computers make all the calculations, and project onto the screen the design that meets all the requirements.

Rolls-Royce used computers originally for research, and more recently for engineering, manufacturing and marketing problems as well. They instruct machine tools, simulate engine performance, maintain records, issue procurement schedules and handle registration and issuance of company stock and dividends.

◁ **The Silver Ghost.** One of the more unlimited aspects of Rolls-Royce seems to be the life of a Rolls-Royce car. This splendid vehicle, for example. It's the original Silver Ghost, built in 1907 to represent Rolls-Royce at endurance trials. Among its laurels are a 400-mile trip from London to Glasgow in third gear, and in 1907 a world record of 14,371 miles without an involuntary stop. After a few years of record-breaking, this Silver Ghost was sold to a private owner, who used it for years. Rolls-Royce reacquired the car, and when it isn't on tour, it's on display at the company's London showroom. It's still in excellent running condition after 500,000 miles.

The body of the original Silver Ghost is polished aluminum, and all the external metalwork is silverplated. It's very advanced for its vintage, with a "square" engine, 4½-inch bore and stroke, 48 horsepower (British). The Silver Ghost line was in continuous production for nineteen years.

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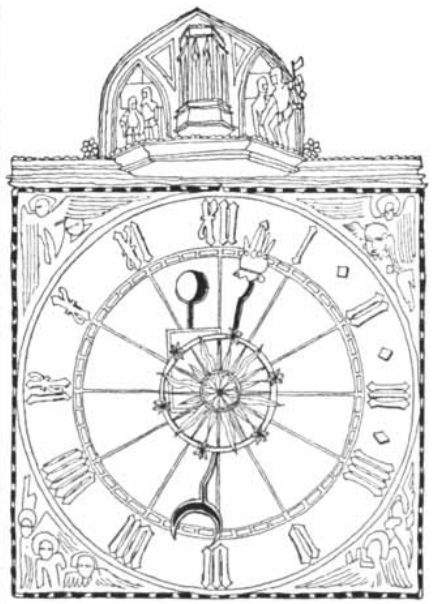
SCIENCE AND



The Nobel Prizes

The Nobel prizes in science for 1968 were awarded for elucidation of the genetic code, for experimental advances in high-energy physics and for theoretical contributions to thermodynamics. The prize for physiology and medicine was shared by Robert W. Holley, H. Gobind Khorana and Marshall W. Nirenberg, who worked independently, "for discoveries concerning the interpretation of the genetic code and its function in protein synthesis." The prize for physics was given to Luis W. Alvarez "for his decisive contributions to elementary particle physics." The prize in chemistry was awarded to Lars Onsager "for the discovery of the reciprocal relations bearing his name, which are fundamental for the thermodynamics of irreversible processes."

Holley, now a member of the Salk Institute for Biological Studies, carried out the investigation that brought him the Nobel prize at the U.S. Plant, Soil and Nutrition Laboratory at Cornell University. He reported in 1965 that he and his associates had established the chemical structure of one of the ribonucleic acids that transfer amino acids to the site of protein synthesis inside the living cell. Because of their function these ribonucleic acids, of which there is at least one for each of 20 amino acids, are called transfer RNA's, or tRNA's. Holley had found evidence for the existence of the tRNA's and their possible role in protein synthesis in 1957.

Subsequently he and others established that each of the tRNA molecules contains no more than about 100 of the subunits called nucleotides, of which there are several varieties. Each nucleotide consists of a base linked to a sugar (ribose) and phosphate; in different nucleotides only the bases differ. It was evident, therefore, that the tRNA's differed from one another in the assortment and sequence of their bases. Holley and his co-workers devised methods for isolating from yeast cells the tRNA that transfers the amino acid alanine and established its nucleotide sequence. The task took five years (see "The Nucleotide Sequence of a Nucleic Acid," by Robert W. Holley; SCIENTIFIC AMERICAN, February, 1966).

Nirenberg's work led to the decipherment of the genetic code; it was done at the National Institutes of Health beginning in the late 1950's. According to a hypothesis put forward by François Jacob and Jacques Monod (who won Nobel prizes in 1965), the sequence of amino acid units in a protein is established by the sequence of nucleotides in the form of RNA called messenger RNA, or mRNA. This RNA, in turn, was believed to carry a direct transcription of the genetic message originally embodied in the cell's DNA, a substance quite similar to RNA. The hypothesis was that a particular sequence of nucleotides—probably three—in RNA (transcribed from a complementary sequence in DNA) was sufficient to specify each of the 20 amino acids the cell links together in long chains to form proteins. The nucleotides in messenger RNA can comprise any of four different bases: adenine (A), uracil (U), guanine (G) and cytosine (C). Thus the job of deciphering the genetic code reduced to finding which sequence of three bases specified each of the 20 amino acids.

Nirenberg and his co-worker J. Heinrich Matthaei devised a cell-free system that would produce protein-like molecules (polypeptides) when they added synthetic RNA-like molecules containing one or more of the bases. By analyzing the polypeptides so produced they could tell which of the amino acids had been incorporated in response to particular combinations of bases present in the synthetic mRNA. Their initial finding, announced in 1961, was that a synthetic RNA containing only uracil stimulated production of a polypeptide chain consisting exclusively of the amino acid

phenylalanine. This became the first entry in the genetic-code dictionary: —UUU— equals phenylalanine (see "The Genetic Code: II," by Marshall W. Nirenberg; SCIENTIFIC AMERICAN, March, 1963).

In rapid succession Nirenberg and various co-workers tested all possible combinations of U, A, G and C in synthetic mRNA's until the code-word dictionary was complete. In the original method the exact sequence of bases in the RNA was not known, and therefore Nirenberg was unable to specify the sequence of the base triplets; thus one did not know whether one of the codes for leucine was CCU, CUC or UCC. Later Nirenberg and Philip Leder found a way to resolve this uncertainty.

Meanwhile Khorana and his associates at the University of Wisconsin were devising methods for synthesizing long RNA chains in which the base sequence was precisely known. They found, for example, that an RNA-like molecule containing alternating triplets of CUC and UCU directs the synthesis of a polypeptide in which leucine alternates with serine. Thus one knows that CUC is a code word for leucine and UCU a code word for serine. Khorana's work provided independent and convincing proof of the code assignments (see "The Genetic Code: III," by F. H. C. Crick; SCIENTIFIC AMERICAN, October, 1966).

Alvarez has been running high-energy experiments at the University of California at Berkeley for more than 30 years. Among the first to recognize the importance of the hydrogen bubble chamber for recording the tracks of short-lived elementary particles, he built a succession of chambers with diameters of two, four, 10, 15 and finally 72 inches. Coupled to Berkeley's large particle accelerator, the Bevatron, the 72-inch chamber soon provided such a flood of photographs of nuclear events that Alvarez and his associates undertook the design of automatic systems for measuring particle tracks and computing the properties of the particles that made them.

Onsager was appointed J. Willard Gibbs Professor of Theoretical Chemistry at Yale University in 1945. Born in Norway, Onsager came to the U.S. in 1928, teaching first at Johns Hopkins University and soon afterward at Brown University. The theory for which he was

principally honored is concerned with the thermodynamics of irreversible processes, of which events inside the living cell are an example. This theory deals with systems that are not in true thermodynamic equilibrium but are in a steady state in which the inflow and outflow of matter and energy are coupled. A simple example is a thermocouple, a device consisting of two dissimilar metal wires joined at both ends. If the two junctions are maintained at different temperatures an electric current will flow in the assembly and can be used to move a pointer in a measuring instrument. The flow of current, however, itself generates a flow of heat; it is apparent that the two flows must affect each other. Onsager proposed that the two coefficients of the mathematical terms that express the interdependence of the two flows are equal. This is known as the Onsager reciprocal relation. It is fundamental to any theoretical treatment of irreversible processes and is sometimes termed a fourth law of thermodynamics.

Pulsars and Supernovas

Evidence that a newly discovered pulsar may be the final collapsed stage of a star that exploded is presented in *Nature* by M. I. Large, A. E. Vaughan and B. Y. Mills of the Cornell-Sydney University Astronomy Centre in Australia. Pulsars emit closely spaced radio pulses with extreme regularity. The new pulsar, PSR 0833–45, has the highest flicker rate yet reported: more than 11 pulses per second. Its exact period is .0892 second. The periods of the other 11 pulsars now known range from .25 second up to two seconds.

Since their discovery a little more than a year ago pulsars have been the most intriguing mystery in astronomy (see "Pulsars," by Antony Hewish; SCIENTIFIC AMERICAN, October). The prevailing view is that pulsars are stars that have used up all their nuclear fuel and have collapsed to objects the size of the earth or smaller. Thus they may be a peculiar type of white-dwarf star or they may represent a new class of objects: a neutron star. None has yet been identified with an optically visible object.

PSR 0833–45 is situated within the boundaries of a complex radio source that is thought to be the remnant of a Type II supernova. The position, of course, could be fortuitous; the pulsar might actually lie in front of the remnant or behind it. The distances to the two objects can only be estimated, but they appear to be the same: roughly 500 parsecs, or 1,600 light-years.

The discoverers of the new pulsar believe that its fast pulse rate favors the hypothesis that it is a rapidly rotating neutron star left behind after the supernova explosion. It has been estimated that there have been 10^8 Type II supernova explosions during the lifetime of our galaxy. According to present statistics, based on an admittedly tiny sample, there may be about 10^5 pulsars in the galaxy. This suggests either that only one Type II supernova in 1,000 leaves a pulsar behind or that the remnant neutron stars go through a pulsar stage that lasts only about 10^7 years.

Contraception among Catholics

The majority of Roman Catholics in the industrialized countries practice some form of birth control, and the form they are most likely to practice is not the church-approved rhythm method, according to a summary of evidence presented by Gavin Jones and Dorothy Nortman of the Population Council. In the U.S. only about a third of the Catholics undertake to limit births, and the proportion appears to be decreasing. Whereas in 1955 only 30 percent of all Catholic women in the U.S. had used a "forbidden" form of contraception, 53 percent had done so in 1965.

The summary points out that, although Catholics in industrialized countries have somewhat larger families than non-Catholics do, the average Catholic family is smaller (two to four children) at every economic level than would be expected if fertility were not regulated. Yet the proportion of Catholics who use the church-approved method of fertility regulation is only 22 percent in Britain, 18 percent in Canada and 13 percent in the French city of Grenoble. In urban areas of Latin America it appears that as many as half of the Catholics have used contraceptive methods other than the rhythm one, and hospital records suggest that a common way of regulating fertility is induced abortion. The summary by Jones and Mrs. Nortman appears in the Population Council's publication *Studies in Family Planning*.

Common Causes?

Coronary heart disease, stroke and aortic aneurysm (a ballooning of the great artery descending from the heart) have much in common, including particularly the presence of atherosclerosis, in which the arterial wall is thickened by an accumulation of fatty plaques. The actual mechanisms that cause the diseases remain unknown, however, and so it was not known how closely they are related. Now a new analysis by E. Cuyler Hammond of the American Cancer Society has shown that the same factors apparently lead to increased death rates from all three diseases: heavy cigarette smoking, lack of exercise and overweight. This is important, Hammond points out, because it suggests that "measures taken to prevent any one of them would probably reduce the risk of all three." If they had turned out to have completely different causes, "the problem of controlling them would be far more difficult."

Working with data from a large group of men and women enrolled in a prospective study in the winter of 1960 and followed for six years, Hammond analyzed mortality rates in relation to cigarette smoking, weight, exercise, sleeping habits, "nervous tension" and high blood pressure. Below the age of 60, he found, smoking was the most important factor and obesity was next; beyond 60, lack of exercise seemed to be the most important. A new finding was a correlation between long hours of sleep and deaths from coronary attack or stroke. For example, the death rate from stroke was almost twice as high for men between 60 and 79 who slept 10 or more hours a night as among those who slept seven hours. High blood pressure, as expected, had a large effect: subjects with hypertension had far higher death rates from all three diseases whether they smoked or not, were heavy or thin, took much or little exercise. Surprisingly, there was scant relation between death rates and the amount of nervous tension the subjects had said they were under.

The evidence suggests, Hammond told a symposium at the Albany Medical College, that cigarette smoking acts somehow to promote the formation of atherosclerotic plaques (provided that there is at least a certain minimum amount of saturated fat in the diet, which Hammond thinks is probably the case for most Americans). The level of saturated fats is presumably decreased by exercise, which tends to burn the fats as fuel; the level is presumably increased by obesity, which provides ample alternative fuel. It is considered possible that long periods of sleep, and therefore of decreased metabolism, may fit into the same process.

U-233 Reactor

A nuclear reactor using uranium 233 as its fuel has gone into operation at the Oak Ridge National Laboratory of the Atomic Energy Commission. The

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Teaching avionic systems to get along in close quarters.

Within the limited confines of airframes, Lockheed avionics experts are closely integrating increasing numbers of increasingly complex electronic systems. By thus "teaching" diverse systems to be compatible, previously impossible aircraft capabilities are becoming routine. Some brief examples follow.

Advanced Sub Hunter. Nuclear submarines—faster, quieter and deeper-running—are becoming ever more elusive game for U.S. Navy sub-hunting aircraft. To keep ahead, Lockheed is developing the most sophisticated version yet of the P-3 Orion.

Designated P-3C, this electronics-packed plane has the first general-purpose digital computer for automatic ASW (antisubmarine warfare) data processing. Besides many subsystem improvements, other sharpened capabilities come from interfacing the computer with existing subsystems, maximizing their effectiveness. Totally, the P-3C's is the fastest, most accurate ASW tactical data retrieval, transmission and display system yet devised.

An example of the integration problems solved involves the MAD (Magnetic Anomaly Detection) gear. This

LOCKHEED
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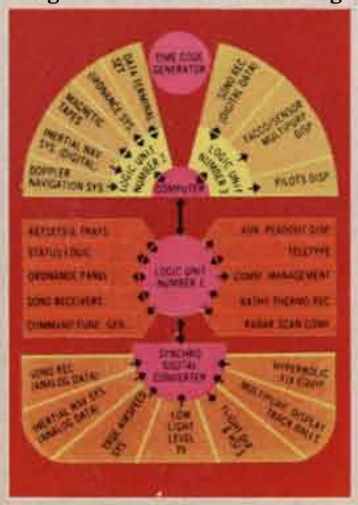
sensor detects aberrations in the Earth's magnetic field—such as those caused by large metal bodies. Although initial design provided the most magnetically clean tail environment possible, the gear still must operate surrounded by hundreds of magnetic fields generated by other on-board subsystems. For instance, fields are induced by transmitters. And small localized radio frequency currents generated in the plane's skin create tiny circulatory currents, inducing weak fields. Enabling the MAD gear to maintain maximum sensitivity, these disturbances are neutralized by compensation. Result: Most aircraft systems can be operated while flying MAD patterns, with confidence that any submarine in range can be detected.



R3C, simplified ASW data flow diagram.

When all the P-3C's electronic parts are fitted together, its data processing capability is expected to more than double the present ability to detect, classify and localize targets. And the MTBF (mean time between failure) for certain systems may be 5 to 7 times greater.

Although the P-3C has about twice the P-3B's black boxes, they are condensed into the same space by miniaturization and electromagnetic interference control techniques. And next, as 1 of 2 Contract Definition contractors for the VS(X) (new Navy carrier-based ASW plane), Lockheed will equal the P-3C's avionics capability in about one-fifth the fuselage volume.

Fully Integrated Armed Compound Helicopter. The U.S. Army's winged AH-56A Cheyenne is the first production helicopter using Lockheed's Rigid Rotor and the first manned Army craft with fully integrated avionics. One gives inherent stability and superior handling; the other puts these to maximum use for battle.

The heart of Cheyenne's avionics system is a computer central complex. It includes 3 data processing units, a signal transfer unit and a digital interface unit. Integrated with it are the various subsystems. Assuring compatibility of all subsystems—the substance of avionics integration—comes through careful component interfacing.

The central complex, besides processing information related directly to sensors, navigation, control and data display, computes for the weapon system. Example: When the gunner sights a target, the computer is fed data by a laser range finder, flight velocity from a doppler radar, stabilization information from an inertial platform, plus inputs from other sensors. Then it adjusts for the weapon's ballistics using precisely stored information, aims and fires the gun with deadly accuracy.

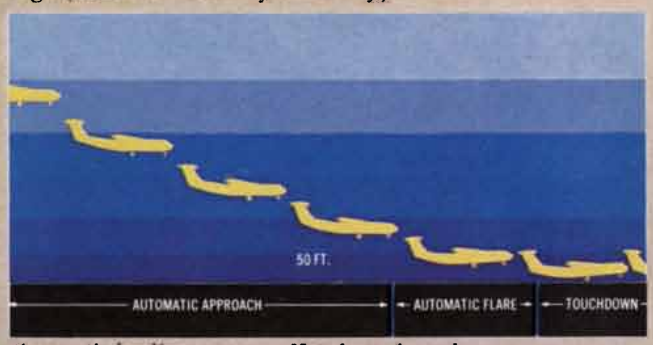
Some other Cheyenne avionics systems include: Terrain following and avoidance radar for safe automatic low-level flight. Station-keeping radar for automatic close-formation flying in any weather. And FLAWS, a Fault Location and Audio Warning System that monitors critical avionics and flight systems, beeps a warning and pinpoints malfunctions on a display panel.

Advanced avionics such as these, properly mated, will make Cheyenne one of the most effective weapons in the Army's arsenal. And, with extensive use of microelectronics, Cheyenne's avionic functions fit into one-third the space required by previous technology.

First Fully Automatic Landing System. Typical AWLS (All-Weather Landing Systems) guide a plane only to within 100 ft. or so of the runway, then return control to the pilot. Now Lockheed has developed a fully automatic system. Complete with automatic flare, it inclines the plane to touch down at the proper angle.

Lockheed's AWLS is completely integrated, rather than devised through the "building block" approach. Also, through microminiaturization and high-density packaging, the number of circuit components per cu. in. was increased by up to 50%. It was initially developed jointly by Lockheed, the U.S. Air Force and the FAA for use on Lockheed-built C-141 StarLifter transports. Besides automatic piloting and flare-computing, it can give the pilot an instant position fix any time, automatically control the throttle, and guide the aircraft to smooth touchdowns. If a go-around is necessary, it gives the pilot proper commands. For added safety, a test and logic computer was developed for automatic in-flight system testing, subsystem monitoring, failure warning and fail-safe disengagement of faulty components.

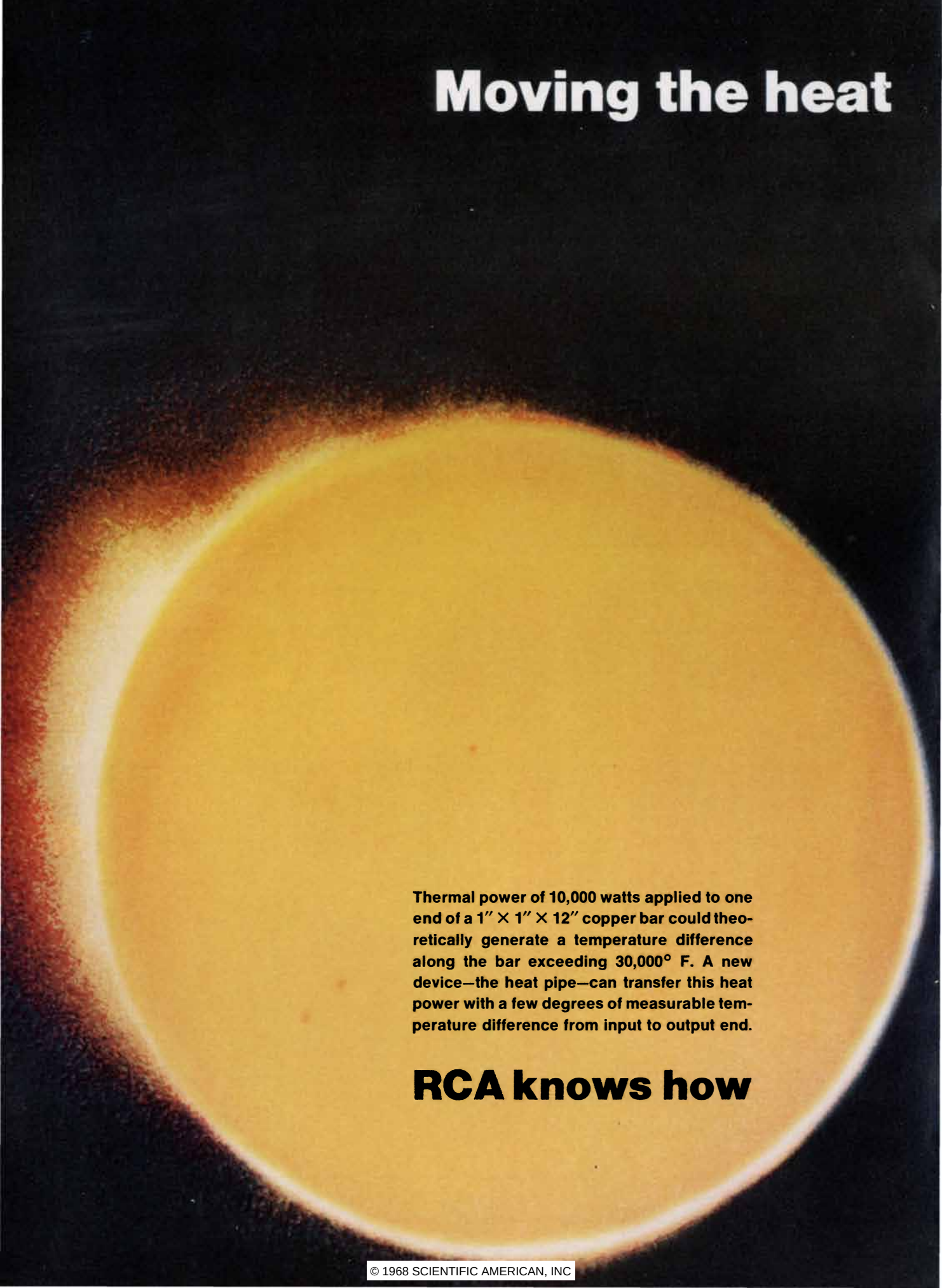
This AWLS is the first fully automatic military system certified by the FAA for Category II approaches (100-ft. ceiling and 1,200-ft. runway visibility), with further FAA approval to continue the approach automatically through touchdown. Demonstrating its capability, the system brings huge C-141s in for perfect landings within 300 ft. of a designated touchdown point and within 12 ft. of a runway center line. Lockheed's latest test program, recently completed, will aid the FAA in establishing equipment criteria for certification of Category III landings (near zero runway visibility).



Automatic landing sequence. Not shown in scale.

The activities mentioned here are only a few of Lockheed's current projects in avionics R&D. If you are an engineer or scientist interested in this field of work, Lockheed invites your inquiry. Write: K. R. Kiddoo, Lockheed Aircraft Corporation, Burbank, California 91503. An equal opportunity employer.

Moving the heat



Thermal power of 10,000 watts applied to one end of a 1″ × 1″ × 12″ copper bar could theoretically generate a temperature difference along the bar exceeding 30,000° F. A new device—the heat pipe—can transfer this heat power with a few degrees of measurable temperature difference from input to output end.

RCA knows how

of man-made suns

Modern technologies in science and industry often require the transfer of large amounts of heat from man-made "suns" or heat sources. Heating and cooling each require moving such thermal power for varying distances. For example, the initial energy produced by a nuclear power plant is in the form of heat which must be brought out from the reactor core to generate steam that produces useful electric energy. Almost every electrical or electronic device generates useless heat energy which must be disposed of outside the immediate environment by some form of heat sink. Major research efforts have been devoted—at RCA and elsewhere—to finding more efficient ways of moving this heat energy from one place to another, either for heating or cooling purposes.

Chief design problem has always been that metals, in many applications, are relatively poor conductors of thermal energy. For example, 10,000 watts of thermal power applied to a bar of copper at ambient temperature can theoretically produce a 30,000°F Δ_t along the bar—sufficient heat to vaporize solid copper.

Newest answer to this problem of transferring thermal energy—developed originally for highly-specialized power-

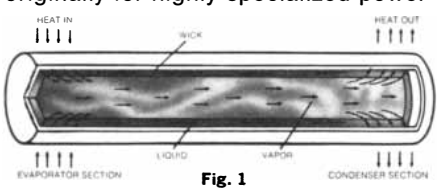


Fig. 1

generating units in spacecraft—is the *heat pipe,* an example of which is shown in cross-section drawing in *Fig. 1.* This device, now emerging from development at RCA, is basically a closed and evacuated chamber whose walls are lined with a wick that is saturated with one of a number of selected liquids. Under applied heat, this fluid absorbs the heat, is vaporized, and then moves the thermal energy from one end of the pipe to the other. There it condenses back to liquid form, and "wicking" or capillary action returns the liquid to the input end of the containment vessel to complete the cycle. The heat pipe owes its unique capabilities to the combination of these two actions—vapor-transfer of heat and capillary return of liquid—which define the areas of its practical application.

Heat pipes, such as those RCA has developed, are several thousand times as effective as the best metallic conductors, such as silver or copper. A one-inch diameter heat pipe just over two feet in length has been used to carry 11,000 watts of thermal power with a temperature rise that is barely measurable from input to output end. It would take a metal block nine feet in diameter, weighing nearly 40 tons, to cope with an equal amount of heat energy. Because the heat pipe is essentially an isothermal device, its output surface temperature remains highly uniform. This creates an important application advantage for the heat pipe. For example, this device can be used to enhance the low power output from radioactive isotopes to provide sources for space-power systems through heat concentration. Conversely, the concentrated high heat at the anodes of thermionic tubes in radio and TV transmitters can be disposed of by using a heat pipe to conduct it to some form of heat sink, where a low-pressure fan or blower disperses the heat energy.

One type of RCA-made heat pipe can hold delivery temperature at a relatively constant level regardless of variations in power input. RCA engineers have achieved variations of less than 1% in temperature with this type of heat pipe while input power levels change by a factor of ten. The way that non-uniform heat inputs can produce closely-controlled thermal output gives the heat pipe application potential for such uses as chemical process temperature control; maintaining the oscillation frequency of piezoelectric crystals; controlling heat treating processes closely. Conversely, removal of large amounts of heat is an ideal assignment for the heat pipe where considerations of weight, size and operating life are paramount. The bank of heat pipes shown in the Air Force photograph in *Fig. 2* was developed to dissipate unwanted heat generated within orbiting space vehicles. This complete unit—developed for the Air Force by RCA—is only 23″ x 43″ in size, only weighs 17.6 pounds and was designed to have

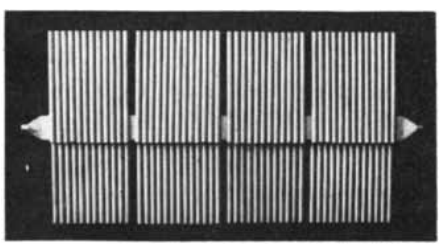


Fig. 2

reliability typical of manned spacecraft. It will dissipate 50,000 watts of heat energy at 1420°F.

In making heat pipes, RCA has employed many different configurations of outer envelope and wick. Glass, ceramics, copper, stainless steel, nickel, molybdenum, columbium and various alloys have been used in outer containment vessels. The wick or capillary structures have included various types such as sintered porous materials, woven mesh, fiber glass, longitudinal slots and combinations of these structures. To the skills in mechanics and metallurgy involved, RCA engineers bring the result of more than 40 years' specialization in vacuum-tube technology and vacuum physics not found

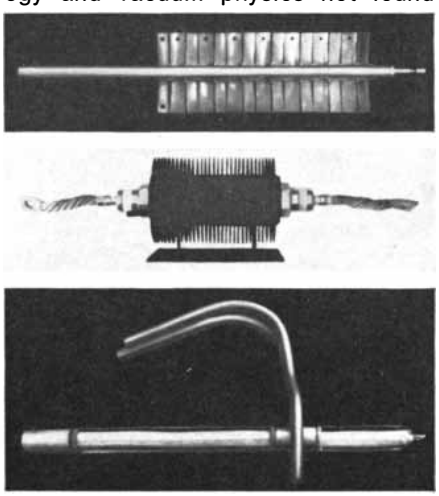


Fig. 3

elsewhere—to aid in building heat pipes in diameters from over six inches down to fractions of an inch, and in lengths up to several feet. Some of these RCA-made units are shown in *Fig. 3.*

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RCA

U-233 was converted from nonfissionable thorium 232 by neutron capture. The reactor thus brings closer to realization the long recognized possibility that thorium, which is available in larger quantities than uranium, can be used as a source of energy. The time when it will be widely exploited as a fuel may be far off, however, because such nuclear fuels as U-235, which is in comparatively limited supply, and plutonium 239, which can be created from the nonfissionable but fairly abundant uranium 238, are also available. Moreover, the technology of creating plutonium from U-238 in breeder reactors, which produce more fuel than they consume, is advancing.

The U-233 reactor's fuel is in the form of a molten salt of uranium fluoride–lithium fluoride into which U-233 was processed at the Oak Ridge laboratory. At present the reactor produces only heat, but the hope of the AEC is that such reactors will become not only an economic source of electric power but also breeder reactors. A molten-salt breeder reactor would operate on the thorium-uranium fuel cycle, in which atoms of nonfissionable thorium would be converted into fissionable atoms of U-233. At ceremonies accompanying the start-up of the reactor Chairman Glenn T. Seaborg of the AEC said: "Uranium 233 and plutonium 239 (which opens up the abundant but nonfissionable isotope uranium 238), when added to the relatively more scarce but fissionable isotope uranium 235, make the nucleus of the atom a virtually unlimited source of energy."

Colds and Cold

The common notion that exposure to a chilly environment makes one likely to catch a cold has failed to stand up in a series of experiments conducted at the Baylor University College of Medicine and the National Institutes of Health by R. Gordon Douglas, Jr., Keith M. Lindgren and Robert B. Couch. "This study," they write in *The New England Journal of Medicine,* "demonstrated no effect of exposure to cold... that could account for the commonly held belief that exposure to cold influences or causes common colds." The findings are in accord with those made over a period of years by the Common Cold Research Unit of the British Medical Research Council (see "The Common Cold," by Christopher Howard Andrewes; SCIENTIFIC AMERICAN, February, 1951).

Douglas and his colleagues worked with healthy male volunteers. All were inoculated with Type 15 rhinovirus, one of the cold-producing viruses. A majority of the men were exposed to a chilly environment (they were either lightly dressed in a room at a temperature of 40 or 50 degrees Fahrenheit or were immersed in a tank of water at 90 degrees F.); the others were not exposed to chilling. The subjects were exposed at various times in five separate experiments: at the time of inoculation, during the incubation period of the disease and several days after inoculation. Results were similar for both the exposed and the unexposed group.

Since it is a fact that colds are more common during the winter months than at other times of the year, the authors inquire what the connection might be between cold weather and colds. One possibility, they write, is that "increased crowding indoors occurs as a result of colder weather, providing an increased opportunity for transmission." Another possibility is that "the changes in environmental conditions that occur in winter months may create a favorable situation for survival of certain respiratory viruses in the environment, also allowing increased transmission."

Sagging Electrons

A small electric potential set up by the centrifugal movement of electrons in a rapidly spinning metal rotor has been detected by an experimenter at the University of Virginia. Attempts to measure this effect, which theoretically resembles the much weaker effect of gravity on electrons, have been made by a number of investigators since its existence was first predicted in the 1900's. Until now, however, the equipment used was not precise enough to allow a conclusive measurement. The successful test was conducted by Jesse W. Beams, who describes his technique in a recent issue of *Physical Review Letters.*

The apparatus developed by Beams consists of a four-armed, cross-shaped metal rotor, mounted inside an evacuated metal chamber on a thin, flexible shaft, which is spun by an air-supported, air-driven turbine. Electrical contact with the rotor was made through a water-cooled liquid-mercury contact with the drive shaft. Two metal capacity pickups mounted in the vicinity of the rotor arms made it possible to detect a potential change of a few microvolts between the axis and the periphery of the rotor.

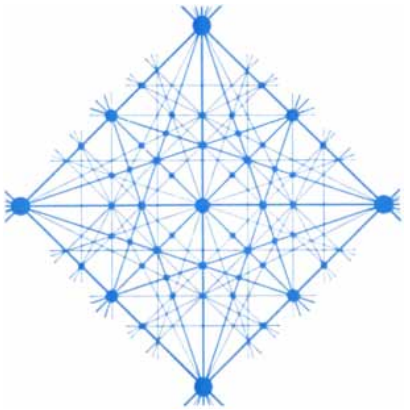
Beams found that the electrical potential of the rotor surface at a given radial distance remained constant for long periods if the rotor speed and temperature were held constant. When the rotor speed was increased, the potential of the periphery became slightly positive with respect to the axis. When the rotor speed was then reduced to its original value, the potentials of the rotor surfaces returned to approximately their original values. For a given experiment this radial potential change across the rotor was roughly proportional to the square of the rotor speed. With a change in rotor speed from 6,000 to 39,000 revolutions per minute, for example, the potential changes were on the order of one millivolt and hence were much larger than the sensitivity of the apparatus. The results obtained were independent of the direction of rotation of the rotor, provided that the earth's magnetic field was carefully compensated.

Beams points out that his results are in "reasonable agreement" with theoretical estimates of the effect of centrifugal force (or gravity) on the movement of electrons through a crystal lattice. His work is also expected to have a bearing on a series of experiments now being conducted at Stanford University to determine whether a free-falling positron (the antiparticle of the electron) will fall down or up inside a vertical metal cylinder under the influence of gravity.

Self-shearing Sheep

An end to sheep-shearing—a hot, hard, odorous, dirty but skilled occupation that pays as much as $12 an hour—may be in sight. Experiments conducted by the Agricultural Research Service of the U.S. Department of Agriculture show that a substance belonging to the nitrogen-mustard family, known as a drug that interferes with the multiplication of cancer cells, also interrupts the growth of hair cells at the root. E. H. Dolnick of the Agricultural Research Service gave varying doses of the substance to sheep; a week or so later the drug-induced constriction in each hair had grown out to a point just above the surface of the animal's skin. The fleece could then be pulled off the sheep without waste of wool, discomfort to the animal or skill on the part of the puller.

The effective dose, about 20 milligrams of the drug per pound of body weight, is less than a quarter of the amount found to be lethal to sheep and is without apparent side effects. Further studies are needed to determine if chemical defleecing alters either the growth or the quality of the wool and if residues accumulate in the animal's tissues. If they do not, the use of the drug could go far to relieve sheep raisers of the difficult and costly job of mechanical shearing.



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SEA-FLOOR SPREADING

Geophysical phenomena ranging from earthquakes to continental drift are being explained by a new theory that gives promise of eventually relating geomagnetism and the earth's internal and orbital dynamics

by J. R. Heirtzler

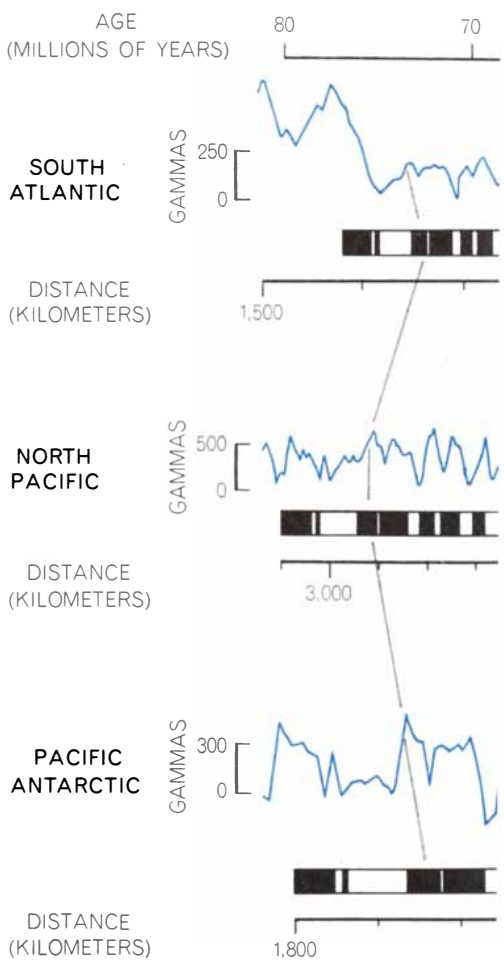
Comprehensive new theories that rationalize large numbers of observations and explain major aspects of the physical world are rare in any field of investigation. Such a synthesis may be within reach in geophysics. The past few years have seen the emergence of a new theory concerning systematic movements of the sea floor. It deals with vast and formerly unsuspected forces that churn the interior of the earth and account for the arrangement of ocean basins and land masses as we know them today. The theory is based on a variety of observations and hypotheses concerning the topography of the sea floor and the distribution of its sediments, the occurrence of faults and earthquakes, the internal structure of the earth, its magnetic field and periodic reversals of the field. It neatly supports the developing theory of continental drift. Together these theories have already been successful in explaining many surface features of the earth and providing information on internal earth processes. And it is possible that their full importance has yet to be appreciated—that they point toward a major synthesis relating the internal dynamics of the earth, its magnetic field and the dynamics of its orbital motions.

History of the Theory

The stage was set for the discovery of sea-floor spreading by the long debate over continental drift [see "Continental Drift," by J. Tuzo Wilson, SCIENTIFIC AMERICAN, April, 1963, and "The Confirmation of Continental Drift," by Patrick M. Hurley, April, 1968]. Evidence from the shape, geological structure and paleontology of various continents and, within the past 20 years, studies of the "paleomagnetism" frozen into volcanic rocks had suggested that the continents have drifted to their present locations from appreciably different positions in the course of millions of years. Even after the possibility of such drifting began to be recognized, it was not at all clear what forces could have caused great land masses to move over the surface of the globe.

By the late 1950's oceanographers had discovered that a continuous range of undersea mountains twists and branches through the world's oceans, that this ridge is usually found in the middle of the ocean and that earthquakes are associated with it. Marine geologists were aware too of the striking youth of the ocean floor: no bottom samples were ever found to be older than the Cretaceous period, which began some 135 million years ago. About 1960 Harry H. Hess of Princeton University proposed that the ocean floor might be in motion. He suggested a kind of convective movement that forced material from deep in the earth to well up along the axis of the mid-ocean ridges, to spread outward across the ocean floor and to disappear into trenches at the edges of continents. (The hypothesis seemed particularly attractive in the case of the Pacific Ocean, which is bordered by trenches, but it was less satisfactory for other oceans, which lack them.)

At about the same time Ronald G. Mason, Arthur D. Raff and Victor Vacquier of the Scripps Institution of Oceanography discovered that the ocean floor off the west coast of North America exhibited a remarkably regular striped pattern of variations in magnetic intensity [see "The Magnetism of the Ocean Floor," by Arthur D. Raff; SCIENTIFIC AMERICAN, October, 1961]. The pattern suggested great filamentary magnetic bodies, oriented north-south and offset at intervals along distinct lines running approximately at a right angle to the lineations. No structural features that could explain such a pattern had ever been observed. The origin of these unique magnetic bodies remained a mystery for nearly five years. In 1963, after it had been noted that a distinct magnetic body could often be detected at the axis of a



MAGNETIC ANOMALIES (*color*) recorded in all the world's oceans reveal the same succession of magnetic bodies (*black and white bands in strips*) parallel to the mid-ocean ridge. The bodies represent rock that

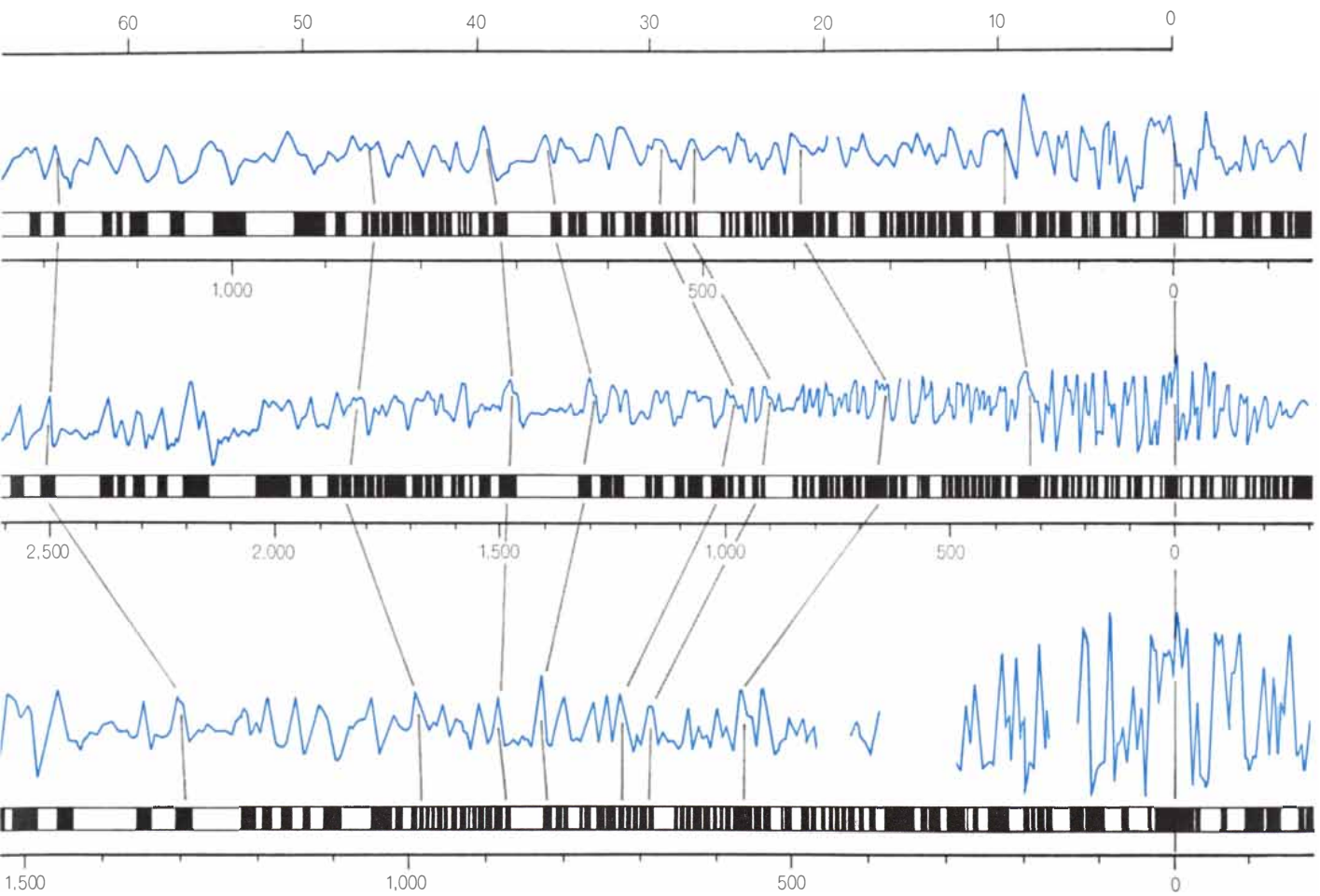
mid-ocean ridge, F. J. Vine and D. H. Matthews of the University of Cambridge proposed a convincing test of the hypothesis advanced by Hess. It was based on the discovery (which was just then being confirmed in detail) that the earth's magnetic field had reversed direction a number of times in past ages. They reasoned that if molten rock were pushed up along the axis of the mid-ocean ridge, it would become magnetized in the direction of the earth's prevailing magnetic field as it cooled. If the newly cooled material was subsequently pushed out away from the ridge, it would form strips of alternately "normal" and "reversed" magnetism, depending on the polarity of the earth's magnetic field when the rock solidified. A magnetometer at the surface of the ocean should detect these strips as positive or negative anomalies in the earth's smooth field.

Confirmation

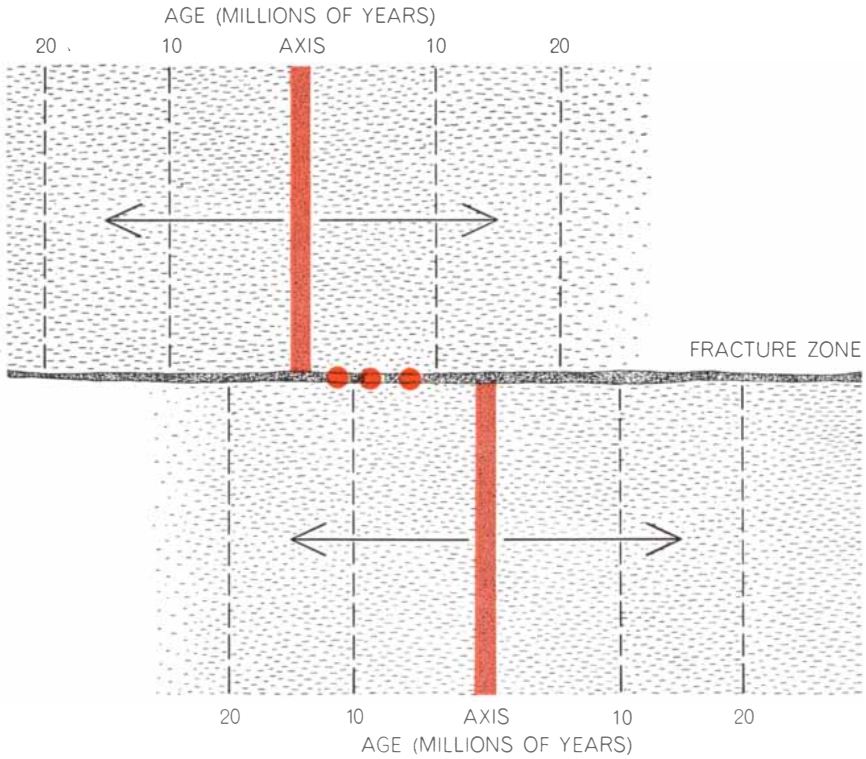
As the Vine-Matthews proposal was being published, I was engaged, with colleagues from the Lamont Geological Observatory of Columbia University and the U.S. Naval Oceanographic Office, in a careful magnetic survey of the Reykjanes Ridge, a section of the Mid-Atlantic Ridge south of Iceland that was known to have large magnetic anomalies. We found that the anomalies were linear and symmetrically distributed parallel to the axis of the ridge. This strongly supported the idea of sea-floor spreading from the ridge and the formation of magnetic anomalies, just as Vine and Matthews had suggested. A little later Vine and J. Tuzo Wilson of the University of Toronto pointed out that the recent reversals of the field matched, one for one, part of the extensive pattern of magnetic lineations recorded just off the west coast of North America by Mason, Raff and Vacquier.

By 1965 it was clear to us and others that magnetism could be the key to reconstructing the history of the ocean floor and the movements of the continents. In only three years a great deal has been learned. Indeed, so many different workers have made significant contributions that it is impossible to name them all in a brief review or even always to know who was the first to make a new observation or propose a new model.

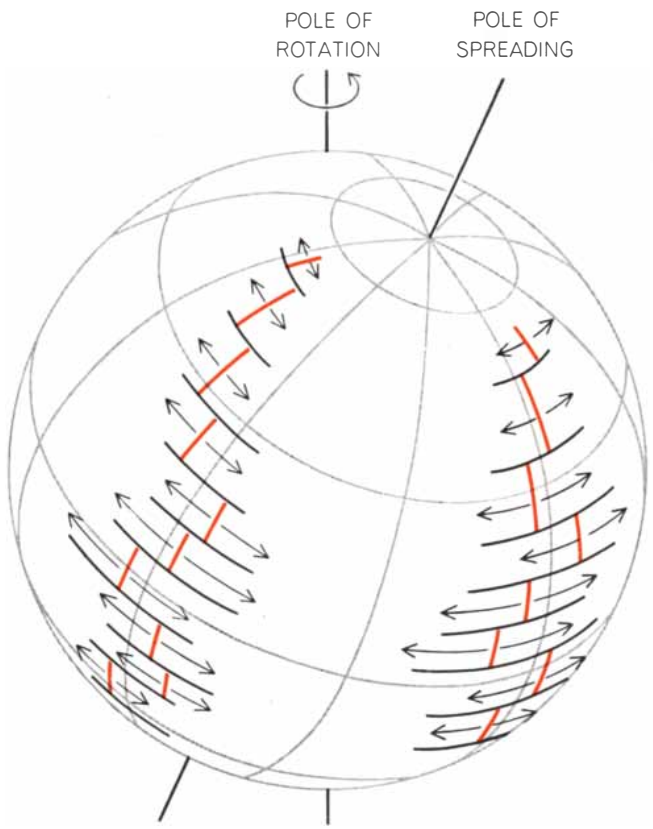
Pioneering efforts to measure the earth's magnetic field at sea had begun at Lamont about 20 years ago. Simple and precise instruments were designed to be towed behind ships and in time efficient techniques were devised for recording, storing and interpreting the data to delineate sea-floor structures hidden under layers of sediments. In 1965, when the new importance of magnetic anomalies became apparent, we had a large stock of data from all the oceans of the world and computer techniques with which to process the data. Examining the data in the light of the new hypotheses, we were able to recognize the same sequence of magnetic bodies extending away from the axis of the mid-ocean



welled up along a "spreading axis" at the ridge during successive periods when the earth's magnetic field was "normal" as it is today or "reversed." The rock was magnetized in the ambient field and later forced out from the axis by subsequent flows. Here three magnetic traces are shown, from three oceans. The anomalies (in gammas, a measure of field intensity) and the magnetic bodies associated with each are spaced differently in each ocean because the spreading rates were different (the rate in the South Atlantic is believed to have been the most constant), but each ocean has the same sequence of 171 reversals extending back 76 million years.



MOLTEN ROCK wells up from the deep earth along a spreading axis, solidifies and is pushed out (*arrows*) by subsequent upwelling. The axis is offset by a fracture zone. Between two offset axes material on each side of the fracture zone moves in opposite directions and the friction between two blocks of the crust causes shallow earthquakes (*colored disks*).



GEOMETRICAL RELATION between ridge axis and fracture zone becomes evident if one conceives of lines of latitude and longitude drawn about a "pole of spreading" rather than the pole of rotation. In each ocean the fracture zones are perpendicular to the spreading axis, and the rate of spreading (*arrows*) varies directly with distance from the equator.

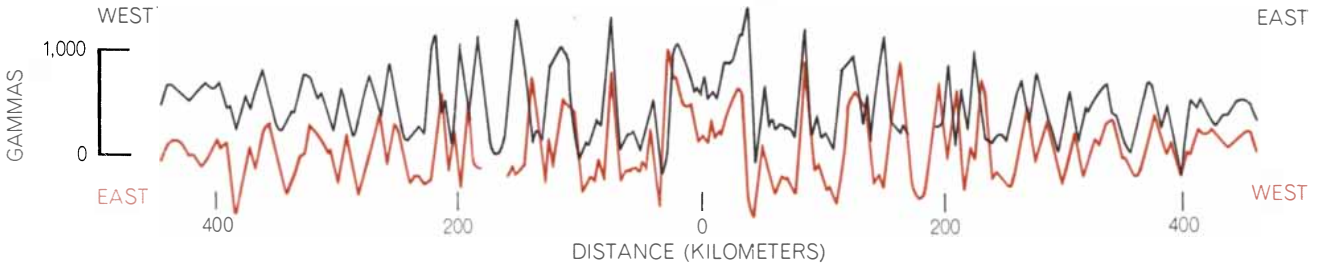
ridge in the South Pacific, South Atlantic and Indian oceans.

