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January 1971

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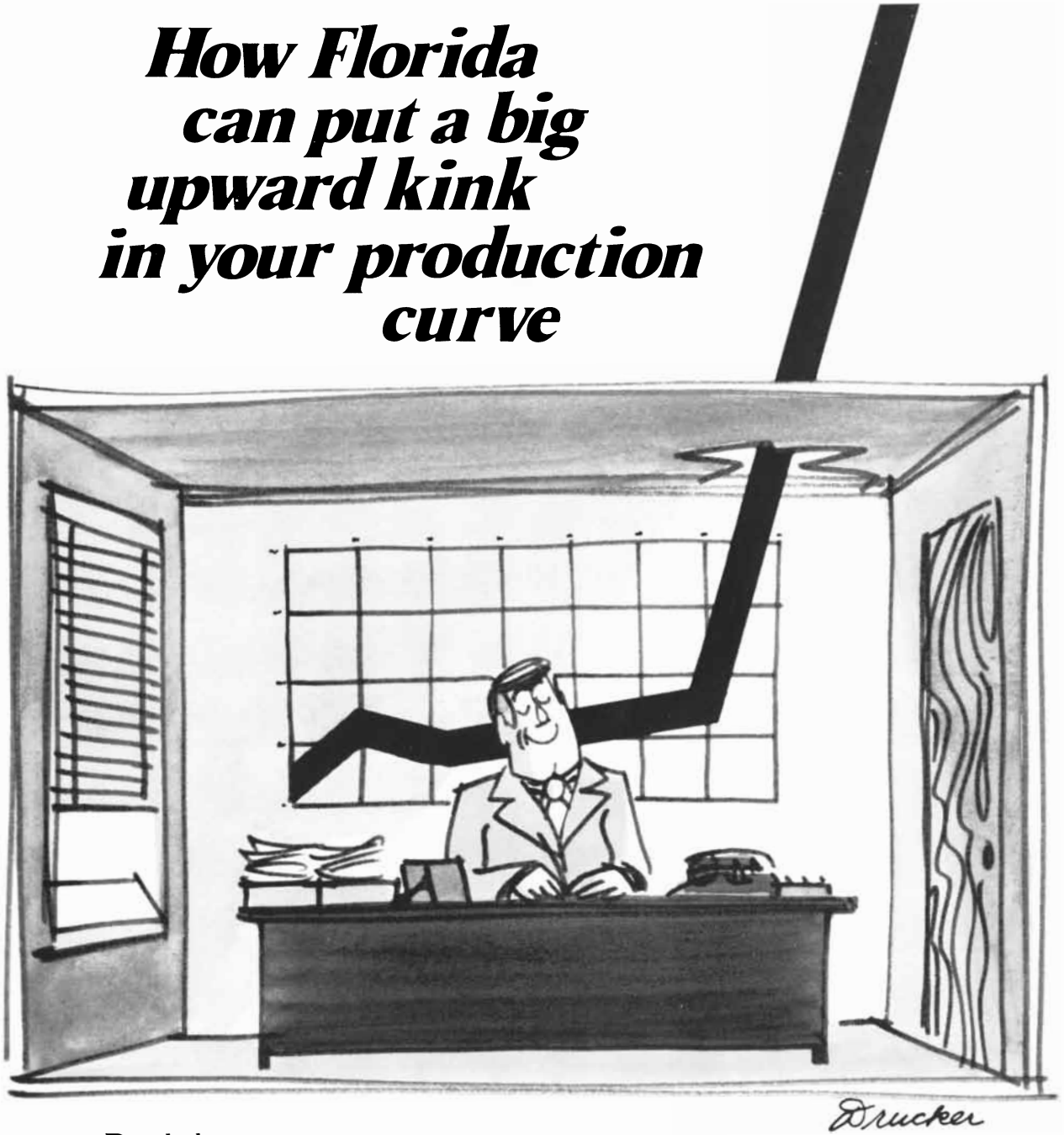

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In the minds of many, modern technology has created a monster.

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We've all heard the stories about people making, say, a $30 purchase. And then being billed for $3,000 by the computer.

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Yet, computer-assisted instruction is not a concept which has been enthusiastically embraced by all. There are many who feel that the computer will replace teachers.