Further examination has revealed a worldwide pattern of sea-floor spreading that makes sense of a wide variety of observations. It seems to explain the occurrence of many earthquakes. It establishes a detailed time scale for magnetic reversals and accounts for the direction and rate of continental drift. However, the precise geological events involved in the upwelling along the ridge and the downwelling at the edges of continents are still not understood in detail.

The Worldwide Pattern

At this point we know the main features of the spreading pattern in about half of the world's ocean areas, for the most part those that are adjacent to the better-explored sections of the mid-ocean ridge. The areas where the spreading pattern is unknown either are unexplored or simply resist explanation. For example, many oceans are not wide enough to show the very oldest magnetic bodies, and so not enough magnetic anomalies can be recorded to establish a rate of spreading. Some areas of the ocean floor show no magnetic anomalies. This may be because they are actually not part of the moving floor or because they were created in ancient geologic ages when the earth's field may not have been reversing. There may be places where the spreading is so slow that magnetic bodies crowd one another and confuse the magnetic-anomaly pattern. We have even found places where the axis of spreading is apparently under the continents or does not coincide with the axis of the mid-ocean-ridge system.

The mid-ocean ridge, the axis of the sea-floor spreading, does not meander smoothly from ocean to ocean; instead it is abruptly offset at many points. The offsets, or fracture zones, often extend to great distances on each side of the axis and are usually marked by some irregularity in the topography of the sea floor. Since material wells up at the axis and moves outward on both sides of a fracture zone, it is clear that there will be substantial friction along the zone between offset sections of the axis, where the material is moving in opposite directions [*see top illustration at left*]. Earthquakes, of course, are generated by just such rubbing and scraping between blocks of the earth's crust. Seismologists are now able to pinpoint the location and depth of an earthquake to within a few miles and also to identify the direction of initial motion of the crustal blocks in-

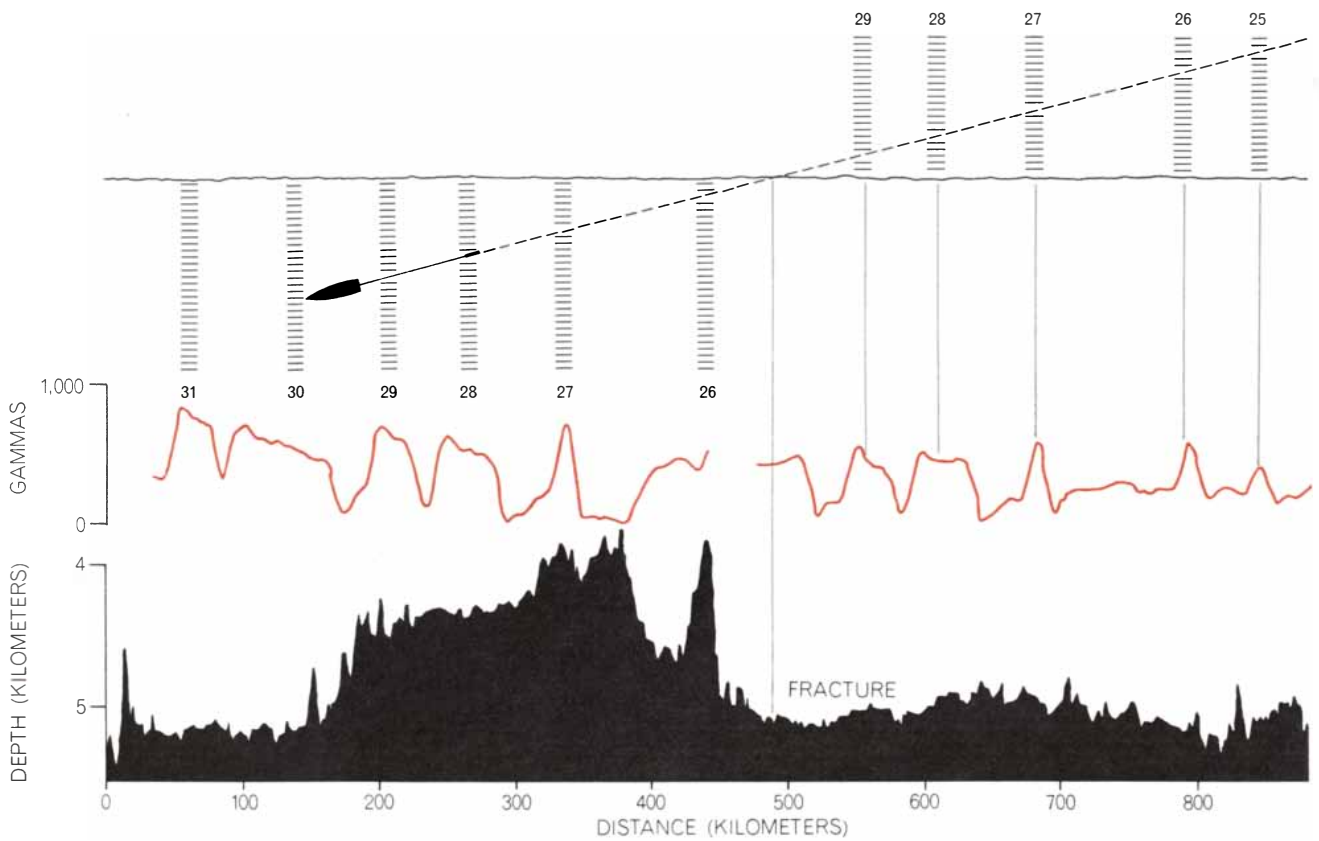


SYMMETRY of the magnetic record reflects the fact that similarly magnetized rock is pushed out on both sides of the axis. The symmetry is demonstrated by reversing a record covering about 1,000 kilometers (*color*) and superposing it on the original (*black*).

volved. Such measurements confirm the theory of sea-floor spreading: Most earthquakes along the ridge system occur in fracture zones between offset sections of the spreading axis—and the direction of first motion is just what one would predict on the basis of the sea-floor motion.

Although it does not appear so on a map with the usual Mercator projection, an axis of spreading and its associated fracture zones are at right angles. In the case of the Pacific and South Atlantic oceans the relation is particularly clear and includes even the rate of spreading. If one conceives of latitude and longitude lines drawn not about the earth's pole of rotation but about a "spreading pole," then the axis of spreading is parallel to the new lines of longitude and the fracture zones are perpendicular to the axis and parallel to the lines of latitude [*see bottom illustration on opposite page*]. Furthermore, the fastest spreading occurs along the equator of this new coordinate system and the rate decreases regularly with distance from the equator—as if giant splits in the floor of the oceans were taking place along the axes. The spreading poles vary for different oceans. For the Pacific and South Atlantic they appear to be very close to the earth's magnetic poles: near Greenland and in Antarctica south of Australia. Spreading in the Indian Ocean seems to be related to a different pair of poles, which can be located, with less certainty, in North Africa and in the Pacific north of New Zealand. Present information indicates that spreading in the North Atlantic occurs about a third set of poles, and fracture zones in older parts of the northeast Pacific floor seem to have been associated with yet another set of poles. There are indications that at least some of and perhaps all the spreading axes are themselves in motion, so that the location of their poles must be changing.

Some workers, notably W. Jason Morgan of Princeton, have attempted to generalize the motions of the earth's crust still further, suggesting that the crust of

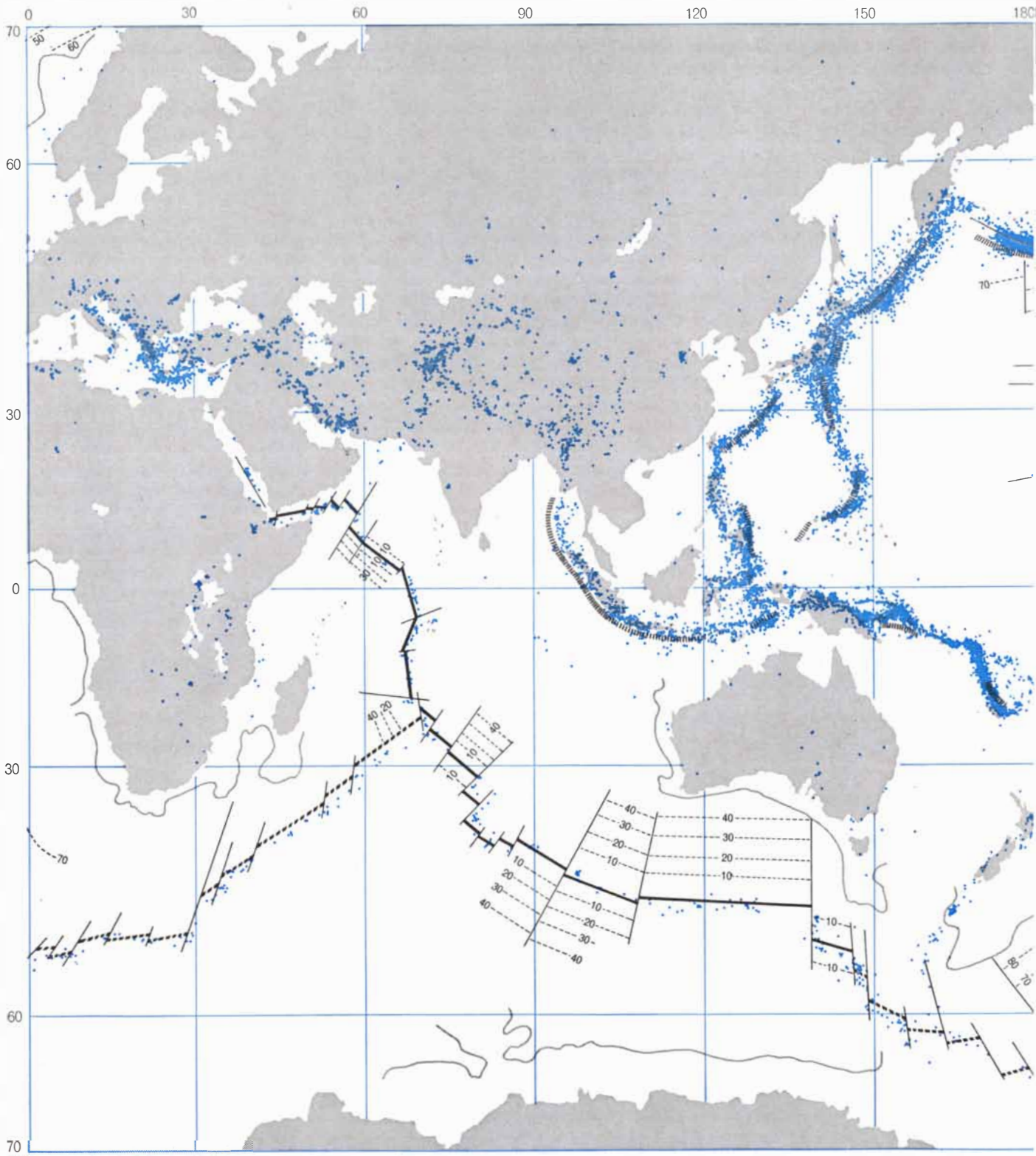


FRACTURE ZONE is identified by magnetic and bottom-profile data. A magnetometer was towed along a course (*broken line at top*) that twice crossed the same magnetic bodies (*Nos. 26–29*), offset along a fracture zone. The bodies caused similar magnetic anomalies, recognizable in the magnetic record (*middle*). Soundings revealed a prominent feature near the fracture zone (*bottom*).

the earth is divided into perhaps six rigid plates. These plates grow by the addition of new crust as new material wells up at the spreading axis; at their outer edges they override or are overridden by other plates. The concept of such strong and rigid plates is appealing to the seismologist since, as will be explained later, deep earthquakes seem to be located at the proposed edges of many of them.

The Geomagnetic Time Scale

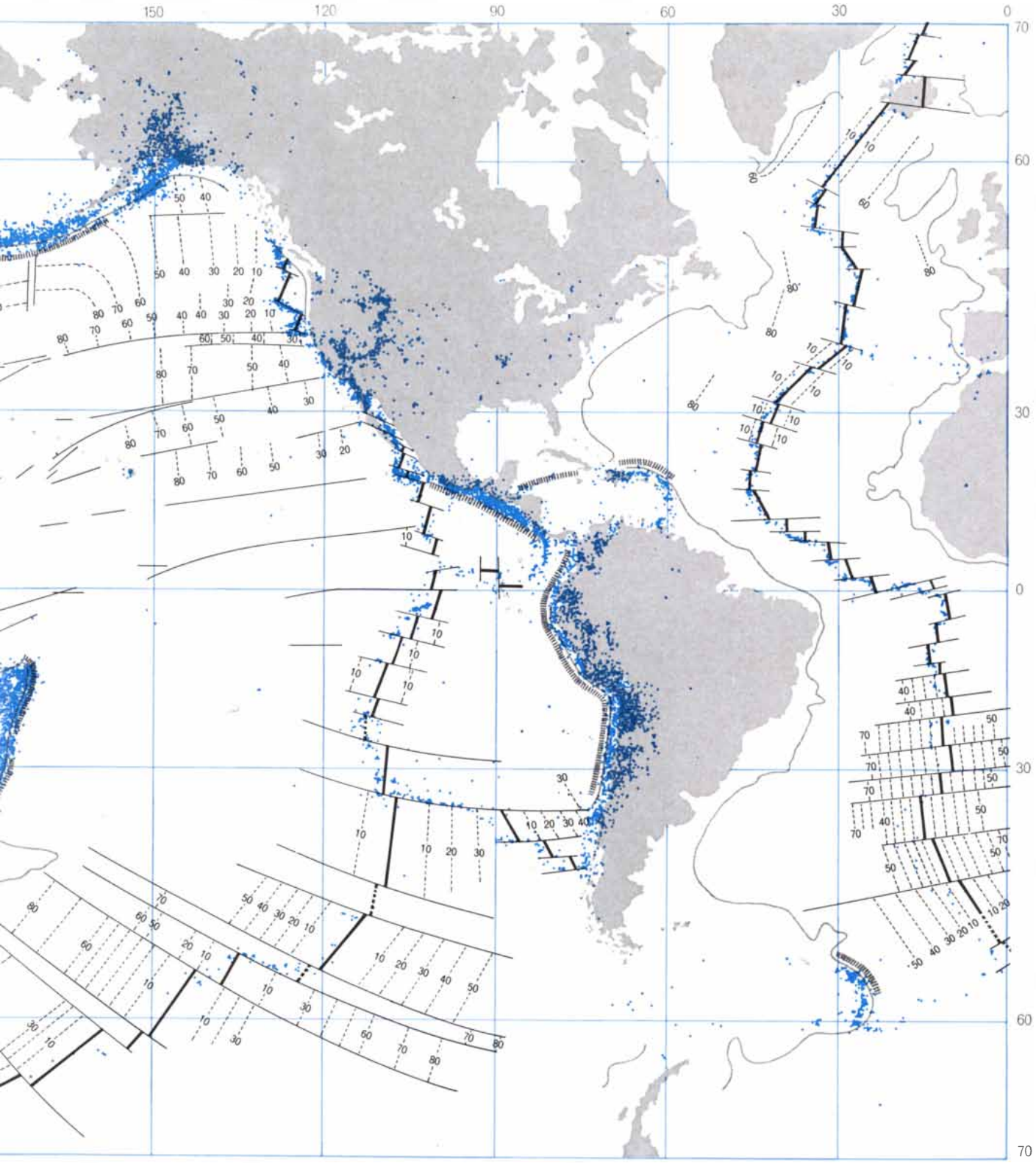
The magnetized bodies in the ocean floor have provided an amazingly complete history of magnetic-field reversals that now extends back about 76 million years, into the Cretaceous period. We began with a time scale that had been established by workers at Stanford University and the U.S. Geological Survey,



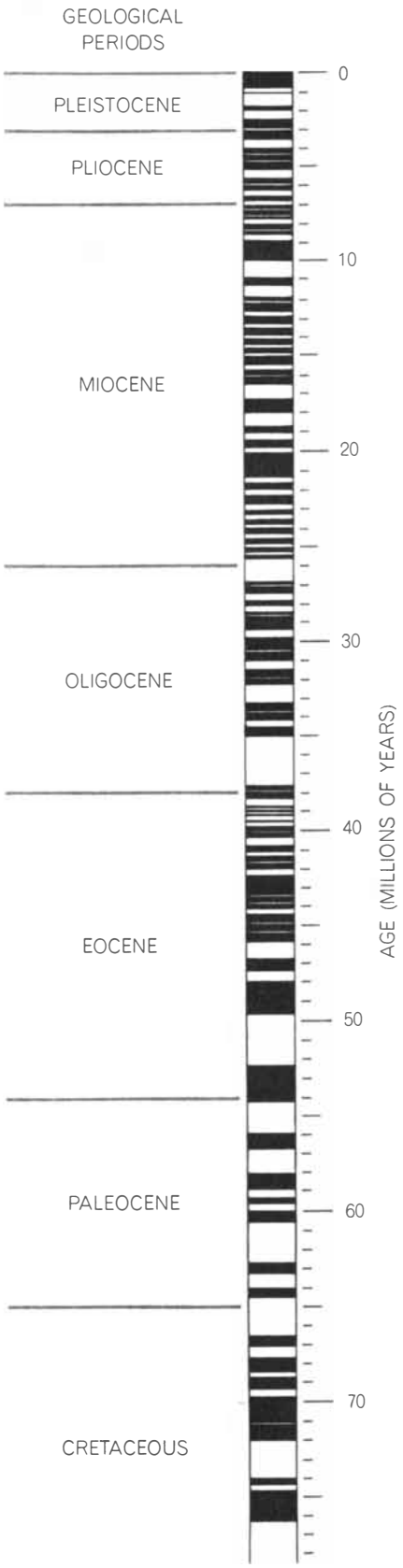
WORLDWIDE PATTERN of sea-floor spreading is evident when magnetic and seismic data are combined. Mid-ocean ridges (*heavy black lines*) are offset by transverse fracture zones (*thin lines*). On the basis of spreading rates determined from magnetic data the author and his colleagues established "isochrons" that give the age of the sea floor in millions of years (*broken thin lines*). The edges

who correlated the magnetism and radioactive-decay dates of rock samples going back some 3.5 million years [see "Reversals of the Earth's Magnetic Field," by Allan Cox, G. Brent Dalrymple and Richard R. Doell; SCIENTIFIC AMERICAN, February, 1967]. By comparing the ages they had assigned to specific reversals of the geomagnetic field with the distance of the corresponding anomalies from the ridge axis, we were able to extend the observations of Vine and Wilson over much of the ocean floor and thus to determine the rate at which the floor had spread in the various oceans.

The rates were found to be different for different sections of the ridge but seemed to have been remarkably steady over the ages in many areas. They vary from about half an inch to a little more



of many continental masses (*gray lines*) are rimmed by deep ocean trenches (*hatching*). When the epicenters of all earthquakes recorded from 1957 to 1967 (plotted by Muawi Barazangi and James Dorman from U.S. Coast and Geodetic Survey data) are superposed (*colored dots*), the vast majority of them fall along mid-ocean ridges or along the trenches, where the moving sea floor turns down.



CHRONOLOGY of geomagnetic-field reversals was worked out by extrapolation, beginning with the dates that had been established for recent reversals and assuming a constant rate for spreading within each ocean. The dates were confirmed by geological data.

than two inches per year away from the axis of spreading. Although these rates of movement are small by everyday standards, they are large on a geological time scale. Their magnitude came as a surprise to geophysicists even though comparable rates of slippage had been observed along the San Andreas fault, an exposed fracture zone in southern California.

In several areas we saw that there was no obvious hiatus in spreading. We therefore felt free to assume a constant spreading rate and on that basis to assign dates to geomagnetic field reversals extending far beyond the 3.5-million-year scale. This extrapolation of spreading rates may not seem justified at first, but it is supported by consistency from ocean to ocean and by agreement with other geophysical evidence, such as radioactive and paleontological dating of rock samples. Within the probable errors of the methods no discrepancies have been found. We have now identified 171 reversals of the earth's magnetic field over the 76 million years and believe that the dates assigned to each are quite accurate. (Of course, if spreading stopped abruptly all over the world for a certain time, our time scale before the spreading stopped would be too young by that number of years; this is improbable but cannot be entirely ruled out.) On the whole the evidence for the correctness of the time scale is so strong that it can now be used in turn to study variations in spreading rates over the ages in certain disturbed areas.

The average "normal" interval (when the magnetic field was oriented as it is today) works out to 420,000 years and the average "reversed" interval to 480,000 years. The closeness of the two numbers means that the earth is just about as likely to be found in one state of magnetic polarity as in the other. The present era of normal polarity has lasted 700,000 years. Are we due for a change? Only 15 percent of the normal intervals have been longer than that, although some were apparently as long as three million years. The shortest intervals seem to have been less than 50,000 years, but brief instants of geologic time are difficult to confirm by absolute dating methods. This suggests one of the drawbacks of the magnetic scale: simply because it is so detailed, it is unlikely soon to be proved wrong; by the same token, however, it is difficult to use to date a piece of magnetized earth material. Just as one may need a "finder" telescope to orient a high-powered telescope, so one must start by knowing the approximate age of materials in order to utilize the geomagnetic time scale.

The geomagnetism I have been discussing is frozen into igneous rock of the basaltic type that wells up from deep within the earth. Over much of the ocean floor, of course, this bedrock is not exposed but is covered by varying thicknesses of accumulated sediments. These sediments can also be magnetized, since the tiny particles of which they are composed can become oriented in the earth's field as they settle slowly to the ocean floor. (They are magnetized only one ten-thousandth as strongly as the basalt, however, so that even a thick layer of sediment does not interfere with measurements of anomalies caused by the underlying basalt.) By dropping a hollow cylindrical pipe into the bottom mud one can bring to the surface long "cores" of successive layers of sediment, each constituting an undisturbed record of magnetic-field reversals. Workers at Scripps and Lamont have recently developed sensitive techniques for measuring these weakly magnetized specimens, and the record of geomagnetic reversals has been verified back about 10 million years. The ability to correlate sedimentary layers of the same age in different oceans has proved of immense value to marine geologists, who often lack good paleontological or other indicators of geological horizons. In making detailed comparisons of magnetic reversals and the populations of microscopic animal fossils in such cores, investigators have noted a striking correlation between reversals and major changes in microfaunal species. It has been proposed that such changes are the result of mutations caused by increased exposure to cosmic rays if the earth's protective magnetic field is largely attenuated during a reversal. The evidence for this is not strong, however, and an alternative explanation can be put forward, as I shall suggest later in this article.

Footprints of Continents

The indicated movements of the ocean floor are of the right size and in the right directions to account for continental drift. Topographic and geological evidence had pointed to the probable existence some 200 or 300 million years ago of a single large land mass in the Southern Hemisphere (named Gondwanaland for a key geological province in India) that included Africa, India, South America, Australia, New Zealand and Antarctica, and another mass in the Northern Hemisphere called Laurasia. The

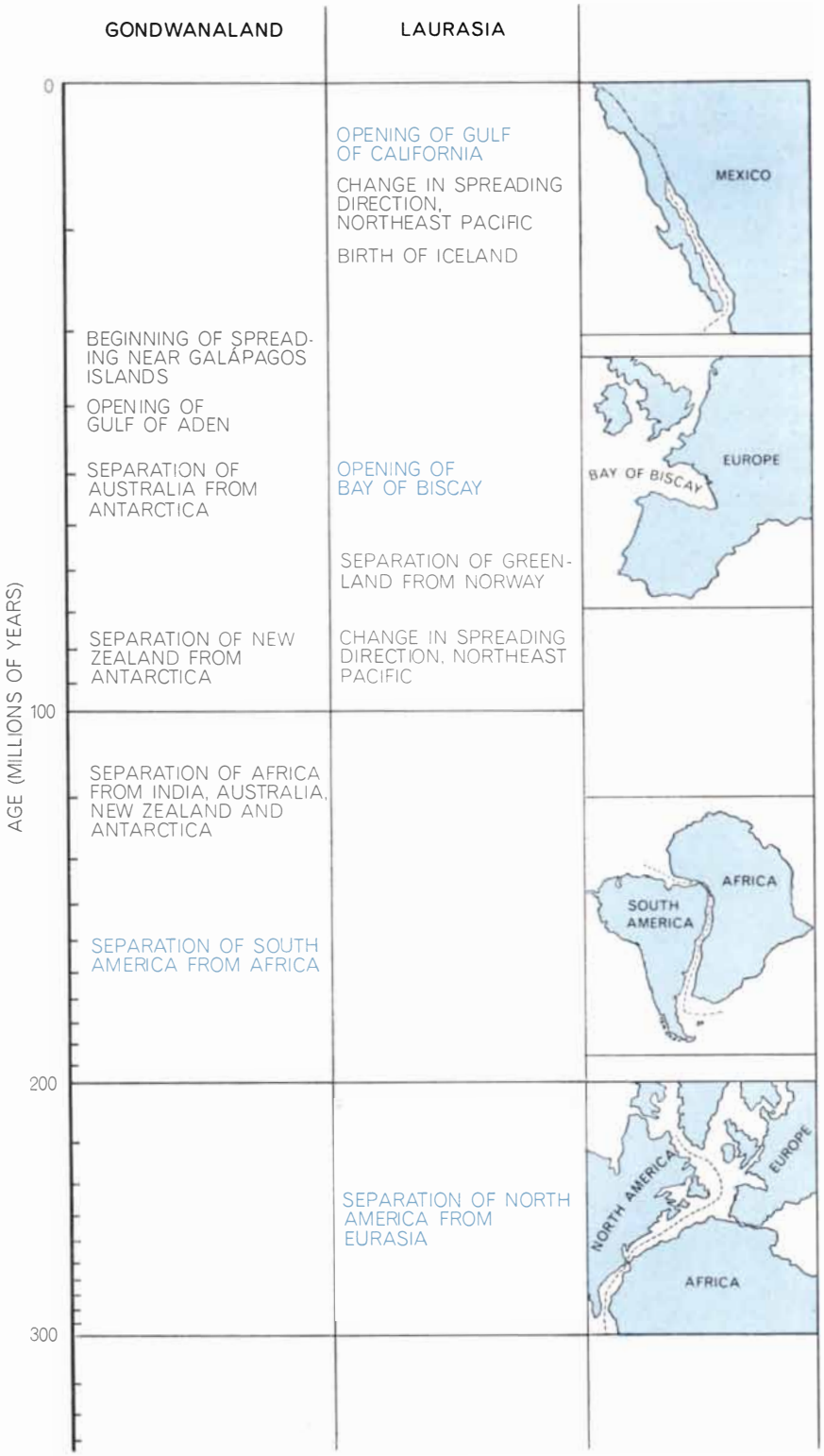
positions of the present continents within these land masses were not clear, nor was it possible to trace in detail the sequence of events in their breakup.

The magnetic lineations in the ocean floor serve as "footprints" of the continents, marking their consecutive positions before they reached their present locations. We found that the slow but steady and prolonged rates of motion were sufficient to separate South America from Africa—thus creating the entire South Atlantic Ocean—in about 200 million years and to separate Australia from Antarctica in about 40 million years. As more of the sea floor was dated we could establish more exactly just when the various continents separated and how they moved [*see illustration at right*]. It is now possible to reconstruct the original positions of the continents and the shallow continental shelves, so that land geologists can go into the field and check the continuity of ancient geological structures that were torn apart when the separations occurred.

Although it is possible to tell when and how the continents pulled away from one another, it is not always entirely clear whether or not—and for how long—a continent may have stood still. The impression is that both Africa and Antarctica have remained fixed with respect to the rotational axis for the last 100 million years, or since Africa split off from the remainder of Gondwanaland. If this is true, then the fact that the spreading axis between South America and Africa remains about midway between them indicates that the axis itself must be moving too.

Source and Sink

Until the theory of sea-floor spreading was advanced the only known sources of deep-earth material at the surface were volcanic eruptions. It now appears, however, that most currently active volcanoes are not at the sites of upwelling along the mid-ocean ridge but rather in areas where the moving sea floor turns down under the continents. Recent volcanic eruptions in the Philippines, Mexico and Guatemala are examples, as is the continuing intermittent activity of volcanoes in western North America, Alaska and Japan. The upwelling that initiates sea-floor spreading must therefore represent some unfamiliar geophysical phenomenon, and investigators have concentrated much attention on the axis of the mid-ocean ridge where it occurs. The axis has several unusual properties: a large heat flux, a concentration of shallow earthquakes, unusual seismic-wave velocities, a lack of sediment and eroded rocks, and the presence of a prominent magnetic anomaly. While most of these unusual conditions extend over a distance of from tens to hundreds of miles on both sides of the crest of the ridge, the magnetic anomaly is sharply localized; by studying the symmetry of the magnetic pattern it is possible to locate the spreading axis to within a few miles. The terrain of the ridge is rugged and it is not possible to associate the spreading axis with any single topographic feature,



TIME SCALE for continental movements and other changes can now be established, since isochrons show the age of the ocean floor and the direction of spreading at any time.

although one can say that when the ridge contains a median "rift valley," as many do, the axis lies within it.

The magnetized plate is not very thick. Analyses of the observed magnetic anomalies suggest that the thickness is from a half-mile to a few miles; studies of the transmission of seismic waves and the distribution of heat flux, on the other hand, indicate a thickness of a few tens of miles or perhaps 100 miles for the moving plate. The precise linearity of the magnetized bodies shows that the upwelling material was not tumbled about after it became cooled and magnetized; in this it is different from the usual folded rocks seen on land or the irregular flows that surround a volcanic eruption. Attempts to locate the axis with a magnetometer submerged near the sea floor show that there are a number of very magnetic bodies where the axis would be expected.

The evidence suggests to most investigators that the upwelling mechanism is an injection of molten deep-earth material by linear intrusions called dikes. Such bodies have a high probability of being injected along the line of the spreading axis. Each injection may be quite localized rather than greatly elongated along the axis. The new material is hot enough to reheat adjacent rock so that both the new material and the slightly older material nearby is magnetized in the direction of the ambient field before being quenched by the cold seawater. This explanation does not indicate anything precise about the thickness of the moving layer; it does account for the lack of tumbling of magnetized blocks, since a dike would tend to push the older material horizontally away from the ridge.

The deep oceanic trenches found around the periphery of the Pacific are thought to be places where surface material returns to the deep earth; so, very likely, are smaller trenches in the North Atlantic and South Atlantic and the Indian Ocean. In many parts of the world where plates of moving sea floor have been identified the outer edge of the plate has not been located, and so we probably do not know where all the sinks are. In most places the spreading sea floor seems to be turning down under the continents, but in some places it seems to be pushing continents ahead of it or even tearing continents apart; we know of no place where the spreading floor is overriding a continent.

If the epicenters of deep earthquakes are mapped, they are almost all found to be on a plane that starts at the floor of a trench and makes an angle of about 45 degrees with the horizontal [*see top illustration on page 70*]. The slippage of earth material parallel to the plane and extending hundreds of miles below the surface is the cause of the earthquakes. These earthquake planes almost certainly define regions of downwelling; studies of first motion in such areas show that the sea floor moves down with respect to the adjacent continent. A thin crustal layer with a characteristic speed of seismic-wave propagation has been shown to underlie the ocean sediments and turn down at 45 degrees to great depths.

The magnetic evidence for what happens at the trenches is ambiguous, however. The sea-floor magnetic pattern is altered suddenly. Measurements at the Aleutian Trench, for example, show a

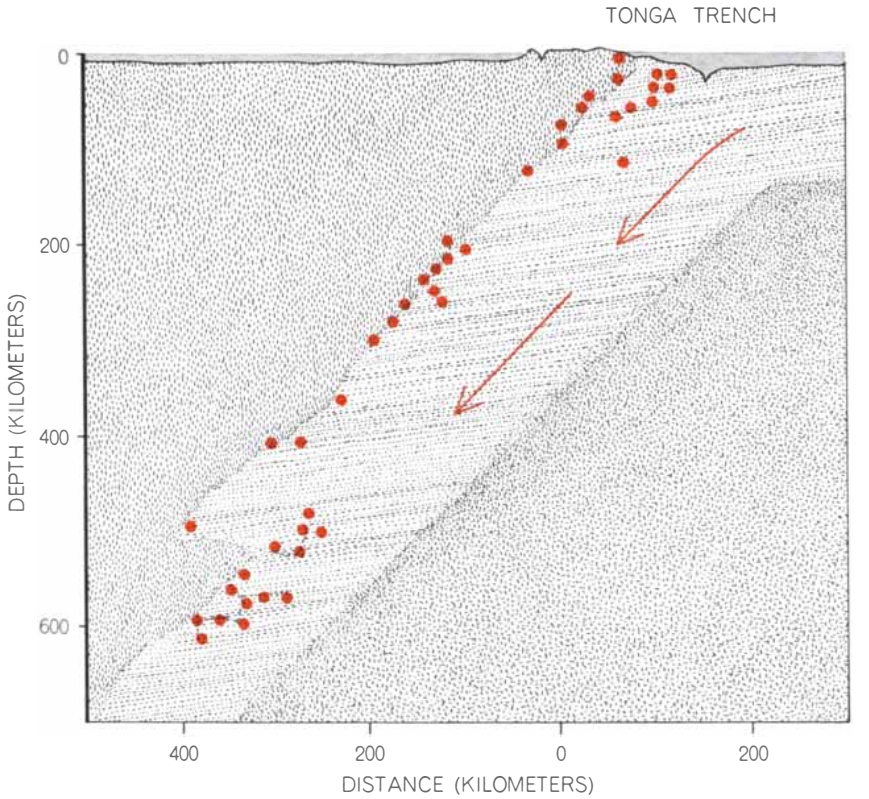
ANCIENT POSITIONS of the continents can be plotted on the basis of the time scale. This map shows the relation of the Americas to Eurasia and Africa 70 million years ago. The continents fitted together generally along the edges of continental masses (*light grey*) rather than of present dry-land areas (*dark gray*). Broken lines trace directions of movement.

sharp discontinuity [*see bottom illustration on next page*]. There is no sign of a magnetic body that should (on the basis of measurements made elsewhere) be located about three kilometers below the trench floor. Its absence might be explained by heating or mechanical deformation, but neither sufficiently high temperatures nor enough seismic activity to cause deformation are indicated so close to the trench floor. Another problem at the Aleutian Trench is that the magnetic bodies seem to be in the wrong sequence. If the trenches are sinks, the older bodies should be in the trench and the younger ones to seaward; the opposite seems to be the case! Moreover, south of the Alaska Peninsula bodies oriented essentially north-south turn and run east-west, parallel to the coast. This complexity is difficult to explain if trenches are sinks. It is one of the most awkward sticking points in the theory.

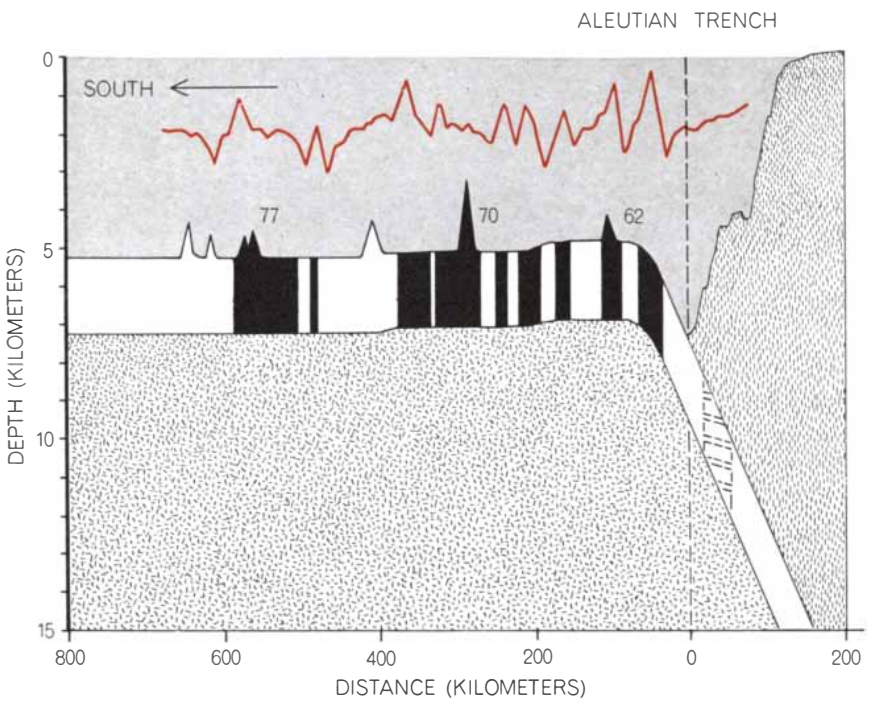
Speculations

The feeling among many geophysicists that we are on the brink of even more comprehensive theories about the earth stems from the striking geographic or temporal coincidence of certain geophysical phenomena, many having to do with the dynamics of our planet. Existing theories suggest no clear causal relation among these phenomena, and so one hopes for some higher-order synthesis that will establish such a relation.

What are some of these coincidences? The present pole of spreading (for several of the oceans, at least) is near the geomagnetic axis; in Cretaceous times the spreading pole for the North Pacific was near the Cretaceous geomagnetic pole. There have often been significant changes in the microfaunal population of the sea at magnetic reversals. A major meteorite (tektite) fall occurred just at the time of the last reversal [see "Tektites and Geomagnetic Reversals," by Billy P. Glass and Bruce C. Heezen; SCIENTIFIC AMERICAN, July, 1967]. Some authors have speculated recently on a relation between mountain-building activity and magnetic reversals; others see a relation between changes in seafloor spreading and mountain-building. Mechanisms have been suggested whereby the earth's magnetic field could be generated by convective motion caused in turn by irregularities in the earth's orbit. There has been a revival of a 30-year-old theory that the glacial ages were caused by changes in the tilt of the earth's axis. Finally, there is clear evidence that large earthquakes occur



MOVING SEA FLOOR turns down at the trenches rimming the Pacific Ocean. Deep earthquake epicenters line the downward path where floor material moves under land masses. Symbols (*color*) show epicenters recorded at the Tonga Trench in the South Pacific.



ALEUTIAN TRENCH data fail to fit the model, however. The magnetic record (*color*) shows the expected sequence of normal and reversed bodies (*black and white bands*) approaching the trench, but there is no evidence of the next body, which should appear about three kilometers below the trench (*hatched band*). Moreover, the magnetic bodies seem to be younger (*77 to 62 million years*) as one approaches the trench rather than older.

at about the same time as certain changes in the earth's rotational motion.

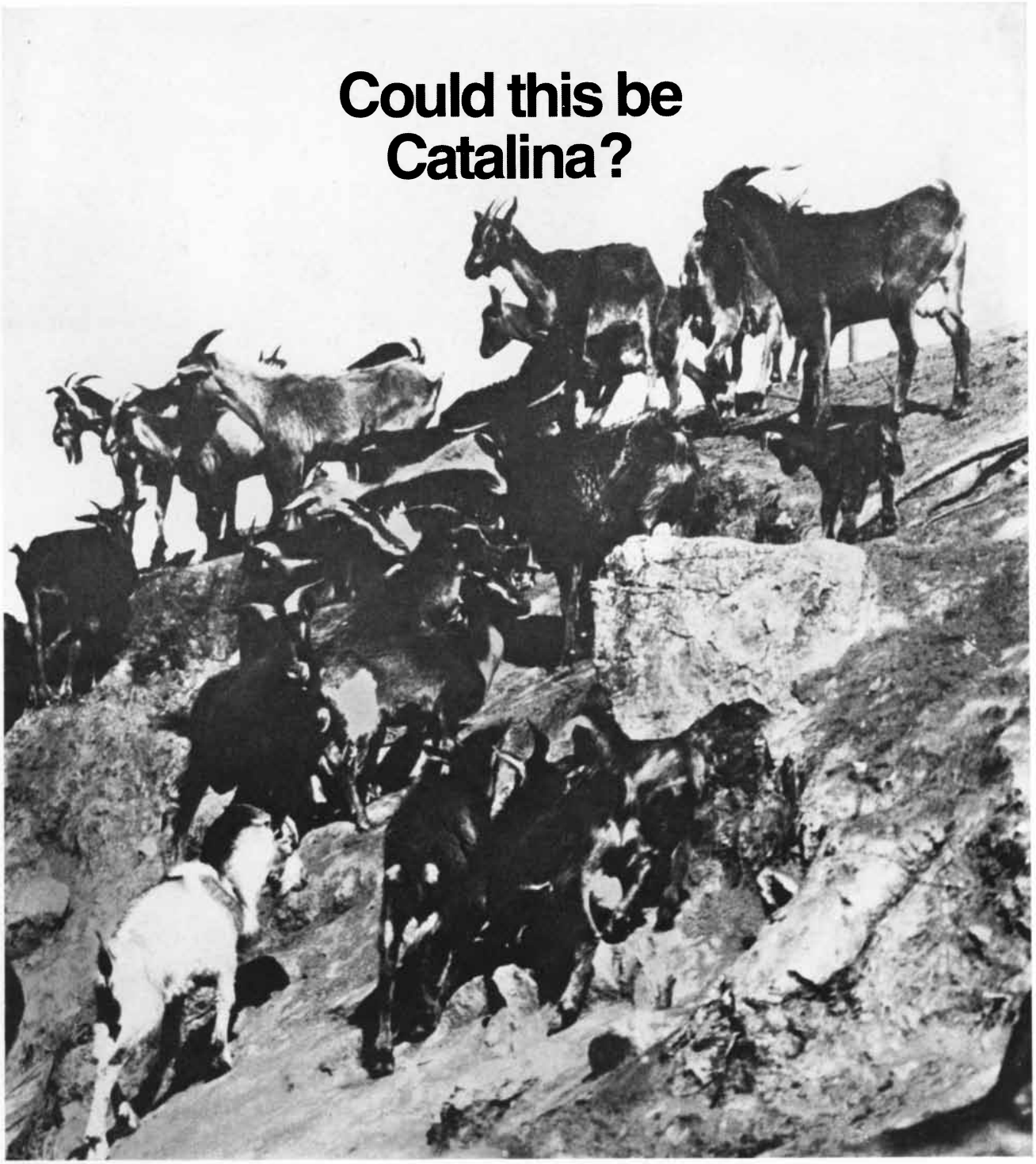
This article is not the place for a full evaluation of all these developments. It is interesting to note, however, that a common thread running through these and many other proposals at the frontier of geophysical research is the role played by displacements of the earth's axis of rotation. It seems that rather minor variations can affect to a surprising extent both the climate at the surface of the earth and forces and stresses within the earth.

The intimate relation between the spreading pole and the magnetic pole suggests that the convective motion within the earth and the earth's field may have a common cause. It could be due to the proposed effect of orbital irregularities or to some dynamo action within the earth. Since the direction of convection does not reverse when the field reverses, it is clear that the convective motion does not simply generate the field, nor is it likely that the reversing field could "pump" convection cells. Whatever the driving force is for these two phenomena, it would seem to be related to the motion of the earth. Recently it has been shown that earthquakes of a magnitude of 7.5 or greater on the Richter scale either cause or are caused by changes in the earth's "wobble," a small circular motion described by the north pole of rotation [see "Science and the Citizen," November]. Whatever the mechanism of these changes, it is not hard to believe that similar changes in the earth's axial motion in times past could have caused major earthquake and mountain-building activity and could even have caused the magnetic field to flip.

To summarize: Every few months there are changes in the earth's rotational motion that affect sea-floor spreading and cause the earthquakes associated with it. If such a change is large enough, it may even reverse the earth's magnetic field. (Both the presence of a geomagnetic field and the spreading of the sea floor seem to be due to the mere fact that the earth is rotating; it is only the changes in motion that are associated with certain large earthquakes and reversals of the field.) Changes in the microfaunal population of the sea are related to changes in the climate, which are related in turn to variations in the earth's motions.

Such speculation cannot yet be confirmed but neither can it be firmly denied; indeed, it is no more outlandish than theories of sea-floor spreading seemed to be a few years ago.

Could this be Catalina?



Maybe you picture Catalina Island as a lush green paradise. It is not. Over 90% of the island is barren and dry—a great place for wild goats.

Yet fresh water, so conspicuously absent, could turn Catalina into a rich green oasis almost overnight. And it's only 30 miles away, in Los Angeles.

Is there a practical, low-cost way to bring that Los Angeles water to Catalina?

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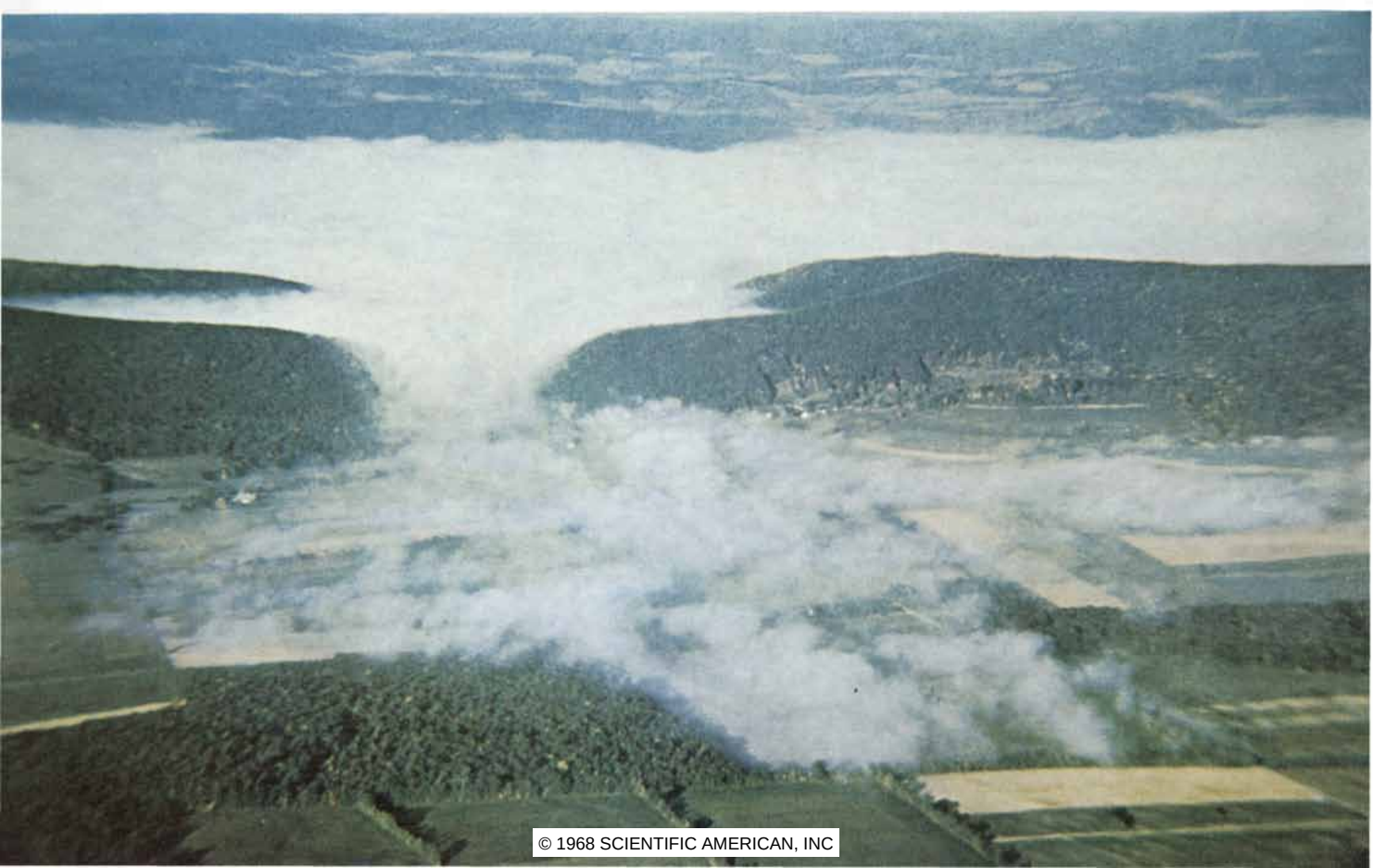
ICE FOG (*above*) fills the Nenana River valley near Fairbanks, Alaska. Ice fogs consist mainly of ice crystals that form in air cooled to 30 degrees below zero Celsius or lower. They may appear because a temperature drop has produced nearly 100 percent humidity or because the air is saturated by the addition of water vapor.

RADIATION FOG (*below*) spills out of Bald Eagle Valley through a mountain gap near Lock Haven, Pa. Radiation fogs are caused by the night cooling of the earth's surface, which reduces the air temperature and raises the humidity to near-saturation. In Bald Eagle Valley industrial wastes contribute to the fog-forming processes.



FOG

A kind of grounded cloud, fog can halt sea, air and highway travel. When combined with air pollutants, it can be lethal. Ways are known, however, not only to dissipate fog but also to inhibit its formation

by Joel N. Myers

Fog, once little more than a nuisance except at sea, has become an important hazard to modern man. Its effects on travel are intensified by the speed of the airplane and the automobile. Dense fogs close airports in the U.S. for an average of 115 hours per year, and in 1967 they cost the nation's airlines an estimated $75 million in disrupted schedules as well as inestimable inconvenience to passengers. On present-day turnpikes fog can be disastrous; a single pileup on a fog-shrouded freeway in Los Angeles involved more than 100 vehicles. Above all, fog in combination with air pollution now increasingly afflicts large cities. Its potential was suggested alarmingly by the London smog of December, 1952.

On December 5 a dense fog settled over the city. A strong inversion—warm air lying above cold air—blocked the removal of polluted air by vertical movement, and at the same time the winds were so light that such air was only gradually removed by horizontal movement. Within 24 hours the tons of smoke, dust and chemical fumes given off by the city's furnaces, factories and automobiles turned the fog brown and then black. Two days later the visibility in the city had been reduced to a matter of inches. People fell off wharfs into the Thames and drowned. Others wandered blindly until they died of exposure to the cold. The toxic air afflicted millions of Londoners with smarting eyes, coughing, nausea and diarrhea. It was estimated that the smog killed at least 4,000 persons, mainly from respiratory disorders, and caused permanent injury to tens of thousands.

The principal source of toxicity in most pathological smogs appears to be sulfur dioxide from the smokestacks. The sulfur dioxide is oxidized in the air to sulfur trioxide, which in turn combines with fog droplets to form sulfuric acid. One therefore inhales sulfuric acid with each breath, with resulting acute irritation of the throat and lungs. This seems to have been the chief cause of injury and death in the London smog and in the 1948 smog in Donora, Pa., which killed 20 victims and sickened nearly half of the 14,000 inhabitants.