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The computer is indicative of our present-day technology —a technology which has advanced to such an extent that man now is capable, literally, of changing his world.

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ARE THEY FOR US OR AGAINST US?

Established 1845 **SCIENTIFIC AMERICAN** January 1971 Volume 224 Number 1

ARTICLES

DEPARTMENTS

PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK, N.Y. 10017. SECOND-CLASS POSTAGE PAID AT NEW YORK, N.Y., AND AT ADDITIONAL MAILING OFFICES. AUTHORIZED AS SECOND-CLASS MAIL BY THE POST OFFICE DEPARTMENT, OTTAWA, CANADA, AND FOR PAYMENT OF POSTAGE IN CASH. SUBSCRIPTION RATE: $10 PER YEAR.

THE COVER

The photograph on the cover shows three of the circuit breakers that protect a 500,000-volt line at the Brown's Ferry, Ala., switchyard of the Tennessee Valley Authority. Built by the General Electric Company, the circuit breakers employ a blast of high-velocity air to extinguish the intense arc that forms between the electrodes of the breaker when the circuit is opened. The various stratagems that can be employed to tame such arcs are described in the article "Circuit Breakers" on page 76. The air-blast mechanisms are housed in the horizontal tanks directly below the silver-colored canisters at the top of each unit. The canisters are mufflers that reduce the sound of the rushing air when the breakers are actuated. The path of the high-voltage current through an air-blast breaker is depicted on page 82.

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Cover photograph by Paul Weller

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LETTERS

Sirs:

"Intelligence and Race," by Walter F. Bodmer and Luigi Luca Cavalli-Sforza [SCIENTIFIC AMERICAN, October, 1970], neglects the possibility that I have stressed since 1966 of using gene frequencies, for example T. Edward Reed's Caucasian gene (*Science*, August 22, 1969), to analyze the effect of race mixture on intelligence within uniform slum environments. My own preliminary research suggests that an increase of 1 percent in Caucasian ancestry raises Negro I.Q. about one point on the average for low-I.Q. populations. The authors' neglect of these research possibilities is in keeping with their irresponsibility toward the essential moral point.

If what I fear is true, our society is being profoundly irresponsible. Our nobly intended welfare programs may be encouraging dysgenics—retrogressive evolution through disproportionate reproduction of the genetically disadvantaged. This national illness probably occurs for whites as well as blacks. But it may be much easier to diagnose for the blacks because of the research possibilities offered by the Caucasian-gene effect.

To fail to use this method of diagnosis for fear of being called a racist is irresponsible. It may also be a great injustice to black Americans themselves. If those Negroes with the fewest Caucasian genes are in fact the most prolific and also the least intelligent, then genetic enslavement will be the destiny of their next generation. The consequences may be extremes of racism and agony for both blacks and whites.

I believe that a nation that achieved its 10-year objective of putting a man on the moon can wisely and humanely solve its human-quality problems once the objective is stated and relevant facts are courageously sought. I urge your readers to write to their legislators to demand high-priority research on what I maintain is our nation's most agonizing problem.

W. SHOCKLEY

Stanford, Calif.

Sirs:

Although I agree with the statement of Bodmer and Cavalli-Sforza that in a genuinely democratic society the demonstration that there are genetically determined racial differences in I.Q. should not "make any difference," I must disagree with their conclusion that the only approach to the question of the existence of such differences is through the study of transracially adopted children.

Another approach is available owing to the peculiarity that American society treats as black anyone who derived even a relatively small portion of his genes from the African gene pool. Consequently it should be possible to obtain a series of I.Q. measurements from persons living under essentially identical social conditions but who have different portions of their genotype derived from the African gene pool.

If the hypothesis of a genetically controlled inferiority of I.Q. in the black as compared with the Caucasian race is correct, then there should be a strong positive correlation between I.Q. and the fraction of the genotype derived from the Caucasian gene pool. I personally do not expect such a correlation to exist.

WERNER G. HEIM

Professor of Biology
Colorado College
Colorado Springs, Colo.

Sirs:

I sincerely hope that the article "Intelligence and Race" in the October *Scientific American* is published as a result of a momentary lapse of consciousness on the part of your editorial board and is not indicative of a new policy regarding the quality of material acceptable to your magazine. Quite aside from the outrageous conclusion regarding acceptable areas of research, the article is a mine of unwarranted assumptions, logical inconsistencies, unfounded conclusions and biased emotional rhetoric.

Publication of such material, more properly in the realm of the radical press, detracts severely from the status of *Scientific American* and, by implication, the work of other scientists who are published in your journal. In the now slightly passé phrase, your credibility is diminished by articles such as this. In an era in which intellectual rigor is increasingly scorned and pride of place given to emotional "relevance," a journal such as *Scientific American* has an even greater responsibility to maintain standards in the material it accepts for publication.

Let us have no more of this kind of thing.

ALFRED E. BIGOT

Minneapolis, Minn.

Sirs:

Both Dr. Shockley and Dr. Heim suggest another method for attempting to demonstrate the existence of a genetic component in the racial differences in I.Q. The method is based on the estimation of the degree of racial admixture, mainly using polymorphic genes but also perhaps using skin color and other phenotypic differences. An assessment is then made of the correlation between the degree of racial admixture and the average I.Q. We omitted this possibility not, as Dr. Shockley suggests, because of lack of responsibility but because we believe the method does not allow the necessary separation of genetic and environmental components of the variation between races. With the use of a single marker, as Shockley is apparently suggesting, the method has to be applied to entire groups and not to single individuals, and even then there are appreciable

Scientific American, January, 1971; Vol. 224, No. 1. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York. N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and treasurer.

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

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problems in establishing, even approximately, the extent of racial admixture; this has been shown by the work of Glass and Li, of Workman and his colleagues and of Reed, in which several markers were actually employed. Groups with different degrees of admixture of white and black genes would have to be studied for their average I.Q. It is known, however, that the degree of white admixture in different U.S. black communities varies from less than 10 percent to 30 percent or more, with a South-North gradient and possibly other important sources of geographical variation. For this knowledge to be useful in solving the problem at issue, the assumption has to be made that the environment is the same for all these populations and that there is no correlation between differences in the environment and the extent of black-white admixture. It is difficult to believe such an assumption could be correct.

It is of interest that the preliminary report by Dr. Shockley that "an increase of 1 percent in Caucasian ancestry raises Negro I.Q. about one point on the average" in itself throws considerable doubt on the validity of the approach, although it is not clear what Shockley really means by "low-I.Q. populations." If there were a clear-cut genetic difference between blacks and whites for I.Q. based on a mean race I.Q. difference of 15 to 20 points, an increase of 1 percent in Caucasian ancestry should lead to an increase in I.Q. of at most .1 to .2 point, which is at least five times smaller than what is claimed by Shockley. The discrepancy is such that the increase he claims would make a black with 50 percent white genes much more intelligent on the average than an average white, and a black with 100 percent white genes (who would be an average white) an absolute genius. This absurd result must derive from there being in the material examined genetic components that are far from additive or, more probably, from complex genotype-environment interactions. To put it simply, "uniform slum environments" surely do not exist, and sociocultural effects are too complex to be straightened out by some simple statistical analysis.

The letter from Mr. Bigot reflects the kind of emotional and irrational response that any attempt to discuss such delicate social issues as the race-I.Q. difference can engender. We leave it to the reader to judge how seriously such a response should be taken—or whether in fact Mr. Bigot himself is serious.

Dr. Shockley and Dr. Heim obviously disagree on the social conclusions to be drawn from the research they suggest. Dr. Shockley does not in his letter, and to our knowledge has not in the past, clearly stated what social measures (other than the differential restriction of reproduction) would follow if his fears concerning dysgenic effects turned out to be true. As we have stated, we believe that neither the existence nor the nonexistence of a genetic component in race-I.Q. differences should have an effect on educational and social practices. Our suggestion that appropriation of public funds for the support of studies on the genetic component of the race-I.Q. difference should not be particularly encouraged was not meant as a proposal to bar well-founded research on this question but was especially directed against the "putting a man on the moon" approach apparently being advocated in the last paragraph of Dr. Shockley's letter. In our view it would be more responsible to devote that kind of effort in the U.S. to solving social and economic problems, racial or otherwise, in terms of the environment.