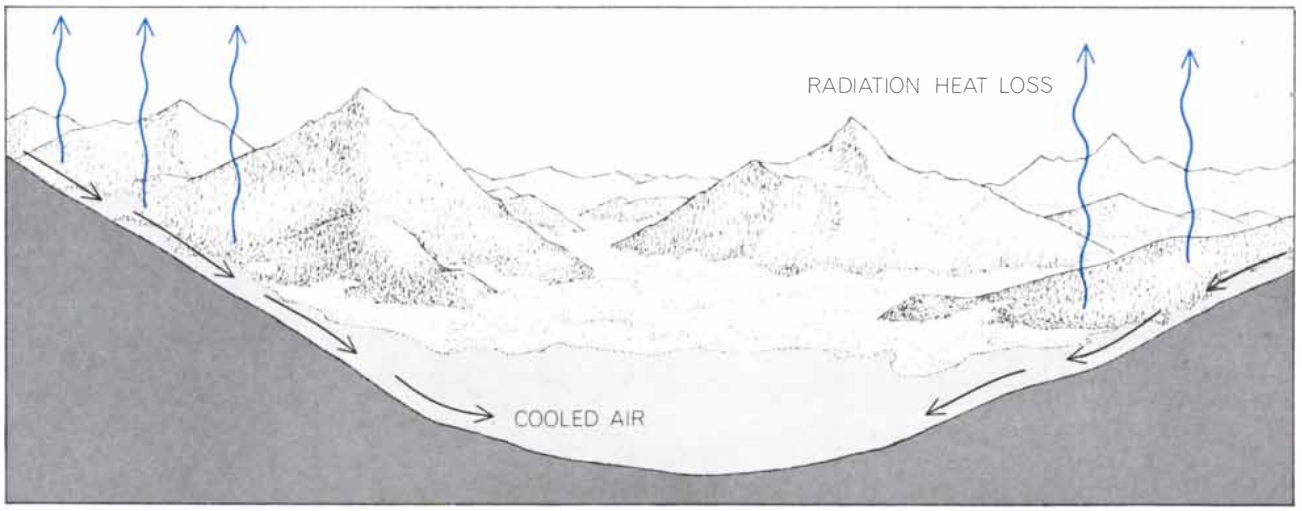
Strictly speaking, the perennial "smogs" of Los Angeles are misnamed, as they frequently consist of a haze of pollutants that are trapped by an inversion layer of dry air rather than by fog. Polluted air, however, can generate fog and cause it to persist. Once formed, the fog reflects solar radiation back into space, thereby providing an environment favorable to the accumulation of further pollution. In effect fog, itself partly a product of pollution, causes pollution to increase.

Some metropolitan areas in the U.S. suffer from light smogs up to 100 days of the year, and during fall and winter dangerous smog conditions can become frequent. The long-term effects of the urban smogs are believed to include chronic bronchitis, emphysema, asthma and lung cancer. The polluted air corrodes metals, rots wood, causes paint to discolor and flake and may cause extensive damage to vegetation and livestock. In addition to the directly damaging effects, there are indications that the combination of fog and air pollution may be upsetting the delicate balance of man's ecosystem. Smog plays an important role in influencing the earth's gain and loss of radiation, which ultimately determines most of the climatic variables. Smog reduces sunlight, lowers daytime temperature and wind speed, raises humidity and is even suspected of causing a decrease in rainfall. Thus for many reasons—the hazards to travel, the damaging effects of smog, the modification of climate—fog is a growing problem that will demand increasing research attention in the years ahead.

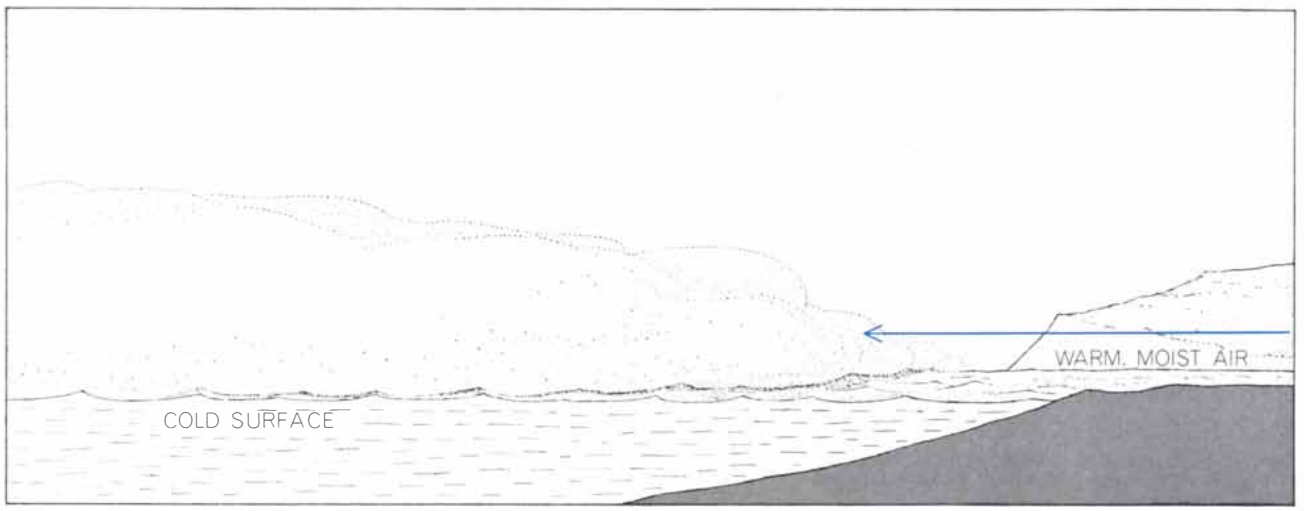
Fog is simply a cloud on the ground, composed, like any cloud, of tiny droplets of water or, in rare cases, of ice crystals, forming an ice fog. Ice fogs usually occur only in extremely cold climates, because the water droplets in a cloud are so tiny they do not solidify until the air temperature is far below freezing, generally 30 degrees below zero Celsius or lower. The droplets of fogs are nearly spherical; they vary in diameter between two and 50 microns and in concentration between 20 and 500 droplets per cubic centimeter of air. The transparency of a fog depends mainly on the concentration of droplets; the more droplets, the denser the fog. A wet sea fog may contain a gram of water per cubic meter; a very light fog may have as little as .02 gram of water per cubic meter.

Since water is 800 times denser than air, investigators were long puzzled as to why fogs did not quickly disappear through fallout of the water particles to the ground. Even allowing for air resistance, a 10-micron water droplet falls in still air with a velocity of .3 centimeter per second, and a 20-micron droplet falls at 1.3 centimeters per second. To explain the persistence of fogs many early investigators concluded that the droplets must be hollow (that is, bubbles). It turns out, however, that the droplets are fully liquid and do fall at the predictable rate, but in fog-creating conditions they either are buoyed up by rising air currents or are continually replaced by new droplets condensing from the water vapor in the air.

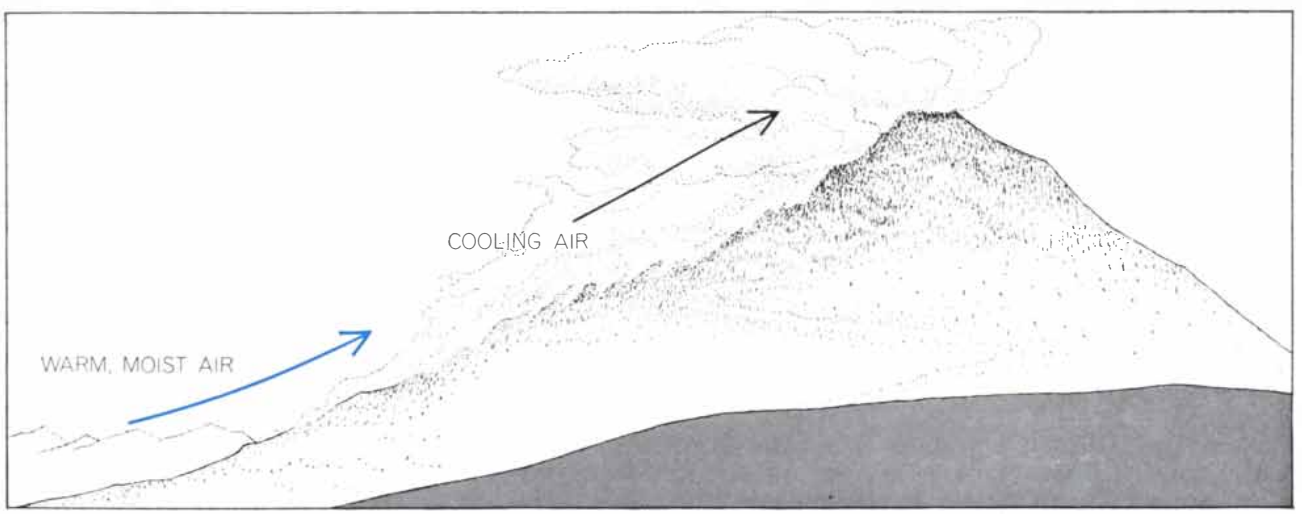
The atmosphere always contains



FOG IS FORMED when moist air is cooled; the air then cannot hold as much moisture in the form of water vapor as it can when it is warmer. As the humidity approaches the saturation point tiny water droplets form, obscuring visibility. The diagram indicates how a radiation fog, one of three kinds of "cooling fog," forms. Night cooling has reduced the air's temperature and caused water droplets to appear. The cold, fog-filled air drains downhill and accumulates in low-lying areas (*see bottom illustration on page 74*).



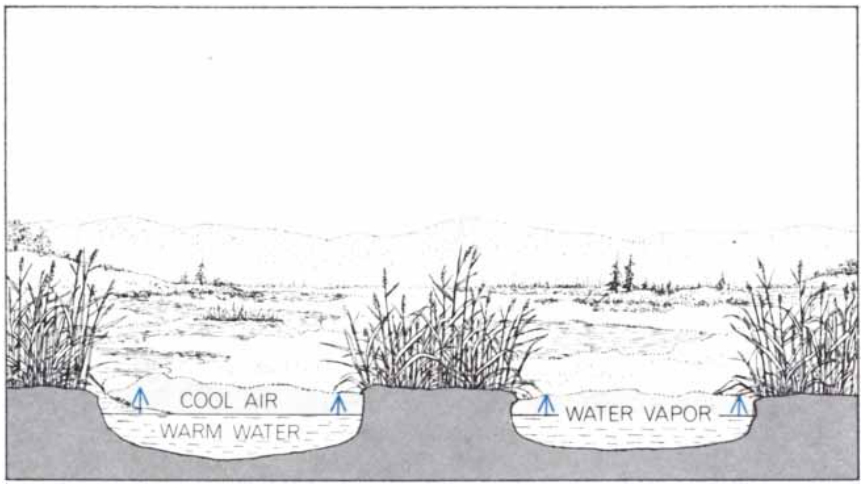
ADVECTION FOG, the second kind of cooling fog, forms when warm, moist air is carried across a cold surface and is cooled to the saturation point. Advection fogs are common at sea where warm air masses come in contact with cold ocean currents (*see top illustration on pages 78 and 79*) and on land during the cold months when moist tropical air masses are carried across chilled ground.



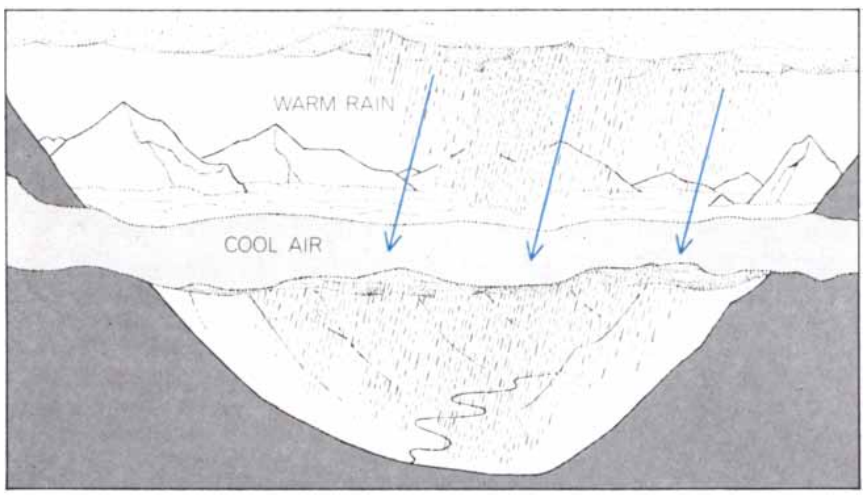
UPSLOPE FOG, the third kind of cooling fog, forms when an air mass is forced upward. In the diagram a topographic barrier forces the air mass to rise. As pressure diminishes the air mass expands, grows cooler and, as in both other cases, soon becomes saturated.

some water vapor, supplied by evaporation from bodies of water, vegetation and other sources. Since the air's capacity for holding water in the form of vapor decreases with falling temperature, even comparatively dry air will reach the saturation point—100 percent relative humidity—when it is cooled sufficiently. At that point the vapor of course begins to condense into liquid water. Fogs often form, however, at humidities well below 100 percent. The droplets condense on tiny particles of dust in the air called condensation nuclei. These are hygroscopic particles, which, because of their affinity for water vapor, initiate condensation at subsaturation humidities—sometimes as low as 65 percent. The nucleus on which the water condenses, which may be a soil particle or a grain of sea salt, a combustion product or cosmic dust, usually dissolves in the droplet. Because the saturation point is lower for solutions than it is for pure water, the droplets of solution tend to condense more water vapor on them and grow in size. A rise in the air's humidity will also enlarge the droplets and will form more of them, thereby thickening a light fog into a dense one.

Given suitable conditions of temperature and humidity, the density of a fog and its microphysical properties will depend on the availability of condensation nuclei and their nature. Fogs become particularly dense near certain industrial plants because of the high concentration of hygroscopic combustion particles in the air. This is not to say that air pollution is generally a primary cause of fog formation, but it does cause fogs to form sooner and persist longer, and it makes them dirtier—hence less transparent—than fogs that develop at higher humidities in relatively clean air.



WARM-WATER FOG forms like steam over water that is covered by a much colder air mass. Water vapor from the comparatively warm water rises into the colder air and is rapidly condensed into fog droplets. The fog's intensity depends on the temperature differential.



WARM-RAIN FOG is formed when raindrops from higher clouds encounter a layer of cooler air near the ground; evaporating raindrops saturate the cold air layer. As the diagram indicates, the fog looks like a low cloud to an observer looking up from the valley floor.

From a meteorological point of view fogs are classified in several types according to the gross natural processes that generate them. Over land the most common type is the "radiation fog" that arises from nighttime cooling of the earth's surface and the lower atmosphere. As the earth radiates away its heat during the night, fog may form if the air in contact with the cooling ground is moist or, even though it is fairly dry at first, if it is cooled a great deal. Radiation fogs occur most frequently over swampy terrain and in deep, narrow valleys where cold air draining down from the hillsides concentrates in the valley bottom. The likelihood of fog formation depends considerably on the wind speed. A moderate to strong wind, by moving the air about and diluting the cooling effect, tends to prevent the formation of fog. If the air is calm, only a thin layer of air next to the ground is much affected by the cooling, so that the condensation may be restricted to dew or a shallow ground fog. The condition most likely to produce an extensive fog is a slight breeze; by generating turbulence near the ground such a breeze may spread out the cooled surface air to form a layer of fog several hundred feet deep. Above this cold layer the air remains warm.

One might suppose that radiation fogs should reach a maximum around dawn, when the air temperature ordinarily is at its daily low point. Actually it has been found that this type of fog sometimes becomes thickest shortly after sunrise. The reason appears to be that the sun's early rays, not yet strong enough to evaporate the fog droplets, generate turbulence that intensifies and thickens the fog layer. The fog does not begin to dissipate until the sun is high enough to heat the atmosphere, stirring the foggy air so that it mixes with the warm, dry air above. Obviously in pockets that are topographically shielded from the sun the fog will remain longer.

A somewhat different process produces what are called advection fogs. In this case the fog arises from the movement of humid air over a surface that is already cold. Most sea fogs are of this type; indeed, the foggiest places in the world are the areas above cold ocean currents. Advection also commonly plays a part, in combination with nocturnal cooling, in the generation of land fogs. In a different way air moving up a mountainside sometimes produces fog: the air expands and cools as it rises because the atmospheric pressure diminishes with altitude. Advection and upslope fogs can

provide additions to the water supply. On some coastal mountains in California, for example, the ground receives more water from fog dripping off vegetation than it does from rain. Residents of some arid regions take advantage of this phenomenon by suspending arrays of nylon threads to extract water from drifting fogs.

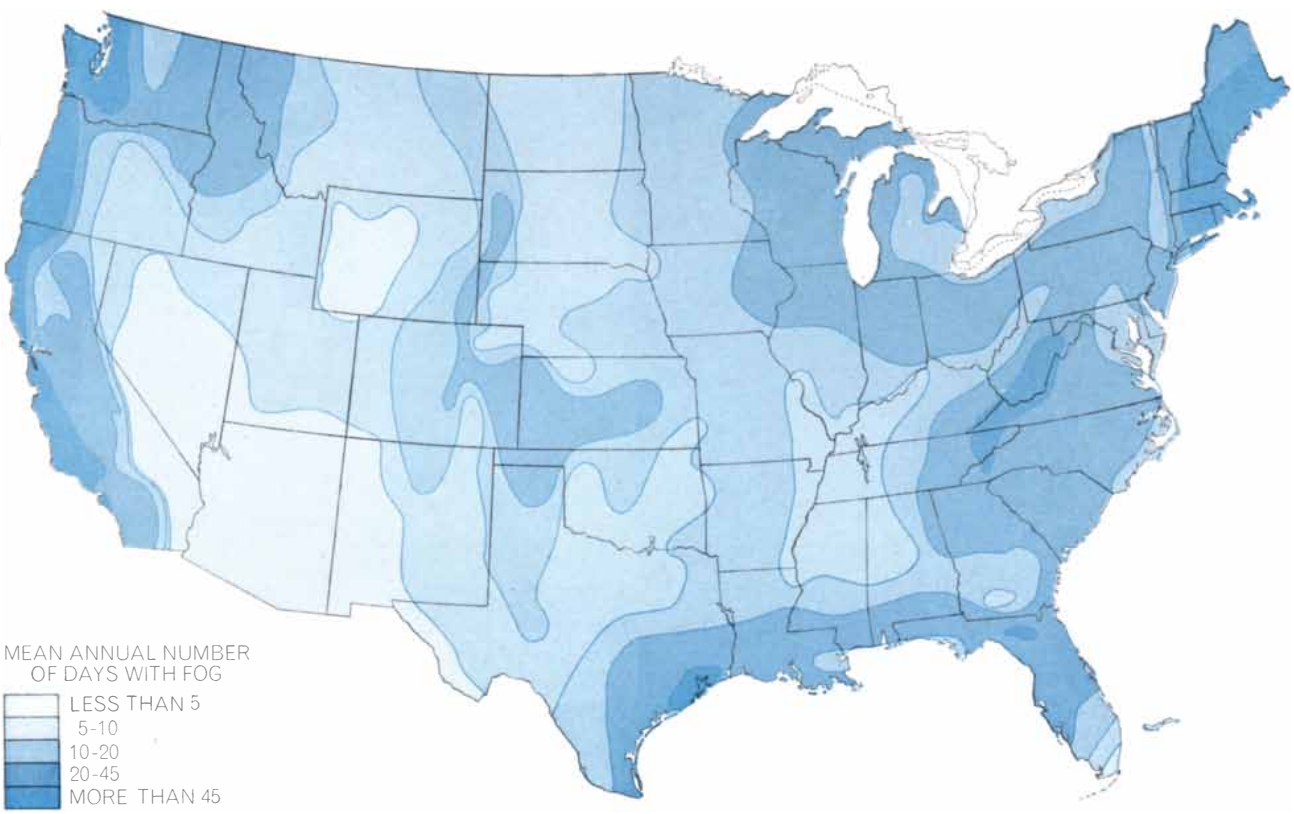
Fog is also produced by the familiar steaming process we observe above a hot bath or a heated kettle or on a hot roof or parking lot after a summer shower; the vapor rising from the warm water quickly condenses into steam in the cooler air above. In this way the evaporation from a body of water on an unseasonably cold night may generate a shallow fog (up to perhaps 50 feet). Warm rain falling through cool air also can give rise to a steamlike fog; it is a common cause of the fogging in of airfields during rainy weather.

The principal natural agents of fog dispersal are sunshine and brisk wind, but a dense fog has built-in resistance to the sun. Because fog is an excellent reflector of sunlight, only 20 to 40 percent of the impinging solar energy penetrates it to warm the ground and the foggy air, and only part of that heat is available to evaporate the fog droplets. Consequently a dense fog strongly resists dissipation by the sun. Moreover, the resistance is increased when the fog becomes a thick smog.

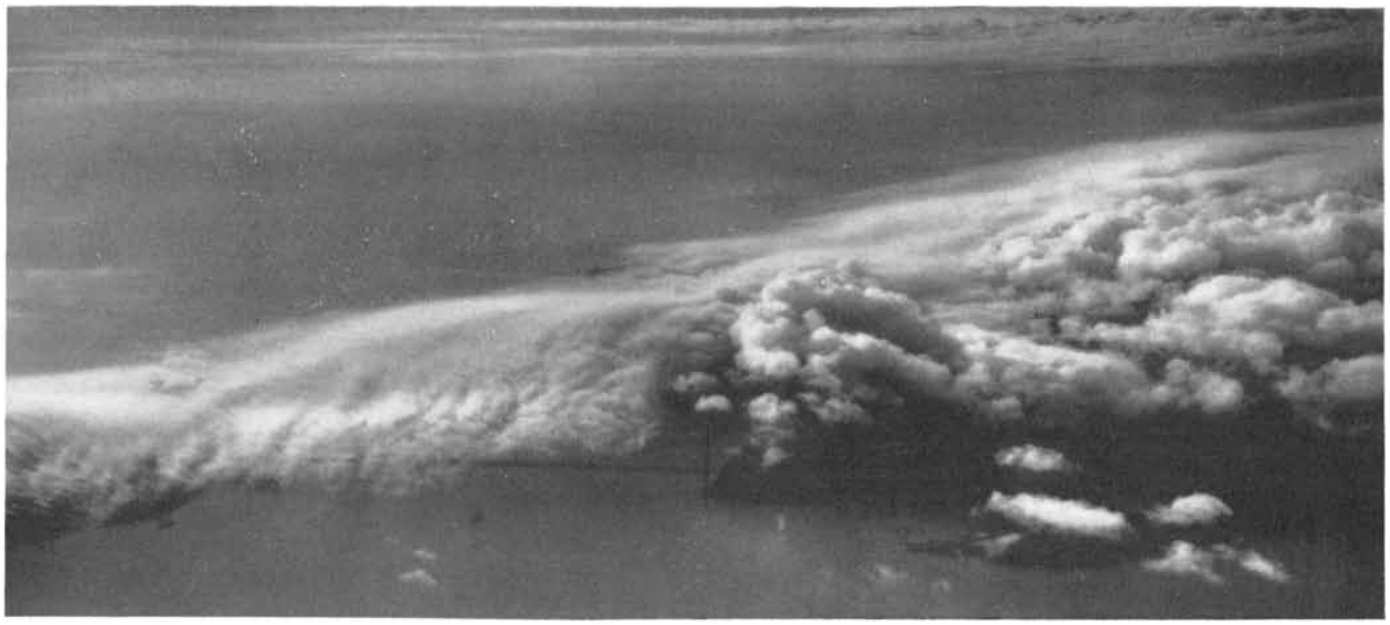
To what extent has our era of industrialism intensified the fog problem? This is very difficult to determine, because the meteorological records are incomplete and the phenomenon itself is highly variable. The incidence and intensity of fogs vary widely with time and season in any given place and from one place to another, even within a few miles. Furthermore, weather-observation practices have changed considerably over the past century: the observations are much more frequent than they used to be, cover many more locations and are complicated by changes both in the location of observatories and in the observers' nomenclature. The definition of "dense" fog, for example, has been revised repeatedly by the U.S. Weather Bureau. Nevertheless, although reliable comparisons cannot be made in detail, a survey of past records indicates some general trends. It appears that the incidence, duration and probably the density of fogs vary directly with the amount of industrial activity and air pollution in the area involved.

Perhaps the most reliable set of data for a single location is the one for the city of Prague in Czechoslovakia, where consistent observations of fogs have been made for the past century and a half. The records show that in the period since 1881 Prague has had nearly twice as many fogs as in the preceding 80-year period. In general it appears

CLASSIC EXAMPLE of an advection fog is the light, low-lying bank seen obscuring



DISTRIBUTION OF FOGS in the continental U.S. is shown by area shading that indicates the days of dense fog per year reported by 251 weather stations from 1900 to 1960. The least foggy parts of the mainland are the desert areas of Arizona, California and Nevada; foggiest are the Pacific and New England coasts. Appalachian hills often have rain fogs; the valleys, radiation fogs.



the Golden Gate Bridge at the entrance to San Francisco Bay in the aerial photograph. When a warm, moist air mass passes over the cold waters of the California Current, it is cooled to the saturation point and some of its water vapor is condensed into fog droplets.

that fog tends to be more frequent in and near cities than in unpolluted rural areas. The available data do not indicate, however, if fogs tend to be denser in cities than they are elsewhere. It is conceivable that the relatively warm microclimate of large cities (due to the solar heating of their streets and buildings and the urban artificial heat) may prevent the strong nocturnal cooling that is usually a prerequisite for dense fogs. If that is so, perhaps the places where dense fogs occur most frequently are highly industrialized small cities and suburban communities that lie downwind of metropolises.

A fog recently studied by Charles L. Hosler, Jr., a meteorologist at Pennsylvania State University, may serve as an illustration of the problem. The fog is seen shortly after sunrise in Bald Eagle Valley in central Pennsylvania on days when little or no fog is observed elsewhere in the state. The valley contains large industrial plants that daily discharge billions of hygroscopic particles and tons of water vapor into the atmosphere. Although fog formation is aided by the overnight drainage of cold air into Bald Eagle Valley, the pollution is a major contributing factor.

What can be done about the growing fog problem? The phenomenon has become a matter of active concern for many interests—government, industry, the airlines, the military—and it is being attacked by investigators in a wide range of disciplines. Clearly one of the prime needs is a vigorous assault on the complex problem of air pollution. Nor is pollution confined exclusively to the atmosphere. A form of pollution that is responsible for some fogs and that has received little attention is the "thermal pollution" of natural water resulting from industrial practices. It gives rise to the formation of fogs by increasing the normal rate of water evaporation.

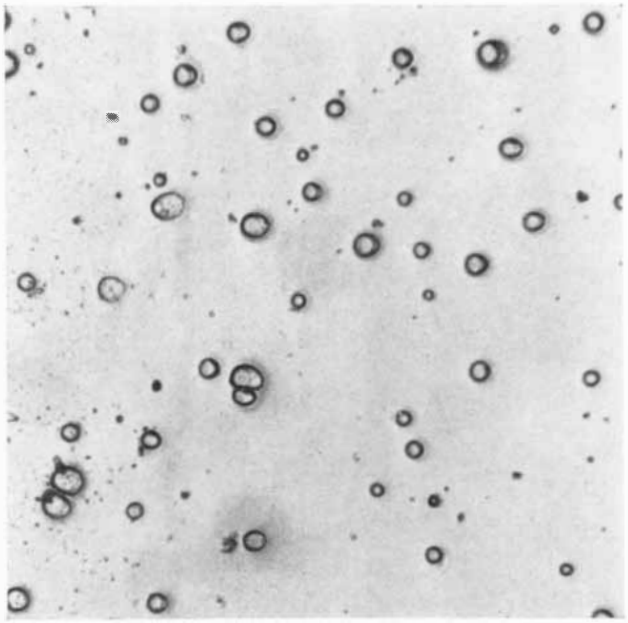
Enormous quantities of heated water are discharged into our streams and lakes by industrial operations that use water for various cooling purposes. The principal offenders are steel mills, paper factories, sewage-treatment plants, certain chemical and manufacturing plants and particularly electric-power generating stations. Power plants based on nuclear fuel, to which many utilities are now turning, use enormous quantities of water for cooling. The power industry estimates that by 1980 it will be using one-fifth of the total free water runoff in the U.S. for cooling. Thus, ironically, nuclear plants, which are counted on to reduce air pollution by replacing plants that use fossil fuels, may become a major factor in spawning fog and thereby trapping air pollution in the form of smog.

Some industrial plants, notably in the power industry, have taken to getting rid of their heated water by evaporating it in massive cooling towers instead of dumping it into bodies of water. Unfortunately this method is expensive and may still produce fogs. Some towers evaporate hundreds of cubic meters of water per hour, and the tremendous flux of vapor, if trapped under an inversion on a windless night, could generate and maintain a dense fog over a large city. Federal aviation officials believe a cooling tower recently built three miles north of the Morgantown Municipal Airport in West Virginia is responsible for local fogs that have begun to trouble the area. And it appears that fog plumes from other cooling towers may have contributed to automobile accidents on highways near them.

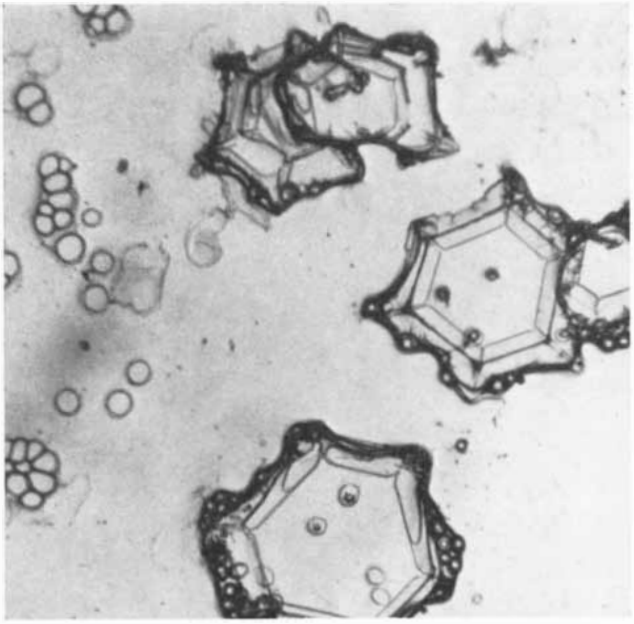
Cooling towers might be turned into assets rather than liabilities in farming areas. The fog they produce could prevent heat from escaping from the soil and thus protect cold-sensitive crops against frost. Some farmers in localities of frequent fogs report that fog blankets extend the frost-free growing season and thereby increase their crop yields. Russian meteorologists have successfully used artificial fogs to protect vineyards from frost. Perhaps power companies should be encouraged to build their new plants in rural regions where farming could benefit from such frost protection.

Among the various possibilities for dealing with the fog problem the approach that has been explored most actively up to now is the idea of dissipating fog by some artificial means. Over the past several decades hundreds of schemes for doing this have been proposed and many have been tried, but so far no universally practicable method has been found. What are the prospects that an effective and not too expensive technique could be developed?

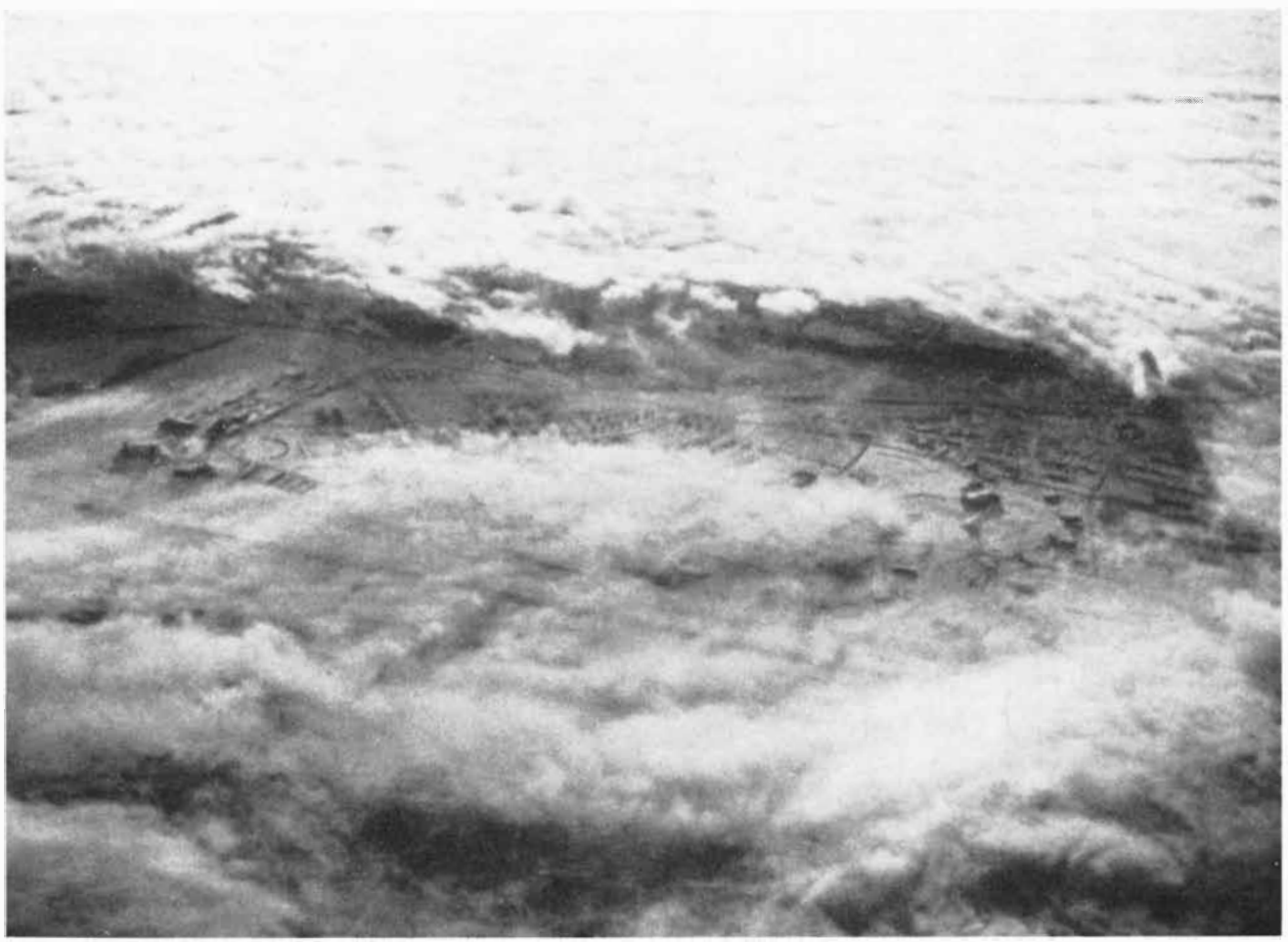
The most direct method would be



WATER DROPLETS that comprise a fog vary in size from about two microns to as much as 50 microns in diameter; their average size is 20 microns. The droplets in the photomicrograph are from a sample of supercooled fog prepared for a "cold seeding" study.



ICE CRYSTALS are formed in a sample of supercooled fog by seeding with propane. The crystals grow as water vapor is deposited on them. Reduced humidity makes the fog droplets evaporate, clearing the air and furnishing more water vapor for crystal growth.

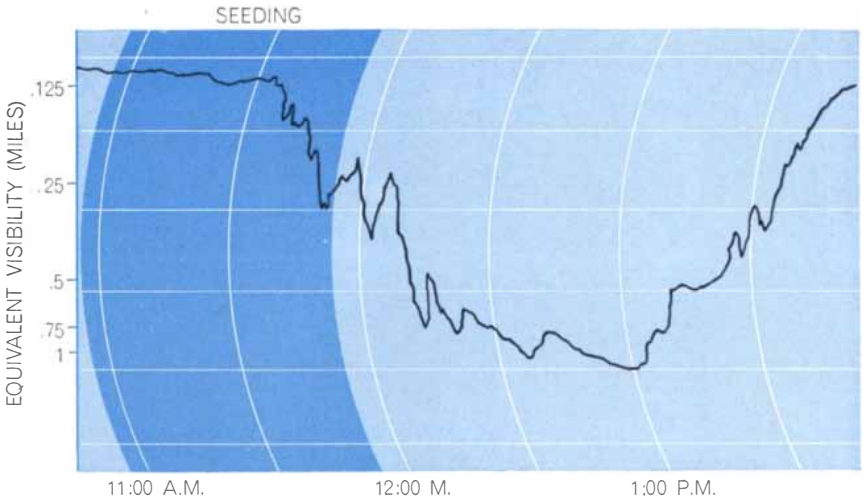


FOG CLEARANCE is achieved by dropping dry ice into a bank of supercooled fog overlying Elmendorf Air Force Base in Anchorage, Alaska. Seeding with dry ice initiated the growth of ice crystals, depriving the air of the liquid water that had made it foggy. Only 5 percent of the fogs in those parts of the U.S. that lie within the Temperate Zone are supercooled and dispersable by cold-seeding.

simply to blow the fog away, using an artificial wind. This tactic is actually employed around some settlements in the Arctic to disperse ice fogs. In the frigid atmosphere the water vapor emitted from human settlements (indeed, even the exhalations of a reindeer herd) can easily saturate the air and produce a local fog; at a temperature of 30 degrees or more below zero C. the fog consists mainly of ice crystals. Giant fans have been used successfully to free settlements of such fogs. Obviously, however, the method is applicable only on a small scale and in special situations.

Another attack on fog, based on the principle of evaporating the droplets by one means or another, has been applied in several interesting ways. The best-known of these is the FIDO method (Fog Investigation and Dispersal Operation), in which fuel-oil fires have been used to burn off (that is, evaporate) fog on airfields. The British resorted to this technique on military fields in World War II and successfully cleared them for more than 2,000 takeoffs and landings that could not have been undertaken otherwise. The method has important drawbacks, however. It is expensive, requiring hundreds of dollars' worth of fuel to clear a jet runway for 10 to 15 minutes; it creates a fire hazard for planes landing on the field, and it cannot dissipate all dense fogs. Moreover, the smoke and moisture released by the combustion of oil hinder evaporation of the fog. It has been proposed that this problem might be obviated by using electricity, jet-engine exhausts or anthracite coal to provide the heat, but the high cost would still remain a major objection. Drying the air with chemicals rather than heat has been effective in clearing fog in some cases; here again, however, the procedure is too expensive for wide use, and the chemicals employed tend to be corrosive.

Among the various principles of fog dispersal that have been tested, the most promising seems to be the injection of a catalyst or some other agent that will cause the droplets to coalesce and thus grow large enough to fall quickly to the ground. This type of attack has proved its worth in fogs consisting of supercooled droplets. By seeding the fog with particles of a very cold substance such as dry ice or liquid propane, one can cause some of the fog droplets to freeze. Water vapor in the air then condenses onto these ice crystals; the resultant drying of the air turns additional fog droplets back into vapor. The vapor, in turn, accelerates the growth of the ice crystals, which fall to the ground as they enlarge. United Air Lines has been seeding supercooled fogs at fields in the Pacific Northwest and in Alaska for several years and has found the method to be about 80 percent successful in dissipating such fogs. The airline estimates that this investment in fog control has repaid it fivefold by maintaining the regularity of flight schedules. The method has also worked well in other areas where it is applicable. It is effective, however, only for supercooled fogs, which account for only about 5 percent of all the fogs in the U.S. Temperate Zone.



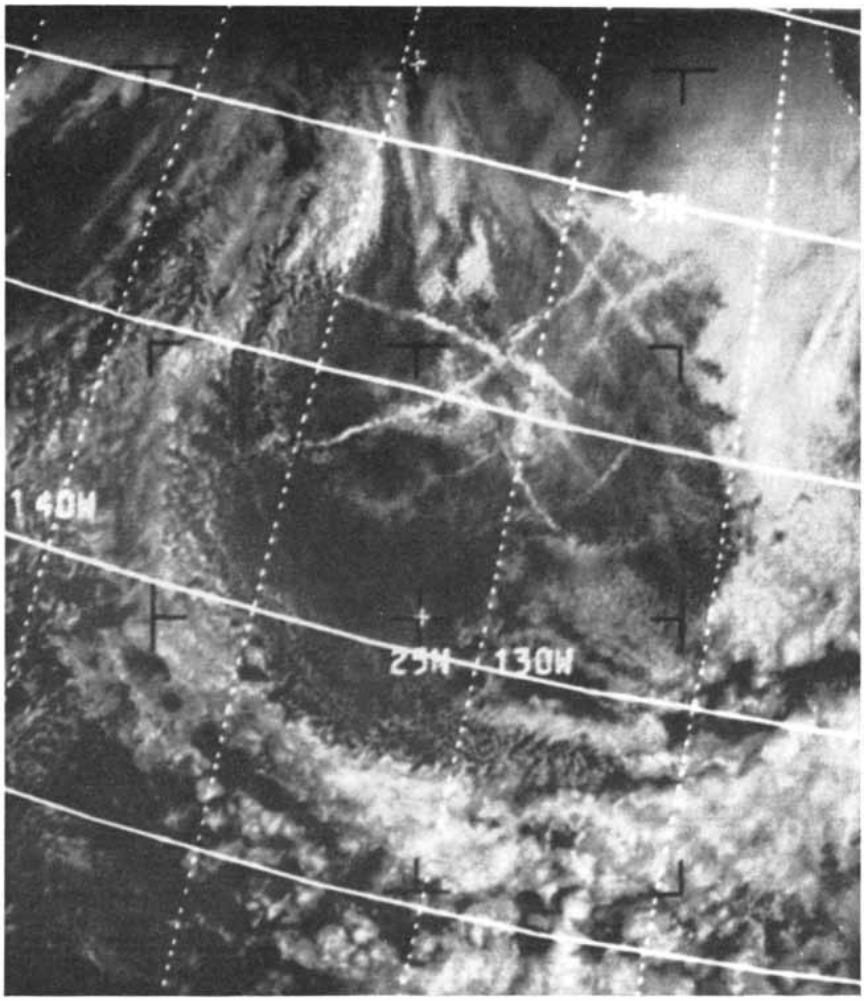
COLD-SEEDING TEST at the airport in Medford, Ore., began shortly before 11:00 A.M.; visibility, as measured by a transmissometer, was less than an eighth of a mile. Thirty minutes after the first seeding run visibility began to improve. By 12:15 P.M. it exceeded the half-mile minimum required at the airport and remained above minimum for over an hour.

Several ideas for dispersing warm fogs by droplet coalescence are currently being explored. The Air Transport Association is sponsoring a series of tests of a chemical mixture (composition undisclosed) that is said to make droplets combine by an electrical attraction effect. It is reported to have achieved some success in dissipating radiation fogs at Sacramento, Calif., during calm or very light winds. The ability of the method to disperse moving fogs, however, remains to be demonstrated. In any attempt to control fog, the wind condition is crucial. When the air is calm, clearing it of fog presents a comparatively uncomplicated problem because the volume of air that needs to be treated is limited. On the other hand, a breeze can quickly refog a space that has been cleared of fog; when moderate or strong winds are blowing, it is almost impossible to maintain a clearing.

Another scheme that has been proposed for fog dispersal involves dropping carefully controlled doses of salt particles into the fog. The theory is that when these hygroscopic particles deliquesce into solution droplets, they will gain water and grow at the expense of natural fog droplets because the humidity is higher with respect to the solution than it is with respect to natural water. It is hoped that the collection of the water into fewer and larger drops will produce a rapid improvement in visibility and that the fall of the large drops to the ground will maintain the improvement for some time after seeding has ended.

For effective progress toward the economical control or modification of fogs we shall have to learn a great deal more about the basic structure of fog and the chemical, physical and electrical properties of the fog droplets. Intensive studies are going forward on various types of natural fogs and on artificial fogs produced in the laboratory. The results of these investigations will be used to test mathematical models that describe fogs in terms of such quantities as temperature, humidity, wind, condensation nuclei, concentration of droplets and amount of liquid water. It should then be possible to obtain insight into the mechanisms and energy exchanges involved in the formation and maintenance of fogs and allow meteorologists to determine which kind of fog will respond to which dispersal method.

The artificial dissipation of fog will be rather costly in any case. Much might be done to prevent the formation of fogs in the first place. For example, spreading a chemical film over swamps and



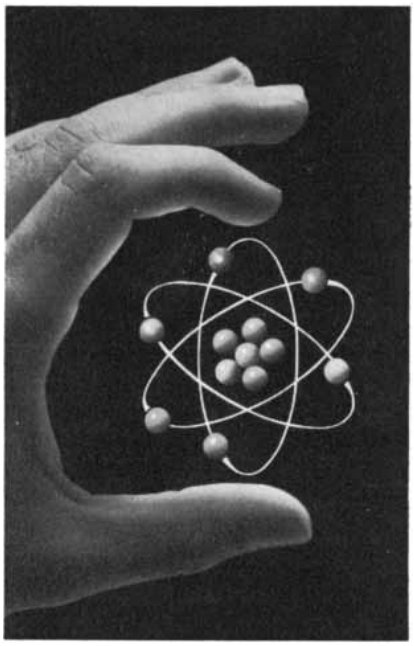
POLLUTION FOGS over the Pacific Ocean off the coast of California are visible in a weather satellite photograph as white trails in the area between 25 and 35 degrees north latitude and 125 and 135 degrees west longitude. Each trail is a narrow fogbank formed in response to the discharge of hygroscopic particles into the atmosphere from the funnels of ships at sea.

lakes in the vicinity of sensitive areas such as airports and highways might considerably reduce evaporation and thus reduce the frequency and intensity of fogs in those areas. There are indications that in places where shallow radiation fogs are common the fogs could be prevented from spreading by planting vegetation thickly around the area of origin. It would be desirable to prohibit pollution-generating factories from operating at times when the air is calm or an inversion is present. And the fog menace could be diminished greatly by giving more careful attention to the selection of proper locations for activities that generate fog and for those that may be troubled by fog.

Factories giving rise to air pollution, for example, should be located at sites where the topography and prevailing winds favor effective dispersal of the pollutants. Plants that must dispose of heated water should not be built near densely populated or well-traveled areas. On the other hand, in the selection of sites for airports, highways, sports stadiums, golf courses and so forth consideration should be given to finding locations where the geography, topography, soil characteristics and other features would tend to minimize the formation and persistence of fogs. For example, ideally an airport should be situated (1) upwind of any nearby source of air pollution, (2) on a plateau that stands high enough to shed cold air into a valley but low enough to avoid hilltop immersion in clouds, (3) away from rivers, lakes or marshy ground and (4) in full, unobstructed exposure to the sun.

By the application of meteorological knowledge to planning and by the development of further methods for fog prevention and dispersal, we may eventually be able to deal with the growing fog and smog problem. The success of these efforts, however, will hinge on the achievement of effective control over the pollution of the air and waters.

The taming of the atom.



Atomic power possesses unequaled potential. An exciting new chapter in the history of peaceful uses of atomic energy is being written in the State of Washington. Scientists have developed new atomic power sources, compact and reliable enough to assist the human heart.

Man made his first successful effort to draw usable energy from the atom in 1951 by using the heat from an atomic reactor to produce steam to generate electricity. Since then, scientists throughout the world have been challenged by the possibilities of less clumsy methods of harnessing the power of the atom.

Exciting breakthroughs in this area have now come from the McDonnell Douglas Corporation's, Donald W. Douglas Laboratories in Washington State. Scientists at the laboratories have now demonstrated the technology of practical conversion of radioisotopic energy to electric power in tiny atomic batteries. Utilizing decay heat and radiation from radio isotopes, these new batteries can provide electric power for years to decades with no moving parts.

One of these power sources, called the Isomite™ battery, is under intensive market evaluation for medical, ecological, aerospace, remote and underwater applications. The Isomite battery combines low temperature thermionic conversion from isotope heat to provide dependable power from tens of microwatts to one watt from the useful life of the selected radioisotope fuel. Smaller than a walnut, the Isomite battery can use various isotopes with a wide range of half-life to extend its usefulness as dictated by application and needs. In addition, the radiation level of the Isomite battery can be made extremely low. The laboratory's latest effort toward the utilization of the atom is its Betacel™ battery, which is inherently smaller than the Isomite battery. Consisting of alternating thin layers of radioactive material and thin semiconductor wafers, the Betacel solid-state device utilizes a conversion method which does not rely on heat production. Variations in numbers and arrangements of the layers can produce a wide range of current-voltage ratings. The Betacel battery is unusually efficient at power levels of 10 milliwatts and below. Operating as a "cool" battery with a lifetime of several years, the Betacel device is a practical power source for implantable biomedical instrumentation and prosthetic devices. Additional applications are for self-powered spacecraft devices, computer circuit stand-by power and many other potentials.

Atomic batteries capable of converting nuclear energy directly into regulated electric current promise a safe, economical answer to some power needs where present-day electrical systems are not available or feasible.

The State of Washington is proving to be a fertile field for the exciting breakthrough industries of the future. In atomic energy as well as aerospace, oceanography, agriculture, and many other areas, the smart money is betting on the State of Washington.

Daniel J. Evans
Governor

STATE OF WASHINGTON

For business location information, write: Daniel B. Ward, Director, Department of Commerce and Economic Development, Olympia, Washington 98501

The Relativism of Absolute Judgments

In which it is proposed that happiness is a negatively skewed distribution. Experiments demonstrate how judgments of personal satisfaction depend on the frequency of different experiences

by Allen Parducci

In the pessimistic mood of his later years Mark Twain mocked man's search for happiness. "Every man," he wrote, "is a suffering-machine and a happiness-machine combined. The two functions work together harmoniously, with a fine and delicate precision, on the give-and-take principle. For every happiness turned out in the one department, the other stands ready to modify it with a sorrow or pain...."

Mark Twain's gloomy assessment of life as a balance of happiness and sorrow may be consistent with a more general relativism of judgment. We are well aware that happiness is in some sense relative; for example, the more we achieve, the harder we are to please. Indeed, this principle is regularly invoked to explain why black Americans have become increasingly resentful during a decade of economic and social progress, a decade in which rising expectations have far outstripped whatever progress has been made. We recognize that judgments such as "fair" and "unfair," "good" and "bad," "large" and "small" reflect a relativism that belies their absolute grammatical form. The pervasiveness of this relativism, however, may be much greater than is commonly believed.

Consider a "test" of moral judgment that was given to a lecture class of several hundred college undergraduates. Each student was asked to rate the moral value of different acts of behavior in terms of his "own personal set of values." His task was to assign each act to one of five categories: "1—not particularly bad or wrong," "2—undesirable, a good person would not do this," "3—wrong, highly questionable," "4—seriously wrong" and "5—extremely evil." Half of the students were given a list made up mainly of relatively mild acts of wrongdoing; the other half got a nastier list, consisting principally of acts that could be counted on to evoke strong disapproval. The crucial feature of the experiment was that, embedded among the other items, each list contained six items that were common to both. The students were cautioned to "judge each act just as though it were the only one you were judging. In other words, don't try to compare the acts or rank them while forming your judgments."

Notwithstanding this instruction, the students' ratings showed that they could not escape the immediate context. The six acts appearing in both lists were rated more leniently by students who judged them in the context of the nasty list than they were by those who encountered them in the context of relatively mild wrongdoing [*see illustration on page 87*]. "Poisoning a neighbor's barking dog," for example, got a considerably harsher rating (a mean score of 4.19) in the mild context than it did in the nastier one (where its mean score was 3.65).

If the relativism of judgments shows up so clearly in a purely verbal context such as this, one must suppose that in the long-term context of lifetime experiences the effects of the context are much greater. Does Mark Twain's conclusion about happiness have a universal validity, so that an overall balance is maintained for "right" and "wrong," "pleasing" and "displeasing" and for any other type of judgment?

Happily the answer seems to be in the negative. Consider the results of a simple game we conducted with college students as players. The player selected one of three cards turned face down and received an amount of money specified on the hidden side of the card; after each trial he was asked to state his degree of satisfaction with his reward. Different amounts were specified by each card, and the player was told what these amounts were and how the probabilities for the various amounts were loaded, that is, with what frequency each amount could be expected to turn up. We divided the players into two groups, each playing with a different set of cards. In one set the amounts on the individual cards varied from one cent to 21 cents, with the higher values occurring much more frequently than the lower ones; in the other set the amounts ranged from seven cents to 27 cents but the low values predominated. In both cases the mean—the expected average reward per draw—was 14 cents. Since the players were all given a predetermined sequence of winnings (unknown to the players, all three cards on a given trial had the same value), every player won the same total amount of money for the series [*see illustration on page 86*].

The reactions of the two groups of players were distinctly different, as shown by their evaluations of the successive rewards. Those who played with the cards valued at one cent to 21 cents tended to be more satisfied with their individual winnings than those who played with the cards carrying rewards of from seven cents to 27 cents. The first group rated a given amount of money at least one degree of satisfaction higher on a seven-point scale than the second group did, and the mean of all their ratings was 4.6 on this scale, whereas the mean for the other group was only 3.4, or below the center of the scale (3.5). These results argue against the notion of an overall balance. Even if other factors such as previous experience were affecting the judgments, the random assignment of players would eliminate any systematic differences between the two conditions with respect to such factors. In fact, 15

of the 20 players in the less satisfactory condition had overall mean judgments that were below those for any of the 20 players in the other condition.

It seems, therefore, that we must reject the idea of a universal balance for judgments. The particular imbalance that is found apparently depends on the frequency distribution of outcomes that forms the context for judgment. Although the players in the first condition never won more than 21 cents on a trial, their most frequent winnings were high with respect to this context. In the other condition the more frequent winnings were from the lower portion of the range of winnings. Although the same total amount of money was won by each player, the ratings of satisfaction were higher for the condition in which more of the winnings were high with respect to the range of possible winnings.

Do the results of this game suggest a way of increasing our satisfactions in everyday life? In principle, at least, we can establish a scale of preference for the various events in our lives analogous to the scale of monetary winnings for this game. People ordinarily try to increase the relative frequency of those outcomes or events they like best. Mark Twain believed such efforts are doomed to failure. If our simple game provides a fair analogy to life, however, he was wrong. In the same way that a particular skewing of the distribution of rewards heightened the satisfaction of the players, we may be able to raise our overall level of satisfaction by adopting modes of life that enhance the comparative frequencies of events we prefer. Conversely, the game analogy warns us that our average level of satisfaction will be lowered if we extend the range of our expectations to include wonderful but rare events.

Empirical data from systematic studies suggest that these notions may have some generality. Fortunately in designing the experiments employed in this research it proved possible to devise games that produced the information we needed without our having to pay the players.

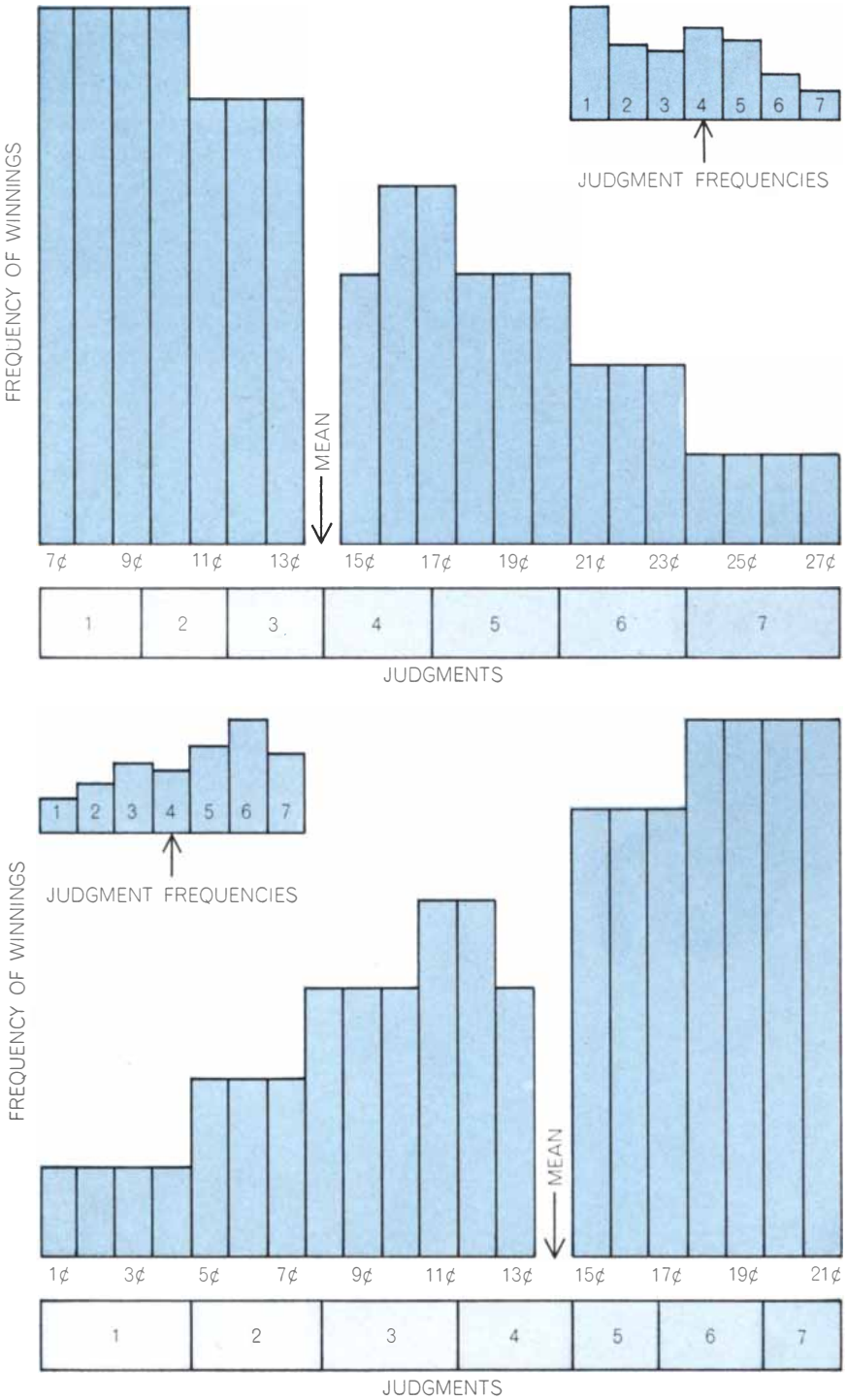
In one group of experiments the subjects compared the sizes of numerals in a given set. A list of numerals was presented, and the player was asked to evaluate the size of each one in comparison with the rest, rating it on a five-point scale: "1—very small," "2—small," "3—medium," "4—large" and "5—very large." As in the card game, we used two differently skewed sets and presented them to two separate groups of students. In this case we skewed the spacing between the numerals—the difference between the values of successive numerals in the list—rather than the frequencies of the various numerical values. For example, in one set of 44 numerals the spacing was greater between the smaller values in the list; in the other it was greater between the larger values. The end values were 108 and 749 for the first set, 351 and 992 for the second set. Both sets, however, had the same mean: 551 (in the sense that the sum of all the numerals in each set when divided by 44 equals 551). Would the judgments be perfectly balanced at 3.0, or would the means of the judgments reflect the difference in the skewing of the values in the two sets?

The results showed that, just as in the card game, the subjects' judgments were indeed influenced by the difference in skewing. In a typical experiment the judgments assigned by the students to any particular value were higher when the list in which it appeared was skewed with greater spacing between the lower values, lower when the same numeral

RELATIVISM OF JUDGMENTS was shown by college students who were asked to rate misdeeds using five moral categories ranging from "1—not particularly bad" to "5—extremely evil." The investigators later averaged for each misdeed the ratings assigned by different students. Half of the students received a list of rather mild actions, such as "Registering in a hotel under a false name" (*top left*). The other half received a list of more serious actions, such as "Murdering your mother without justification or provocation." Six items, including "Poisoning a neighbor's dog whose barking bothers you," were on both lists. The six items were regarded as more serious when they were presented on the mild list. The two lists of misdeeds are presented in full in the illustration on page 87.

appeared in a list that was skewed in the opposite direction [*see illustration on page 88*]. The mean of the average ratings for all the numerals in the first list was 3.5 (above "medium"), whereas the mean for the other list was only 2.7. None of the 30 students judging the second list produced a mean as high as 3.5. Again we find clear evidence that judgments do not balance at the middle of the scale, but rather that the average of the judgments varies with the skewing of the immediate context.

Could one find a systematic pattern that would throw light on how judgments are formed? Analysis of the results of the experiment summarized in the illustration on page 88 produces an interesting finding. In the set of numerals ranging from 108 to 749 it turns out that the mean of those numerals the subjects judged to be "medium" in size lies about halfway between the midpoint in the set, or $(108 + 749)/2 = 428.5$, and the median, which is the dividing point between the 22nd and 23rd values in the set, or $(588 + 599)/2 = 593.5$. In further experiments using more than 20 different sets of numerals with various means, medians and midpoints we found that the center of the scale of judgment usually fell about halfway between the midpoint and the median. Although the mean is intermediate between the midpoint and the median for many frequency distributions, independent variation of the mean did not affect the centering of the scale.

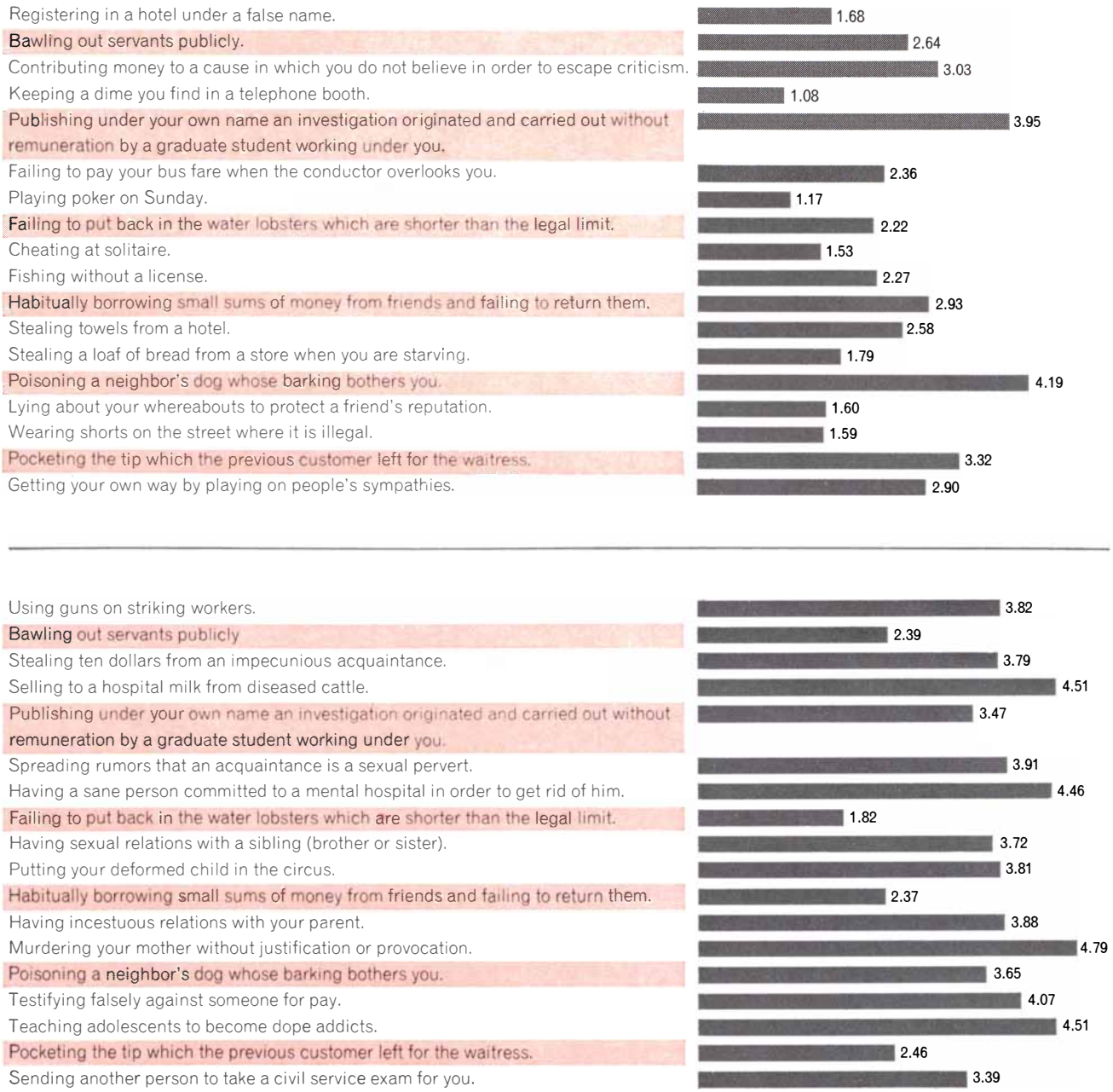


MONEY GAME involved judgments on a scale of 1 to 7 concerning the satisfaction derived from winning the sums shown. Students knew what relative frequencies of the various amounts to expect. In both cases the expected mean was 14 cents. Small bars at top show that the students were less satisfied when winning varied from seven to 27 cents, with smaller sums more frequent, than when it was one cent to 21 cents with larger sums more frequent.

Why should the midpoint and the median have this special significance? Analyzing the way the subjects distributed their ratings of the numerals, we find it useful to picture them as torn between two different tactics for judgment. One was to divide the overall range of numerical values into subranges, all of which had the same numerical spread. By this "range principle," if the numbers in the list ranging from 108 to 749, for example, were to be classified in just two categories, "large" and "small," the break would be at the midpoint: 428.5. Classifying the numerals into five size categories, one would divide the spread into fifths, so that the breaks would come approximately at 236, 364, 492 and 620. Each numeral in the list would then be classified simply by identifying the subrange (1, 2, 3, 4 or 5) in which the number occurred.

The other method, which we call the frequency principle, divides the set (of 44 numerals in this case) into equal groups. Therefore if the 44 numerals were to be assigned to just two categories, the break would come at the median, putting 22 numerals in each category; division into five categories would put about nine numerals in each.

Functionally these two principles serve to identify what is being judged. The range principle minimizes the magnitude of the greatest possible error of identification by making the categories all the same width. Thus with five categories each stimulus value could be located within a fifth of the range of



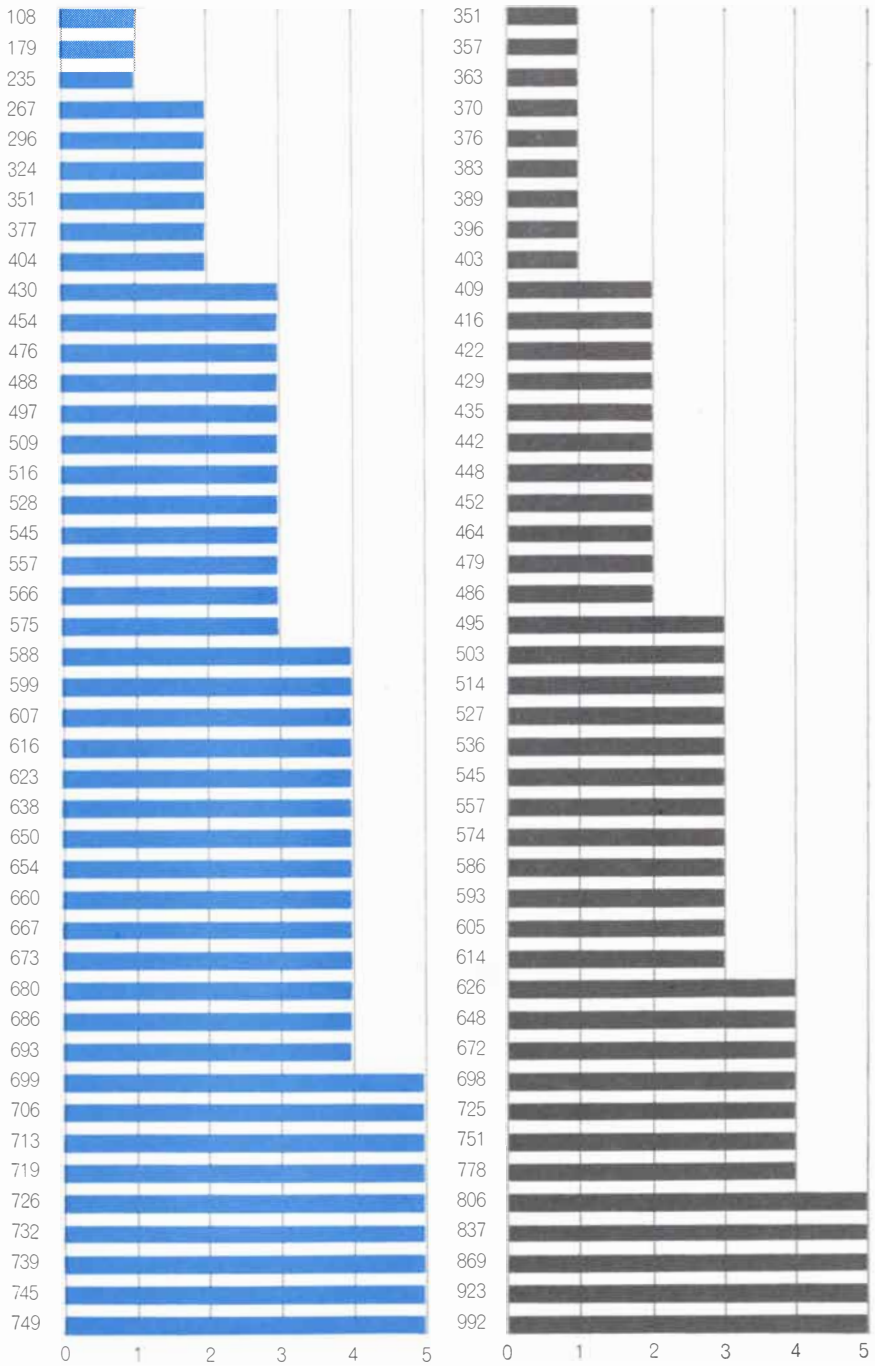
TWO LISTS that the college students used to make judgments included 12 "mild" actions (*top*) and 12 actions thought more likely to evoke moral indignation (*bottom*). Figures adjacent to the bars represent averages of judgments by a large number of students. The bands of light color distinguish the six actions that are common to both lists and were judged more leniently on the bottom list.

stimulus values. The frequency principle minimizes the probability of incorrect identification, without respect to magnitude of error, by having each category refer to the same number of values. Equalization of the frequencies covered by each category is the strategy followed by skillful players of the game called "Twenty Questions," in which the object is to identify a person or thing by asking questions that are answered only by yes or no. The player successively narrows the target by asking each time a question that cuts the number of likely solutions in half, beginning with broad questions such as: "Is it an animal?" "Is it a living American male?" If the game allowed five alternative answers to a question, each response could reduce the number of likely solutions by four-fifths.

Application of the range and frequency principles to our numbers game is complicated by the fact that the differences between successive numbers vary in different parts of the range. As a consequence the two principles yield different locations for the breaks between categories. From the fact that the mean of the ratings by our subjects generally falls halfway between the midpoint of the set (reflecting the range principle) and the median (reflecting the frequency principle), one can deduce that their judgments indicate a compromise between the two principles. The breaks between the successive categories can be predicted rather well by averaging the values they would have had according to the range and frequency principles.

Does the range-frequency theory apply to judgments of materials that are less abstract than numerals? In our Judgment Laboratory at the University of

California at Los Angeles we have tested the theory with various sets of physical stimuli: sounds of different wavelengths, small canisters of different weights, squares of different sizes. In a typical experiment of this kind we presented the subjects with nine different squares shown one at a time; the squares were presented again and again, in random order but all with equal frequency. The subjects were asked to judge the squares using nine alternative categories of size. On the frequency principle they would simply have ranked the nine squares, assigning each square to a different category. On the other hand, if they had applied the range principle, dividing the total range of sizes into nine subranges of equal span, some squares of closely similar size would have been put together in the same category and other categories would have been empty because no square fitted into the corresponding subrange.



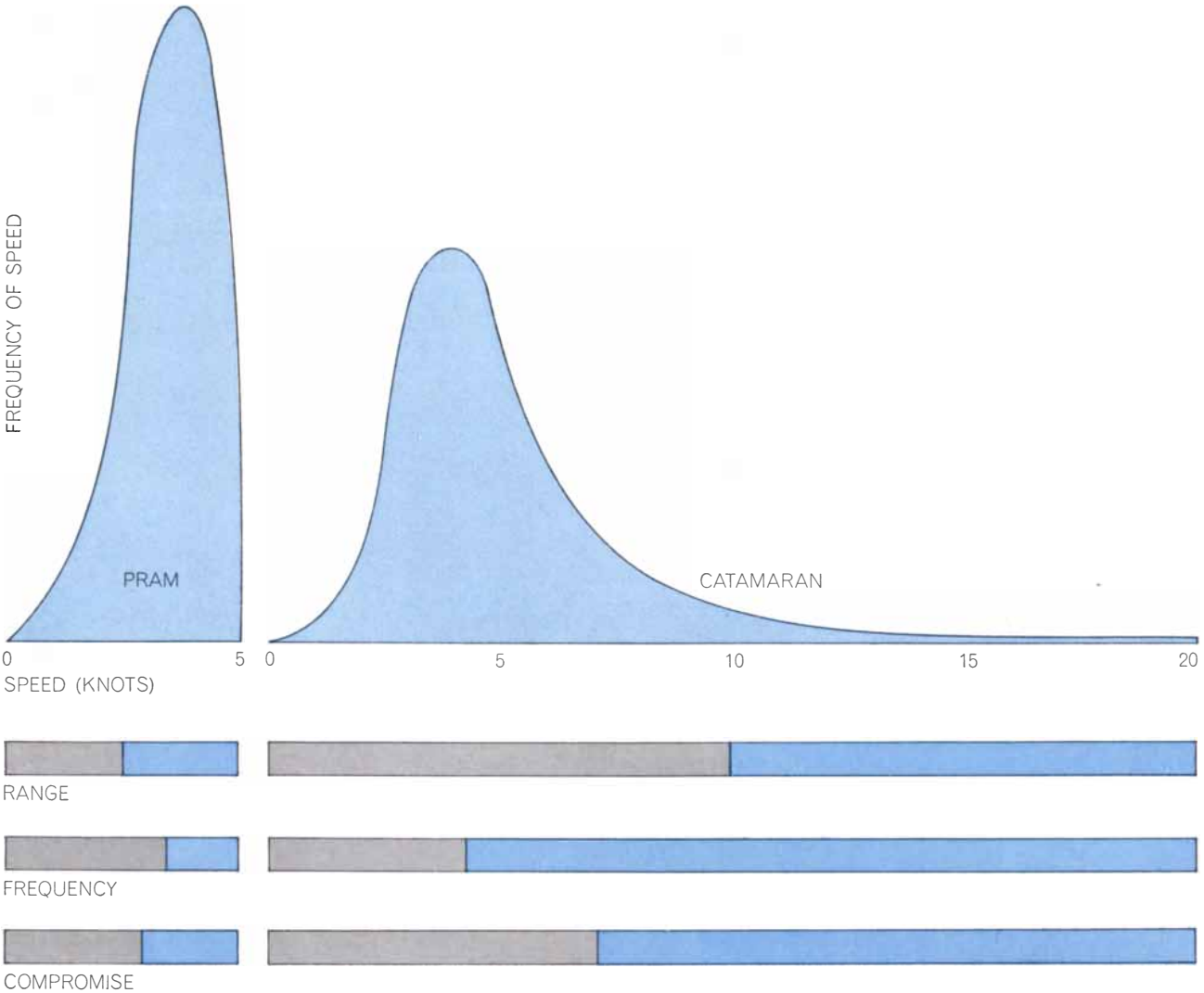
SETS OF NUMERALS were presented to college students for judgment on a five-point scale of relative magnitude. The differences between successive pairs of numerals varied considerably within each list, but notwithstanding the difference in end values, 108 and 749 for the first set and 351 and 992 for the second one, the mean was 551 for both sets of numerals. The mean of the judgments of magnitude (*bottom scales*) made by the students was 3.5 for the negatively skewed list at the left and 2.7 for the positively skewed list at the right.

Again we found that the subjects' judgments represented a compromise between the two principles. In tests on dozens of different sets of squares the judgments of the specific sizes fell approximately halfway between the values expected on the frequency principle and those expected on the range principle. Hence the same imbalance found for the gambling game and for the numerals also characterizes the judgments of squares.

The reader may wonder how the implications of the range-frequency theory might be useful for everyday decisions and behavior. In order to apply the theory to any realm of practical affairs one would have to establish the frequency distribution of values affecting judgments in that realm. The first problem would be to locate each value with respect to the range of relevant values. The late L. L. Thurstone and other psychologists have developed useful procedures for assigning psychological values to complicated stimuli; indeed, we employed these procedures, rather than physical measures, to represent the stimuli in some of our tests. Insofar as one could arrive at an appropriate representation of the frequency distribution of events affecting everyday judgments, he could use the range-frequency theory to predict what those effects would be.

The range principle, for example, suggests that an extreme political position has an influence on opinion far out of proportion to its actual support. Unsuccessful presidential candidates such as Norman Thomas, Barry Goldwater and George Wallace may bring about a greater shift in what is considered "middle of the road" than the moderate candidate who is elected. Although voters reject the extreme position, they include it in their contexts for judgment. This suggests that when voters are attracted to middle positions, the crusader who wishes to draw the weight of opinion toward his view should take a position that exaggerates his deviation from the center of the political spectrum.

As for the question of the balance of pleasure and pain, an example from



PRINCIPLE OF COMPROMISE is represented by judgments of satisfaction for a hypothetical situation in which a devotee of sailing has a choice between a pram (*left*) and a catamaran (*right*). The pram has a narrow range of speeds but usually operates at the upper limits of the range; the catamaran has a wide range of speeds but rarely attains the upper region. The bars at bottom show how the sailor would rate satisfactions if he based his judgment (1) solely on the range of speeds or (2) solely on the frequency with which top speeds are attained and (3) the actual satisfactions that would result from a compromise between range and frequency.

the sport of sailing illustrates how application of the range-frequency theory may swing the balance toward the pleasure side. Let us take the case of a hypothetical sailor whose satisfaction depends solely on the speed of his movement over the water. Would he derive more pleasure from a racing catamaran, which is the fastest sailboat in many conditions, or from the little, blunt-nosed sailing pram, which is the slowest of the popular boats? The catamaran attains its best performance only on rare days when the wind and other conditions are just right. The pram, on the other hand, rarely attains a speed above five knots, but since it is the design rather than the weather that places an upper limit on the pram's performance, the vessel sails at close to its maximum speed a large part of the time.

Consider the comparative plots of hypothetical experiences with the two boats in terms of the range and frequency principles [*see illustration above*]. The range of speeds for the pram, let us say, is between zero and five knots; for the catamaran, between zero and 20 knots. On the range principle the sailor would rate as satisfactory only those occasions on which the boat's speed was above the midpoint of the range: 2.5 knots for the pram, 10 knots for the catamaran. Under the variety of actual sailing conditions this performance will be achieved by the pram most of the time; by the catamaran, only on rare occasions. On the frequency principle the speeds rated as satisfactory would be those above the median, that is, the faster 50 percent of the sailing occasions. Now, if we take the compromise level (halfway between the midpoint and the median) as the dividing line between satisfaction and disappointment, we find that a pram should give such a sailor far more satisfaction than a catamaran. Most of the sailing experiences in the pram would be "satisfactory"; most of those in the catamaran, "unsatisfactory."

Of course, we have been considering an artificially simplified situation. If the pram sailor went sailing in a catamaran, the comparison might drastically alter his notion of a satisfactory sailing speed. Furthermore, in reality a sailor's pleasure is affected by physical factors other

than speed, such as the handling of the boat and aesthetic considerations. These factors must be considered in any application of range-frequency theory. In the simple experiments with money, numerals or squares the context for judgment was the particular set of values the experimeter chose to present. That is the advantage of experimental control. In everyday life, however, we can assess only crudely—much less control—the relevant contexts for our judgments. Even the sailor interested only in speed should take into account not only the actual speeds of the boats but also imagined speeds that may themselves be important features of the context for judgment. Occasional 20-knot days may generate expectations and hope and recurring daydreams of thrilling bursts of speed. Each of these would have its place in the frequency distribution from which the theory predicts the judgments.

Can we take such factors into account? We have to if we wish our decisions to be rational. Reason requires predictions, however crude, of the consequences of each of the choices under consideration. Hence in choosing a job people estimate, among other factors, the income that might be expected. The range-frequency theory would complicate such a choice only because it forces consideration of the relativism of judgments—of how satisfying, for example, the expected income would seem when compared with the incomes of others in the same type of work. Given the difficulty of taking such factors into account, the theory should at best be regarded as a source of hypotheses or suggestions about the effects of different contexts.

What the theory suggests is that happiness is a negatively skewed distribution. If the best can come only rarely, it is better not to include it in the range of experiences at all. The average level of happiness can be raised by arranging life so that high levels of satisfaction come frequently, even if this requires renunciation of the opportunity for occasional experiences that would be even more gratifying. It may sometimes be possible to manipulate the environment to this end, for example by choosing the right kind of boat to sail or the right kind of person to marry. In arriving at such a decision the individual must, of course, give due weight to his daydreams. As Mark Twain observed in his ruminations on the balance of pleasure and pain: "What a wee little part of a person's life are his acts and his words! His real life is led in his head, and is known to none but himself."

The $500 wand that solved a $35,000 problem.

The girls handling miniature diodes at the Western Electric plant in Reading, Pa. couldn't load them into soldering machines without bending at least some of the delicate leads.

Studying the problem, we learned that it would be possible to design a machine to do the job —for about $35,000. But it would still bend some leads. So we tried again and came up with a device we called the magnetic wand. About 16 inches long and made of plastic, the wand was slotted along most of its length, with magnets fitted into the end of each slot.

By shaking this wand back and forth over the bin holding the diodes, a girl could pick up 36 diodes at one time. Since she didn't handle the diodes individually, she bent very few. And she could work so much more efficiently using the magnetic wand that we had to redesign our soldering machine to keep up with her.

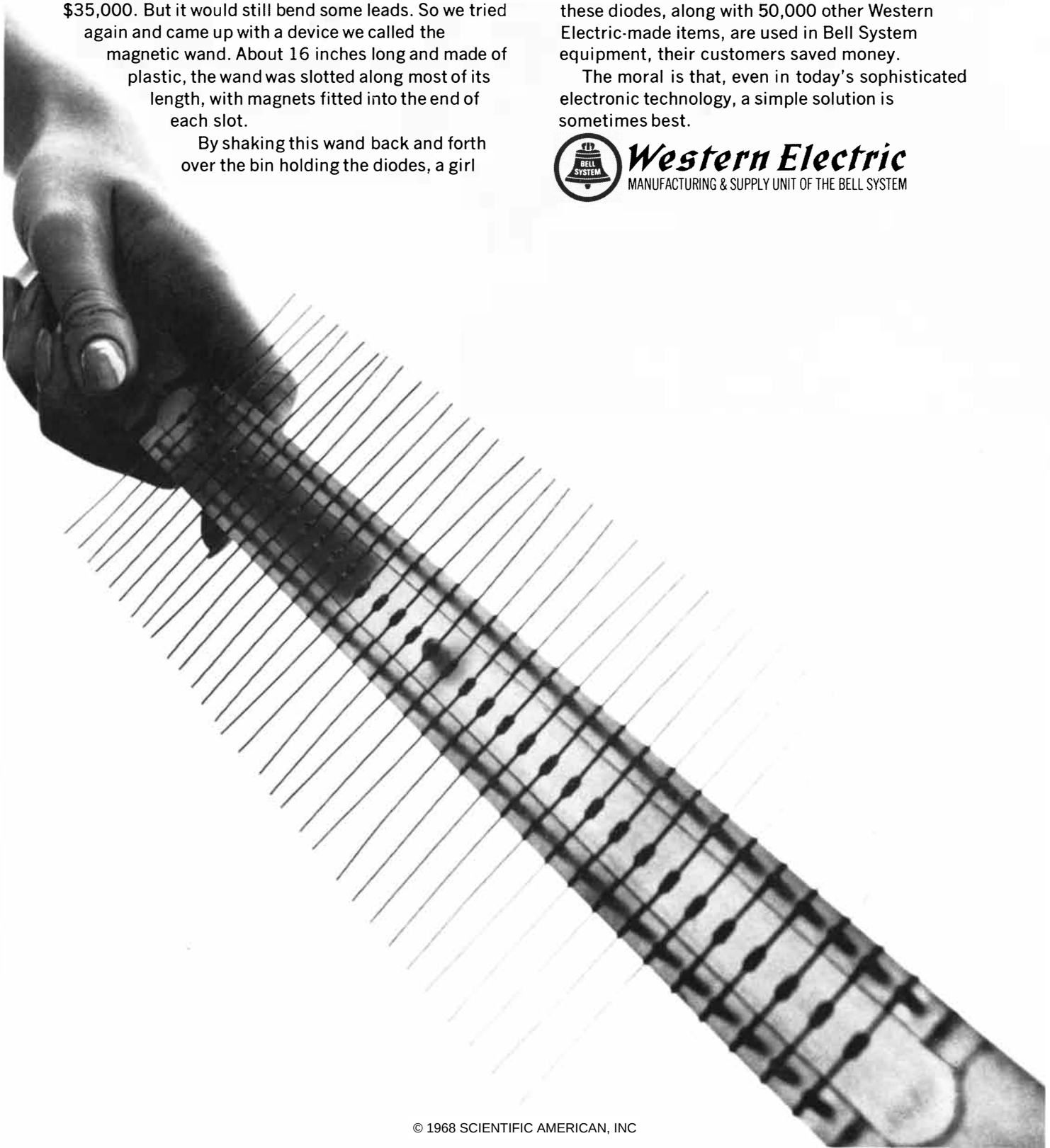
The result: Our girls saved time and effort. And since these diodes, along with 50,000 other Western Electric-made items, are used in Bell System equipment, their customers saved money.

The moral is that, even in today's sophisticated electronic technology, a simple solution is sometimes best.

BELL SYSTEM

Western Electric

MANUFACTURING & SUPPLY UNIT OF THE BELL SYSTEM



Fish used to be scared when we

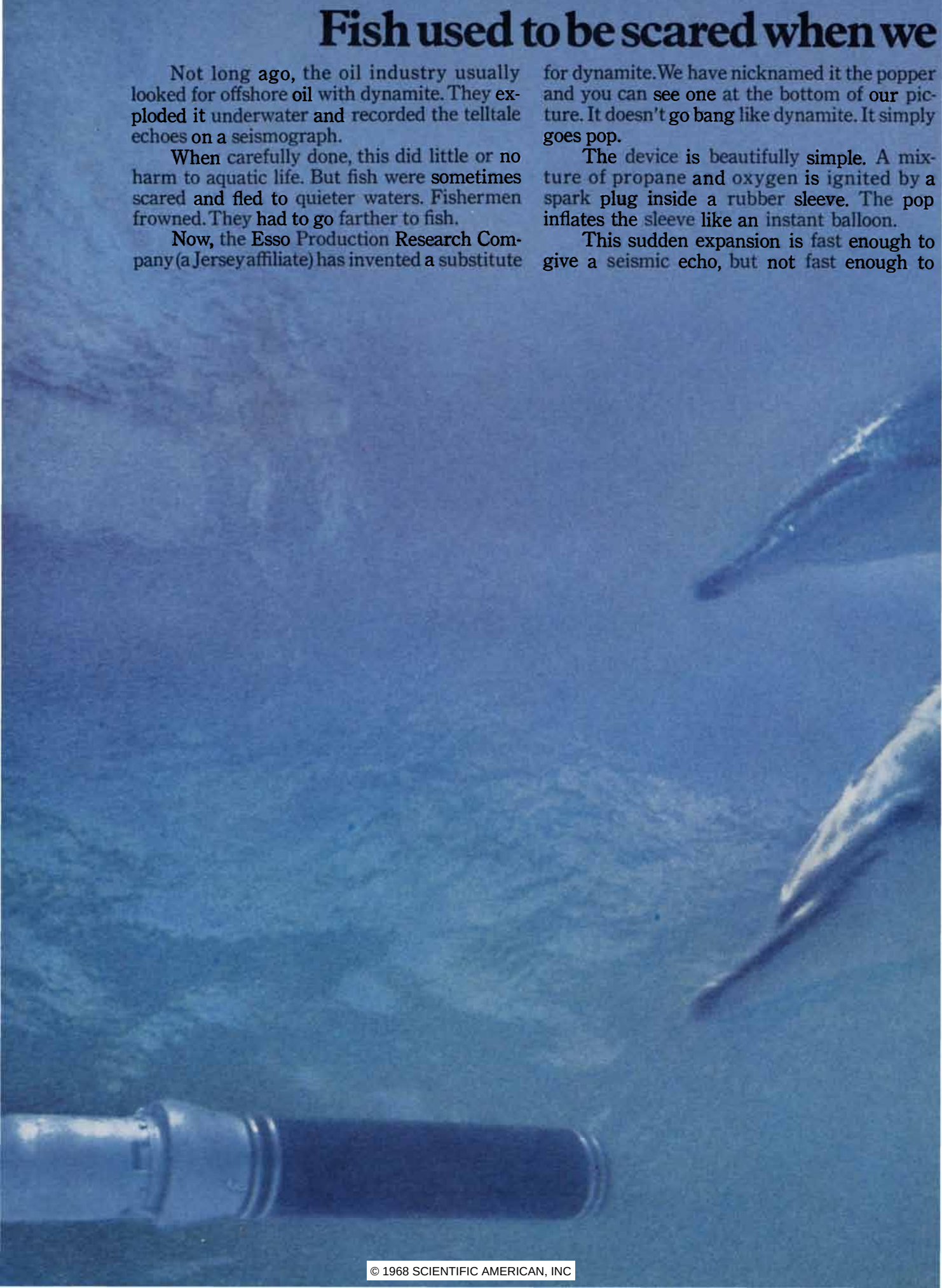
Not long ago, the oil industry usually looked for offshore oil with dynamite. They exploded it underwater and recorded the telltale echoes on a seismograph.

When carefully done, this did little or no harm to aquatic life. But fish were sometimes scared and fled to quieter waters. Fishermen frowned. They had to go farther to fish.

Now, the Esso Production Research Company (a Jersey affiliate) has invented a substitute for dynamite. We have nicknamed it the popper and you can see one at the bottom of our picture. It doesn't go bang like dynamite. It simply goes pop.

The device is beautifully simple. A mixture of propane and oxygen is ignited by a spark plug inside a rubber sleeve. The pop inflates the sleeve like an instant balloon.

This sudden expansion is fast enough to give a seismic echo, but not fast enough to



looked for oil. Now they seem interested.

scare away fish, porpoises or anything else.

What's more, it has a snorkel. This allows burned gases to escape to the surface. So the water stays clean.

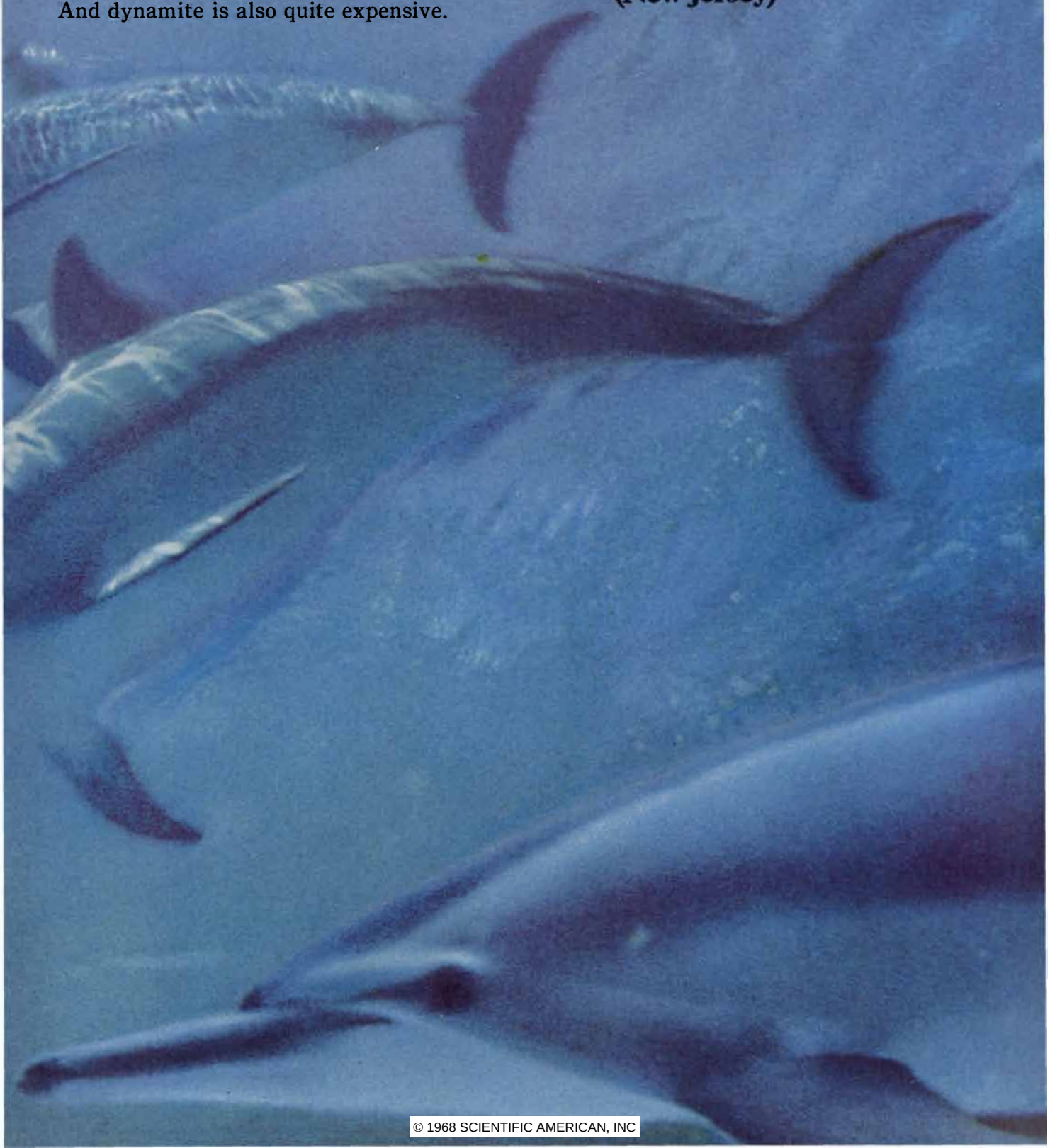
But fishermen aren't the only people to cheer.

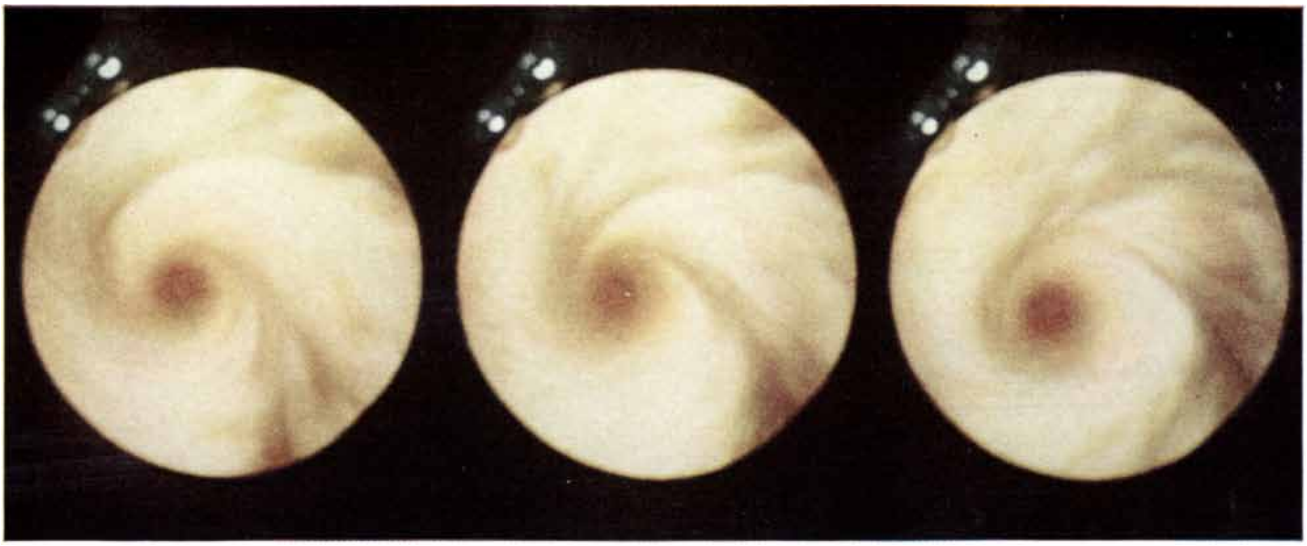
Dynamite is often tricky stuff to handle. The popper is completely safe. Exploration crews have one less danger to contend with.

And dynamite is also quite expensive. Fifteen dollars a shot. The popper costs a penny a pop and gives a better seismic picture in the bargain. At the rate the oil industry is exploring, it could literally save millions.

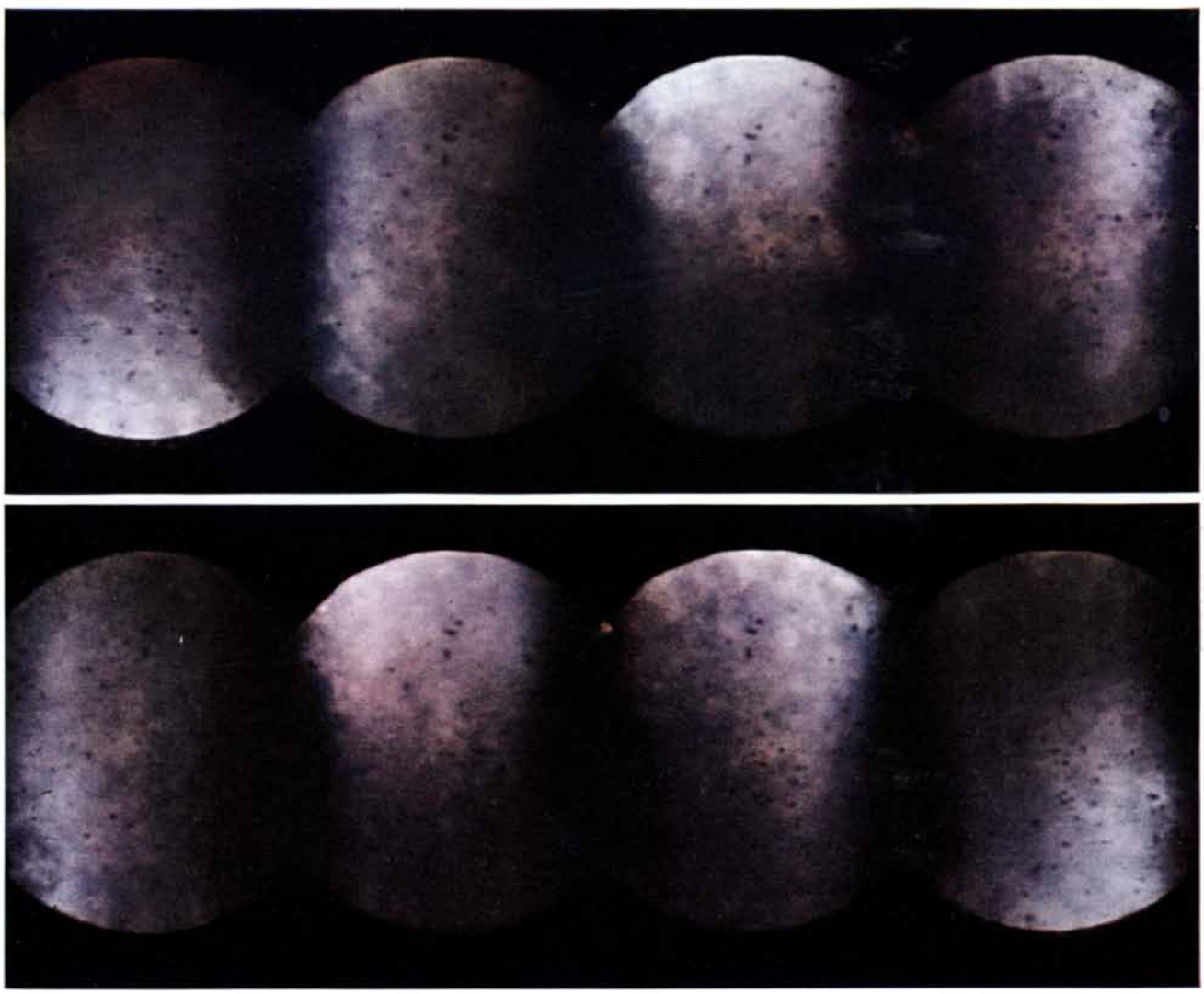
Good news for people. Great news for fish. Quite an invention.

Standard Oil Company (New Jersey)





INTERIOR VIEW of a solid-propellant rocket shows a vortex resulting from combustion instability. Views, which are from a motion-picture film made by one of the authors (Sotter) and J. Swithenbank at the University of Sheffield, are through a window in the head end of the rocket and toward the nozzle from which gases escape. The nozzle is not visible because of smoke and luminosity.



DETONATION WAVE in a liquid-propellant rocket travels clockwise in this sequence of frames from a motion-picture film made by Richard M. Clayton of the Jet Propulsion Laboratory. The camera, mounted in a protective housing, was placed in the exhaust gases just outside the nozzle. Hence the view is into the rocket engine toward the injector, which is a perforated metal plate at the head end of the motor. Through the injector fuel and oxidizer are admitted to the combustion chamber, where they are mixed and burned.

RESONANT COMBUSTION IN ROCKETS

The variety of physical and chemical processes taking place during the release of energy in a rocket engine may create conditions for oscillations to build up to large amplitudes

by J. George Sotter and Gary A. Flandro

Solid-propellant rockets apparently were invented in China about 1,000 years ago. They did not attract much notice until the 13th century A.D., when they began to be used in warfare. From about the 14th century rockets were constantly competing with guns for superiority in battle. Not long after Francis Scott Key wrote of "the rockets' red glare" in 1814 the improved accuracy of guns seemed to have doomed rockets to a secondary role. Consequently the invention in 1895 of the first practical liquid-propellant rocket by Pedro Paulet, a Peruvian engineer, aroused little interest.

Three decades later the American physicist Robert H. Goddard launched a liquid-propellant rocket powered by liquid oxygen and gasoline. Goddard, whose work established the foundation of liquid-propellant technology, was at the time considered something of a crackpot by some of the American authorities who were following his efforts. His work, however, did not go unnoticed in Germany. By 1939 German rocket engineers were pressing to obtain funds for the development of a large liquid-propellant rocket, which later became known as *Vergeltungswaffe* ("vengeance weapon") 2.