WALTER F. BODMER

Oxford, England

LUIGI LUCA CAVALLI-SFORZA

Pavia, Italy

Sirs:

Mr. Pope's letter ["Letters," SCIENTIFIC AMERICAN, September, 1970] concerning the effect of the introduction of the metric system on proverbs and sayings was doubtless written tongue in cheek. However, since this is an item that crops up regularly whenever the metric system is discussed (together with some accompanying ludicrous examples), I should like to point out that there has been no such effect in any other country that has adopted the metric system.

Among examples to support the belief that American proverbs and sayings will be no more easily destroyed than those of other nations are the phrase "penny wise, pound foolish," which, in spite of the change to decimal currency a long time ago, has not vanished from American speech, and that giants still walk in "seven-league boots."

HANS SCHROEDER

Milwaukee, Wis.

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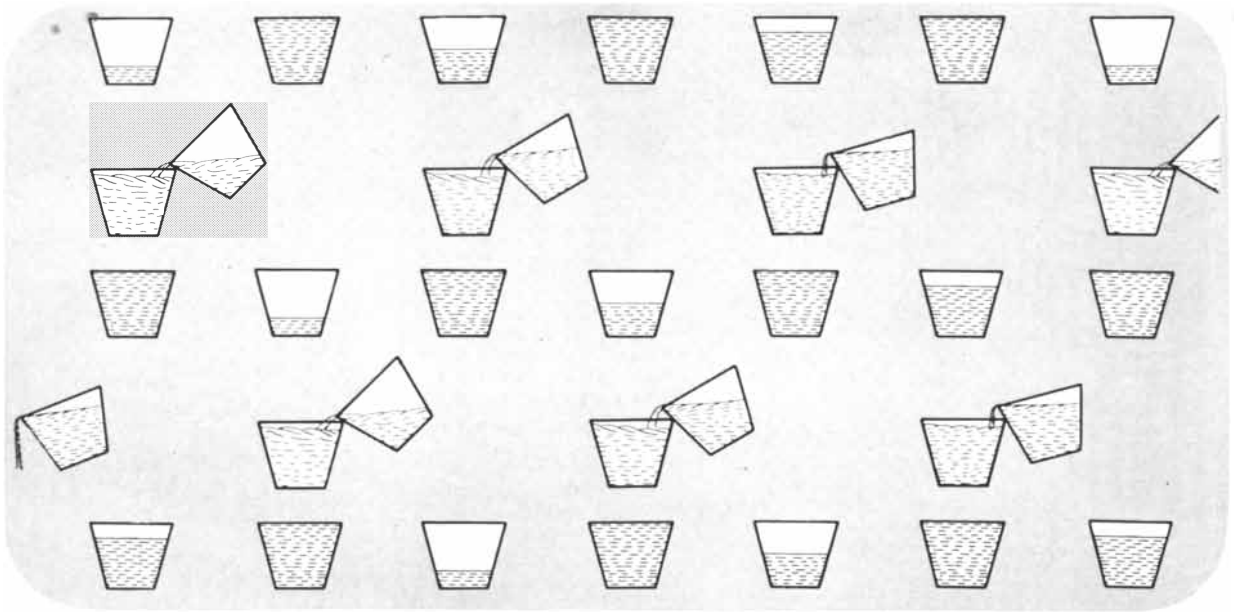


How can you store information in a row of buckets?

Using buckets to store information is hardly a thought that springs readily to mind. Nevertheless our new electronic delay line is strikingly analogous to a row of buckets and in fact, is called the bucket brigade delay line (we did not invent the name, so no double-dutch comments, please).

Until recently, designers were unable to store analogue signals by simple electronic means. The alternatives were all bulky, difficult to vary and relatively expensive.