The V-2 was to usher in the space age and pave the way for man's journey to the moon. In 1940, however, a British team developing a small solid-propellant rocket as an antiaircraft weapon encountered unstable combustion—a phenomenon that has since then plagued nearly every major rocket-engine development program. The British rocket was being given a static ground test at the Woolwich Arsenal, and about halfway through the burning period the pressure in the rocket chamber suddenly rose to more than twice the expected level and then returned rapidly to normal. Such an excursion would have destroyed a rocket engine of flight weight, but the experimenters were working with a test chamber of heavy construction, and it was not damaged.

To investigate the matter further they made firings in which they extinguished combustion when the high pressure appeared. Examining the surface of the partly burned solid fuel, they found that it was rippled. The orientation of the marks suggested that the gases inside the motor had been moving in an intense vortex.

Evidently, then, the instability was attributable to an unusual motion of the gas during combustion. The British workers damped this motion in a simple way: they attached a steel ruler to the forward end of the combustion chamber so that it projected into the flow of gas. Such "resonance rods," made in a variety of forms and materials, are still employed to control unstable combustion in solid-propellant engines. They do, however, have a number of drawbacks. As the size of rocket motors has increased, the rods have had to be bulkier. They interfere with ignition of the charge, they reduce the potential payload and sometimes they do not significantly reduce the instability. Although various other remedies are sometimes effective, unstable combustion in solid-propellant rockets remains a problem.

Liquid-propellant rocket engines did not at first suffer from unstable combustion. The problem materialized when the designers of the German V-2 rocket undertook to make a propellant injector that would be less difficult to fabricate than the one they were using. Their new injector worked well in a small test engine, but when they tried it in a full-sized model, the engine emitted an audible hum that was accompanied by severe vibration. The German workers solved the problem by simply reverting to the original injector. Many modern liquid-propellant rockets, however, are significantly different from the V-2; they use more energetic propellants and have injectors that provide more efficient combustion. All these factors seem to encourage instability, so that instability also remains a problem in liquid-propellant rockets.

By definition a rocket is a vehicle able to propel itself without aid from its environment. Automobile engines and gas-turbine jet engines use the surrounding air as an oxidizer to burn a fuel. The chemical rocket carries its own oxidizer as well as its fuel and thus can operate where there is no air.

Most of the rockets in service today are chemical rockets: they operate by releasing the chemical energy of the fuel and the oxidizer (referred to jointly as propellants). A few other kinds of rocket engine, such as nuclear engines and electrical ones, are in use or under development, but they will not concern us here.

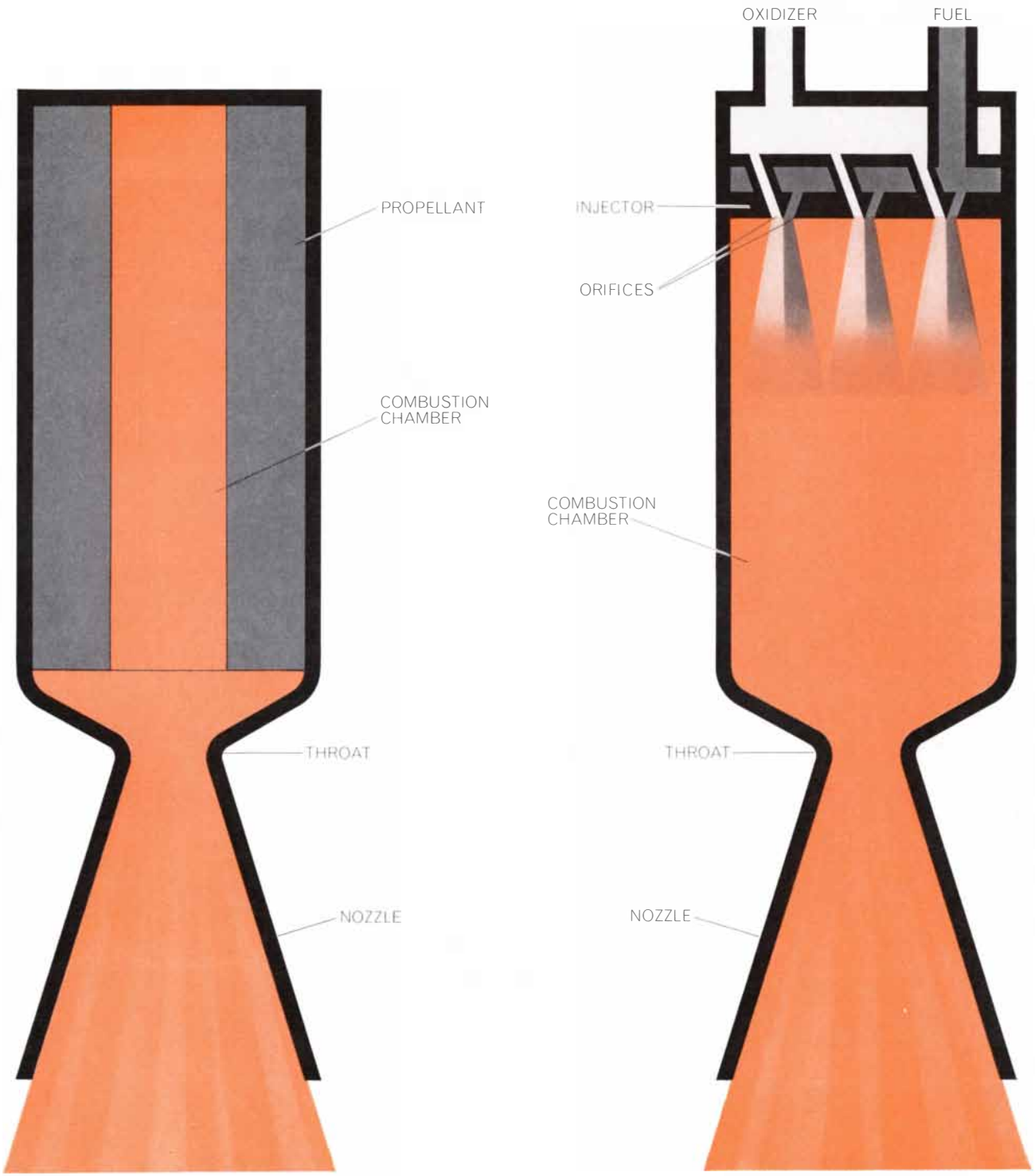
A chemical rocket can have either solid or liquid propellants; in either case combustion converts the propellants into hot gases. The gases expand, creating high pressures that force them through a nozzle, where they become cooler as their thermal energy is converted to kinetic energy. They emerge from the nozzle at supersonic velocities, and the forward movement of the rocket is the recoil from their expulsion.

A solid propellant can be made by mixing a fuel and an oxidizer. (At the time of mixing one ingredient is in liquid form, but it subsequently hardens into a solid.) A typical mixture is ammonium perchlorate in a matrix of an organic fuel such as rubber. A homogeneous mixture of such self-oxidizing substances as nitrocellulose and nitroglycerin can

also be used. In either case the propellant is usually cast in such a way that a central column is left open. Combustion proceeds only on the surface of the exposed material.

In a liquid-propellant rocket engine the oxidizer and the fuel are fed separately into the combustion chamber from storage tanks. They go through an injector that atomizes them and mixes them in the correct proportions so that they can be readily vaporized and burned. Among the oxidizers are liquid oxygen and liquid fluorine; the fuels include kerosene, alcohol and hydrazine.

A solid-propellant engine requires no pumps or pressurization, so that it is mechanically simpler than a liquid-propellant engine. On the other hand, a solid-propellant engine is not as controllable as one using liquids. Only re-



CHEMICAL ROCKETS, which are the kind predominantly in use at present, can use either a solid propellant (*left*) or liquid ones (*right*). A solid-propellant rocket can be the simplest of propulsive devices, consisting basically of a nozzle and a chamber containing the charge. A liquid-propellant rocket burns a fuel and an oxidizer; they are stored elsewhere in the vehicle and fed into the combustion chamber through an injector, which is a perforated plate. A typical propellant combination is kerosene and liquid oxygen.

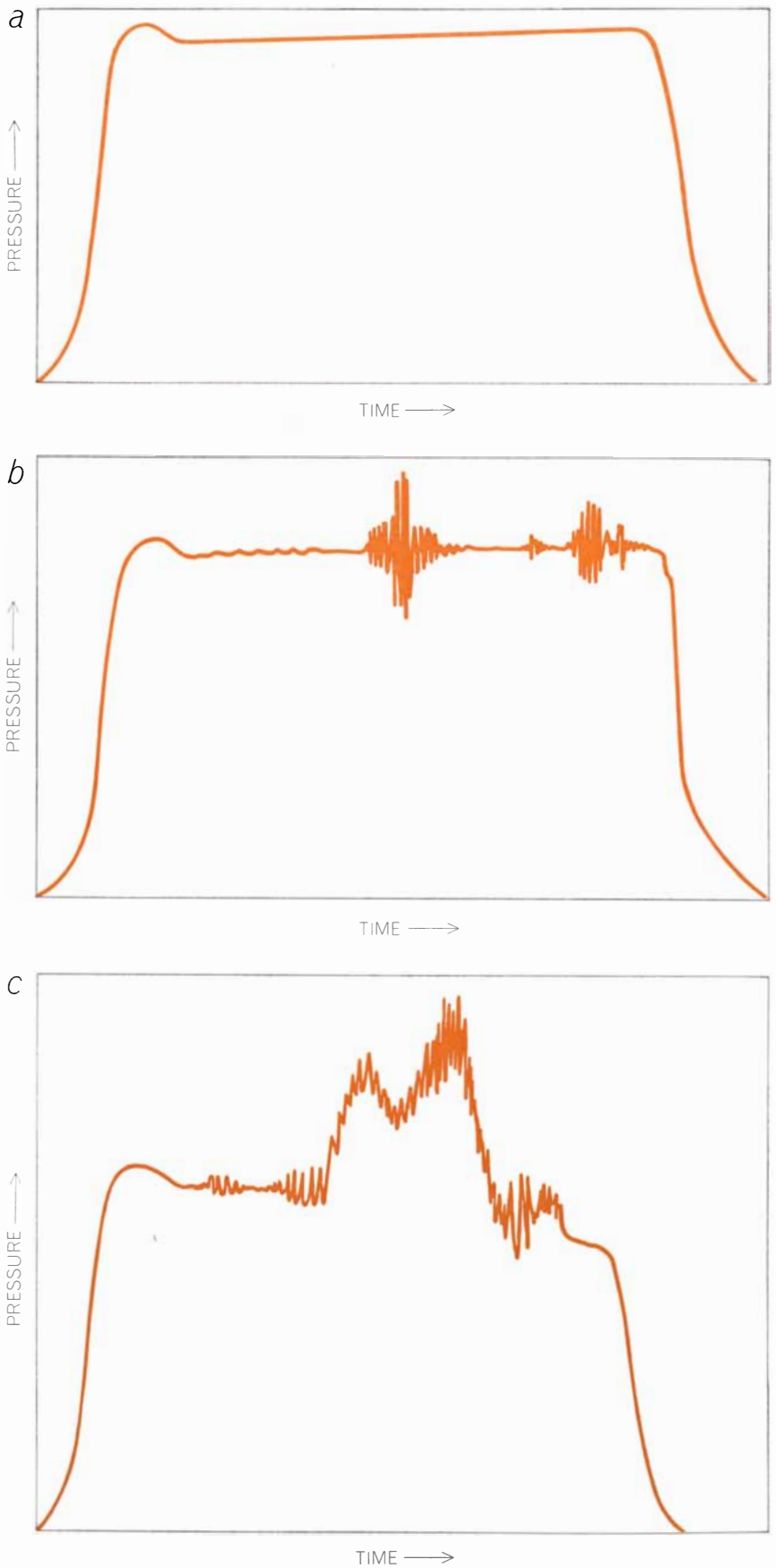
cently, for example, has it become possible to turn off a solid-propellant engine and restart it, whereas a liquid-propellant engine can be stopped and restarted readily. In general a liquid-propellant engine is capable of higher and more adjustable performance than a solid-propellant engine, which is why most of the engines for space vehicles are liquid-propellant ones.

Whether they are in solid or liquid form, the propellants can be regarded as a large reservoir of energy that can be tapped in various ways by the many physical and chemical processes that take place during operation, giving rise to the possibility of self-excited oscillations in the system. Oscillatory behavior is always possible when an energy source is coupled with an object or medium capable of vibratory motion, and when a feedback loop exists between the source of energy and the vibrating system. Perhaps the best-known example of this phenomenon is feedback in a public-address system. Under certain conditions a random sound is picked up by the microphone and fed through the amplifier to the loudspeaker, from which it is again detected by the microphone. The impulse gains strength as it passes through the amplifier (a source of energy), and as the process is successively repeated the sound may build up until it becomes a piercing scream. Damping mechanisms (which are related to room acoustics, amplifier characteristics and other conditions) cause a leveling off of the volume when the gains and losses come into balance.

A similar process takes place in the unstable rocket motor. The analogue of the electronic amplifier is the combustion region in the combustion chamber. Under certain conditions this region can amplify sound waves, and if an appropriate feedback is provided by the boundaries of the chamber, the waves can grow to an intensity dependent on the damping processes that are acting.

Oscillatory behavior in rocket engines takes many forms, some of which are still poorly understood from a theoretical point of view. One form that appears in liquid-propellant engines is a low-frequency vibration, with a chugging sound, that is caused by coupling between the propellant-feed system and the combustion process. The two are coupled because the propellant's rate of flow is sensitive to the pressure in the combustion chamber.

As the pressure in the chamber increases, perhaps at first because of a

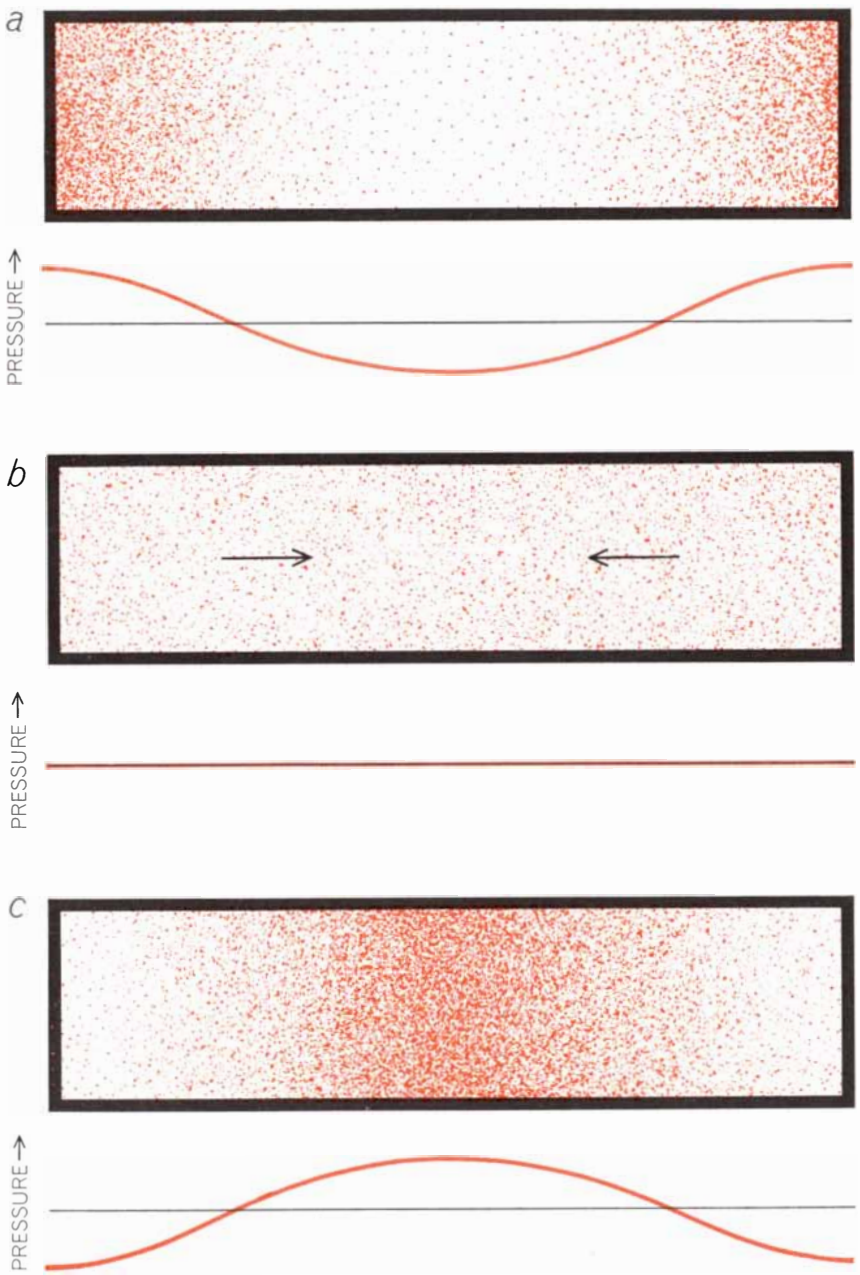


PRESSURE RECORDS characterize various types of combustion in rockets. Normal steady burning (*a*) produces a curve with a smooth profile. Oscillatory burning (*b*) shows various frequencies, sometimes with varying amplitudes. Radical departures of pressure from normal (*c*) are called irregular burning; they are apparently caused by oscillatory burning.

random disturbance, the rate of flow of the propellants through the injector tends to decrease. The slowing rate of flow brings about a decrease in the pressure in the combustion chamber, which encourages an increase in the rates of flow of the propellants. This type of instability could not develop if the system had appreciably different characteristic times for the rise and fall of pressure in the chamber and for increases and decreases in the rates of flow of the propellants. The problem can be solved by tailoring the length of the lines that feed in the propellant, by changing the design of the injector and by other steps that have the same effect: making the characteristic times so different that resonance cannot develop.

A more destructive form of instability, found in both liquid-propellant and solid-propellant rockets, is called acoustic instability. It is basically characterized by high-frequency variations in the pressure of the combustion chamber. The resulting scream from the engine can often be clearly heard.

Acoustic instability can begin with small disturbances in the gas in the combustion chamber. These perturbations are amplified by the combustion process and by the flow of gas through the motor. The sound waves bounce off the boundaries of the chamber and so are fed back into the system. In solid-propellant engines the phenomenon leads to sharp rises in pressure; in liquid-propellant rockets it is the oscillations themselves that can produce severe damage by causing large vibrational accelerations and by transferring excess heat to the walls of the engine.



ACOUSTIC OSCILLATION of the longitudinal type is depicted schematically for a closed tube. The acoustic oscillation, or sound wave, is assumed to be present as one begins observing the process (*a*) at a time when all the particles, or groups of molecules, of gas are at rest and distributed as shown. The graph below represents the distribution of pressure. Soon (*b*) the particles are uniformly dispersed but most of them have a velocity toward the center, as indicated by the arrows. Later (*c*) the particles bunch in the center, building up a pressure that brings them to rest and then forces them back toward the ends.

The effort to eliminate oscillatory combustion in rockets has been largely based on trial and error, which is unavoidably costly and time-consuming. The difficulties would be much eased if there were a theory that would predict the occurrence of high-amplitude waves in a motor of given design and would allow the investigation of possible ways of eliminating them. The first attempt at such a theory was published in 1942 by the Russian physicist Ya. B. Zel'dovich, but attempts to use his analysis to predict the stability of real engines were unsuccessful. Notwithstanding intensive efforts by many investigators in the years since then, a completely satisfactory theory does not yet exist. The reasons for this state of affairs will perhaps be made clearer by a brief outline of the physical processes involved in oscillatory combustion.

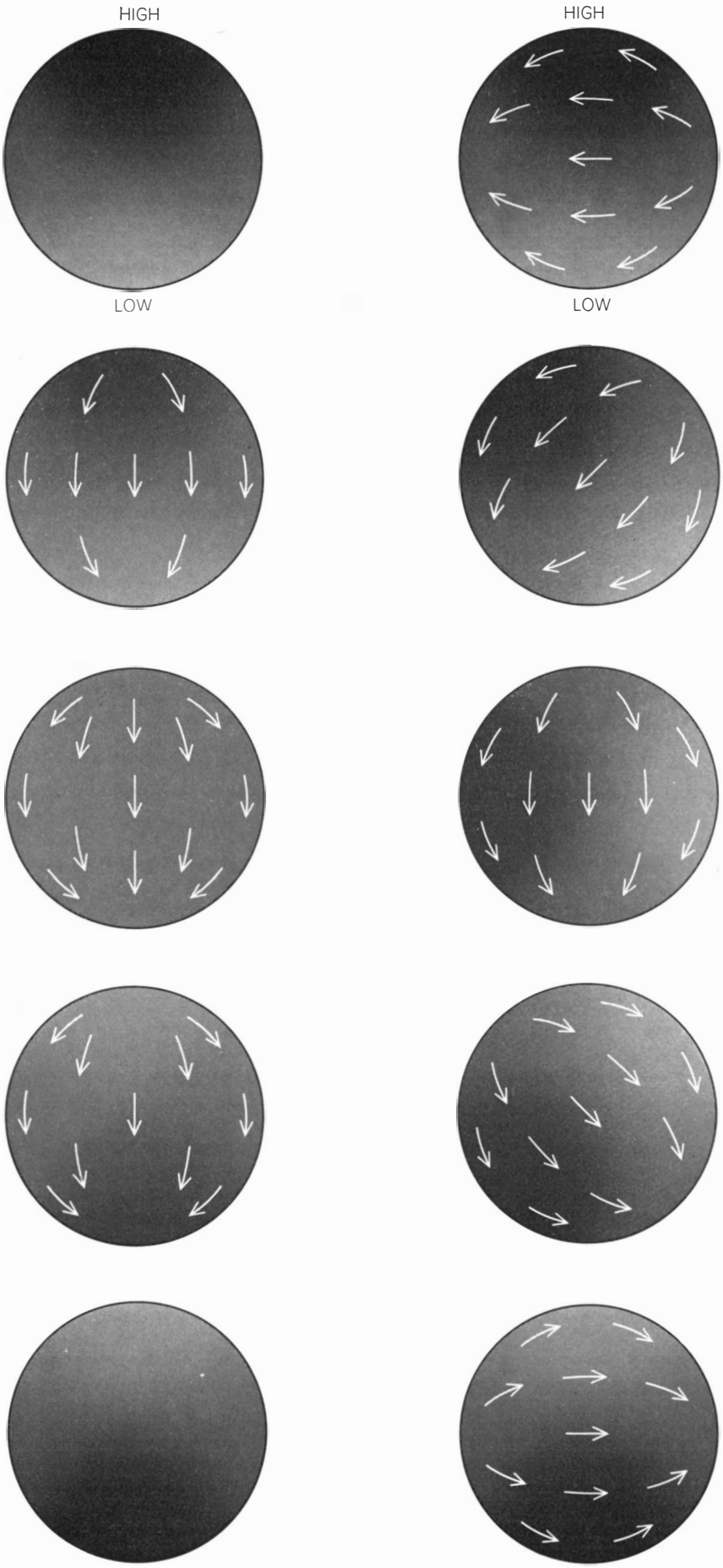
The discipline of acoustics has furnished a frame of reference for much of the theoretical work on instability in rocket combustion. A particularly helpful mathematical formulation has been the acoustic wave equation, which deals with the various ways gases can oscillate. In a closed circular cylinder, which is an approximation of the geometry of certain rocket engines, three "pure" modes of oscillation are possible: longitudinal, radial and tangential. The longitudinal and radial types, as their names imply, involve motions only along the length or the radius of the cylinder. The tangential type involves motions that have both tangential and radial components but that at the wall of the cylinder are only tangential. The three modes can of course be present simultaneously and in various combinations. In addition various modes with inherently com-

bined longitudinal, radial and/or tangential motion are possible.

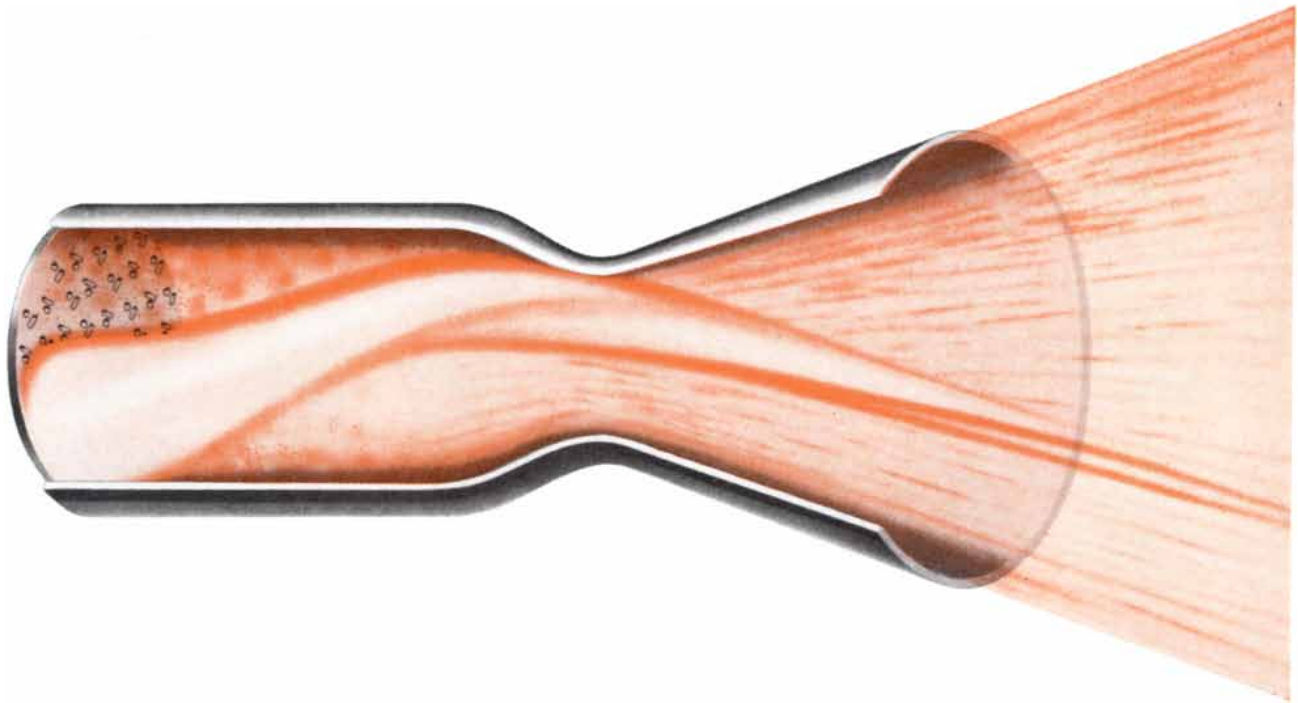
The acoustic wave equation is rather easily solved for vessels of simple geometry, chiefly because it is a linear equation. This important property is achieved at the expense of assuming that the variations in pressure (and the associated variations in gas velocity) are infinitesimal at all times. In classical acoustics such assumptions serve well: ordinary conversation produces pressure excursions of about a millionth of a pound per square inch. In a rocket motor, however, pressure pulses a billion times stronger than such changes have been observed. Thus, as one might expect, there are fundamental differences between the acoustics of a rocket motor and those of a closed resonant chamber. The strong oscillations that can occur in a rocket motor cannot be described by the classical wave equation.

Beyond the high-amplitude effects the acoustics of rocket motors are complicated by the presence of burning solids or liquids; they can add acoustic energy to the system at enormous rates. Another direct source of acoustic energy is the high-speed flow of gases through the combustion chamber. Therefore one must derive more elaborate equations, starting with the laws of conservation of mass, energy and momentum.

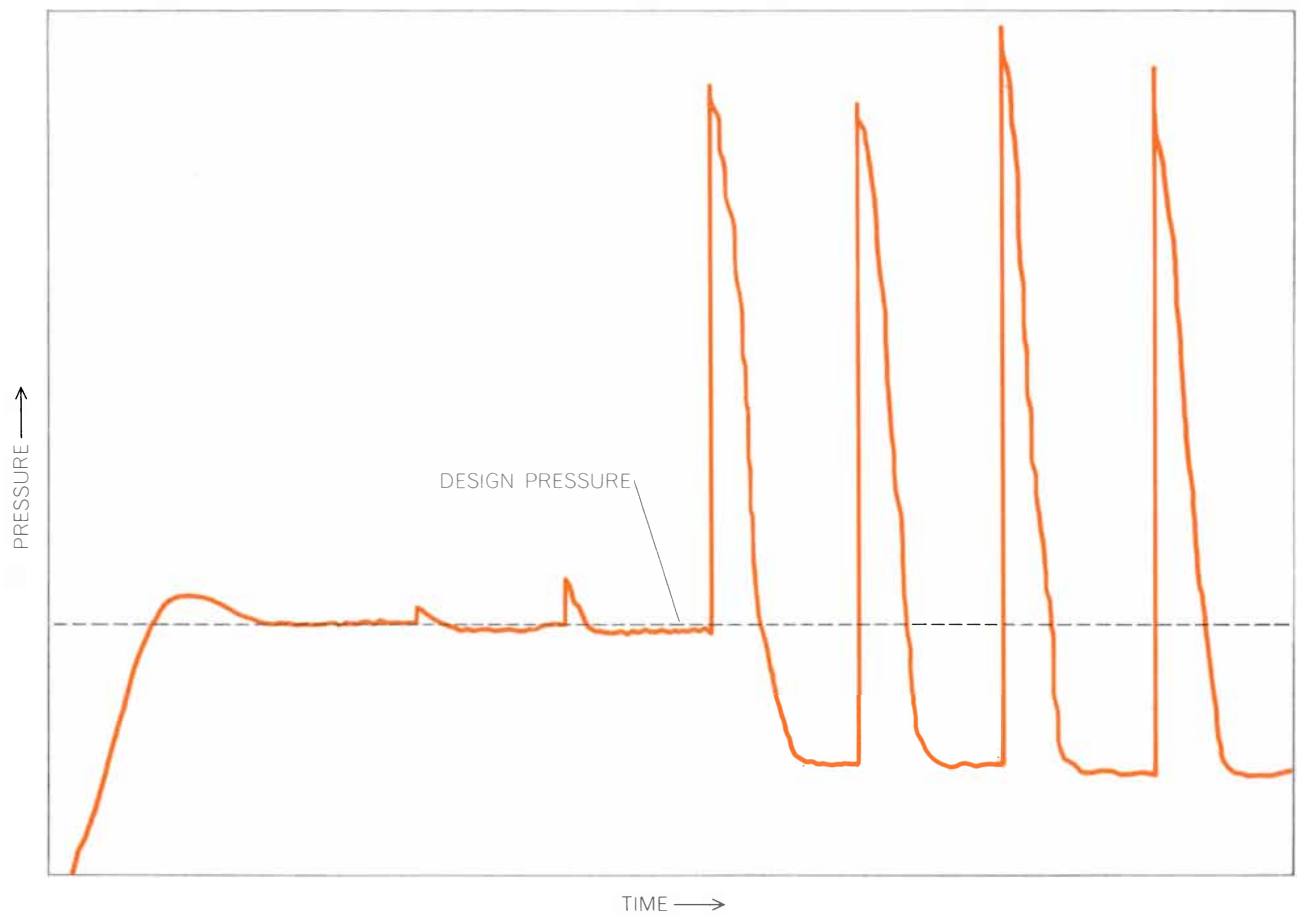
Sound waves in a gas are propagated by molecular collisions, and the speed of sound is of the same order of magnitude as the average molecular speed. In acoustics, however, it is not usually necessary to deal with the statistics of astronomical numbers of molecules. The gas can be thought of as being composed of "particles," or groups of molecules, each of which includes a large number of molecules. Taken together, the particles form a continuum having a definite pressure, density, temperature and velocity at each point. For the gas phase these four variables are related by the laws of mass, energy and momentum conservation together with an equation of state (such as the ideal-gas law). Similar rela-



TANGENTIAL FORM of instability appears in two ways, the standing wave (*left*) and the traveling wave (*right*). In each case the changes of pressure from high (*dark*) to low (*light*) and of velocity (*arrows*) are depicted for a half-cycle. The standing mode is analogous to the sloshing that would be produced if a coffee cup were tilted back and forth; the traveling mode resembles what happens if the cup is moved in a circle.



ROTATING WAVE resembles a detonation. Such a wave is believed to have this appearance as it travels around the combustion chamber of a liquid-propellant rocket. In the bright zone near the face of the injector (*left*) the wave is steep-fronted and extremely strong. Movement is clockwise as viewed from the nozzle end of the rocket. Similar action appears in photographs at bottom of page 94.



RECORD OF PRESSURE produced by a rotating wave such as the one depicted in the top illustration on this page differs markedly from the sinusoidal form produced by an acoustic disturbance. The wave may develop from an acoustic disturbance or it may appear suddenly, as in the condition represented here. Ratios of pressure across such a wave often are more than 20 to one.

tions apply to the solid or liquid propellants.

The two sets of equations are strongly coupled, since the behavior of the gases affects the behavior of the condensed phases and vice versa. Heat from the combustion gases, which are typically at 5,000 degrees Fahrenheit, causes evaporation of the propellants, which apart from a thin heated surface layer may be at or below normal room temperature. Rapidly moving gases increase heat-transfer rates and can erode solids or shatter liquid drops, so that vaporization rates may momentarily be greatly increased. After a short time the additional vapors release their chemical energy through combustion. If only a small percentage of this energy is diverted to drive oscillations, pressure waves of enormous amplitude may be created.

In studying unstable combustion in rockets, one is interested only in the part of the engine upstream of the engine's throat. In the diverging section downstream of the throat the flow is supersonic; any small pressure disturbances (which travel at the speed of sound) will be swept downstream so fast they cannot reach the combustion chamber. For this reason the chamber is considered to be bounded on the downstream end by the gaseous "sonic surface" that exists at the throat.

The tangential modes of oscillation are of special interest because they are apparently the most destructive types of instability. The first tangential mode is best described as a swashing of gases around the combustion chamber; the phenomenon resembles the swashing of a liquid in a cylindrical container. At the chamber walls the velocity nodes, which are the points where the gas velocity is zero, may remain stationary. In this case the motion is termed a standing or sloshing wave. Alternatively, the nodes may move around the walls of the chamber. Here the motion is referred to as the traveling or swashing form of tangential instability.

The traveling form, when it is present at high amplitudes, produces a number of noteworthy effects. One of them is the development of detonation waves, which can be loosely defined as shock waves driven by combustion [*see top illustration on opposite page*]. A shock wave (a familiar form of which is the sonic boom) is an extremely steep-fronted disturbance that sometimes develops from a sinusoidal, or acoustic, type of disturbance. Because gases are heated by compression, the high-pressure part of the

sine wave (where the speed of sound, which is proportional to the square root of the absolute temperature, may be appreciably higher than average) can travel faster than the portions that are at lower pressures. As a result the waves steepen, somewhat in the way that ocean waves steepen into breakers on a beach.

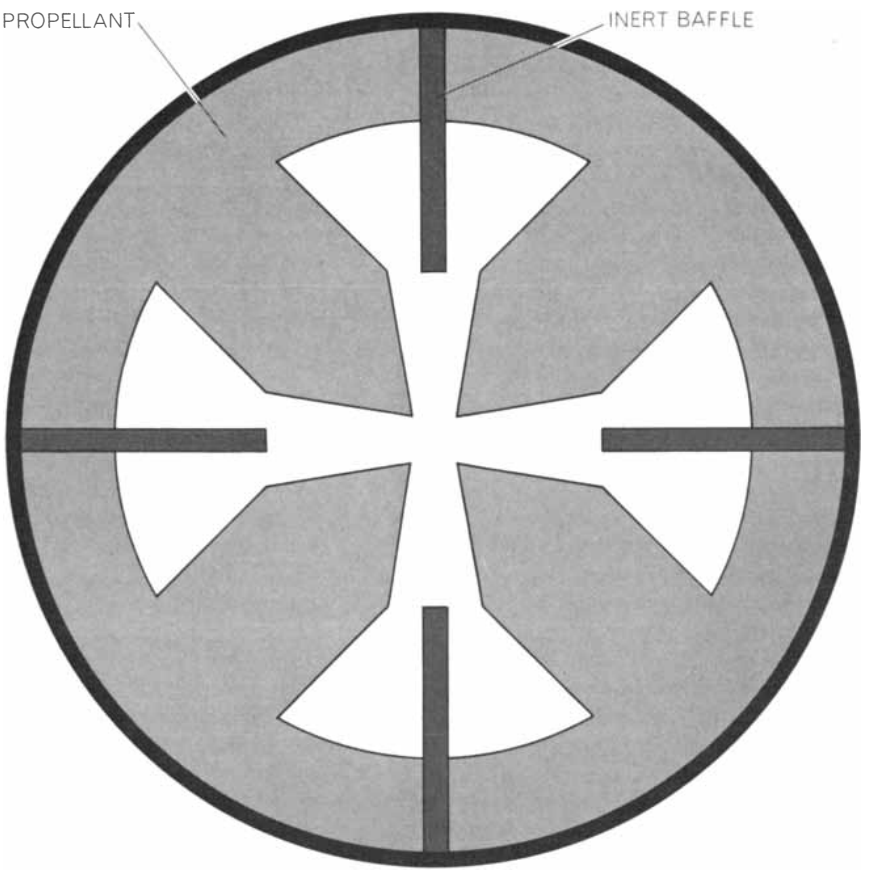
Once a shock wave has formed in a liquid-propellant motor the large gradients of temperature, pressure and velocity can promote drastic changes in rates of combustion. At the walls of the chamber such a wave can increase heat transfer to rates higher than those obtained from an oxyacetylene torch. The chamber can be cut apart in less than a second.

In a solid-propellant motor the wall is protected by the propellant. Here the most striking effect of the traveling tangential wave is the sharp increase it produces in the mean operating pressure of the engine. The effect can lead to the explosion of the rocket engine, and at the very least it impairs performance.

This phenomenon is called irregular combustion. Motion pictures made through the forward end of a solid-propellant engine suggest that the irregularity is the result of the formation of a vortex—a tornado-like motion of the gases [*see top illustration on page 94*]. The vortex is created by the traveling tangential wave. Inside the vortex is a low-pressure core like the eye of a tornado, and the combined effect of the low-pressure core and the swirling can severely hamper the flow of gases through the nozzle. In such a case gases may be generated inside the motor faster than they can escape through the nozzle; the result is a rise of pressure in the motor. With some propellants the rate of burning is increased by the rise of pressure and by the high velocity in the vortex, so that the pressure in the chamber goes up even more. These are the conditions that can cause the motor to explode.

When the vortex is less severe, its most obvious effect may be to generate a torque around the longitudinal axis of the rocket. Torque is difficult to measure in ground tests, and the measurement is seldom attempted. Thus the existence of both the vortex and the torque has sometimes been revealed only when a rocket was tested in flight.

It was the symptoms of vortex formation that the British group discovered at the Woolwich Arsenal in 1940. For reasons that are difficult to explain, the existence of vortexes and the possible side effects seem to have been largely ignored in solid-propellant research since that time. Only in recent years has the significance of the phenomenon been understood.



DAMPING DEVICE in a solid-propellant rocket can be arrangement of baffles between segments of the propellant. A typical geometrical arrangement of propellant is shown in this cross section; the shape provides a large amount of surface for burning. The baffles are designed to break up combustion instabilities before they reach serious proportions.

The rocket designer faced with the problem of suppressing instability in an engine usually attempts to increase the influence of damping effects. A technique sometimes employed with liquid-propellant rockets is to put perforated, sound-absorbing inner walls in the combustion chamber. This solution will not do for solid-propellant motors, in which the propellant lines the walls. It has been found helpful to add metallic particles to a solid propellant. This produces particles of solid or liquid metal oxide in the gases. The oxide particles dissipate acoustic energy. The effect is quite similar to the attenuation of sound in fog, and in many solid-propellant engines it eliminates combustion instability.

Where these various techniques are inadequate or unacceptable there are other alternatives. For solid-propellant rockets it is possible to change the composition or the geometry of the propellant. With liquid-propellant rockets one can change the ratio of fuel to oxidizer or the design of the injector.

These techniques may entail a loss in combustion efficiency. It might seem that, since rocket engines are highly efficient in using the available energy, such a loss would be a small price to pay for stable combustion. With a vehicle the size of the U.S. rocket *Saturn V*, however, a loss of 3 percent in combustion efficiency would require the use of another tank car full of propellants to accomplish the same mission. The result could easily be a drastic reduction in the payload of the vehicle.

A recurring difficulty for designers is that test results in many unstable engines have been difficult to reproduce. With liquid-propellant rockets the trouble lies in the hydraulics of the injection system. A typical injector consists basically of a metal plate that is about 1/4 inch thick and has holes drilled in it to admit propellant to the combustion chamber. Tiny jagged edges on the upstream end of the holes (often in

conjunction with strong cross-velocities in the flow of propellant) make the flow of liquids through the individual holes rather unpredictable. Moreover, slight variations from engine to engine in the machining of injector holes make it difficult to be confident that two otherwise identical engines, from the same assembly line, will have identical stability.

Similar problems are met in solid-propellant motors. Changes in propellant temperature, for instance, can have a drastic effect on stability. Thus a motor that performs perfectly on a cold day may exhibit violent instability on a hot day.

Perhaps the best hope for progress in preventing instability in solid-propellant combustion is a laboratory device called the T burner: a T-shaped solid-propellant motor that is used to measure the amplification tendencies of various propellants. Both theory and experiment have shown that most propellants are capable of amplifying oscillations over a wide range of frequencies. The T burner provides a controlled environment in which the damping mechanisms and the geometry of the combustion chamber are relatively simple. The T burner, with its capability for measuring amplification, adds an important kind of information to the investigator's supply of facts by making it possible for him to characterize the least understood part of the unstable system: the combustion process itself. One can hope that the knowledge of a propellant's amplifying characteristics obtained inexpensively from the T burner will eventually be applied reliably to the prediction of what will happen in a large rocket engine.

Since instability of combustion is sensitive to small changes in engine geometry and operating conditions, a particular engine must be subjected to a large number of firings before its designers can say confidently that it is free from instability. With a large engine such testing can account for a substantial part of development costs. Herein lies the importance of devising reliable theories of instability and inexpensive tests of a propellant's acoustical characteristics. Until instability of combustion is understood well enough so that it can be eliminated while an engine is in the design stage, rockets must continue to be intensively tested for stability—particularly when the lives of astronauts will eventually depend on safe, reliable operation of the engine.

HUMAN STONES

Many pathological minerals can form within the body. The incidence of stones in the kidneys, the urinary bladder and the gall bladder shows remarkable variations with respect to geography and history

by Kathleen Lonsdale

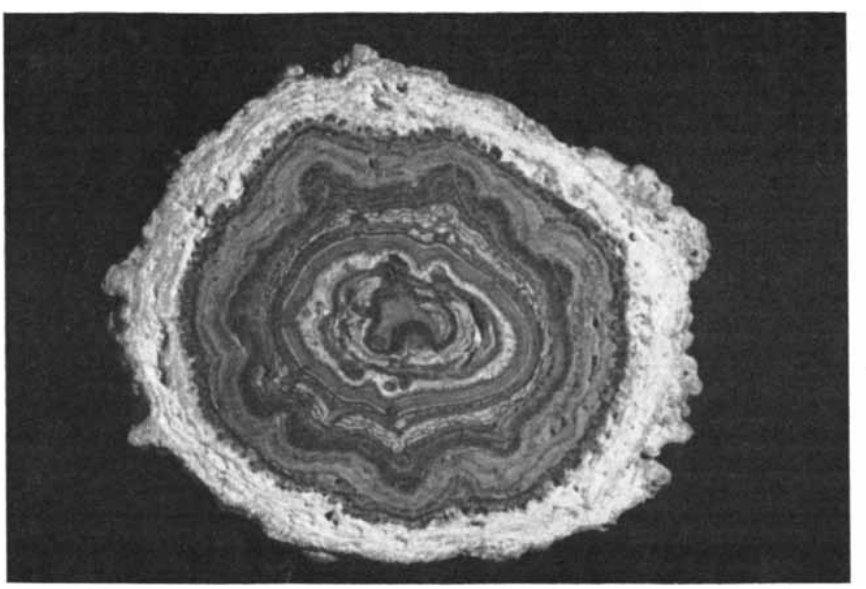
The calculi, or stones, that sometimes form in the fluid within human organs frequently resemble ordinary mineral stones. They form most often in the kidney, the urinary bladder and the gall bladder. They are of various shapes, sizes, textures and colors, and their chemical composition, like the composition of ordinary mineral stones, reveals much about the conditions prevailing when they were growing. Calculi, too, are insoluble, hard and very durable; indeed, many are carefully preserved by those who have suffered from them. Consequently they furnish a record in which one can trace the disorder of "stone" as it has appeared over a considerable period of time. This record shows change both in the incidence of certain human stones and in their composition.

A calculus consists of a seed (or seeds) on which has been deposited substances from the urine (or, in the case of gallstones, from the bile). There may be several layers enclosing a seed, reflecting changes in the composition of the urine or bile over a period of time. Almost all substances that form calculi are crystalline, which is to say that their atoms are arranged in a regular pattern that repeats itself throughout their structure, the pattern varying from substance to substance.

Because calculi are crystalline, they lend themselves to study by means of X-ray diffraction; in this way one can ascertain not only the kinds and relative quantities of the atoms present but also how the atoms forming one layer fit together with the atoms of adjacent layers. These studies show that a major factor in the growth of human stones is the geometric fit between the atomic networks of their layers; a deposit is formed on a seed (or on another deposit) when the fit between the surface atomic networks of the two substances is sufficiently close. It may be possible, then, by modifying the network dimensions of stone-forming substances to prevent the growth of stones beyond the seed stage (when they can still be eliminated from the body naturally).

A number of crystalline substances are normally present in the human body, for example in bones and teeth. As the body grows the mineral content of the bone increases, and with it the fraction of bone that is crystalline. In later life these crystals increase in size; this accounts for the brittleness of bone in old age and may be related to the electrical properties of bone. (An electric current is generated when bone is mechanically deformed.) Some other crystalline substances that form in the body, like those that compose calculi, are not normal but pathological. The dental calculus that forms on the teeth can lead to disease; crystals that are deposited at joints of the skeleton are painful and can cripple and distort the limbs. Human stones may sometimes grow to a large size without giving rise to any symptoms, but they often do cause severe pain. The pain is caused partly by direct mechanical action and partly by inflammation of the surrounding tissue.

The disorder of stone can be traced back 7,000 years, which is the age of a calculus taken from the mummy of an Egyptian pharaoh. The number of bladder and kidney stones that have been found in mummies is small, and they appear not to have been common. Of course, only wealthy Egyptians were embalmed, and since the embalming process involved soaking in an alkaline solu-



HUMAN STONE, seen in cross section, was removed from the urinary tract. It consists of a tiny crystal, or seed, on which substances from the urine have been deposited in layers (*rings*). The stone (more technically termed a urinary calculus) is about one inch across.

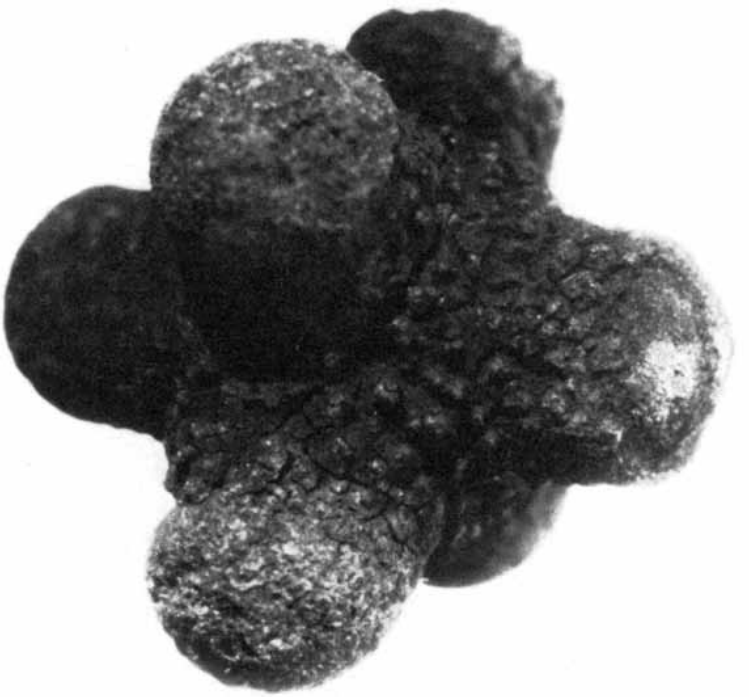
tion, stones formed of acidic substances may have been dissolved.

Lithotomy, or cutting for stone, is mentioned in Sanskrit and Greek documents that go back to about 500 B.C. Hippocrates speculated on the possible causes of stone, particularly in children, and prescribed as a preventive measure a change in liquid diet. Galen, the Greek physician who lived 700 years later, also believed nutrition—together with other factors, among them heredity and climate—was important in the formation of stone. He recognized that immobilized patients were more likely to suffer the disorder, and he linked gout and certain stones of the urinary tract as having a common cause.

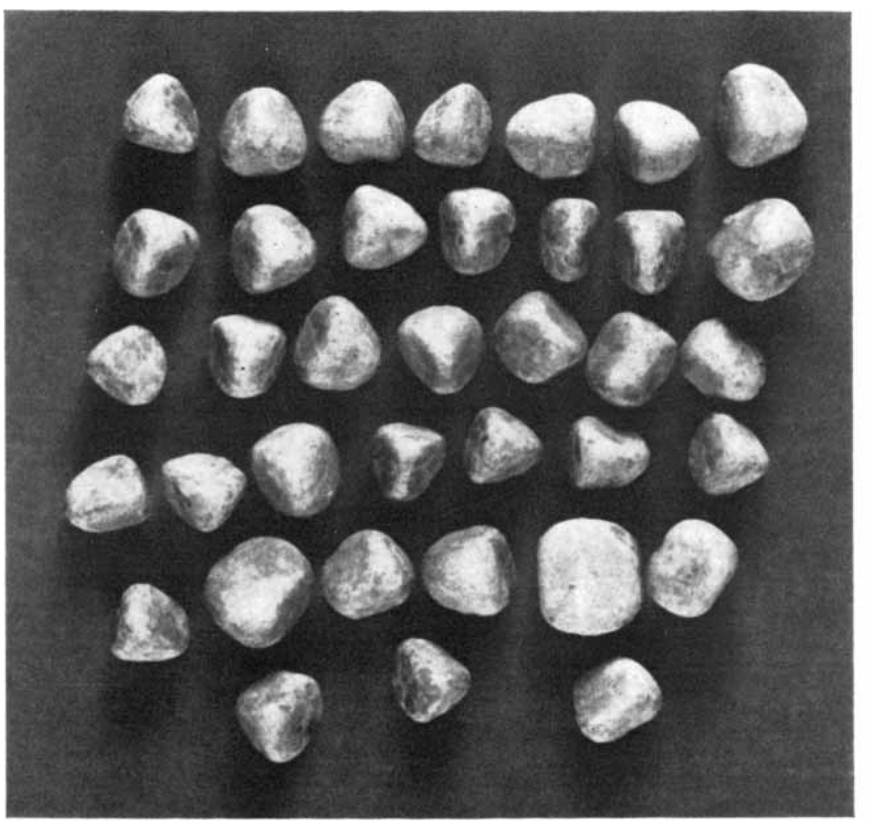
The individuals who are known to have suffered stone in more recent times include Michel de Montaigne, Francis Bacon, Oliver Cromwell, Louis XIV, Isaac Newton, Peter the Great, George IV, Napoleon III and Samuel Pepys. The stone removed from Pepys's urinary bladder was said to be as big as a tennis ball. In his diary Pepys wrote that he had had a box constructed to keep the stone in, a box that cost "a great deale of money, but it is well done and pleases me." Pepys also celebrated the removal of his stone with an annual dinner party.

Pepys's stone was only moderately large compared with a bladder stone reported in a catalogue of medical histories published in 1842 by the Royal College of Surgeons in London. This calculus (the largest then known, according to the catalogue) weighed more than three pounds and measured 16 inches by 14 inches in its major circumferences. Even this pales into insignificance, however, in comparison with a stone removed from the pelvic cavity of an 80-year-old woman in London's Charing Cross Hospital in 1952. It weighed a little under 14 pounds. A stony, hard growth was detected when the patient was operated on at the age of 19, but it was not removed because it was attached to the spine. This indicates that the stone finally removed had been growing for more than 61 years. It is not known what kind of stone it was. The surgeon who removed it suggested that it had originally formed in a diverticulum, or pouch, of the bladder.

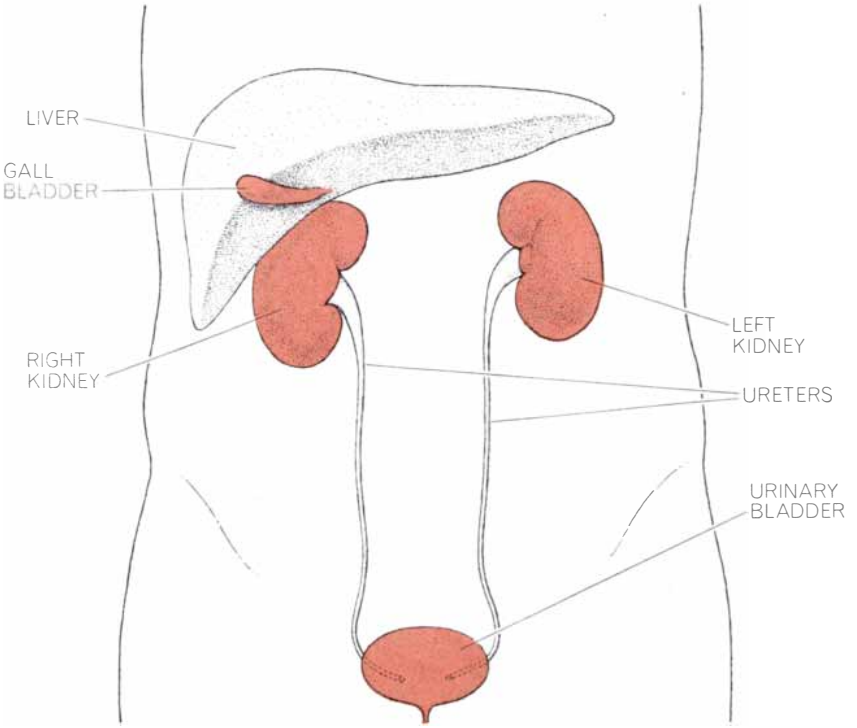
Rather large stones (as well as the small and tiny crystallites respectively known as gravel and sand) are occasionally passed in the urine. The Royal College of Surgeons catalogue reports a stone measuring 2½ by 1½ inches that was passed by a woman without injury. Heroic attempts on the part of stone-suf-



UNUSUAL GALLSTONE is symmetrical. Its composition, also rare, includes three distinct crystalline forms of calcium carbonate, and these do not normally crystallize under the same thermodynamic conditions. The stone is about an inch across. This photograph and the one on opposite page were made in the author's laboratory at University College London.



TYPICAL URINARY STONES were removed from the bladder of one individual. The large square-shaped stone (*lower right*) is approximately half an inch across. This photograph was made by Marvin Ehlin of the Jewish Hospital and Medical Center of Brooklyn.



SITES OF STONES appear in color. Urinary stones are also found in the ureters and the urethra. Lower portion of the liver has been raised to show gall bladder and right kidney.

ferers to treat their condition have also been described. A certain William Hay, after passing red sand without pain, developed a stone that did hurt. He began to doctor himself and continued to do so for 37 years. For the first five years he took three ounces a day of Mrs. Johanna Stephens' stone medicine. (The recipe for these widely used elixirs, which Mrs. Stephens sold for the remarkable sum of £5,000 in 1739, included soap, honey, powdered snails and hips and haws, namely the fruit of the wild rose and hawthorn.) After five years Hay changed his medication to three ounces a day of Castile soap, later reduced to two ounces and finally to one ounce, taken with a pint of milk and limewater. He reported that whenever he suspended this treatment, he again passed red sand.

Hay left instructions that after his death his stone was to be removed from his body and placed in a gold box accompanied by the history of his self-imposed treatment, which was to be written on vellum and framed in gold. In 1775, when he died (of apoplexy), this was done, and the box was given to the Royal College of Surgeons by Sir Joseph Banks (who himself voided a small stone a few days after being overturned in his carriage). Hay's stone weighed only about half a gram, and its surface was easily crumbled; presumably his treatment did restrict its size. (Unfortunately the stone was lost along with other museum specimens during World War II, and its composition cannot be analyzed.)

The self-treatment of another individual whose case is reported was not so effective. This elderly man, having spontaneously passed seven small pure uric acid stones, for several years consumed large quantities of alkali. In principle this was a good idea, but he overdid it. At the age of 77 he was obliged to undergo an operation for stone. In all 307 irregular pieces were removed, weighing about 10 ounces. According to the record, each of the stones consisted of a nucleus of uric acid and ammonium acid urate encrusted with various alkaline substances, almost certainly the result of his treatment. He might have done better to have changed his eating and drinking habits, because uric acid bladder stones of the type once relatively common in wealthy elderly men are now rarely seen in that particular class of patient. They disappeared in England when gargantuan high-protein meals became unpopular.

The proud owners of stones are not always content to have them removed and thrown away or even used for medical research. One of the earliest workers to make a systematic study of urinary calculi by X-ray diffraction techniques, Aksel Tovborg Jensen, reported that he was able to study only the surfaces of the calculi, because he had to promise to give them back to their owners intact.

Urinary calculi, the commonest stones, may be located in the kidneys, ureters, bladder or urethra. A small calculus formed in a kidney may pass down a ureter into the bladder and there grow to a larger size, and calculi also originate in the bladder. Urinary calculi are composed of one or more of the following substances: uric acids (anhydrous or dihydrate), calcium oxalates (known by the names whewellite or weddellite), calcium phosphates, magnesium phosphates (struvite or newberyite), cystine and, very rarely, xanthine. Sometimes urinary calculi also contain organic matter, evidently in noncrystalline form because it gives no diffraction pattern when it is examined by X-ray techniques.

It will be noticed that some of these components carry the names of minerals. Whewellite (calcium oxalate monohydrate) is a constituent of coal beds in Saxony. Weddellite (calcium oxalate dihydrate) was discovered in deposits from the Weddell Sea. Its envelope-shaped crystals are more perfectly formed in the human deposits than in the terrestrial ones. Struvite (magnesium ammonium phosphate hexahydrate), like weddellite a relatively rare mineral, is frequently found in large human stones containing deposits from infected urine. The bright, shining crystals of struvite can be seen in certain rather exotic organic debris: bones of decomposing canned fish or shellfish, beds of bat guano, bird droppings on ancient monuments and the teeth of the extinct mammoth.

There are actually several types of urinary-stone disease. Some are endemic, some are recurrent, some follow urinary infection, others occur in the absence of infection, and at least one type (the cystine one) is hereditary. Until the early part of this century kidney stones were rare, or appear from the records to have been so, and bladder and urethra stones were common only in certain parts of the world known as stone belts.

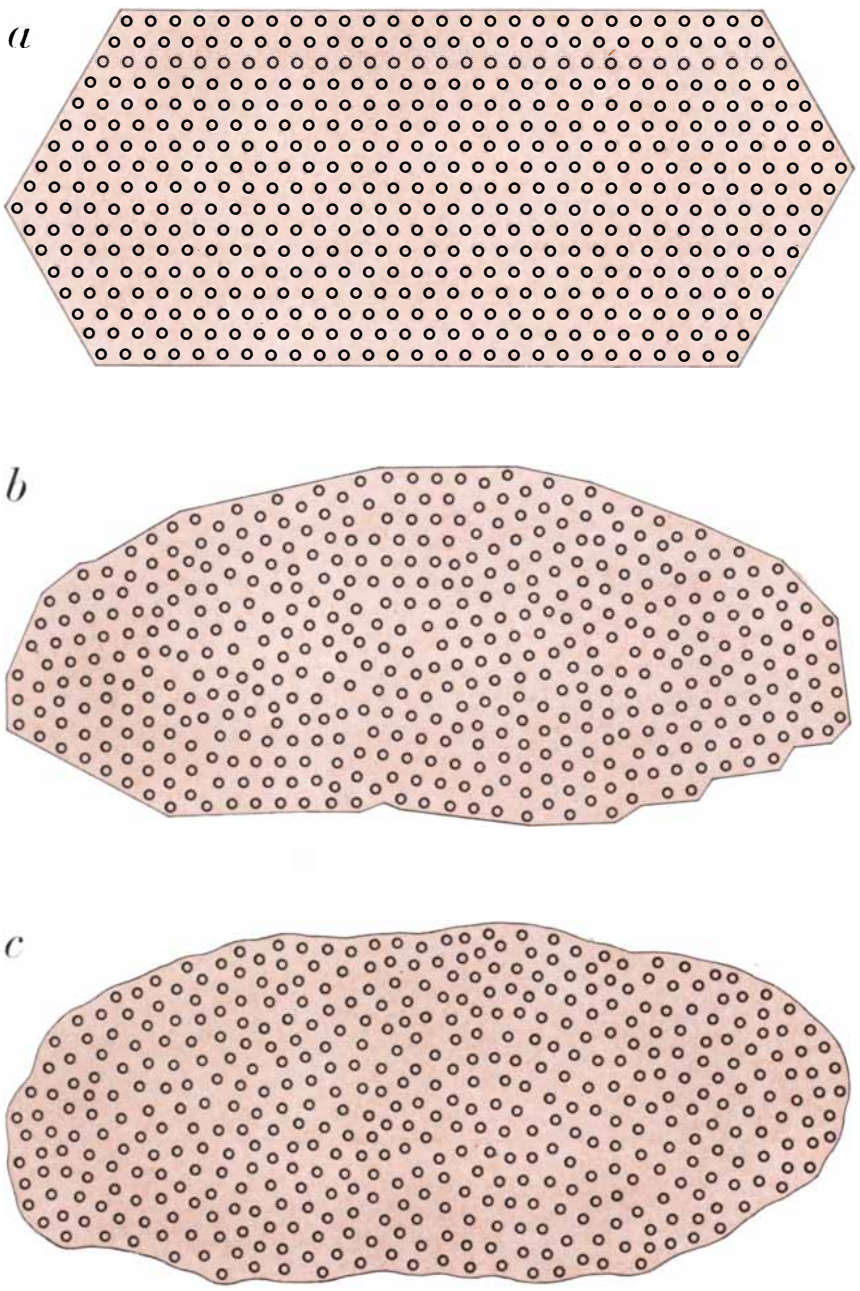
The belts often were very narrow, as narrow perhaps as a region within a town or village. Those afflicted with such endemic stones were chiefly boys. A typical historical example is a group of 3,492 patients (nearly all of them male and about half of them under 20 years old) who were operated on for stone in the Chinese city of Canton between 1861 and 1919. Of these patients 2,962 had bladder stones and 409 urethral stones, whereas only 116 had ureteral stones and five had kidney stones.

Whether kidney stones were rare or only much more difficult to diagnose before the days of radiography is another matter. Bladder stones could be detected by the time-honored method of "taking a sound" (passing an instrument through the urethra into the bladder). There is still in northeastern Thailand a high proportion of bladder-stone cases among boys under five years old (sometimes obliging them to bend over or even stand on their head to urinate), whereas there are relatively few kidney stones in any age group. In other parts of Thailand this disproportion does not exist. In Turkey and in parts of India there is also a comparatively high incidence of both bladder and kidney stones in male children.

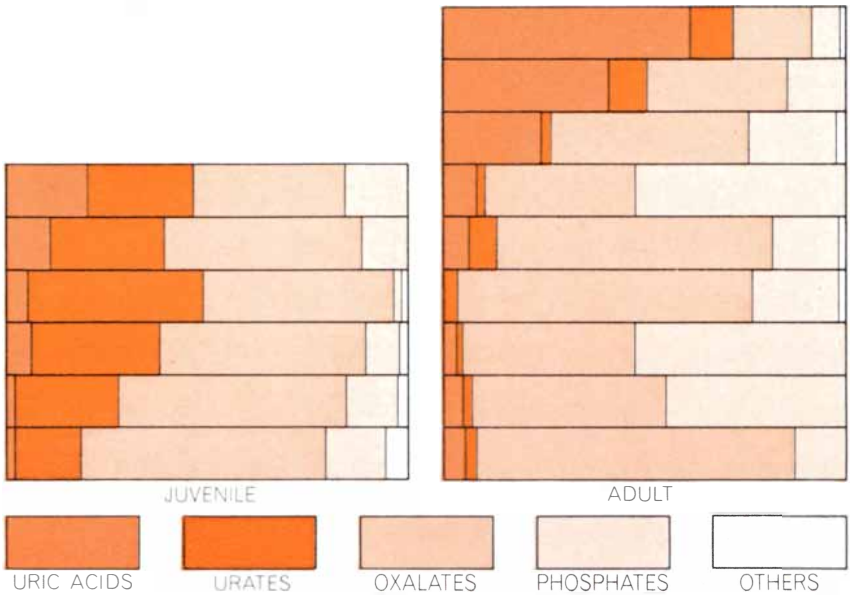
Thailand has been studied more carefully than most other countries; so has Czechoslovakia, because its famous spas attract so many patients afflicted with stone. The absolute incidence of stone is much higher in Czechoslovakia than it is in Thailand, but in both countries the incidence varies with area. About one person in 1,000 of the entire population of Czechoslovakia is likely to enter a hospital for stone each year (some being recurrent cases), as opposed to one person in 3,500 in Thailand. Although more Czechoslovak men than women enter the hospital for stone, a sample of postmortem examinations shows that the incidence in men and women is nearly equal. Fewer than 1 percent of calculi are found in Czechoslovak children. Almost all the cases are kidney or ureteral stones. In the U.S. the pattern is much the same as it is in Czechoslovakia. Among the Bantu in South Africa stone is almost unknown. So it was in Ireland (except for Dublin and Cork) 150 years ago. On the other hand, bladder stones were then as common in England, particularly in Norwich and London, as they now are in northeastern Thailand.

In what ways has the composition of human calculi changed? Many studies have now been made by chemical, optical and X-ray diffraction techniques of the composition of various collections of stones (some from museums, some from hospitals, others from private collections of surgeons) going back to the late 18th century. Chemical analysis, the most common technique, is not really satisfactory in that it does not give the whole story. Early chemical analyses showing calcium carbonate to be a constituent of urinary stones were mistaken; what was actually being detected was carbonate-apatite. Calcium carbonate, the main substance of pearl, coral and seashells, is sometimes found in gallstones, sometimes in stones from animals, but never in a human urinary calculus. X-ray diffraction techniques have the disadvantage that some minor constituents may be missed, and that the method calls for expensive equipment, but they have the great advantage over chemical techniques in that the particular compounds and even polymorphs (different crystalline arrangements of similar atoms) may be accurately identified.

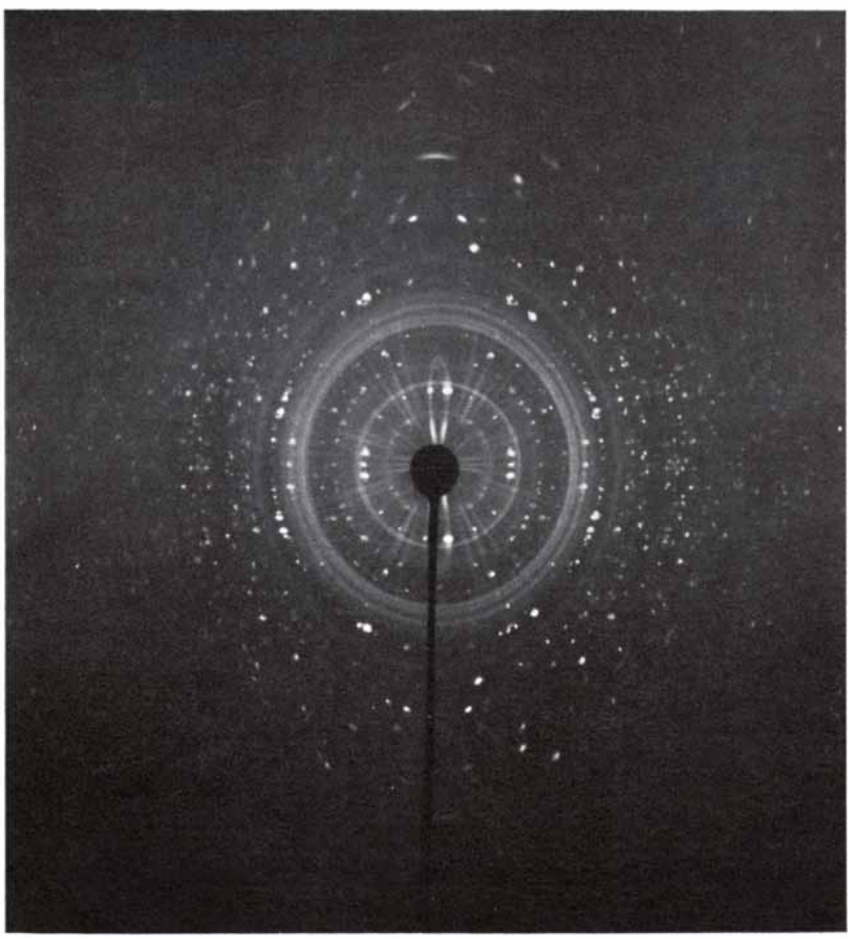
In my laboratory at University College London we have used X-ray diffraction to analyze samples from more than 1,000 stones from a number of countries. The results show that endemic bladder or kidney stones in children (mostly male) contain a high proportion of ammonium acid urate, which is rare in adult stones. This is true both for contemporary stone collections from Thailand, Turkey and India and late-18th- and early-19th-century stones from Britain. Any explanation of this phenom-



ARRANGEMENT OF ATOMS differs in crystalline and amorphous substances, here shown schematically. In a crystal (*a*) the pattern of atoms is repeated without variation. A crystalline conglomerate, such as those that form calculi (*b*), comprises crystals oriented in different ways. An amorphous substance (*c*) displays virtually no regularity of pattern.



COMPOSITION OF URINARY STONES was determined by X-ray diffraction. A higher proportion of urates (in particular ammonium acid urate) was found in stones from children than in stones from adults. The results are based on analysis of about 1,000 stones from Britain and countries in Europe and Asia. The relative proportions of the constituents differed, depending on geographic area, the stone's age and its location in the urinary tract.



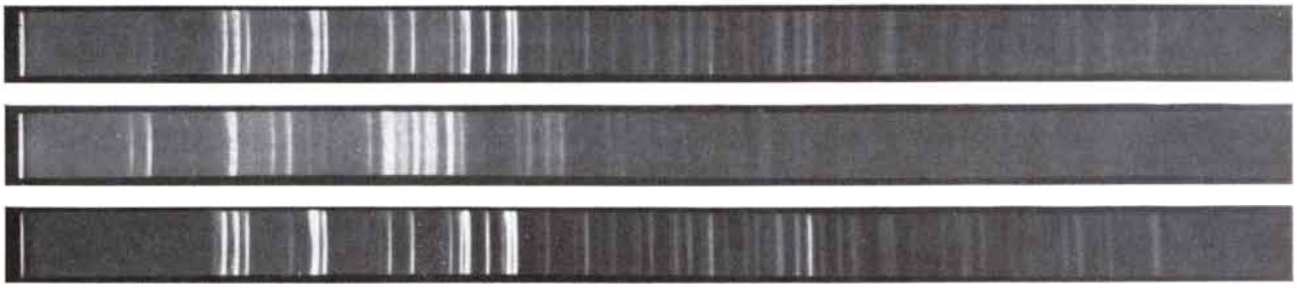
X-RAY DIFFRACTION PATTERN OF STONE FRAGMENT shows the composition to be ammonium acid urate in a finely divided unoriented state (*rings*) and well-oriented crystals of the mineral weddellite (*small dots*). This mineral is also found in geological deposits.

enon is somewhat complicated by the fact that Dalmatian dogs, but seldom other breeds, also have ammonium acid urate stones. It is difficult to see, on the basis of diet, what these groups have in common (although Dalmatian dogs do have certain peculiarities of metabolism). Such stones disappeared in Britain during World War I and are disappearing now in some other parts of the world. This could be due to any of a variety of factors or a combination of them: a more balanced diet, the prohibition (or adoption) of certain food additives, improvement in public health, the elimination of long-lasting fevers, less dependence on certain herbs or the widespread consumption of previously unknown drugs. In short, we do not know what gives rise to these endemic stones or why they disappear. The formation of stones in children is often attended by considerable constitutional disturbance and symptoms of nervous irritation. The stones of children seldom recur.

As I have indicated, the composition of adult stones has changed with time. As late as 1892 Sir Henry Thompson, a fashionable and expensive English surgeon, was still mainly removing uric acid bladder stones from his patients, almost all elderly men. This collection has survived, and we have analyzed samples from it to check on Sir Henry's own chemical analyses.

Like other bladder stones taken from adults in the past, these contained a high proportion of uric acid. There is also a considerable proportion of uric acid in some modern kidney-stone collections (those from Czechoslovakia and Spain, for example, and according to reports, those from Israel and central Europe). There seem to be two possible causes: a consistently high protein (that is, unbalanced) diet combined with little exercise and insufficient intake of water, or substantial protein intake (perhaps on some special occasion) following a period of protein starvation. In either case a change of habits and a balanced diet are necessary to prevent a recurrence of the stones.

Today kidney stones (and some bladder stones) consist mainly of oxalates and phosphates; this is true for both men and women. The nucleus of the stone sometimes contains uric acid, whereas the surface layers are more often struvite. When uric acid kidney stones are found, it is apt to be in men rather than women. Large stones are frequently phosphate stones that have grown fairly rapidly following infection of the urine. It is possible to "tag" phosphate stones with col-



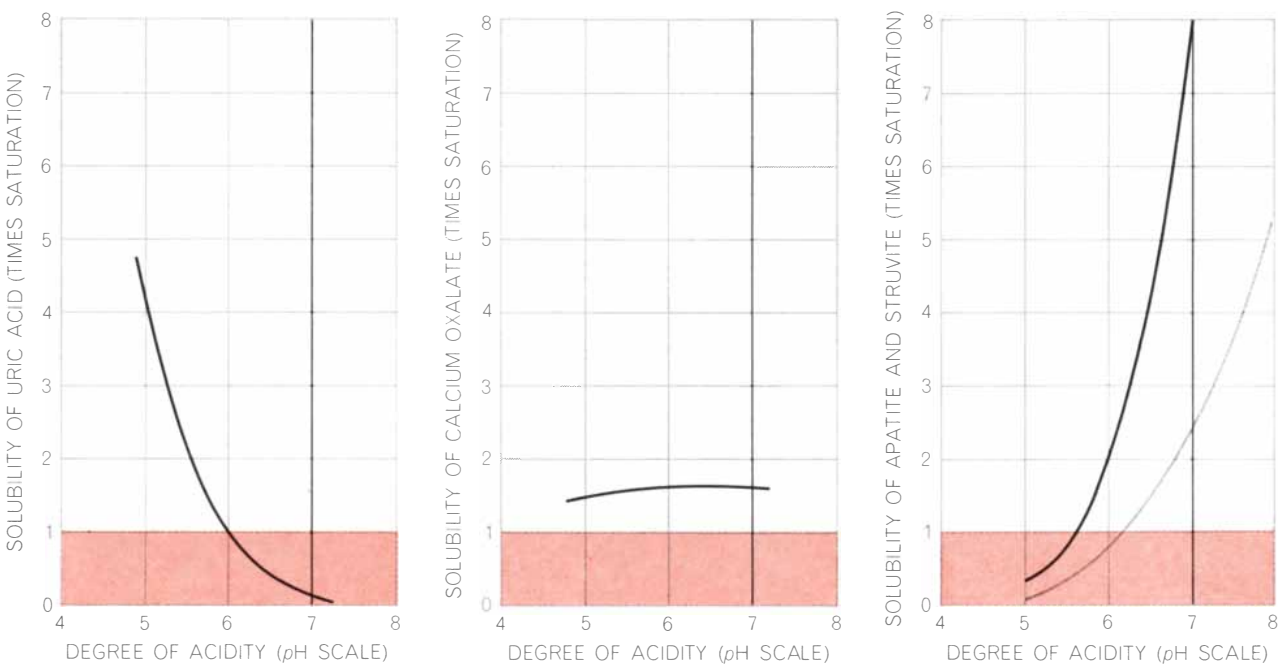
X-RAY PATTERN OF STONE from Napoleon III, removed from his urinary tract in 1873, appears at top. Below it is the X-ray pattern of ammonium acid urate, and at bottom is the pattern of magnesium ammonium phosphate hexahydrate (struvite). The emperor's stone contained both these substances. Struvite is a relatively rare mineral but is frequently found in large human stones containing deposits from infected urine. The X-ray photographs of a crushed fragment of the stone were made in the author's laboratory.

ored drugs and so to measure their rate of growth. In one case, at least, it has been shown that a distinct layer can be added during a 24-hour period. On the other hand, the fact that symptoms of stone can be apparent for 30 years or more before an operation becomes urgent must mean that growth can cease for a time.

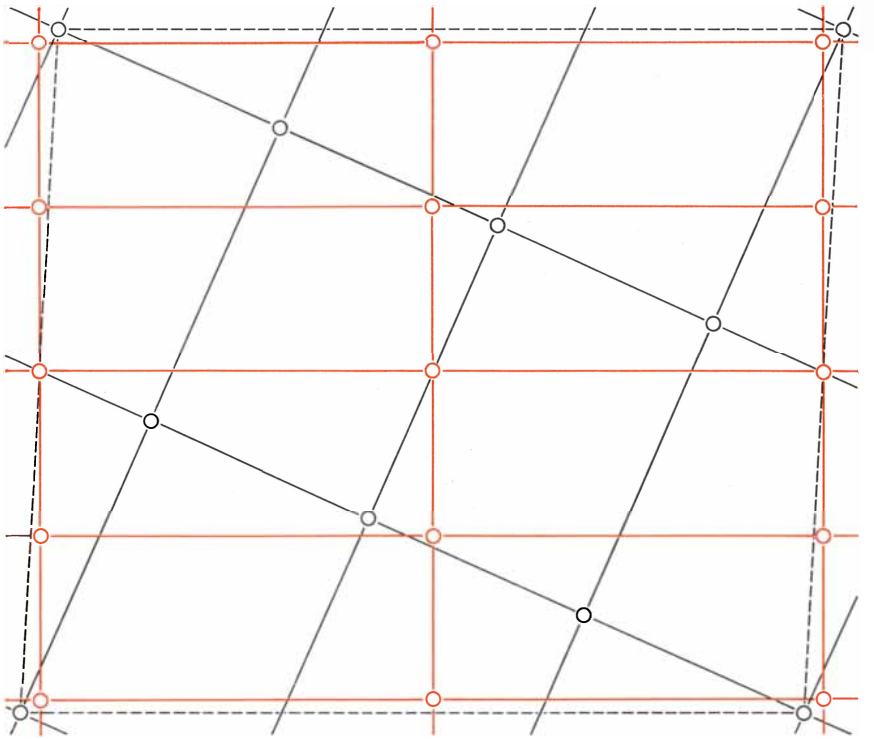
All the studies made of kidney stones in adults suggest that the main factors in their formation are lack of exercise and a warm climate. In Czechoslovakia sedentary workers were found to be 20 times more likely to develop a kidney stone than agricultural workers were. In a 10-year study in the British navy a tropical climate was found to predispose to stone formation, which was less likely the more active the job. Airline pilots and truck drivers are said to have a relatively high incidence, and this is particularly true where journeys involve tropical stations and where liquid intake is insufficient or inappropriate. (Mineral waters are recommended to replace or at least to supplement alcohol or coffee.) Where stone is known to exist, mechanotherapy, the application of controlled vibration, is suggested to eliminate or to fragment stones.

If we knew just how stones grow, it might also be possible to suggest preventive treatment. The first step of course is to know what is there, but the second is to know how it comes to be there. From a crystallographic point of view the problem of urinary calculi, whether they are sand, gravel or stones formed in the urine, is simply one of crystal growth and texture. Although it is possible for crystals to precipitate out of a solution as soon as the solution is saturated, a solution can quite often be supersaturated without any crystals forming. Tests of the urine of healthy young men who are not stone-formers show that only about a third have urine that is undersaturated with respect to uric acid; the urine of the rest is saturated or supersaturated, yet no deposit forms. There is, however, a point at which no further supersaturation is possible and deposition does take place. Then sand or gravel is passed, or a stone begins to form.

There are certain circumstances that prevent or hinder supersaturation and therefore serve to promote crystal



LIABILITY TO STONE FORMATION of substances in the urine depends on their solubility. Calcium oxalate (*center*) is insoluble throughout the *p*H range (a highly acid solution has a low *p*H, a basic solution has a *p*H greater than 7); thus it is dangerous if present in more than a rather small amount. Uric acid (*left*) is dangerous only in an acid urine. Plotted at right are apatite (calcium phosphate) and struvite (*gray*), which present a hazard in alkaline urine. Below saturation point (*color*) stones cannot form.



CLOSE-FITTING CRYSTALS form a human calculus. In this schematic representation the atomic network of vaterite (*color*), a form of calcium carbonate, is superposed on that of cholesterol (*black*) in a possible relative orientation. The lines are drawn to indicate the atomic pattern of the substances. The parallelogram (*broken line*) points out four atoms of cholesterol that are conjoined with four atoms of vaterite, indicating that the substances would closely adhere. Cholesterol is sometimes accompanied by vaterite in gallstones.

growth. One of these is the presence of seeds, either of the solute itself or of some other substance on which deposits of the solute can grow. Another is violent agitation of the solution, and a third is an abrupt change of its composition, which affects the solubility of stone-forming substances. Finally, the presence of a trace impurity may provide dislocations, or growth centers, in incipient crystals and thus prevent the dispersion of what would otherwise be temporary clusters of atoms or molecules.

All the compounds that form urinary calculi are highly insoluble in water. They are not quite so insoluble in urine, which contains, or can contain, ions of sodium, potassium, calcium, magnesium and chlorine, together with urea, ammonia, sulfuric acid, phosphoric acid, uric acid, hippuric acid and creatinine, not to mention traces of other elements and more complex organic material (some giving the urine its color), enzymes and bacteria. The composition varies during the 24-hour cycle and also with circumstances such as weather, physical activity, diet and body metabolism. The acidity of the urine strongly affects its capacity for dissolving stone-forming compounds; to a much smaller degree, so does the urine's temperature. Very soluble salts can obviously never form stones, because the urine never becomes saturated with them, but uric acid is very insoluble in an acid urine. Acid urine easily becomes supersaturated with respect to uric acid (and the urates).

If a person tends to form uric acid stones, it is a sign that his urine is too acid, at least during part of the 24-hour day. Dilution, and also perhaps deliberate alkalization of the diet, is indicated in order that the uric acid may be kept in solution and not deposited. This must not be overdone (as in the self-treatment mentioned earlier) because the phosphates, especially apatite, are very insoluble in an alkaline urine, and it is easy for such a urine to become so supersaturated with them that a phosphate stone begins to grow. This is particularly likely if the urine is also infected, or if there is some foreign body present (a bit of wire or glass, a swab or a piece of string) on which a deposit can form.

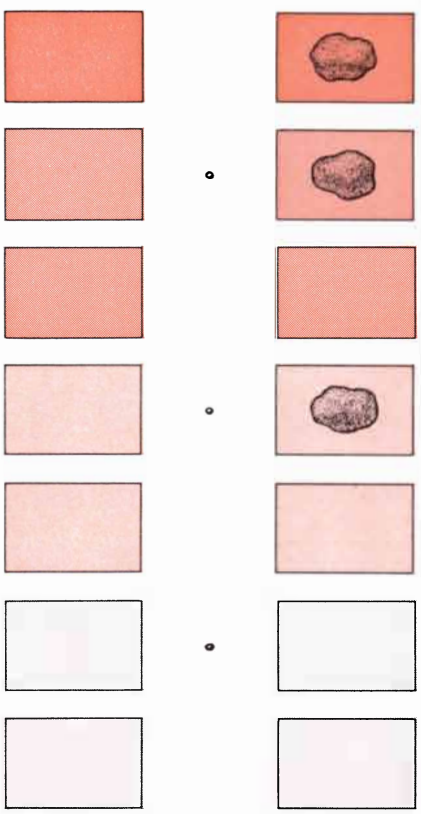
Unfortunately oxalates are insoluble throughout the entire acid-base range of urine. Therefore if oxalates are present in the urinary tract beyond a rather low amount, they will be deposited. People have different tolerances for foods containing oxalic acid (for example rhubarb, spinach and strawberries). A medical man, then in his nineties, once told me that when he was an undergraduate, he passed three small oxalate stones in fairly quick succession after having eaten a good quantity of stewed rhubarb. He gave this food up entirely and never had another stone. Some students of calculi do not agree, however, that they are ever caused by an excess of a food, and regard the presence or absence of one of the vitamins as being of primary importance, or stress the possible function of an element or compound that acts as a growth catalyst. The few percent of organic material in stones is sometimes believed to act as a matrix, furnishing a skeleton on which substances can grow or a cement to hold them together.

Nonetheless, it is possible to grow stones in the laboratory either from urine that is deliberately supersaturated with stone-forming materials or from saturated or supersaturated aqueous solutions that contain no organic material at all. Experiments now in progress are aimed at finding an inhibitor substance that will combine with the stone-forming material to prevent its deposition. This would be quite in accordance with crystallographic practice, since it is well known that certain molecules (by combining with the surface layers of a crystal and perhaps also with the solvent in the neighborhood of the surface) can "poison" it, so that no further deposition is possible. Alternatively, the inhibitor, by changing the composition of the solvent, may change the solubility. Lastly, some atoms might, by entering the crystalline structure itself, change the dimensions of the crystallographic pattern.

It happens, for instance, that the dimensions of the network of atoms in the most common face of uric acid crystals are closely similar to those of certain common faces of the calcium oxalates, although the structures are very different in atomic composition. The misfits in the structure of substances amount to only 1 or 2 percent. By spoiling this structural correspondence one hopes that the really dangerous situation, which is the presence of appropriate seeds in a saturated solution of a substance that tends to grow on those seeds, may be avoided.

Finally, a word about gallstones. These are formed in the bile of the gall bladder when it contains an excess of cholesterol or of calcium or both. Their composition is entirely different from the composition of urinary calculi and yet there are crystallographic similarities. Gallstones may be present in quantity and faceted by crowding, or they

may be single and large. Sometimes they are built up by repeated deposition and display characteristic rings, as in the cross section of a tree trunk. Sometimes they are a simple conglomerate of tiny crystallites; sometimes they contain really large cholesterol crystals. In addition to cholesterol they contain a red pigment called bilirubin that can give the stone a brown color. There is sometimes present another component whose X-ray diffraction pattern shows it to be cholesterol monohydrate, and also noncrystalline material. Often the cholesterol is accompanied by one or more of the three polymorphic forms of calcium carbonate (calcite, aragonite and vaterite) or by a component of urinary calculi: apatite. Studies of the dimensions of the atomic networks in the more common faces of these crystals show that they fit on one another to within a few percent and that therefore it is not difficult for one to grow on the seed of another. As with urinary stones, then, it may be possible to hinder their growth by modifying the dimensions of the crystal structure.



GROWTH OF STONE becomes more likely as the urine becomes more saturated with a stone-forming substance (*bottom to top*). Below the saturation point no deposition of crystals is possible, even on a seed; it becomes possible at saturation point, but only on a seed. Even in a supersaturated urine deposition is unlikely without a seed, but ultimately takes place if saturation continues.

MATHEMATICAL GAMES

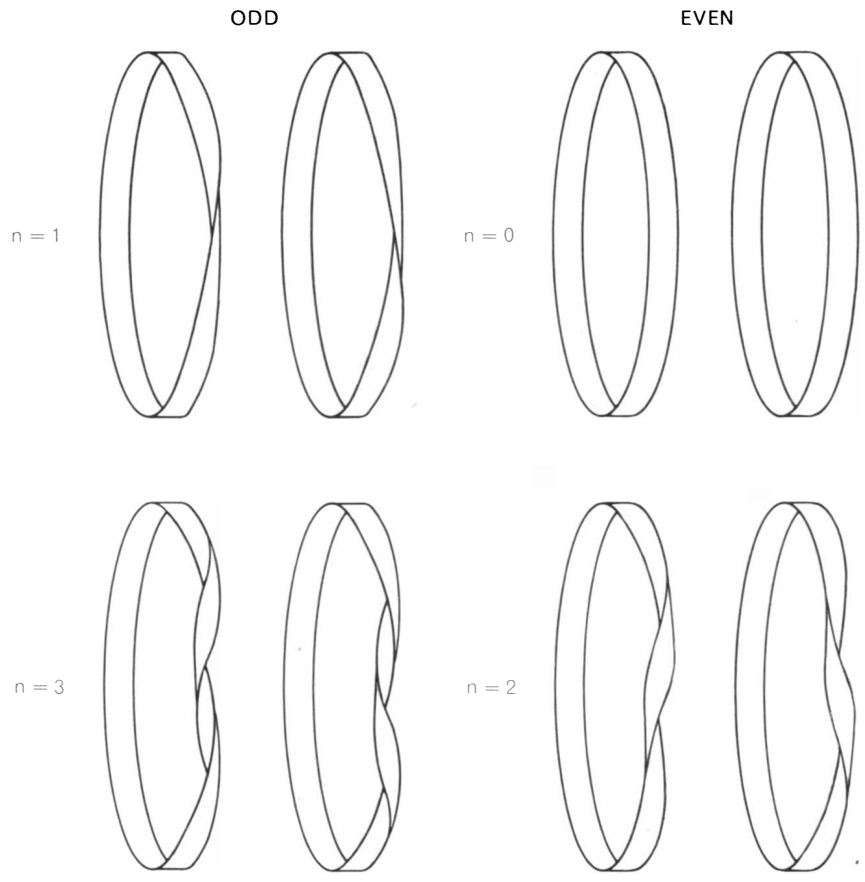
The world of the Möbius strip: endless, edgeless and one-sided

by Martin Gardner

A burleycue dancer, a pip
Named Virginia, could peel in a zip;
But she read science fiction
and died of constriction
Attempting a Möbius strip.
—Cyril Kornbluth

A sheet of paper has two sides and a single edge that runs all the way around it in the form of a closed curve. Can a sheet of paper have a single edge and only *one* side, so that an ant can crawl from any spot on the paper to any other spot without ever crossing an edge? It is hard to believe, but apparently no one noticed the existence of such one-sided surfaces until a band with a half-twist was described by August Ferdinand Möbius, a German mathematician and astronomer who died in 1868 (in his *Werke,* Volume II, 1858). Since then the Möbius strip, as this surface came to be called, has become the best-known of the many toys of topology, that flourishing branch of modern mathematics concerned with properties that remain invariant when a structure is given "continuous deformation."

The deformation that preserves topological properties, such as the one-sidedness of Möbius strips, is often explained by asking the reader to imagine that a structure is made of soft rubber that can be molded into any desired shape provided that it is not punctured or a part of it removed and stuck back at some other spot. This is a common misconception. The kind of deformation that preserves topological properties must be defined in a much more technical way, involving continuous mapping from point to point. It is quite possible for two structures to be topologically equivalent ("homeomorphic," as topologists like to say) even though one cannot in our three-dimensional space transform one to the other by deforming it like a rubber sheet. A simple example is provided by two rubber Möbius strips that are mirror images of each other because they are twisted in opposite directions. It is impossible to deform one to the other by stretching and twisting, and yet they are topologically identical. The same is true of a Möbius strip and a strip with three or any other odd number of half-twists. All strips with odd half-twists, and their mirror images, are homeomorphic even though none can be changed to another by rubber-sheet deformation. The same is true of all strips (and their mirror images) with *even* half-twists. Such strips are topologically distinct from those with odd half-twists but all of them are homeomorphic with one another [*see illustration at left*].



Strips with odd **(left)** ***and even*** **(right)** ***numbers of half-twists***

More strictly, they are homeomorphic in what topologists call an *intrinsic* sense, that is, a sense that considers only the surface itself and not the space in which it may be embedded. It is because our model of a Möbius strip is embedded in 3-space that it cannot be deformed to its mirror image or to a strip with three half-twists. If we could put a paper Möbius band into 4-space, it would be possible to deform it and drop it back into 3-space as a band with any odd number of half-twists of either handedness. Similarly, a band with no twists (topologically equivalent to a cylinder or to a sheet of paper with a hole in it) could be taken into 4-space, twisted and dropped back into our space with any even number of half-twists of either handedness.

When a twisted strip is embedded in 3-space, the strip acquires *extrinsic* topological properties it does not have when it is considered apart from its embedding space. Only in this extrinsic sense can one say a Möbius band is topologically distinct from, say, a strip with three half-twists.

The most whimsical intrinsic topological property of the Möbius strip (or any of its intrinsically identical forms) is

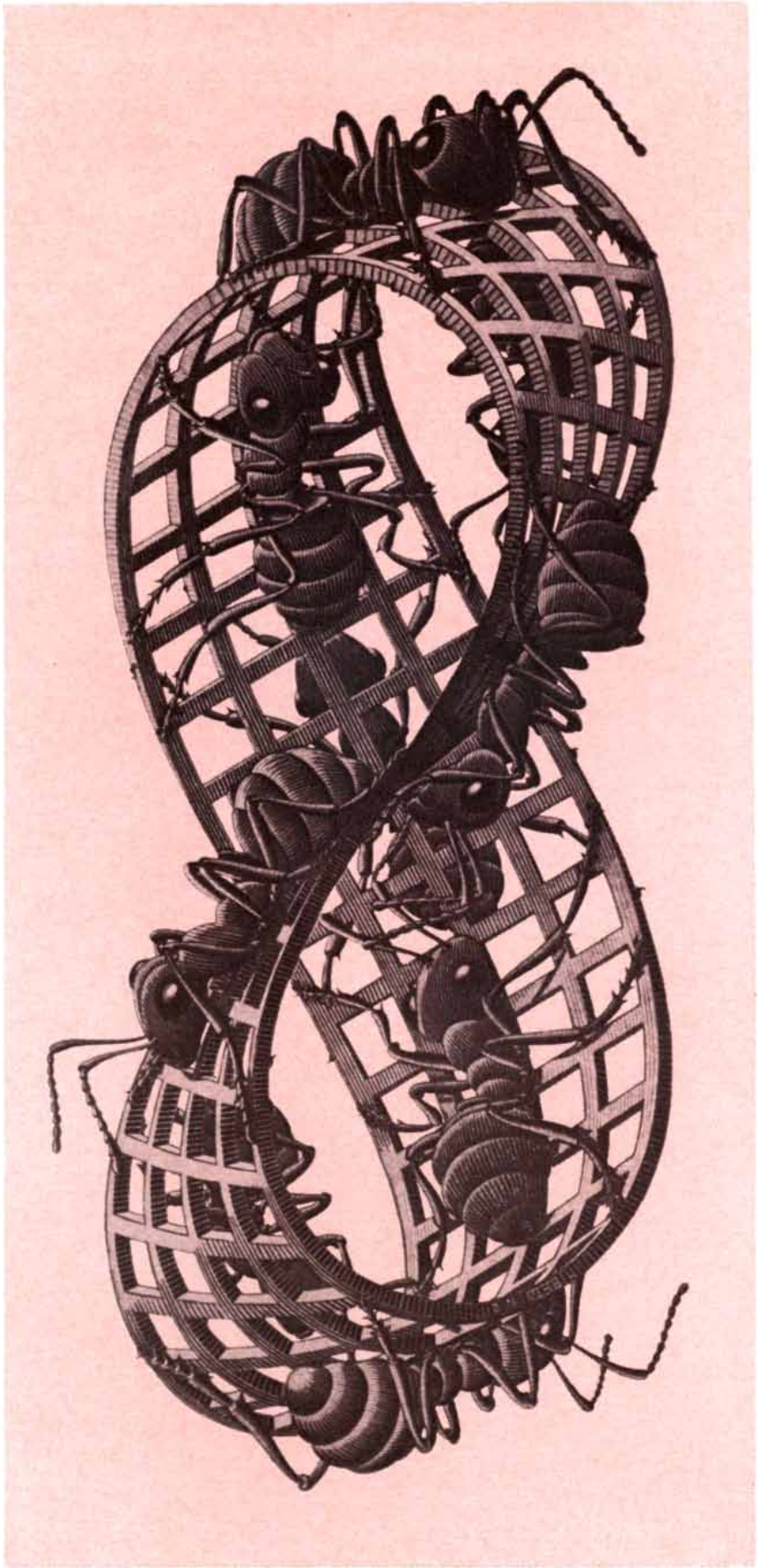
that when it is cut in half along a line down its middle, the result is not two bands, as one might expect, but a single larger band. As an anonymous limerick has it:

A mathematician confided
That a Möbius strip is one-sided.
You'll get quite a laugh
If you cut it in half,
For it stays in one piece when divided.

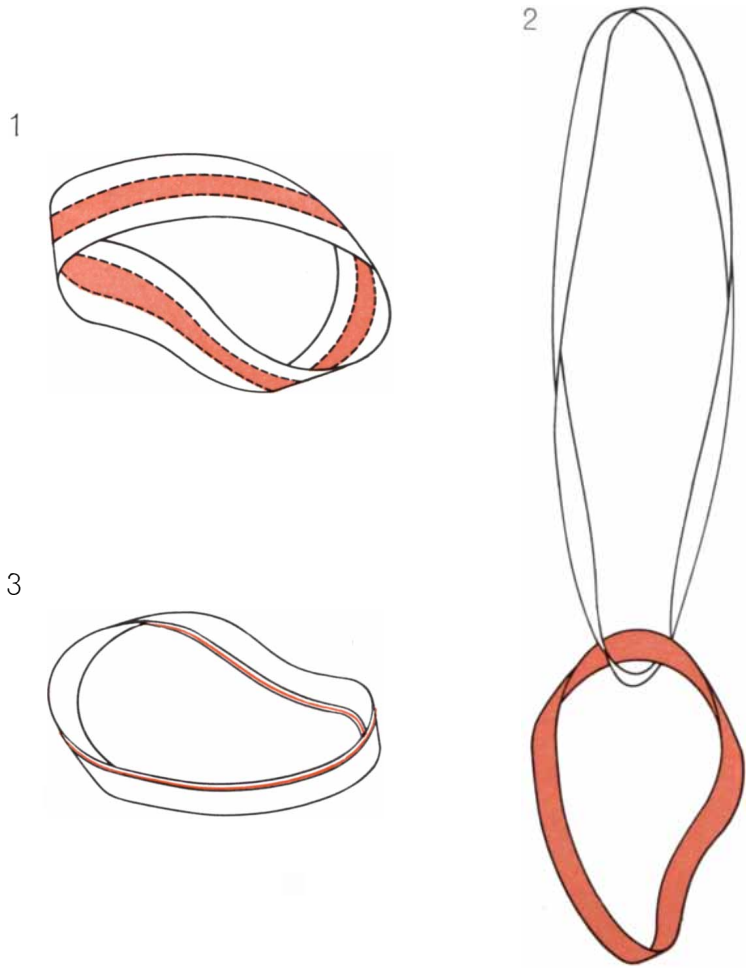
Surprisingly, the new band produced by this "bisection" is two-sided and two-edged. Because the model is embedded in 3-space it will have $2n + 2$ half-twists, where n is the number of odd half-twists in the original band. If n is 1, the new strip has four half-twists, an even number, so that it is intrinsically homeomorphic with a cylinder. If n is 3, the final strip has eight half-twists and is tied in a simple overhand knot.

A band with an even number of half-twists (0, 2, 4, ...) always produces two separate bands when it is cut down the middle, each identical with the original except for being narrower. In 3-space each has n half-twists and the two bands are linked $n/2$ times. Thus when n is 2, bisection produces two bands, each with two half-twists, and they are linked together like two links of a chain. If n is 4, one band is looped twice around the other. In my Dover paperback *Mathematics, Magic and Mystery* I explain how magicians have exploited these properties in an old cloth-tearing trick called "the Afghan bands." Stephen Barr suggests another novel way of demonstrating the same properties. He paints a center line around a large, heavy paper strip with a strong water solution of potassium nitrate, then hangs the band on a nail so that only half of the band's width is supported by the nail. When the painted line is touched at the bottom with the burning end of a cigarette, the line burns quickly upward on both sides until the flames meet at the top, then half of the strip drops to produce either one large strip, two linked strips or a knotted strip depending on whether the original was given one, two or three half-twists.

Another unexpected result occurs when a strip with odd half-twists is "trisected," that is, if the cut is begun a third of the way from one edge. The cutting takes you twice around the band before you return to the starting point. The result is a band identical with the original except for being narrower (it is the central third of the original), linked with a second band, twice as long, that is identical with (but narrower than) the



"Möbius Strip II," a woodcut by Maurits C. Escher



Trisected strip (1) *makes two linked strips* (2) *that can form a triple-thick band* (3)

band that would have been produced by cutting the original in half. When n is 1 (the Möbius strip), trisection produces a small Möbius band linked to a longer two-sided band with four half-twists [*see illustration above*].

A fascinating puzzle (proposed independently by readers Elmer L. Munger and Steven R. Woodbury) now presents itself. After producing the two interlocked strips by trisecting a Möbius band, see if you can manipulate them until they nest together to form the triple-thick Möbius band shown in the illustration above. If you succeed, you will find a curious structure in which two outer "strips" are separated all the way around by a Möbius strip "between" them. One would suppose, therefore, that the Möbius strip is surrounded by two separate bands, but of course you know this is not the case. The same structure can be made by putting three identical strips together, holding them as one, giving them a half-twist and then joining the three pairs of corresponding edges. If this triple-thick band is painted red on its "outside," you will find it possible to interchange the outside parts so that the red-painted side of the larger band goes into the interior and the triple-thick band is colorless on its "outside." It is amusing to form such bands, of m thicknesses and n half-twists, and then to work out formulas for what results when such bands are bisected and trisected.