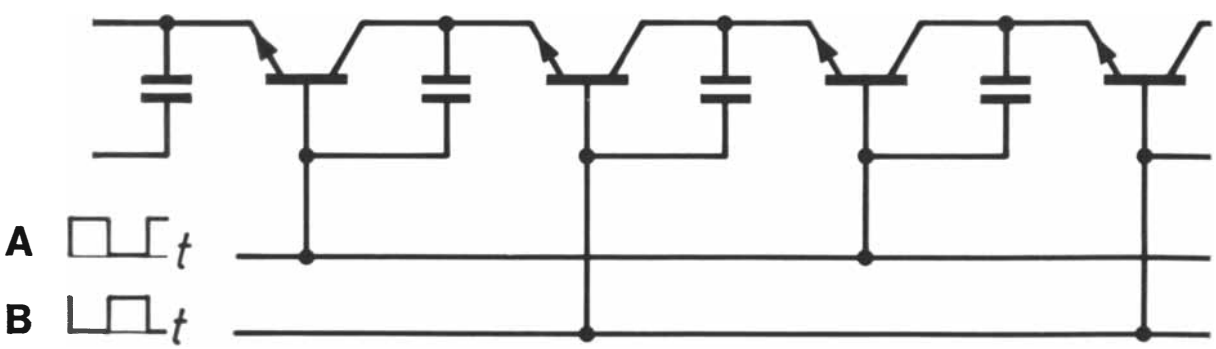
Mr. F.L.J. Sangster of Philips Research Laboratories has found an answer, which is eminently suitable for integration. The function of the bucket brigade delay line can best be explained by referring to the top illustration. Signal samples taken at regular intervals T are stored in alternate buckets in the first row, with the most recent sample on the left. The bucket volume still to be filled with water represents the signal. Now if each odd-numbered bucket is filled from the full bucket to its right (second row), the total signal is shifted one place to the right, as seen in the third row. When we repeat this procedure for the even buckets, the signal pattern is shifted further to the right. At the same time the first bucket is given a new sample. By repeating this sequence in synchronization with the frequency of actually taking the samples (the clock frequency), the original signal is shifted in steps to the right and appears at the end with a delay $^1/_2$nT (n buckets).

In electronic terms, as you can see in the bottom illustration, buckets are replaced by capacitors, water by charge and transistors perform the charge transfer function. Complementary square wave signals A and B are applied to alternate transistors; consequently at each half period, half the transistors conduct and corresponding capacitors to the left are fully recharged. The charge deficit, which is our signal, is then shifted one place to the right.

In developing the delay line Mr. Sangster realized that he could obtain the storage capacitance by increasing the normal "parasitic" collector-base capacitances. This is well suited to integration techniques. Delay lines of up to several 100 "buckets" in one chip have been made as experimental MOS and bipolar integrated circuits. MOS lines have been used for delaying 10 kHz audio bands up to 30 ms (1200 buckets), bipolar circuits delayed 5 MHz video bands up to 20 μs (400 buckets).

One important advantage of the new circuit is that, simply by changing its clock frequency, it is variable over a wide range of delay times. This leads to its use as a time error corrector in video recording, for time compression and expansion in transmission systems, and to solve various filtering problems.

In the Research Laboratories of the Philips group of companies, scientists work together in many fields of science. Among these are: Acoustics, Cryogenics, Information Processing, Mechanics, Nuclear Physics, Perception, Solid State, Telecommunications and Television. This work was carried out at the Philips Research Laboratories, Eindhoven, the Netherlands.



PHILIPS

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JANUARY, 1921: "Mr. Lee De Forest, reviewing the development of the audion in an extensive paper read before the Franklin Institute, brings out some very interesting applications of this apparatus and forecasts the use of it in many new directions. Most striking is the suggestion of producing music electrically. To quote the author: 'The uniform generation of electrical oscillations in a circuit by means of an audion is one of the most fascinating of its applications. If these are of radio frequency there is no sensible manifestation of their presence, but if of audio frequency the telephone receiver or loud-speaker reproducer may be made to give forth sounds from the highest pitch or volume to the softest and most soothing tones. Such wide range and variety of tone can be produced from suitably designed singing circuits that a few years ago I prophesied that at some future time a musical instrument, involving audions instead of strings or pipes, and batteries instead of air, would be created by the musicians' skill.' "

"It gives us the greatest pleasure, and a certain amount of pardonable pride, to announce that Prof. Henry Norris Russell of Princeton University, for some years the contributor of our monthly astronomical page, has been awarded the gold medal of the Royal Astronomical Society of London. This is by all means the highest honor that can come to any astronomer, for it goes to the man whose work entitles him to be regarded as the foremost astronomer of the world for the year. Dr. Russell goes to England this month to receive the medal at the February meeting of the Society. The particular work in recognition of which the award comes is doubtless the theories of stellar evolution which Dr. Russell has been sponsoring for 10 years past. At first regarded as entirely too radical, these are now generally accepted, and they paved the way for A. A. Michelson's extraordinary determination of the diameter of Betelgeuse, which Dr. Russell himself will describe in *Scientific American Monthly* for February."