The Möbius strip has many strange intrinsic properties. It is what topologists call "nonorientable." Imagine the strip to be a true surface of zero thickness. Embedded in this 2-space are flat creatures that are mirror asymmetric (not identical with their mirror images). If such a creature moves once around the band to rejoin his fellows, he will have changed his parity and will have become a mirror reflection of his former self. (Cosmologists have devised analogous models of twisted 3-space in which it would be possible for an astronaut to make a circuit around the cosmos and return with his heart on the other side.) Remember, you must assume that the flat creatures are "in" the zero-thick surface, not "on" it.

All nonorientable surfaces must contain at least one Möbius surface. Stated differently, from any nonorientable surface one can always cut a Möbius surface. Topologists have found many strange kinds of nonorientable surfaces, such as the Klein bottle, the projective plane and Boy's surface (discovered by the German mathematician Werner Boy), all of them closed and edgeless like the surface of a sphere. The Klein bottle can be cut in half to produce two Möbius strips, as explained here in July, 1963. The projective plane becomes a Möbius surface if a hole is made in it.

All nonorientable surfaces are one-sided in 3-space and all orientable surfaces (in which flat asymmetric creatures are unable to reverse their handedness) are two-sided in 3-space. Sidedness is not an intrinsic topological property like orientability. It is only in our space that we can speak of a two-dimensional surface as having one or two sides, just as we can only speak of a closed one-dimensional line as having an outside and inside when it is embedded in a plane.

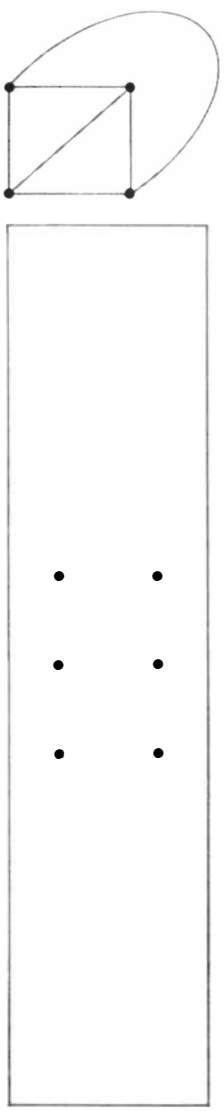
Another intrinsic property of the Möbius strip has to do with graph theory. On the plane, or on any band with even half-twists, four is the largest number of points that can be joined by nonintersecting lines that connect every pair of points [*see top of bottom illustration on opposite page*]. It is not hard to prove that this cannot be done with five points. On a Möbius surface, however, a maximum of six points can be mutually joined by nonintersecting lines. Consider six spots on an opened-out strip [*see bottom of bottom illustration on opposite page*]. Assume that the top and bottom ends of this strip are joined after the strip is given one half-twist or any odd number of half-twists. Can you connect every pair of points with a line without having two lines intersect or without cheating by passing a line through a spot? Here again, assume that the strip has no thickness. Each line must be thought of as "in" the paper like an ink line that has soaked through to the other side. A way of doing it will be shown next month.

The Möbius strip has practical uses. In 1923 Lee De Forest obtained patent No. 1,442,632 for a Möbius filmstrip that records sound on both "sides." More recently the same idea has been applied to tape recorders so that the twisted tape runs twice as long as it would otherwise. Several patents have been granted for Möbius strip conveyor belts designed to wear equally on both sides. In 1963

J. W. Jacobs obtained patent No. 3,302,795 on a self-cleaning filter belt for dry-cleaning machines. It makes possible easy washing of dirt from both "sides" as the twisted belt goes around.

In 1963 Richard L. Davis, a Sandia Corporation physicist in Albuquerque, invented a Möbius strip nonreactive resistor. Bonding metal foil to both sides of a nonconductive ribbon and then forming a triple-thick Möbius band, Davis found that when electric pulses flowed in both directions around the foil (passing through themselves), the strip acquired all kinds of desirable electronic properties. (See Sandia's advertisement in SCIENTIFIC AMERICAN, January, 1965, page 79.)

Modern sculptors have based numerous abstract works on the Möbius surface. The Smithsonian Institution's new Museum of History and Technology in Washington has an eight-foot-high steel Möbius strip that rotates slowly on a pedestal in front of the entrance. Graphic artists have used the strip in advertising and works of art, as in the woodcut by the Dutch artist Maurits C. Escher reproduced on page 113. In 1967 Brazil honored a mathematical congress by issuing a commemorative five-centavo stamp bearing a picture of a Möbius strip.



Points on plane (top) *or strip* (bottom)

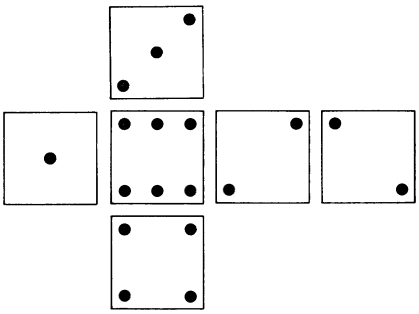
The Möbius surface has played a role in science fiction stories such as Arthur C. Clarke's "The Wall of Darkness," which appeared in *Super Science Stories* in July, 1949. The strip itself has been used for bearing printed messages. The first Möbius strip Christmas card I received was in 1954 from Cody Pfanstiehl of Washington, D.C. The strip, flattened to a triangle for mailing, bore a greeting that circled around it forever. (It is curious that if you keep pulling such a printed strip through your fingers, the endless message is always right side up although at any spot on the strip the printing at the back is upside down.) John Barth's latest book, *Lost in the Funhouse,* exploits the same idea. It contains instructions for cutting out and making a Möbius band that reads endlessly: "Once upon a time there was a story that began once upon a time there was a story that began once upon a time...."

This is the old children's tale that has an infinite beginning with no middle or end. Once I wrote the following middleless metapoem that has an infinite beginning and an infinite end:

One day
A mad metapoet
With little to say
Wrote a mad metapoem
That started:
"One day
A mad metapoet
With little to say
Wrote a mad metapoem
That started:
' "One day

.
.
.

Sort of close," '
Were the words that the poet
Finally chose
To bring his mad poem
To some
Sort of close,"
Were the words that the poet
Finally chose
To bring his mad poem
To some
Sort of close.



Solution to die problem

Unfortunately I have not yet found an appropriate topological surface on which to print it.

The first dice problem last month concerned a magician who turns his back while someone rolls three dice, adds the faces, adds to this sum the bottom number on any one die, which he then rolls again, adding the new number on its top to the previous total. The magician turns around, glances at the three dice and is able to name the final total. How does he know?

To the sum of the three top faces he adds seven. The final total is the sum of the three top faces plus the previous top and bottom of one die. Since opposite sides of a die total seven, the working is obvious.

The answer to the second problem is that the mis-spotted die shown from three angles must have a deuce opposite the six. The illustration above shows how the die would look if its faces were unfolded.

The third problem is from *100 Brain-twisters,* by D. St. P. Barnard, a collection of original puzzles published in England in 1966 and distributed here by D. Van Nostrand, Inc. Since there are 36 ways two dice can fall, if sums from 1 through 12 are to be made with equal probability, each must be made in three ways. The only way to make 12 in three ways is by having a 6 on one die and three 6's on the other. The only way to make 1 in three ways is to have a 1 on one die and three blanks on the other. This leads to the only solution: one standard die, the other with three 6's and three blanks.

The method applies to any of the five regular solids. For example, consider a pair of icosahedral dice. If the numbers 1 through 20 appear on one icosahedron and the other die has 10 blank faces and 10 faces bearing 20's, the pair will throw with equal probability any sum from 1 through 40.

THE AMATEUR SCIENTIST

How to make a wave machine to simulate the building and destruction of beaches

Conducted by C. L. Stong

Among the many interesting features of a seashore is the manner in which the sea constantly reshapes a sand beach. Frank Pattee, a high school student in Columbus, Ohio, makes a hobby of investigating the mechanisms through which surf transforms the substance and structure of the beach. Pattee's selection of the hobby involved the solution of a major problem—the fact that he lives some 500 miles from the Atlantic coast. He solved the problem by constructing a mechanized model of a beach. The apparatus simulates several types of wave behavior. In particular it demonstrates how waves attack, transform and reshape the earth's ever changing coastlines.

"Of necessity," Pattee writes, "my apparatus had to be scaled to the proportions of my basement. For this reason it cannot duplicate precisely the phenomena that are observed at a natural beach. For example, it generates waves of relatively low energy, whereas waves that break against a typical beach may span a broad range of energy. During periods of calm at a natural beach the surf may develop forces of only a few ounces per square foot—barely enough to destroy a sand castle. On the other hand, violent storms generate waves that often crash against the shore with forces of up to three tons per square foot.

"In addition the small tank that confines my 'sea' functions under certain conditions as a resonant cavity for waves, and the walls of the tank introduce weak reflections that are not present at a natural beach. Doubtless these spurious effects influence both the manner in which the model beach erodes and the way in which the eroded materials are transported and distributed by the moving water. Even so, the apparatus appears to simulate closely many phenomena of wave action that are observed in nature.

"My experiments have been concerned primarily with shallow waves, which travel in water that does not exceed in depth half the length of a wave. (The length of a wave is the distance from one crest to the next one.) Waves that propagate through water of greater depth are formed by the mass movement of water particles, each of which follows a slightly elliptical path in a vertical plane aligned in the direction in which the wave travels. The particles move upward at the rear of the wave, bend over toward the beach at the top, curve downward at the front and return to their starting point at the bottom. Substantially no net displacement of water occurs in any direction.

"When the wave enters shallow water, however, the natural orbit of the particles is distorted. The velocity and length of the wave decrease and the height increases. As the wave continues to roll inshore it grows in height. The crest runs ahead of the trough, becomes unstable and eventually breaks. The result is a turbulent mass of water that races toward the beach. Under proper conditions the wave may re-form and break again.

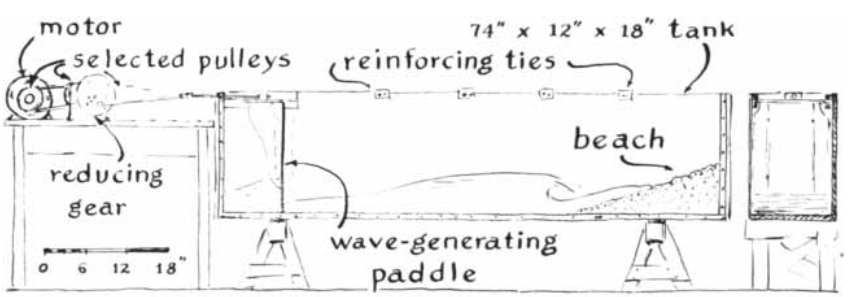
"Shallow waves may be either constructive or destructive in their effect on a beach. Constructive waves are relatively smooth. They break slowly and deposit suspended materials on the beach. Destructive waves are usually generated by storms. They are large and steep; they break violently, eroding beach materials and carrying them out to sea.

"My apparatus generates waves of both types in shallow water and projects them against a model beach. Designed to demonstrate the effects of wave action on sand, the apparatus consists of a slender tank, a supply of sand and a wave generator. The tank is 74 inches long, 12 inches wide and 18 inches deep. The bottom, ends and one side of the tank are made of 3/4-inch marine plywood. The remaining side, cut from a sheet of clear plastic 1/4 inch thick, serves as a window for observing the wave action. The joints were caulked with aquarium cement.

"The waves are generated at one end of the tank by an oscillating paddle that is driven by a motor-actuated crank [*see illustration on this page*]. The paddle, together with a pair of brackets, is attached to the bottom of a flat plate that moves back and forth in a pair of grooves at the upper edges of the tank. The grooves are lubricated with soap.

"The paddle assembly is linked by a rod, a universal joint and a connecting rod to a crank in the form of a disk equipped with a movable wrist pin. The crank is driven through a 40-to-1 reduction gear that is coupled by pulleys and a belt to an induction motor. The motor develops 1/4 horsepower at 1,750 revolutions per minute.

"The period of the water waves is adjusted by altering the speed of the



Side and end views of Frank Pattee's wave machine

crank. With a pulley 5½ inches in diameter on the motor and a pulley eight inches in diameter on the input shaft of the reduction gear, the crank is operated at 30 revolutions per minute. A 7½-inch pulley on the motor and a 5½-inch one on the reduction gear increase the speed of the crank to 60 revolutions per minute.

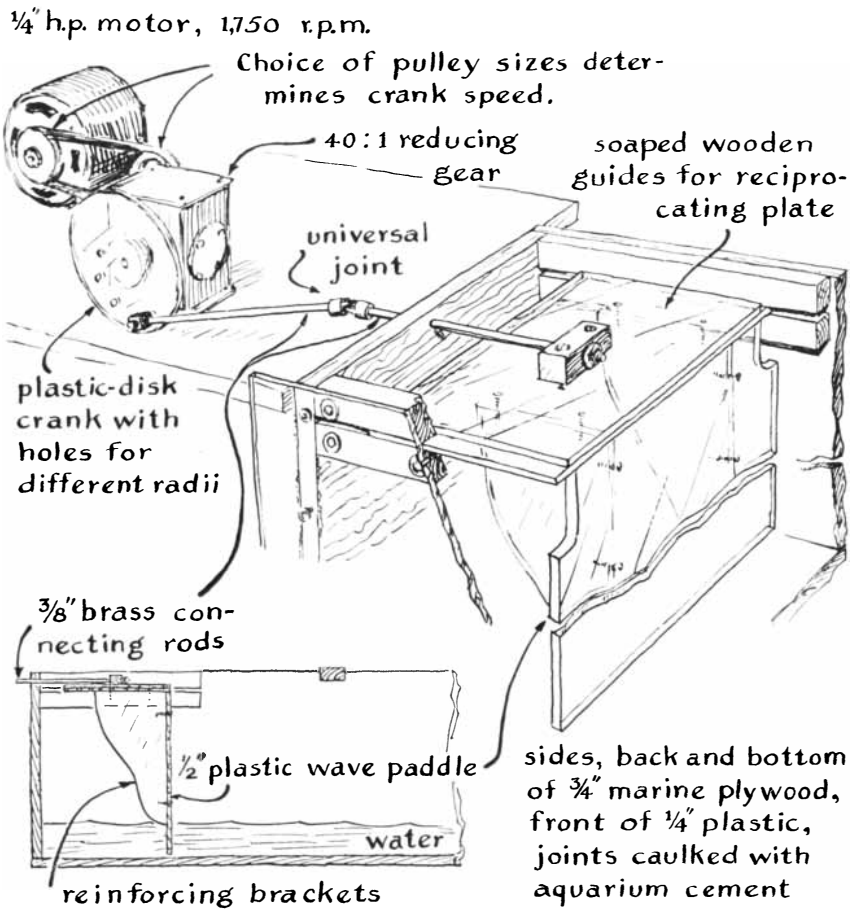
"All my experiments so far have been made at these speeds. The longer period generates constructive waves; the shorter, destructive waves. Speeds in excess of 60 revolutions per minute cause excessive splashing in the tank. The height or amplitude of the waves is adjusted by altering the distance of the wrist pin from the center of the disk.

"The beach is composed of white silica sand that occupies the free end of the tank. The slope of the sand is arranged by hand prior to the beginning of each experiment. The particle size of my sand varies considerably. The larger grains are about the size of granulated sugar. Other materials I have used include magnetite sand, granulated lead, granulated zinc and powdered titanium. I was able to get all the materials locally, with the exception of the magnetite sand, which I bought from Ward's Natural Science Establishment, Inc., 3000 Ridge Road, East Rochester, N.Y. 14445.

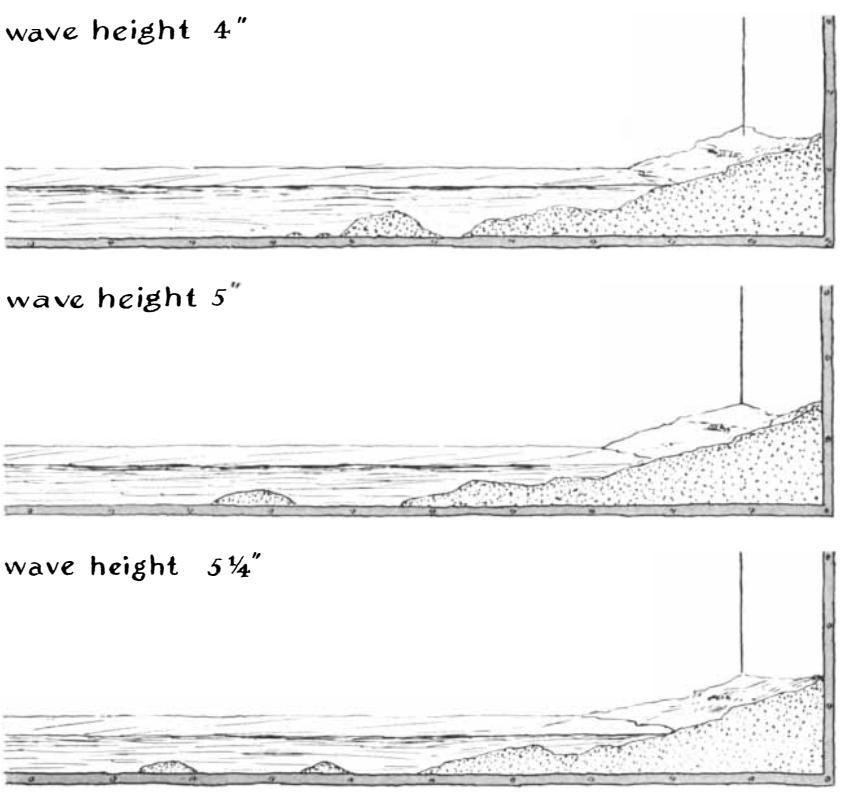
"To investigate beach erosion, the formation of sandbars and other phenomena that involve the transportation of sand, I first adjust the machine to generate destructive waves. Usually I make a series of three test runs in which the amplitude of the waves is increased from four inches to five inches and finally to 5¼ inches. The wave period is maintained at one second. The results are photographed at the end of each 15-minute run.

"At the start of each experiment the sand is smoothed and arranged at an angle of approximately 15 degrees. The photographs clearly indicate that the rate at which sand is transported increases with wave amplitude [*see bottom illustration at right*]. Not as evident are the mechanism of sand transport and the process of bar formation.

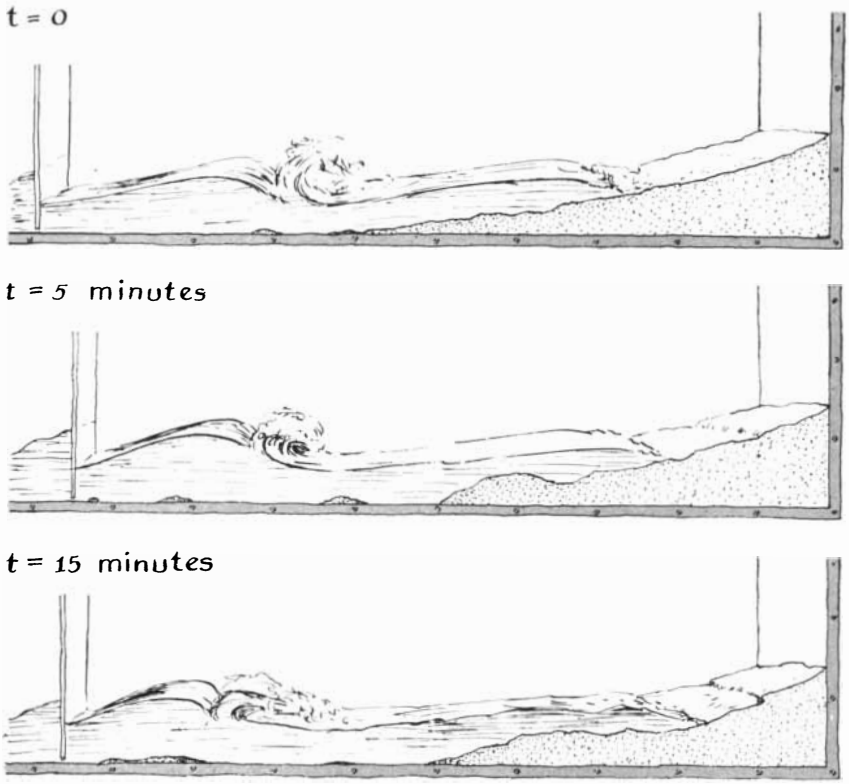
"The mechanism of sand transport was investigated in another experiment in which destructive waves of 5¼-inch amplitude eroded the beach for 15 minutes and were photographed at five-minute intervals. (The waves broke approximately 27 inches from the paddle and created a turbulent surf.) The force of the water's impact dislodges particles of sand high on the beach, and



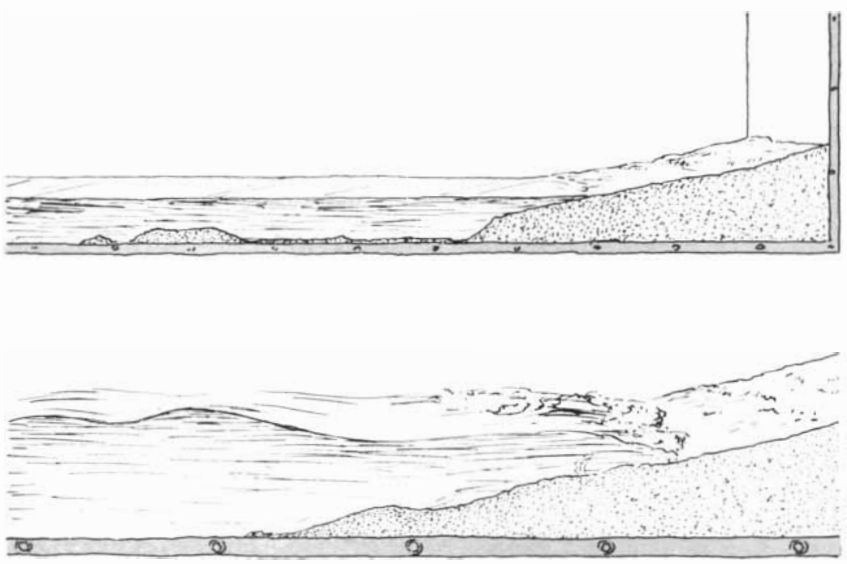
Details of the wave generator



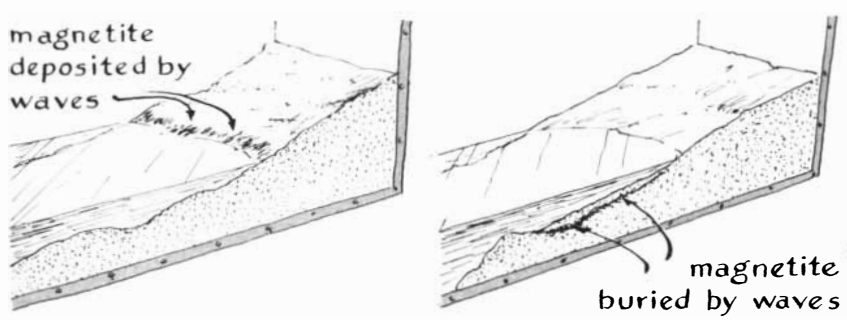
Effects of increasing wave amplitude



Construction of a sandbar over a period of time



Elimination of a sandbar by constructive waves



Concentration of ore by wave action

turbulence keeps them in suspension for some time. As the surf recedes much of the material is carried seaward by the undertow.

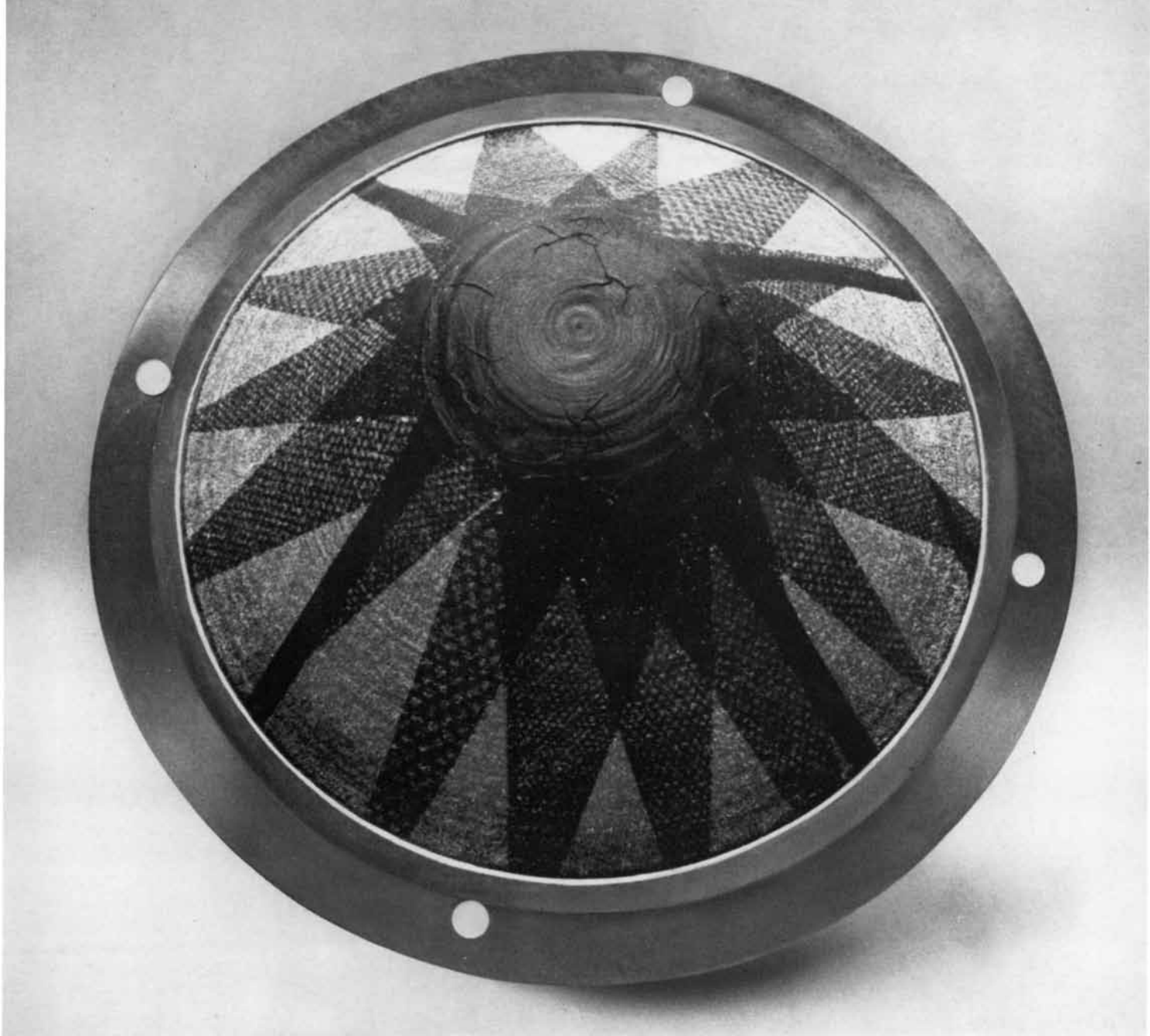
"As the turbulence subsides the water gradually loses its capacity to keep the sand in suspension. It then distributes the sand in one or more well-defined zones on the bottom, thus initiating a sandbar. When the growing bar has decreased the depth of the water sufficiently, the waves break earlier, that is, farther out to sea. Thereafter turbulence attacks the landward side of the bar and eventually shifts it farther from the beach. When the separation between the bar and the beach becomes great enough, surf re-forms between the two as a translational wave that usually constructs intermediate bars by the same mechanism [*see top illustration at left*].

"The seaward movement of bars was observed by having destructive waves act for 45 minutes. Photographs were made at 15-minute intervals. A pair of bars formed within 15 minutes, as in the preceding experiment. During the next 15-minute interval the waves redistributed the sand well out to sea, where it came to rest as a permanent bar, indicating that the system had attained equilibrium. No substantial change was seen during the final 15 minutes.

"Long-term stability is never observed in natural beaches. Tides vary throughout the year, storms periodically generate waves of abnormal destructiveness, coastwise currents shift in response to the ever changing shape of the coastline and geological forces at work in the interior of the earth gradually elevate or lower the land with respect to the level of the sea. Such variables can be controlled in the wave machine, and their effects can be observed one at a time.

"The gently sloping beach that is characteristic during the summer is the product of constructive waves. They are long and relatively flat and do not break violently on the beach. They rebuild beaches eroded by winter storms by removing sand from offshore bars, transporting it landward and depositing it on the face of the beach. Under optimum conditions the process may extend a beach as much as 10 feet per day.

"Constructive waves can be generated in my apparatus by increasing the period and hence the length of the wave, a dimension that is equal to the velocity of the wave divided by its frequency. I determined experimentally that in my machine a period of two seconds quadrupled the deep-water wavelength and simultaneously generated constructive waves approximately equal in amplitude



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GENERAL ELECTRIC

to the destructive waves that were investigated during earlier experiments.

"Starting with a gently sloping beach, destructive waves were generated for 15 minutes. A record was made of the erosion and the sand formations. The apparatus was next adjusted to generate constructive waves for observing how the beach was rebuilt.

"As a crest passed over the first bar the wave would become unstable and break over the interior bars. Turbulence gradually increased during the transit. The growing surf picked up particles of sand along the way and carried them into shallow water, where the waves lost velocity. Part of the sand was scattered as it was carried along and part was deposited on the beach. The process of reconstruction was accelerated as sand accumulated in the trough between the inshore bar and the beach and reduced the depth.

"In the meantime the trough of succeeding waves passed over the bar. The backward movement of water in this lowest part of the wave scoured the sand at the top of the bar, causing it to enter suspension. In that condition it was easily carried forward by the crest of the next wave. Eventually this action leveled the outer bar. The inner bars were then subjected to the full force of the waves and also disappeared. Sand transferred from the bars was deposited on the beach and eventually erased all trace of the previous erosion [*see middle illustration on page 118*].

"A series of experiments that I found particularly interesting was designed to demonstrate how minerals are deposited on the beach and sorted according to the size and specific gravity of the particles. Constructive and destructive waves were used separately and together. Beach materials consisted of silica and magnetite sands and of granular metals that simulated minerals of various specific gravities.

"Destructive waves were first allowed to break for 15 minutes against a beach of silica sand. The apparatus was shut down. Specimens in the form of core samples were removed for examination. The crests of bars were found to be composed chiefly of coarse grains, whereas fine particles had collected in the troughs. Evidently this separation had been produced by differences of turbulence in the two regions.

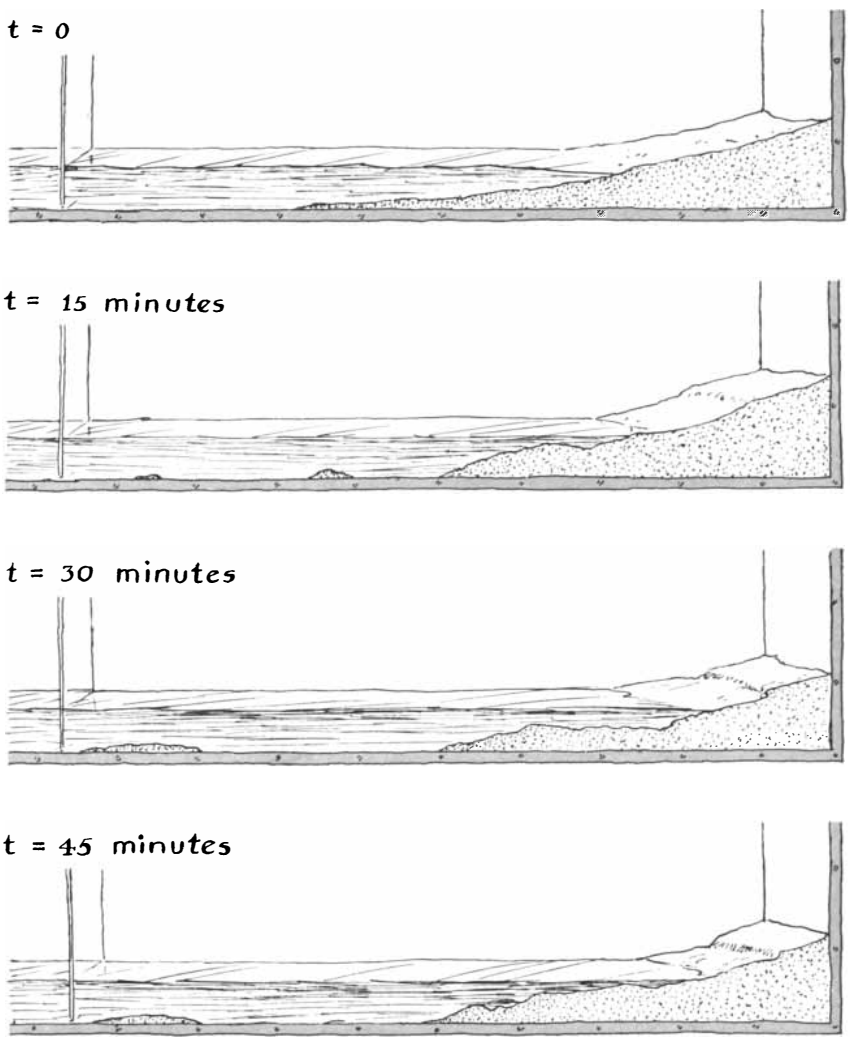
"Constructive waves were generated for 15 minutes. All signs of erosion disappeared. Both the exposed and the submerged portions of the beach were then examined to learn where sands of particular grain size had been deposited. The coarser particles had formed a ledge at the top of the beach, and another zone of coarse particles was deposited across the bottom. The face of the beach was composed entirely of fine sand.

"I do not know why or how this separation occurs. Perhaps only a little water seeps into the beach during the brief interval when the sand-laden wave rushes up the exposed face. Thereafter, as the water recedes, loses energy and soaks into the sand, the wave loses its lifting power. This combination of events might cause coarse sand to drop out of the water first and form the upper ledge, because maximum force is required to hold the large particles in suspension. The remaining fine particles would then be distributed over the face of the beach. This theory does not account for the distribution of coarse particles across the bottom of the beach, which is a puzzle I am still trying to solve.

"Magnetite sand was selected for another series of sorting experiments because its specific gravity of 7.5 is significantly higher than that of silica sand (2.5) and because the black particles are easily seen. The material is also ferromagnetic and can be recovered easily from silica sand, particularly when the sand is dry, by means of a magnet.

"To do the sorting experiment, I first made a standard beach of white sand. The beach sloped at an angle of 15 degrees. Next I released a stream of magnetite into surf produced by a series of destructive waves. The magnetite spread across the beach but did not move out to sea in significant quantity. Thereafter the size of the patch did not change appreciably, apparently because the particles could not be lifted by the water. Sandbars formed as usual.

"Several constructive waves were then launched. They returned sand to the beach, completely covering the magnetite. After the magnetite was buried destructive waves were generated for



Action of destructive waves

Nancy and John Seletti aren't trying to save the world. Just a little piece of it.

About a mile outside the Korean village of Ku Am there are a few dozen young, still-tender mulberry trees growing on a small hill. Someday these trees and their succulent leaves will be the heart of a new village industry—a silk raising farm. That day is still many months off, but it doesn't stop the village men from making daily inspection treks up the steep hill, just in case. Just in case something miraculous has happened since yesterday. After all, it wouldn't be the first miracle to happen in Ku Am. Everyone in the village knows the story of Chang Sook, the daughter of the widow.

Ten years ago Chang Sook's chances of survival were as slim as she was. Her father had disappeared during the family's flight from North Korea. Her mother, a seamstress, worked a backbreaking day and most of the evening to earn $10 a month. Barely enough to keep them from starving.

But today that's all changed because an American couple named Seletti are sharing a little of their good fortune with a girl to whom a little means everything. Nancy, John and five-year-old Alexandra Seletti are New Yorkers. They're not fabulously wealthy as the villagers of Ku Am believe. But, they're not poor either. *Comfortable* probably describes them best. They have everything they really need, but give them ten minutes and they'll come up with ten things they want that $15 a month would buy. Luckily, they thought of Chang Sook first.

Through Save the Children Federation, the Seletti's $15 a month is doing a remarkable number of things. First, Chang Sook's immediate needs and future schooling are being taken care of. The family is getting help, too: Enough to enable Chang Sook's mother to start a small knit shop.

And with all this, there is still some money left over. This money, together with money from other sponsors, was borrowed by the village to start its precious mulberry farm. Someday silk raising will mean a permanent increase in the village's income—and permanently end the need for charity. That's what Save the Children Federation is all about. Although contributions are tax-deductible, it is not a charity. The aim is not merely to buy one child a warm coat, a new pair of shoes and a six month supply of vitamin pills. Instead, your contribution is used to give the child, the family and the village a little boost that may be all they need to start helping themselves.

Sponsors are desperately needed for children in Korea, Vietnam, Latin America, Africa and Greece. You can select the child's nationality. You will receive a photo of the child, regular reports on his progress and, if you wish, a chance to correspond.

Chang Sook writes to the Selettis. She also sends small homemade gifts to Alexandra. And she tells them of her dreams of becoming a nurse. She'll probably make it. If she does, the Seletti's investment in one girl will be repaid a thousand-fold.

The Selettis know they can't save the whole world for $15 a month. Just a small corner of it. But, maybe that is the way to save the world. If there are enough people like the Selettis. How about you?

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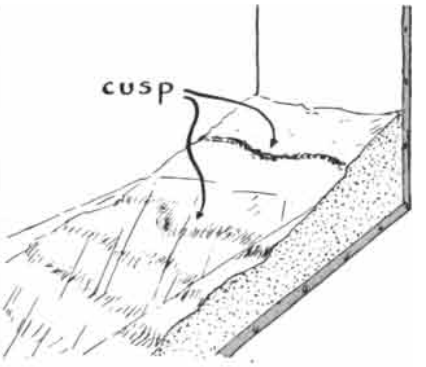


Formation of cusps

the same interval of time as before. This action laid the beach bare to the level of the magnetite. The beach was then reconstructed by wave action and again exposed to destructive waves while additional magnetite was added to the surf. Wave action again eroded the beach to the previous level and combined the added magnetite with the original layer [*see bottom illustration on page 118*].

"The experiments demonstrated interesting features of the deposit on beaches of minerals that are too heavy to be lifted and carried by waves. Such minerals are transported to the beach by rivers or by the weathering of rocks along the shore. If the minerals arrive during a period of beach construction, they will be buried by sand. During the next period of destructive waves the beach will be eroded and the minerals will be exposed. Eventually the heavy materials mix with those deposited by earlier storms to form a mineral layer at a depth determined by the maximum erosion of the beach. Should the beach then be lifted above sea level by some geological disturbance the layer can be exposed as a valuable mineral deposit.

"Experiments were also made to observe the sorting and deposition of minerals heavier than silica sand. Magnetite was mixed with granulated zinc and lead. The specific gravities of the three are 7.5, 7 and 11.5 respectively. The mixture was deposited on the beach and covered and uncovered by wave action as in the preceding experiments. Little sorting took place. The larger particles of lead remained in place. Zinc particles and the smaller particles of lead moved about slightly, but little if any separation occurred. Next I rebuilt the beach with clean sand.

"A mixture of magnetite and titanium was then tried. The density of titanium is 4.5, not quite twice that of silica sand. The mixture was poured on the beach at the waterline and subjected to a series of destructive waves. The magnetite behaved as in the earlier experiments: it spread slowly across the beach but did not move seaward.

"The titanium behaved quite differently. It disappeared even before the distribution of the magnetite was completed. Only a few particles remained on the slope of the beach. Most of the material was carried out to sea.

"Specimens were taken from the sandbars. They were saturated with titanium but contained only a few grains of magnetite. A series of constructive waves was launched to rebuild the beach. The magnetite was buried as usual, but a search of the rebuilt beach disclosed little titanium. Several small ripples of sand marked the former location of the sandbars. Most of the titanium was recovered from these remnants.

"Other consequences of wave action include characteristic markings, such as cusps and ripples, that often appear in the sand. In nature cusps frequently are seen in a regularly spaced pattern along the beach. In the wave tank two pairs of cusps similarly form, one pair on the exposed portion of the beach and an identical pair just below the waterline. A mirror image of the first two cusps also appears farther out to sea.

"Ripple marks are roughly parallel sets of wave-shaped ridges and troughs. They form on the beach chiefly during constructive-wave experiments. The few that are developed by destructive waves are usually found in sand deposited between the offshore bar and the next inshore bar.

"Although I have had a lot of fun with my present apparatus, I look forward to enlarging it so that other aspects of wave action can be demonstrated. Some actions are known to exert a major influence on the rate of sand transport, on beach erosion and on bar formation. One factor is the steepness of the beach. Steep beaches erode more rapidly than those of gentle slope, although more bars and ripples form on a flat beach. My apparatus is too short for demonstrating wave action on a flat beach.

"The apparatus is also much too narrow for investigating currents that move along the shore. These currents develop when waves advance against the beach at an acute angle. Such a wave may create a breaker that travels along the beach. For example, a wave might approach the observer from the left and sweep along the waterline to the right, followed by a succession of similarly directed waves.

"This action causes water near the

edge of the beach to oscillate as a pattern of scallops that constitute a net flow to the right. The flow is capable of transporting beach materials. Longshore currents shift enough sand to fill harbors, seal off bays, create lagoons and even construct bars that link offshore islands to the mainland. A square or rectangular tank with a movable wave generator on one of the long sides should be capable of demonstrating longshore currents, and I look forward to making such a wave machine."

STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION (Act of October 23, 1962; Section 4369, Title 39, United States Code). *1.* Date of filing: October 1, 1968. *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), c/o United States Trust Co. of N.Y., P.O. Box 456, Wall Street Station, 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; Buckley & Co. (for Elinor Gottlieb Manucci), c/o Fiduciary Trust Co. of N.Y., 1 Wall Street, New York, N.Y. 10005; Cudd & Co. [(a) for Helen Rosenwald Snellenburg, John Crisona and Frank M. Tait, Trustees u/a 2/17/66 F.B.O. Helen Rosenwald Snellenburg and (b) 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; Martin M. Davidson, 11 River Lane, Westport, Conn. 06880; 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., Kaiser Foundation Hospitals, 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, Room 726, 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, P.O. Box 3235, Norfolk, Va. 23514; 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; 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; Sydney S. Spivack, Far Hills, N.J. 07931; John Hay Whitney, c/o Frank S. Streeter, J. H. Whitney & Co., Room 4600, 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.* Not applicable to this organization. *10.* Extent and nature of circulation: *A.* Total number of copies printed (net press run): average number of copies each issue during preceding 12 months, 459,416; actual number of copies of single issue published nearest to filing date, 453,000. *B.* Paid circulation: *1.* Sales through dealers and carriers, street vendors and counter sales: average number of copies each issue during preceding 12 months, 84,281; actual number of copies of single issue published nearest to filing date, 83,854. *2.* Mail subscriptions: average number of copies each issue during preceding 12 months, 333,800; actual number of copies of single issue published nearest to filing date, 328,000. *C.* Total paid circulation: average number of copies each issue during preceding 12 months, 418,081; actual number of copies of single issue published nearest to filing date, 411,854. *D.* Free distribution (including samples) by mail, carrier or other means: average number of copies each issue during preceding 12 months, 16,150; actual number of copies of single issue published nearest to filing date, 15,500. *E.* Total distribution (sum of *C* and *D*): average number of copies each issue during preceding 12 months, 434,234; actual number of copies of single issue published nearest to filing date, 427,354. *F.* Office use, leftover, unaccounted, spoiled after printing: average number of copies each issue during preceding 12 months, 25,182; actual number of copies of single issue published nearest to filing date, 25,646. *G.* Total (sum of *E* and *F*—should equal net press run shown in *A*): average number of copies each issue during preceding 12 months, 459,416; actual number of copies of single issue published nearest to filing date, 453,000. 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 selection of books on science for younger readers

by Philip and Phylis Morrison

Herewith this department presents its annual survey of books about science for younger readers.

Physics and Astronomy

MODEL-MAKING FOR PHYSICISTS, by A. D. Bulman. Thomas Y. Crowell Company ($4.50). A British book always calls some things by British names, for example "soldering bolt." This book describes and shows a couple of dozen devices that a young physicist—in his teens—might make if he had a shop that allowed him freedom to solder, burn gas, use epoxy resins and work freely with alternating-current power. Even so, the book sets a high standard; it is much like the thick Victorian guides for the boy mechanic in that many of the designs described are beyond the skill and patience of any but very determined and able boys. Even to read about them, however, induces understanding and delightful dreams. The heat engine is the hardest task here; the clever disk for spinning on the phonograph turntable to see various illusions and watch moving models of wave phenomena is perhaps the easiest. The book is suitably transistorized and up to date, without loss of that old do-it-all-yourself flavor.

BATHTUB PHYSICS, by Hy Ruchlis. Illustrations by Ray Skibinski. Harcourt, Brace & World, Inc. ($3.25). Crisp, sensible and intriguing, the book by a veteran writer on science produces plenty of good physics from everyday experience in the household pool. The reader is invited to experiment, but he can get a good deal in the armchair. That way, however, he will miss the magnetic properties of the iron bathtub, the beauties of the elegant ripples, the fun of lifting water above its own level in an inverted glass and the solution to how to weigh a drop of water with a coin and a bathtub and a small glass vial. You had better be ready to run the water. For many experiments, of course, a smaller scale will work—a sink or even a soup bowl. The question of why the water rises as long as the inverted glass is held with its edge below the level in the tub but drains out as soon as the glass is lifted out of contact with the water—air pressure or no air pressure—is evaded. It is too bad, since stability is discussed in terms of sticks with weights. This is an agreeable book for experimenters in the upper school grades.

SNOW STUMPERS, by David Webster. The Natural History Press ($3.50). This sharp-eyed and cheerful author has made a small book that deserves to be regarded as a study in the field geology of that transient mineral, snow. About 100 photographs appear, each with the question "Why?" or "How?" "Why is there more snow on the right side of the garage roof after one storm . . . and more on the left side after another?" The pictures are clear, and the answers (which, since they depend on significant details, are by no means always immediately apparent) are given. Those who live in snowy places will find every page evocative; those who do not know snow will hardly believe what they see. A delightful exercise in inference, plus some things youngsters might do in snow study and in snow architecture.

WHEN AIR MOVES, by Mae Freeman. McGraw-Hill Book Company ($3.95). Experience counts. Mrs. Freeman has written several dozen small books for small experimenters, and her pedagogical understanding shows. The reality of air comes clear to anyone whose finger is pressing on a blown-up plastic bag, and the photograph encourages you to try. A parachute for drag, blowing on paper for lift, throwing a ball backward while on skates for jet and rocket propulsion, and pictures of the real thing (including hovercraft and helicopter) comprise the book. It is characteristic of the empathy of this splendid teacher that the idea of a cross section is not left to words alone but is made plain by a picture of a cut strawberry, in preparation for the section of an airfoil.

IT'S ALL DONE WITH MIRRORS, by Irving D. Gluck. Illustrations by James McCormack. Doubleday & Company, Inc. ($4.95). The excellent idea of studying the simplest optical device in some depth as an introduction to optics is well carried out in this almost entirely nonmathematical book. The plane mirror is the leading actor, although the spherical mirrors are certainly featured players. There are experiments to do, hints on obtaining mirrors, optical history and simple explanations of devices from the kaleidoscope to the laser. Not all the explanations are equally successful on this simple descriptive level, but the ones that call for plane mirrors, or simple spherical ones that are not foreign to the household, are almost always satisfactory. The rest—Schmidt camera, laser, radio dish—give a real sense of continuity with the great world even when they do not explicate. This is a fine book for people brave enough to start some physics on their own, at any easy reading age.

COMETS, by David C. Knight. Franklin Watts, Inc. ($2.65). The schoolish appearance of this book makes it look as though it were meant for fifth-graders, who indeed can grasp it, but the richness of its text, photographs and diagrams extends its readability and interest upward many years. Much is owed to the paintings of famous comets from the American Museum of Natural History, reproduced here in black and white, and the excellent astronomical photographs from the big telescopes. The six-tailed comet of 1744 was a wonder; Halley's comet is treated in an excellent chapter. Only sun-grazers are somewhat slighted. The great Siberian explosion of 1908 is very sensibly ascribed to a comet head falling to earth.

Mathematics

NUMBERS OF THINGS, by Helen Oxenbury. Franklin Watts, Inc. ($3.95). The

very young mathematician from kindergarten up is here shown—without any notational jargon—sample sets for the cardinal numbers, from one ruffed lion made of roses through 50 delightful pink ladybugs on a white ground. The next page is an endearing surprise. The whole book is one slender, beautiful thing.

LINE DESIGNS, by Dale G. Seymour and Reuben A. Schadler. Creative Publications ($1). CREATIVE CONSTRUCTIONS, by Dale G. Seymour and Reuben A. Schadler. Creative Publications ($1). Two soft-cover booklets of geometric fun and fascination. The first is a splendid collection of designs, all made solely of straight lines drawn between sequences of points usually marked out on polygons. The second booklet contains a more complicated set of designs, in which multiple intersections of arcs and polygons are generated, then particular areas chosen for systematic shading and coloring. These are all but addictive for mathematics students from the seventh grade up.

SECRET CODES AND CIPHERS, by Bernice Kohn. Illustrations by Frank Aloise. Prentice-Hall, Inc. ($3.95). This lively little book is a practical introduction to the subject for readers of 10 and up, and it is great fun. It proceeds from Morse code and price-tag cipher through Rosicrucian and Pigpen up to double-substitution methods: the classic Vigenère and Playfair schemes. Everywhere there is an interesting thread of history, including recognition of Colonel Friedman of *Magic* fame and an up-to-date mention of the redoubtable National Security Agency. Tables of letter, word, digram and trigram frequencies in English conclude the work very professionally.

MATHEMATICAL SNAPSHOTS, by H. Steinhaus. Oxford University Press ($7.50). A justly prized book in a third American edition, sure to please every mathematical amateur. Its strength is the great variety of its topics and the elegance of its interests and its methods.

Animals and Plants

THE MARVELOUS ANIMALS: AN INTRODUCTION TO THE PROTOZOA, by Helena Curtis. The Natural History Press ($5.95). The invoking of Antony van Leeuwenhoek ("Thousands of living creatures, seen all alive in a drop of water") begins this book, written with a depth and a grace rarely found in such essays. It is an account much fuller than the usual chapter of a general biology book, and it is wholly free of the special pleadings and technicalities of the more advanced monographs. It will work for high school readers. The text, with many photographs and drawings (properly described as to scale), gains depth through a genuine understanding of the ideas of evolution, of ultrastructure and of biochemistry that illuminate modern biology. The grace is the author's own; her special touch is that her writing is never impersonal and yet her presence is never obtrusive. There is plenty to wonder at in the book, but here there is room to cite only one argument: Termites live because their intestinal protozoon symbiont converts cellulose into termite food. Now, an Australian version of this termite symbiont is covered with rows of tiny cilia. This earned it the appellation *paradoxa,* because it plainly bears four flagella, and no forms have both cilia and flagella. The cilia turn out to be spirochetes, bacterial cells each hanging on to a little knob on the protozoon's wall, capable of beating in unison so that their host can move. Termite, protozoon, bacterium—is there perhaps a latent virus within?

MARSUPIALS AND MONOTREMES OF AUSTRALIA, by Gordon Lyne. Taplinger Publishing Company ($5.95). Dr. Lyne is a distinguished Australian mammalogist; even more, he has a keen eye and a loving and able hand with words and pictures. This book is a straightforward account, superbly illustrated mostly with large, detailed drawings by its author, of the living animals of these orders. It is a sober, grown-up reference work, but it is never solemn or obscure, and it should be a joy to children in many libraries.

THE BOOK OF THE GIRAFFE, by C. A. Spinage. Houghton Mifflin Company ($6.95). Paleontologists have learned that 40 million years ago giraffe ancestors, forest rather than savanna beasts, were found in most of the Old World. In the time of man only the African savanna holds the modern giraffe and the African forest its close cousin the okapi. Neolithic painters depicted the giraffe, and it is often seen in the art of Egypt. Nubian giraffes were sent as tribute from Egypt to the emperor in Constantinople or his successors from the third or fourth century up until the 1820's. The first giraffe reached China by way of East Africa and Bengal during the Ming dynasty, in 1414. It was a sensation; its shape and gentleness recalled the mythical *kilin,* whose appearance was the sign of a benevolent sovereign. Direct trade between East Africa and China began as a result of the giraffe, although it did not persist. To this delightful scholarship the naturalist author adds a fine account of the physiological puzzles and the evolutionary uncertainties of the giraffe, which are still not fully clarified, although not for want of theory. This is a book for good readers past the sixth grade, who will be drawn to its heady mixture of history and zoology.

THE WORLD OF THE WOLF, by Russell J. Rutter and Douglas H. Pimlott. J. B. Lippincott Company ($5.95). "There is little doubt that the wolf is the most adaptable mammal, other than modern man, that the world has ever known." Social, intelligent, genetically plastic, a predator on the same big game that men hunted, and later on domestic herds and flocks, the wolf has stood in direct competition with man over most of the life of our species. We somehow formed dogs partly out of the wolves, but we mostly remain unthinking enemies of the true wolf long after his valuable testimony to our mutual history outweighs the price of letting him share at our enormous table. That is the burden of this excellent firsthand book, written by two Ontario naturalists who are knowing friends of the wolf. Healthy wolves rarely, if ever, attack man. They cost the human species little. Their complex society, their beauty and their symbolic wildness are worth much in a crowded world. There is no hope for the wolves of Europe; even in the U.S.S.R. only vast spaces may save them. In the U.S. wolves are in a precarious state; Canadian wolves will survive, although the overuse of land and game presses hard even on them. Here are profuse photographs of wolves, and much wolf lore, season by season, about individuals and about packs, based not on rumor but on sound study and observation. From junior high up—all the way up—readers who are fond of big dogs will find this book outstanding.

THE REMARKABLE CHAMELEON, story and photographs by Lilo Hess. Charles Scribner's Sons ($3.25). The adjective "remarkable" is hardly strong enough to carry the impression made by this family of Old World lizards, whose grotesque head ornaments, noduled skin, slow ratchet movements and fearsome shape bring every viewer at once to the age of dinosaurs. The text and photographs, for readers in the early school grades, tell the story in a fascinating way. That the author has reared these fellows is plain; one of them bears a lettered brand stenciled temporarily on

its skin with the aid of a bright lamp. It says "Lilo Hess." The baby lizards look just like their parents, only tiny and less ornate around the head. That marvelous projectile tongue is caught here stretching twice the length of the animal's body after flying food. We are told how to keep chameleons, and how much truth and how much fancy lies in accounts of their proverbial color changes. Shown here is a monochrome chameleon sitting quite contentedly on a plaid ground. Two warnings: "They are extremely delicate and difficult to keep," and the little lizard so often sold for a coin or two at fairs is a clever color-changer, the American anole; it is not a proper dinosaur-like chameleon.

TREES OF NORTH AMERICA: A FIELD GUIDE TO THE MAJOR NATIVE AND INTRODUCED SPECIES NORTH OF MEXICO, by C. Frank Brockman. Illustrations by Rebecca Merrilees. Golden Press ($2.95). Trees clothe the natural landscape in most of America. They are not easy to know and to identify. This bargain paperback guide, pocket-sized and sturdily made, should be a genuine help to all walkers in the woods. It has neat marginal distribution maps, and more than 1,000 clear, attractive small colored illustrations of tree habit, twigs, leaves and fruit. It is not too pure to include the important naturalized trees; altogether it is a little beauty. It is, of course, a book for the entire family.

Biology in General

TRACKS, by E. A. R. Ennion and N. Tinbergen. Oxford University Press ($4.25). The distinguished ethologist Niko Tinbergen has photographed some 60 animal-track patterns in snow or sand, and one or two from an airplane over the Serengeti Plain. Here they are, as small as a weevil's toolmarked trace or as big as the tracks of a herd of hartebeest. Most of the photographs, made in England, show the tracks of the familiar small animals of woodland, meadow and shore. All of them tell a tale, sometimes quiet, sometimes dramatic, and it is brought to life by a drawing of the animal as though "caught in the act" by Dr. Ennion. This is a unique and thoroughly beautiful book that exemplifies both content and the method of inference.

OUT OF THE ARK: AN ANTHOLOGY OF ANIMAL VERSE, compiled by Gwendolyn Reed. Illustrations by Gabriele Margules. Atheneum ($5.75). More than 100 poems are here from all lands and times (from the ancient Chinese *Book of Songs* there is a verse of a unicorn dance). They celebrate species from the termite to the whale, and beyond Linnaeus as well. Miss Reed knows and loves poetry; her taste is sure. More than that, she includes enough of the great familiar examples ("wee, sleekit . . . beastie") so that the reader is fulfilled, yet she boldly calls on many poets all but unknown except to specialists. Most of the verses, although not all, are more about people than about animals. The delicate line drawings embellish this genuinely beautiful book.

HATCH AND GROW, by Ivah Green and George A. Smith. Abelard-Schuman ($4.50). With his 35-millimeter reflex Smith has produced elegantly clear photographs, three or four to a sequence, showing life stages for some 30 common species of insect. Their metamorphoses seem very real here in these photographs, all taken from life. ("An insect captured on film should be alert.") There are several expert pages on insect photography. The explanatory text by Green describes what one sees and supplements the pictures with straightforward information about the stages of each species and their timing. The baroque spiny caterpillar of the royal walnut moth, called the hickory horned devil, steals the show.

BONE FOR BONE, written and illustrated by Margaret Cosgrove. Dodd, Mead & Company ($3.95). Since the days of T. H. Huxley comparative vertebrate anatomy has been the foundation of biological and medical education. How many dogfish have been dissected with an eye for homologies! Nowadays biochemistry and genetics are much more fashionable. Nonetheless, this book, written for youngsters in the upper grades, seems to have found precisely the right niche for the old tales of sequence and correspondence in living forms, in the fossil record and in the development of each individual. Nor are these ideas, freed from formaldehyde and a surfeit of Latinity, too difficult for schoolchildren. On the contrary, they make a convincing story of how life works. Vertebrae? Look in a can of salmon. Proportions? Examine the attractively drawn boy, standing on the tips of his fingers and toes, wrists and hands enormously lengthened, proximal limb bones shortened, neck long and sinuous. He has been turned into a hairless deer. The author does not refer to the various books and curricular materials that lead children to seek for themselves the homologies in the bones of a chicken; it is plain that this much more inclusive book is a splendid capping of such activity for the interested somewhat older schoolchild.

HEAR YOUR HEART, by Paul Showers. Illustrations by Joseph Low. Thomas Y. Crowell Company ($3.50). Easily read by eight-year-olds, with plenty of simple diagrams and cheerful pictures of kids and their families, the text tells how to do what the doctor does: hear your heart. You can hear your friend's heartbeat, a baby's faster one and a father's slower one, all with a cardboard tube. A clear account of the heart as a pump is neatly pinned to this experience, although pulse-taking by light touch perhaps comes less easily to children than is made out. The tone is pleasant and thoughtful throughout.

THE LAST FREE BIRD, by A. Harris Stone. Illustrated by Sheila Heins. Prentice-Hall, Inc. ($4.95). Melancholy, strangely serene and handsomely painted, this book tells its eloquent parable in fewer than 100 words. The opening endpapers show a sky of delicate blue with its cumulus billows, strewn with a flock of birds. The final endpapers present the same sky, empty. "Once we were many," the text begins, "before the people changed the land. . . . We could not compete. . . . I am the last free bird."

A PLACE IN THE SUN: ECOLOGY AND THE LIVING WORLD. Written and illustrated by Lois and Louis Darling. William Morrow and Company, Inc. ($3.95). The farms of Connecticut—all but the best land—are going back to woodland. So it is with the quiet valley home of these two experienced artist-authors, who use the place where they live to introduce the story of the abstract chain that begins with the sun and spreads in the cycles of flow and change to all life. It is no easy task to put this attractively for grade school children. The glibness of many such expositions is missing; instead the notion of a model is made clear. Still, the task remains difficult. There are a few pages each on eight other kinds of ecosystem, from ocean to tundra. The chapter on the future breathes an urgent concern, yet a reasoned and hopeful one. This is a good start for a serious young biologist.

The Seas

THE SEA SEARCHERS: MEN AND MACHINES AT THE BOTTOM OF THE SEA, by Terry Shannon and Charles Payzant. Golden Gate Junior Books ($4.50). Drift-

ing silently in the Gulf Stream from Palm Beach to Halifax, Jacques Piccard and an expert crew of five will see and hear the ocean depths in a new way in their deep-research vessel *PX-15,* linked by ultrasonic telephone to the surface tender floating 1,000 feet above them. Here are a few pages describing the plans for the voyage, a photograph of a scale model of the *PX-15* and renderings of the next versions to come. This thin book is an up-to-date account, for sixth-graders and older children, of a whole collection of novel machines and unusual tasks, some accomplished, most still in the future. Some of the machines are manned; some of the unmanned ones have submarine ears, eyes, a magnetic sense and hands for the men on the surface. They are here at every scale of cost and ambition, from a family submarine called *Submaray* to *Deep Star* and *Aluminaut.* There are work boats and recovery sleds, explorers and salvagers, tenders for manned bases and even a two-man archaeological submarine with stereoscopic cameras. It is all, however, rather ugly, very Californian, corporate, insistent and military, like the Antarctic or the moon. It is nonetheless what is happening, briskly told and hard to find out about elsewhere. Captain Nemo of the old *Nautilus* dealt with the big firms too.

IN THE WAKE OF THE SEA-SERPENTS, by Bernard Heuvelmans. Translated from the French by Richard Garnett. Drawings by Alika Watteau. Hill & Wang ($10). Ancient legend and puffed hoax, sober specimen and detailed analysis are spread out in this marvelous mystery for any reader past grade school age who is drawn to the sea. The Belgian scholar-zoologist has combed the world's libraries and newsprint to build his strong case, woven out of 600 sightings considered in detail, that "the legend of the Great Sea-serpent... has arisen by degrees from chance sightings of a series of large sea-animals that are serpentiform in some respect.... Most remain unknown to science, yet can be defined with some degree of exactitude." One chapter, abridged from a second French volume, distills the unshakable arguments (mostly from animals cast ashore) by which the fearful *kraken,* the colossal octopus of medieval writers, was made out to be the real giant squid *Architeuthis,* with measured overall length upward of 50 feet, plus two longer thin tentacles. There is strong reason to believe, from fragments found in sperm-whale stomachs and from huge round sucker scars on the whale's skin, that the biggest squid may well bulk 100 tons and more, with a length of a couple of hundred feet. What a monster to spot at sea watching you with his keen 18-inch eye! The rest of this detailed and well-illustrated book, standing on the firm realities of the arch-squid, spins out its sea-serpent story to the incredulous reader. It is written for people who like to read and to muse; it is not easy or compact, but it is everywhere lively, reasoned and deep, a book to read and dip into year after year, particularly in salt air, anywhere in the world.

THE ELIZABETH: PASSAGE OF A QUEEN, by Leonard A. Stevens. Drawings by Martin Pickwick. Alfred A. Knopf ($7.95). Launched three days before Munich, the 83,000-ton queen of the Cunarders made her final voyage in November. This account of her life and times, complete with pictures from the austere, steely years at Clydebank to rail-perching Folies Bergère girls, centers on Voyage 424 through a severe April storm in 1966. The liner and her people present a familiar romance of her fading era, expressed in the sharp contrast between the technical mastery of the strong hull cleanly cutting the dark and unresponding ocean and the familiar work, warmth and artificial glitter of the small barony within her. Here is the deck chair, the first-class menu and the cutaway drawing of the ship, with attractive interviews with captain, engineer, stewards, chef, pilots, purser, under-officers and others of the traditional cast. The captain is concerned about his waistline but is cooly confident of his ship's safety. There is radar nowadays, and an Ice Patrol, although the ocean is still a testing ground for well-joined steel, good design and craftsmanlike handling. It is difficult to put aside the symbolic quality of such a liner. She hauled anxious crowded troops, nearly a million of them, a division at a time, during the eight years between her first wartime voyage and her demobilization. Her successor will be smaller and less spacious—the jets overhead get bigger each year. Slow giant tankers, longer and three times the bulk of the *Queen Elizabeth,* are the biggest ships today. The book is exactly right for young readers who have sailed or ever hope to sail a voyage by liner.

FOUR WALRUSES: FROM ARCTIC TO OCEANARIUM, by Lou Jacobs, Jr. Young Scott Books ($3.95). SHAMU: THE KILLER WHALE, by Lou Jacobs, Jr. The Bobbs-Merrill Company, Inc. ($4.95). Jacobs tells the story of two pairs of walruses, caught in the Bering Sea and flown to southern California to grow up in special pools, fed as infants on whipping cream and nursed lovingly through an epidemic of lice and through more serious infectious diseases by their keepers. Infant walruses suck their flippers. The droll walrus faces—stout, whiskery and quizzical—are the point of this endearing and simple book. Only Woofy kept his long, shiny white tusks; the others wore them down so severely, even against the rubber-coated sides of the pool, that they loosened and were finally lost to infection of the roots. Another California oceanarium proudly holds the world's only trained killer whale. This second book by the same author-photographer tells about the species, dread predators, and of the capture and training of the half-grown 16-foot Shamu, who gives whale-back rides, jumps precisely to touch a pole held far out of the water, fetches and carries, rolls over on command to play patient, and holds her "doctor's" head in a friendly manner deep inside her toothy two-foot jaws. Sometimes she shakes her head in an irritated way; once or twice she seemed to be angry at too much work. Shamu will grow bigger, until she hits four or five tons. Although the prose may be a little flat, the story of this extraordinary pet will delight and amaze many a young reader.

SEALS OF THE WORLD, by Gavin Maxwell. Houghton Mifflin Company ($6.95). There are 32 living species of the fin-footed order: the true seals, the walrus and the eared sea lions. Every species is described and 28 are shown in photographs in this serious and charming work of reference, each with its distribution, appearance, habits, reproduction and relation to man. The northern fur seal of the Pribilofs (recently found to breed also on an island off the California coast) presents the "largest aggregation of wild mammals... in the whole world." There are half a million pups born every year. For 50 years this species has been maintained and cropped by strictly controlled hunting, after an orgy of killing that would have ended the species had it continued even a few years longer. "I met my mates in the morning,/A broken scattered band./Men shoot us in the water/And club us on the land" wrote Kipling. Men still wreak havoc cruelly on the unprotected species, often skinning baby seals alive in a frenzy of hasty slaughter. "Few people... can view the sealing industry as anything but a degradation to human nature." The text remains calm and factual. There is the other side too. In the legend of the Hebrides

the seals are all but human; they take human form at will, they talk, save fishermen, warn of storm, and men may marry seal women. This is not an intimate book like Gavin Maxwell's famous account of his otters, but it is a readable and yet detailed volume, excellent for library or enthusiast.

PENGUINS: THE BIRDS WITH FLIPPERS, by Elizabeth S. Austin. Random House ($1.95). The endpapers show those little formal fellows, flippers held just so, in procession across the featureless ice. The simple but never stilted text tells something of the life of many species, and something more of how men came on them, tried to understand them, sometimes harmed them, sometimes only admired them. This wife of an ornithologist has had expert counsel to aid her good taste in word and photograph; the result is an inexpensive and attractive thin volume for middle-graders.

THE TIDES: PULSE OF THE EARTH, by Edward P. Clancy. Illustrated by Warren H. Maxfield. Doubleday & Company, Inc. ($1.25). Dr. Clancy is a physicist, a sailor and a writer of imagination and flair. Beginning with the landing of Caesar near Dover (which was ruined by the strong tides unfamiliar to the Roman sailors), he proceeds to tell the story of the theoretical understanding of the tides of ocean, earth and air, and of their practical and scientific uses. He starts off with the inverse-square gravitational law, and produces by clear graphical arguments the results of the tide-raising force that points away from the moon on the earth's far side. (The gradient estimate is made without proof, merely as an argument to show that the vertical forces can be neglected.) The distinction between the theory of tide-raising forces and the true tides is given much in the classic manner of George Darwin. The bore and the seiche are not neglected. Particularly pleasing is Dr. Clancy's habit of making quantitative estimates as he goes along to guide the argument, for example in deriving a plausible estimate for the tidal current flowing into a harbor. This is physics as it is but rarely as it appears in books. There is a well-informed and candid account of tidal power in Brittany and in Maine, and a fine discussion of the ancient earth-moon system, marked by daily rings in the growth of fossil corals. The future of the earth-moon system is clear enough, but the past remains, as Dr. Clancy tells us, uncertain. This is a first-rate book for its own subject and as a model of how theoretical physics ought to work. There are a few good photographs of tidal phenomena, many diagrams, some maps but alas not one real tide curve.

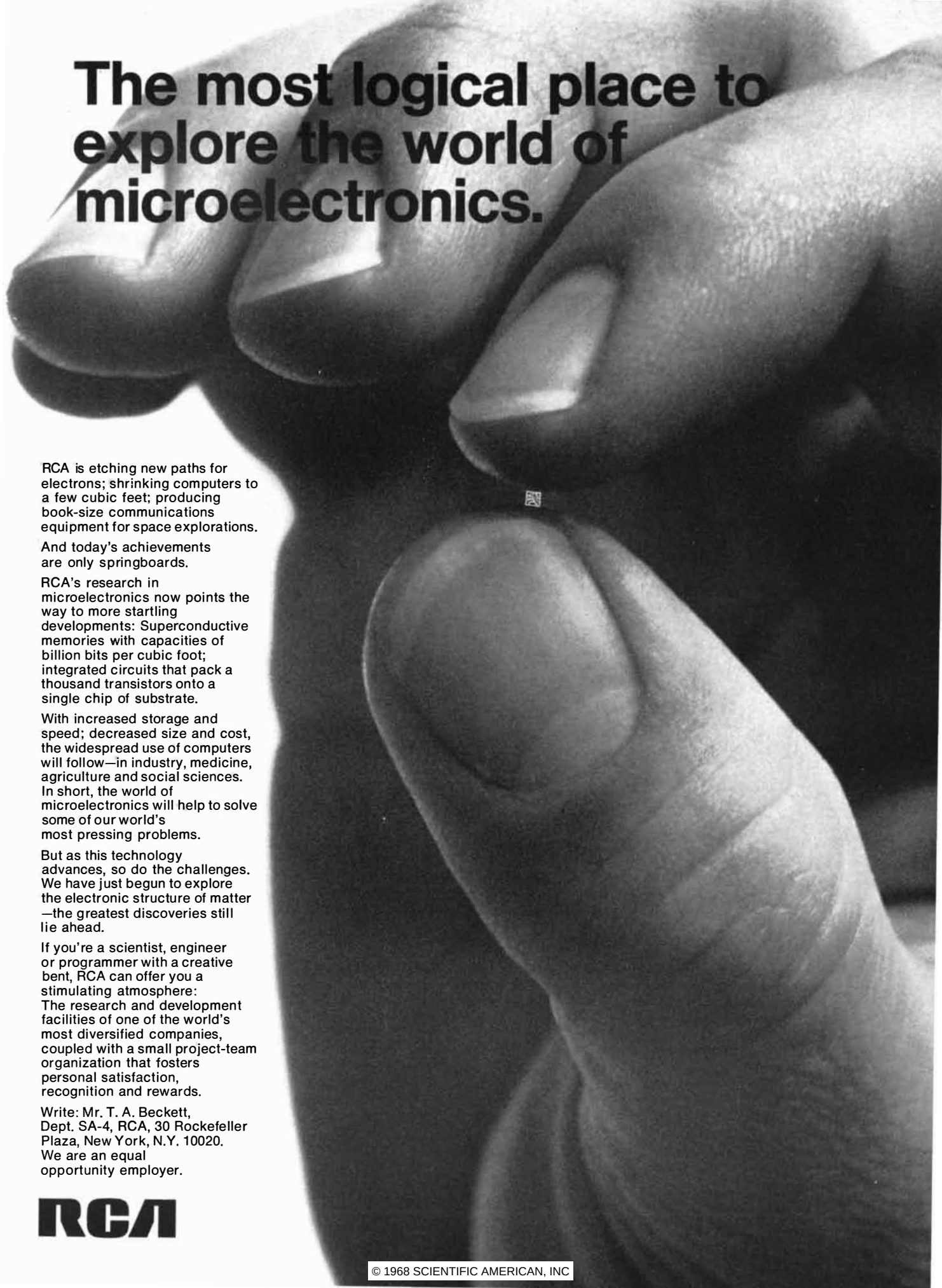
THE SANDY SHORE, by John Hay. Illustrations by Edward and Marcia Norman. The Chatham Press, Inc. ($2.95). Detailed and richly textured paintings ornament this small, handsome book. They present bayberry and blue crab, lobster and moon snail, quahog and scallop and many more shore forms in the style of jewels, each colorful against a blank white background. The account is brief, knowing and devoted, the work of a distinguished Cape Cod naturalist. It could serve as a small field guide (there are many black-and-white sketches too), but it is rather more of an evocation and a souvenir. The herring gull, a scavenger by trade, has multiplied on our careless, rich garbage dumps of the past 40 years; man's relation to the shore is a complex net of many strands. There is no scale indicated in the fine paintings, so that a novice might become confused between a striped bass and a finback whale, which on successive pages appear at about the same size.

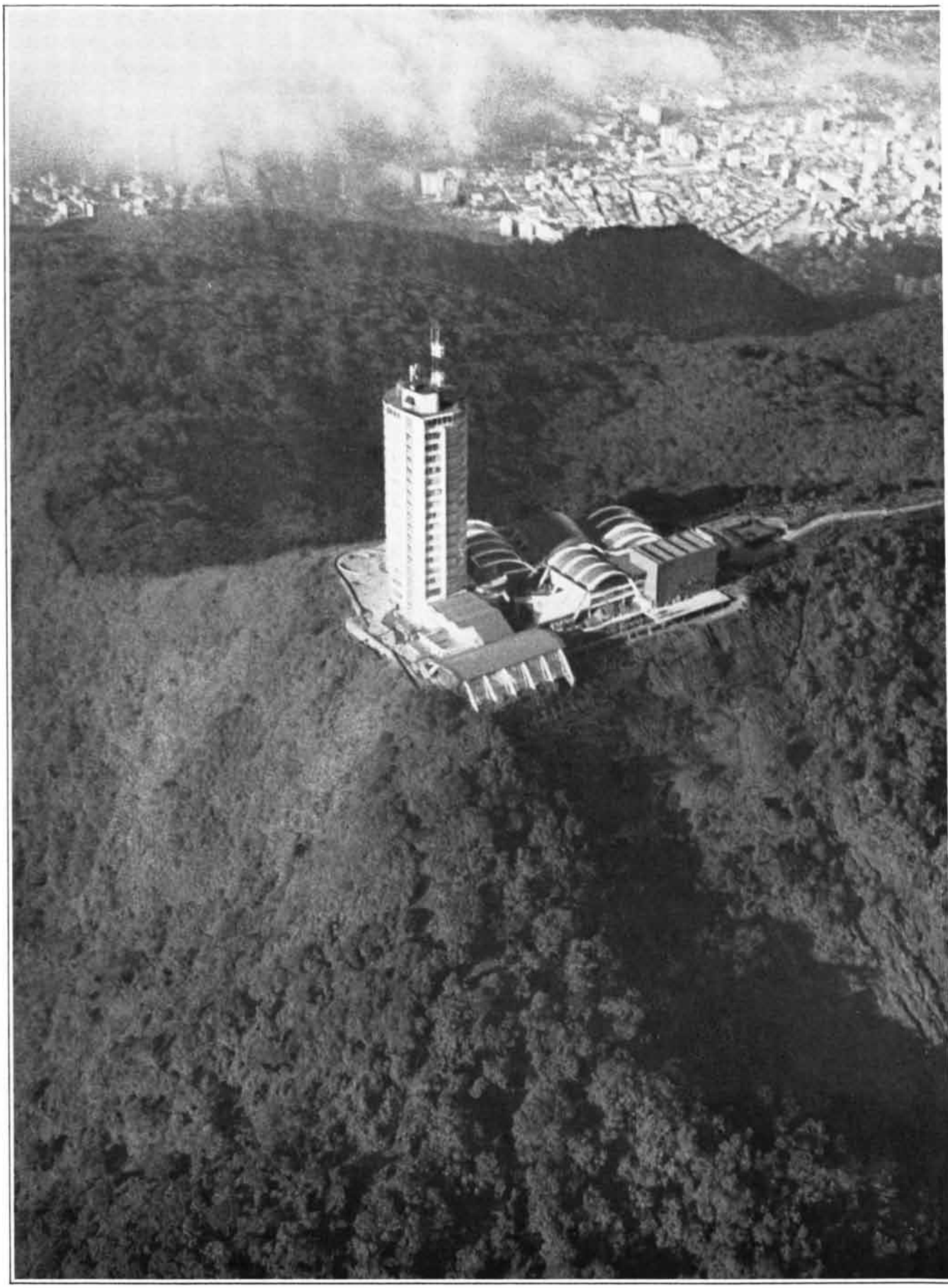
Technology

THE CRIME LABORATORY: CASE STUDIES OF SCIENTIFIC CRIMINAL INVESTIGATION, by James W. Osterburg. Indiana University Press ($5.95). Here is a paperback manual presenting examples of physical evidence found in real cases of detective investigation. The author is an experienced New York detective turned professor of criminology. He aims his text at police officers interested in home study, at police recruits engaged in a course of in-service training, at law students and the like. High school students with a flair for mystery will enjoy the realism of this book, which includes the harsh quality of studying violent crime, probably making the book emotionally, although not logically, unsuitable for younger Sherlocks. The methods are never complex; they always consist in presenting photographs in the range from natural size to 30 times enlarged, and in looking for significant points of similarity in form and marking between a surface of broken glass, a fingerprint, a cut hose end, a cartridge case, a heel mark, a paint chip found at the scene of the crime, and its counterpart associated with a suspect. The cases are presented as problems, and marked photographs are given as solutions by experts. These are not cooked-up examples but real data, and the difficulty of finding the signal buried in the world's noise becomes fascinatingly clear. Which way is right side up? There is no recourse to X rays, spectrochemistry and so on. The instruments used are camera and eye alone, a mirror reversal or a composite photograph marking the edge of sophistication. Even these methods go very far. The world is highly particular on the scale of millimeters. The realism gives the text a rather strong flavor of the prosecution. Professor Osterburg mostly wants to get his man, not to free an innocent. He is not unfair, but he presses. The Supreme Court comes in for some strictures, although objectively he shows that the recent trend away from confessions and bargains in favor of pretrial counsel for all is bound to place more weight on careful physical detective work, and in the end to gain more frequent justice, most particularly for the poor.

CARS, by J. D. Storer. Roy Publishers, Inc. ($3.25). Based on British practice, most of the photographs coming from the big British Ford plant at Dagenham, this is a brief account of how cars are made. The tale begins with design and pricing, with twin teams of stylists and engineers, through sheet-steel procurement, diemaking, stamping and assembling and finishing the bodies with "trim," then mating them on the assembly line with the running gear and the engine, the products of highly automated machine tools. The wheels come last, and testing begins. The automobile industry is international enough to make this British story understandable to car-minded American children; a few terms such as "vetting," "saloon" and "boot lid" may add a puzzling and exotic note. There seem to be too few books on cars, considering their importance and interest; this is a workmanlike example.

CREATIVE GLASS BLOWING, by James E. Hammesfahr and Clair L. Stong. W. H. Freeman and Company ($8). If metalworking is worldwide and ancient, the joining and shaping of manufactured glass tubing by hand in a gas flame, called "lampwork" in the trade, is a small and specialized craft that is indispensable to science. It is only a century since Hammesfahr's grandfather first brought some of the techniques to this country from Germany and Bohemia. With a few specialized store-bought gas burners at a couple of dollars each, the compressor from a junked refrigerator, a household gas supply, a stock of four-foot lengths of tubing and rod, a few ordinary tools and "a good fire and a pair of dexterous hands" you can become a glassblower. Students in chemistry, biology and phys-





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The Sheraton-Humboldt is one of an international Sheraton chain of hotels and motor inns that can now serve you better because it is part of ITT.

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Such a facility is to be built close to the University of Vermont Medical Center Hospital in Burlington. Rates will be substantially lower than the existing private and semi-private rates at local hospitals.

This unique development is but another example of how ITT's resources and philosophy of competitive growth can respond to changing needs in a changing world.

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ics once had to learn this craft; now they come to depend on the wider range of machine-made items and on the professionals. Here is how that expert works Colorful, droll figurines and jewelry can also be made by lampwork as an absorbing hobby for young and old. It is fun to watch, and it is more fun to do—although it can be frustrating to learn. It is all remarkably vivid in the clear, detailed, scientifically insightful text and marvelously penetrating line drawings of this book, a model of how-to-do-it books that has few peers for quality of teaching. School shops, attention! The reader has a rare advantage here: the book makes everything seem so real he will understand what he has only read about almost as though he had actually done it. Let us hope there will still be plenty of doers.

METAL TECHNIQUES FOR CRAFTSMEN, by Oppi Untracht. Doubleday & Company, Inc. ($19.95). This remarkable volume is by no means aimed at young people; it is subtitled "A basic manual for craftsmen on the methods of forming and decorating metals," and that it is. It is also much more than that. It contains some 700 photographs and drawings throughout the text. In these pictures there is spread before the happy reader not only a treasury of beautiful objects in metal from all the world and all the past but also many sequences showing craftsmen (and craftswomen) at their work. On one pair of pages you can see a careful piece of repoussé being done on a silver water pitcher by a Copenhagen worker for the firm of Georg Jensen, a Tibetan craftsman in Kalimpong chasing a silver spoon and a Bangalore metalworker working a large copper plaque in high relief. All these men hold the work by a single technique: pressed against pitch. The text pages tell how to prepare and use the pitch medium for each purpose, and include a paragraph on how to remove the work from the pitch and the pitch from the work. Overleaf is a catalogue display of the tools and stamps listed by a New York supplier. A long and detailed list of sources of supply (for the U.S. and Britain) is given at the end, and there is a photograph of a sidewalk jeweler's supply shop, its owner crouched beside his tool-crowded shelves, taken in the Indian city of Tiruchirapalli. Many of the photographs are the fruit of travel by the author himself, particularly in India. The book is short of encyclopedic; one big volume cannot encompass the fullest detail, but it provides a genuine start toward a dazzling variety of techniques. The book opens with an introduction to metals and their properties, with small-size wire-drawing and sheet-making in sterling silver described fully as an example. All the schemes of hand cold-working and finishing, such as chasing, etching and stamping, are next, followed by the inlaying methods, then by soldering, niello, mokume and granulation. The forming of metals by raising, spinning, forging, welding and casting are here, methods as old as lost wax and as new as centrifugal investment casting and electroforming. The last chapter is a guide to hand tools, and there is a long appendix of tables for wire sizes, sheet weights, densities, areas and the other hard facts useful for the handcraftsman in metal. Any young craftsman working in metal would find this book a practical guide and a constant inspiration. It would be a prized possession for any school or group shop working in metals by hand. It never recognizes the machine tool, except for a metal-spinning lathe. Nonetheless, it invests the objects one sees with a sense of their origin.

WE FLY, written and illustrated by Alfred Olschewski. Little, Brown and Company ($3.75). A gay history of man's flight, from Icarus through Montgolfier, Zeppelin and Lindbergh to the moon voyage. Colorful and childish drawings, with a text sentence or so per page, that capture the spirit more than the letter of aeronautical design. Apollo astronauts will surely wish they were given such a fine clear nose cone through which to view the man in the moon!

THE STORY OF COINS, by Sam Rosenfeld. Illustrations by James E. Barry. Harvey House, Inc. ($3.95). A smooth and interesting path for young people into the collecting of coins, this book at first presents a garish appearance that is not at all borne out by the intelligence and attractiveness of the text and the many illustrations. Barter is the ancient means of trade, still familiar in the boy's world of baseball cards; coinage followed barter, first in China, when small bronze models were substituted long ago at the end of Shang time for bronze farming implements used as standard trade goods. Here we see the old knife coins, then examples of those die-stamped owls and fish and gods that mark antique coinage. The history of American coins is told in some detail with many illustrations of coins as well as curiosa. Old and new means of stamping are shown. The young collector is introduced to how to store and clean (don't do it) his coins, how to find mint marks

and is given a plausible price list. This is an exemplary primer. Collecting is not science, although this form of it teeters on the brink of the history of art and technology. It could be given depth by discussing coin weights and coin wear with age, and by suggesting the interesting statistical conclusions one can obtain from recording and measuring the coins of common usage. Nonetheless, the book does provide the context for such a study, and after all numismatists are numerous.

SOLAR ENERGY, by John Hoke. Franklin Watts, Inc. ($2.65). Clearly written, this unusual little book is based on the availability of small boron-diffused silicon photovoltaic cells, which are now the common power sources for space probes. A brief, well-illustrated review of the larger context of the use of solar radiation begins the book. With very little demand on theory, the text then tells young readers—say junior high school students—how to make a number of clever and attractive devices by the assembly of commercial components. Even the ideas of series and parallel are fully here in a low-key way. There is a simple solar still that collects energy with a sheet of plastic wrapper, but most of the devices are solar-cell users. The directions are not at all in cookbook style but rather conversational accounts of the general plan and the trickier points. One must learn how to solder. The sun-hunting sundial is the most charming device described. Full addresses of suppliers and a catalogue of parts that can be bought are given. The list is indispensable, but the unfortunate suppression of even approximate prices will lead to many a disappointed young engineer. These parts cost dollars, not dimes.

HOW TO READ A CITY MAP, by Dorothy Rhodes. Photography and cartography by the Aerial Surveying and Engineering Co. Elk Grove Press, Inc. ($3.79). Almost every geography book has a page on which an aerial photograph is confronted by the corresponding map; this page is intended to give the young reader some understanding of the subtle symbolism that is the convention of the map. One knows how many people grow up foreign to maps, and how much they lose. Here is an attractive effort to bring about a change. The long pages of this book for young children contain photograph after photograph—school, freeway, reservoir, bridge and so on—and the map segment, carefully and boldly abstracted, that the photographs represent. Even here it may be that the abstractness even of the direct but tiny projection we call the aerial photograph is approached too quickly. Nonetheless, this book is a most serious effort to meet the real problem. Any family that wants its youngest to learn about maps can make good use of this book; it is the next best thing to getting aerial photographs of your own home or school.

THE FIRST REACTOR, U.S. Atomic Energy Commission, Post Office Box 62, Oak Ridge, Tenn. 37830 (free). This small booklet, whose covers bear a color painting of the 1942 day in Chicago when the "Italian navigator... landed in the New World," tells the story three ways: first, in a journalist's breezy coverage of the event, carefully assembled in 1946; second, in a few pages by Enrico Fermi himself, written in 1952; third, in a few graceful pages by Laura Fermi of how it seemed to her. This excellent work—a real best buy, considering the price—is a superior member of a continuing series of free booklets (listed on the cover) that intend to open the complex nature and history of atomic energy to young people. They deserve wide diffusion, particularly to schools and libraries.

Man

SURVIVAL ARTS OF THE PRIMITIVE PAIUTES, by Margaret M. Wheat. University of Nevada Press ($10). In the salt desert sinks of western Nevada, from Walker Lake north to Pyramid Lake, there live three bands of the northern Paiutes. They were a roaming people, gathering their food from the briny lakes, the desert plants and the wary jackrabbit. They went naked most of the time; in winter they used a rabbit-skin blanket both as clothing and as bedding. They built their round willow shelters as they needed them, often returning to the same place in the cycle of the year. Their life was not much easier than that of the Kalahari bushmen of Africa. This book, devotedly written, filled with clearly sequenced photographs, precise oral accounts and the testimony of people we come to know, is the work of a woman who for 20 years has traveled among her Paiute friends with camera and tape recorder. Here she displays their subtle and often beautiful handiwork: the arts of survival and the arts of pride. The duck decoy with a cattail frame inside a real duck's skin; the harpoon with point and shaft held together

with pine pitch; the deadfall, made of four sticks, two pine nuts, a piece of string and a flat rock; the boat fashioned of tule reeds and cattail. "Lacking nails, bolts and screws, and having little to use for adhesives, the Paiute Indians tied their world together." One is shown how to make a net of dogbane stalks; "the string about the size of kitchen twine is so uniform it is hard to believe it was made by hand." Not long ago a great rabbit net 300 feet long was so made. Here too is the boat-cradle woven for the newborn out of willow. "Childless couples were pitied"; the Paiutes savored the gift of life. This poignant and valuable work, a treasury of detail, was issued without an index. The University of Nevada Press should have one made.

PIRATE PORT: THE STORY OF THE SUNKEN CITY OF PORT ROYAL, by Robert F. Marx. The World Publishing Company ($4.95). THE SEARCH FOR ATLANTIS, by Henry Chapin. Crowell-Collier Press ($3.50). Archaeology today digs and dives. Marx is a diver, Underwater Archaeologist for the Government of Jamaica. He is leading the divers who slowly reclaim the artifacts and debris of the sunken pirates' town, a sister harbor to Kingston wrecked and mostly submerged by an earthquake and tidal wave in 1692. His is a firsthand account, in the nature of an abbreviated journal, and it is salty with the sea. Pieces of eight and clay pipes and pewter bowls come up. The second book is a small gem, carrying the reader from Plato and the scholars past the bizarre cultists of lost Atlantis to the modern reasoned guess that there in the Aegean, on an island called Thera, a huge volcanic explosion sank the great city, stranded its far-flung colonies to wither and cut off the mainland Greeks from that heritage they dimly knew as the Minoan culture. This is a book of hope, not of solutions, and it is a diver's invitation to the future.

ANIMALS THAT CHANGED THE WORLD, by P. D. C. Davis and A. A. Dent. Crowell-Collier Press ($3.95). This small, dense book—well made apart from a slightly dark halftone reproduction or two—is an adaptation of the almost classic monograph *A History of Domesticated Animals*, by Frederick E. Zeuner. It covers all the old successes of domestication, from dog and horse to cheetah and cormorant. The familiar domesticated forms were social in the wild state, save the cat, who "walked by himself." It is a first-class work for teen-agers; it is different from the Zeuner in price, in

length and in the absence—an all too complete absence—of notes and reference to sources.

STILTS, SOMERSAULTS, AND HEADSTANDS: GAME POEMS BASED ON A PAINTING BY PETER BREUGHEL, by Kathleen Fraser. Atheneum ($3.75). Almost everyone knows the painting by the elder Breughel that forms the opening pages of this book. The author, a young American poet and a new mother, presents details of the painting in which she recognizes nearly 40 games and forms of play. She gives us a poem for almost every game, bridging the 400 years since that time with our own memories. "The recipe for mud pie/is one cup of water/ and enough dirt..../But don't eat it!/ Give it to a beetle."

WHY THE SUN AND THE MOON LIVE IN THE SKY, by Elphinstone Dayrell. Illustrations by Blair Lent. Houghton Mifflin Company ($3.25). A CROCODILE HAS ME BY THE LEG, edited by Leonard W. Dobb. Illustrations by Solomon Irein Wangboje. Walker and Company ($2.95). AFRICAN VILLAGE FOLKTALES, by Edna Mason Kaula. The World Publishing Company ($3.95). THE LONG GRASS WHISPERS, by Geraldine Elliot. Illustrations by Sheila Hawkins. Schocken Books Inc. ($3.95). WHERE THE LEOPARD PASSES, by Geraldine Elliot. Illustrations by Sheila Hawkins. Schocken Books ($3.95). In increasing order of reading difficulty these are five books of African folklore. The first is a simple tale, explaining that the water and all his people were invited to visit, and were so numerous that the sun and moon had to leave their crowded home and go up into the sky. It is an authentic tale told by the river people near Calabar, first published in 1910. The little book is stunningly illustrated, with bold designs of huts and masked actors all done in blues and browns, very like indigo and ocher. The pictures are not intended to be ethnographic; they have been "influenced by all Africa and they do not represent any one tribe or African country." They are nonetheless truly lovely, and they seem at home with the tale. They present the cosmological myth as a piece of high theater, enacted by real people wearing magnificent masks and costumes. The second work, whose editor is a well-known Africanist, sets out direct, often moving folk verse collected from many parts of Africa. "Why do you cry? You are the child of a yam farmer. Why do you cry?" The book is handsomely illustrated with strong warm woodcuts in red and black by a Nigerian artist and teacher. The third book is more prosy; it is a collection of folktales from all Africa, each with a clarifying introduction as to the people whose story is told. They are good stories, told simply enough to be read by children in the middle grades, or aloud to younger ones. The author has included her own pencil sketches of animals, of village and of modern city life, drawn on her own widespread travels. The last two books, which are related collections of Bantu tales from around the big Rift lakes, hold many stories "full of laughter." They are told straightforwardly in a rather motherly style; the typography of the two books differs sharply, the last one striking a somewhat old-fashioned note.

History and Biography

THE STORY OF SCIENCE IN AMERICA, by L. Sprague De Camp and Catherine C. De Camp. Illustrations by Leonard Everett Fisher. Charles Scribner's Sons ($4.95). Franklin and Cotton Mather, Audubon and Rafinesque, Gibbs and Veblen, James Watson and Thomas Watson—a long and varied parade of many more Americans saunters by. This book, with its elegant white-on-black scratchboard drawings of telescopes and travelers, manages to convey a sense of coherence, even though it deals at staccato length with so many men, trends and ideas in science, engineering and exploration. The reason is partly in the expert writing—smooth, unusually candid, cheerful and sometimes a bit condescending (as in the two or three pages about Veblen). The book is coherent partly because of its very catholicity, which quite properly recognizes that the sociologists and the anthropologists and the time-study men belong to the story as much as the inventors of aircraft and the explorers of the Colorado valley do. Not all the dicta of the authors seem reasonable, but to find any personal judgment at work is so rare in this kind of pedagogy that one is pleased by the De Camps even when one disagrees with them. For children of 12 and up (not much up).

WILHELM CONRAD RÖNTGEN AND THE DISCOVERY OF X RAYS, by Bern Dibner. Franklin Watts, Inc. ($3.95). In the decade after the discovery of X rays papers on the subject appeared at the rate of 15 a week. Röntgen himself was so modest and earnest a researcher that in seven years he launched into the torrent just

two papers after the initial one, which is reproduced here. One can also read of the University of Pennsylvania physicist who had found strange black spots on plates kept near a cathode ray tube six years before Röntgen but couldn't see how they got there. The brave Elihu Thompson, reading in the fall of that first frenzied year of X rays that long exposures perhaps burned the skin, exposed his left little finger close to a tube for half an hour. The scar after the slow healing remained all his life—the first controlled evidence for the fact of radiation damage. There are many original photographs, drawings and facsimiles in this authoritative book, which will be good reading for teen-agers and their parents.

CHARLES DARWIN AND THE ORIGIN OF SPECIES, by the editors of *Horizon Magazine*, Walter Karp and J. W. Burrow (consultant). American Heritage Publishing Co., Inc. ($4.95). CHARLES DARWIN, by Robert Olby. Oxford University Press ($1.55). Indian and Javanese audiences will sit for hours to hear once again the tales of the *Ramayana*, which everyone knows well. Indeed, much of the art of these lands features the same events. One begins to have the impression that the life of Darwin will become the *Ramayana* of science. There is dear Emma to play Sita, there is the fatherly advice of the sage Uncle Jos. Wedgwood that makes possible the pilgrimage of the *Beagle*. There are the terrible but essential Galápagos; there is the war against the demons, and the staunch allies, the apes; there is the faithful Huxley for brave Lakshman at one's side; there is the beetle's bite and the strange affliction; there is triumph. Here are two new versions. The first, the product of a high-quality book factory, is well written and is illustrated with an attractive and wide-ranging, if sometimes mainly decorative, set of colorful pictures. Victorian London and the voyage are evoked, but they are a bit overwhelmed by an East Indian tree of life and by hunting prints. The contemporary watercolors of the Darwins, and of ships and jungles and houses, are nonetheless good to have. The second book, which has nearly as much text in less than a third of the weight, is a spare, clear narrative by one author. It presents the needed photographs in black and white. Uncle Jos.'s words are here (they are not in the grander book). Taste and pockets differ; all are well served by one or the other of these books, which are for readers in their teens.

ANNUAL INDEX

The following index lists all the authors and articles that appeared in SCIENTIFIC AMERICAN *during 1968. Also indexed are "Mathematical Games," "The Amateur Scientist" and the principal book review in each issue.*

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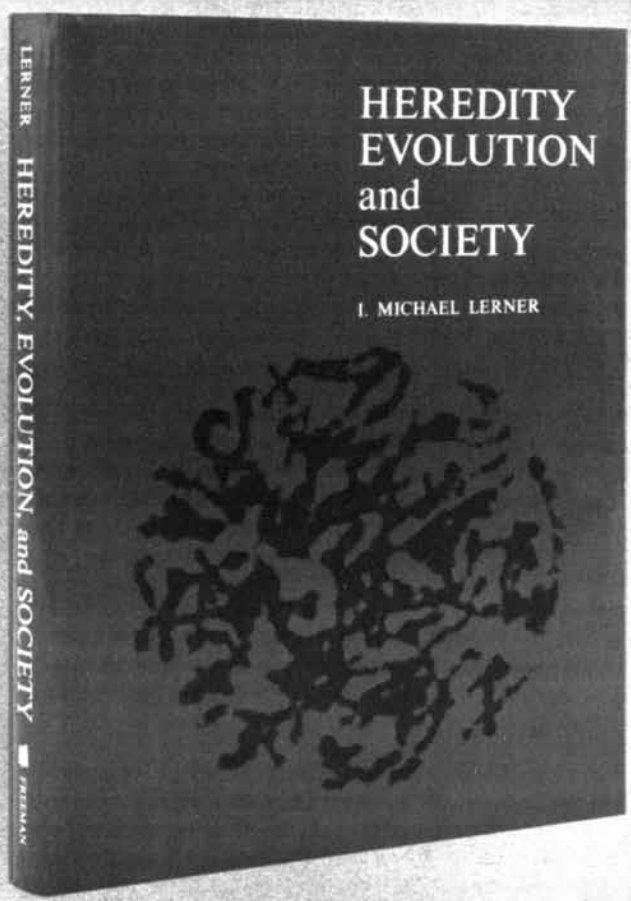
ARTICLES

MATHEMATICAL GAMES

THE AMATEUR SCIENTIST

BOOKS

"a review of human biology for every thinking citizen in the latter third of the twentieth century"



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I. MICHAEL LERNER University of California, Berkeley

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—Askell Löve, Chairman, Department of Biology, University of Colorado

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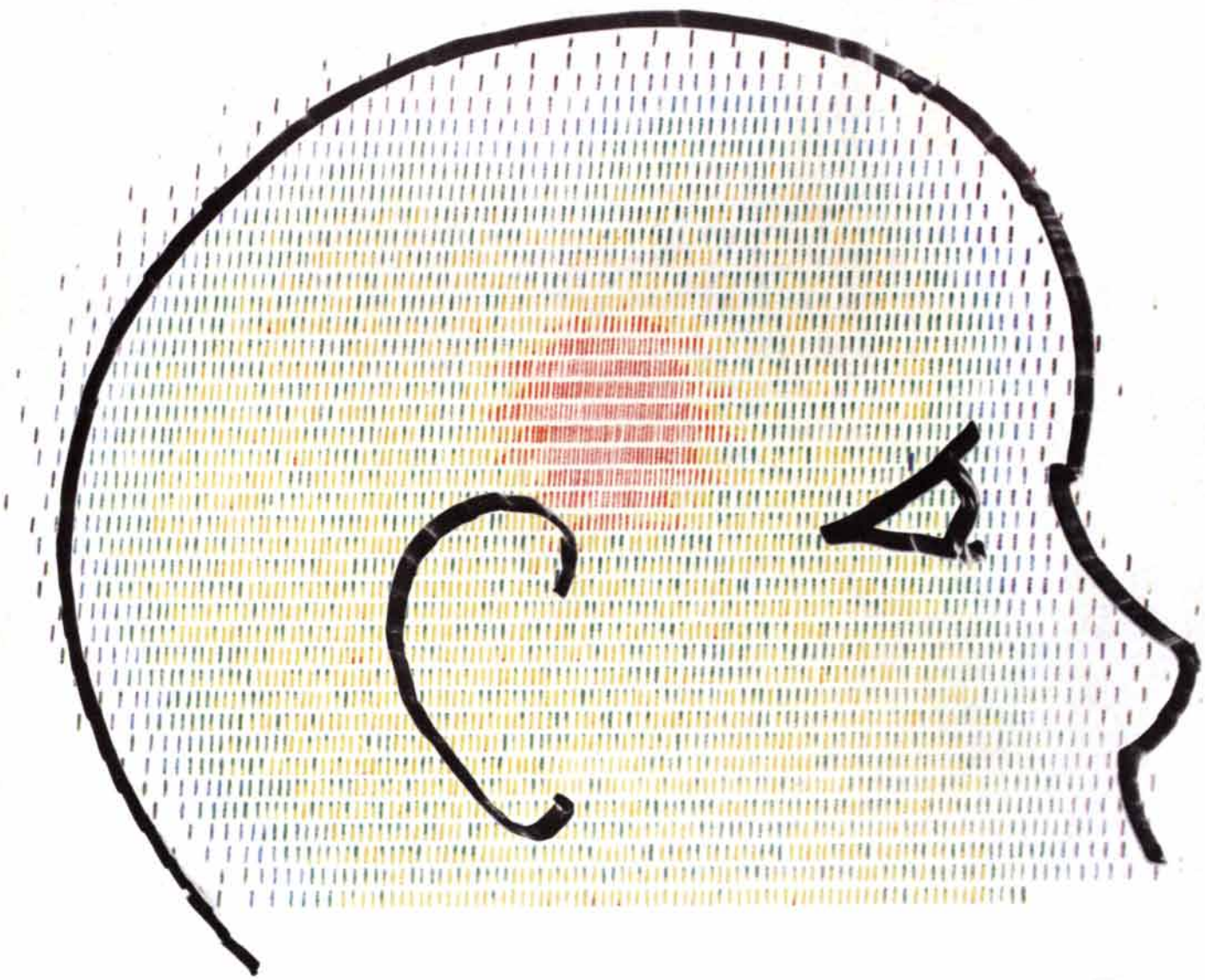

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