"In spite of the mortification with which the great body of the American people have witnessed the recent militaristic 'swash-buckling' of Secretary of the Navy Daniels, it has not been without its good effects. It has served to call forth, mainly through the efforts of one of our great leading dailies, a widespread protest against the continuation of huge appropriations for naval and military construction, which has been surprising in its worldwide range and unanimity of sentiment. Both here and abroad statesmen of all shades of political opinion, naval and military officers of the highest rank, leaders of thought in the church, at the bar, in education and in literature have responded in no unmeasured terms of approval to the suggestion that the nations of the world should get together in an endeavor to reduce their existing naval and military programs and cut down future appropriations for such programs to the requirements of post-war conditions."

SCIENTIFIC AMERICAN

JANUARY, 1871: "Professor Huxley, the eminent naturalist, has sometimes been accused of exhibiting a pugnacious and acrimonious spirit. At one of the meetings of the British Association, Samuel Wilberforce, Bishop of Oxford, blandly asked him in the presence of a large audience: 'Is the learned gentleman really willing to have it go forth to the world that he believes himself to be descended from a monkey?' Professor Huxley rose and replied in his quiet manner: 'It seems to me that the learned bishop hardly appreciates our position and duty as men of science. We are not here to inquire what we would prefer, but what is true. The progress of science from the beginning has been a conflict with old prejudices. The true origin of man is not a question of likes or dislikes, to be settled by consulting the feelings, but it is a question of evidence, to be settled by strict scientific investigation. But, as the learned bishop is curious to know my state of feeling upon the subject, I have no hesitation in saying that, were it a matter of choice with me (which clearly it is not) whether I should be descended from a respectable monkey, or from a bishop of the English church, who can put his brains to no better use than to ridicule science and misrepresent its cultivators, *I would certainly choose the monkey!*' "

"At the meeting of the Royal Geographical Society, held on Nov. 20, 1869, a paper was read 'On the Geography of the Sea Bed' by Capt. Sherard Osborn, R.N. The author gave an account of our present knowledge of the configuration of the bed of the ocean, as derived from Admiralty surveys and submarine telegraph expeditions during the past 15 years. His explanations were illustrated by a number of diagrams showing sections of the North Atlantic and other oceans. It has been definitely ascertained that the greatest depth of the ocean does not reach 3,000 fathoms in any part where telegraphic lines have been laid. The bed of the North Atlantic consists of two valleys, the eastern valley extending from 10° to 30° west longitude and the western from 30° to 50° west longitude. The eastern valley is separated from the western valley by a ridge at 30° west longitude, in which the average depth is only 1,600 fathoms. This ridge terminates to the north in Iceland and southward at the Azores, so that it is volcanic in its character at both extremities. Its extreme width appears to be under 500 miles, and the Atlantic deepens from it on both sides."

"We see in the future of this country no danger more threatening than the growth and existence of enormous monopolies, particularly railroad monopolies. The past has demonstrated that our system of government gives almost unlimited scope for the growth of these enormous fungi upon the body politic. Their roots have struck deep, and their crimes against public morals smell to heaven. The great problem has been to devise any check that could be hoped to prove efficient under our present system of government. The corruption which exists in our civil service, the ease with which legislative bodies are manipulated, the lack of fidelity in judicial administration, each of which evils are mainly attributable to the corrupt influence of these bloated corporations, render almost any scheme of railroad reform hopeless. Lest we should be classed among those pessimists who believe the world is going to the bad altogether, and that nothing whatever can stop it, we hasten to say that we do not believe the evils complained of are perpetual, but we do believe no harder problem has ever presented itself to American statesmen than this of railway reform."

THE AUTHORS

HERBERT SCOVILLE, JR. ("The Limitation of Offensive Weapons"), is director of the arms-control program of the Carnegie Endowment for International Peace. Following his graduation from Yale University in 1937 he did graduate work in physical chemistry at the University of Cambridge and the University of Rochester, obtaining his Ph.D. from Rochester in 1942. After several years of work on defense-related contracts he became, in 1948, technical director of the Armed Forces Special Weapons Project. From 1955 to 1963 he was with the Central Intelligence Agency, first as assistant director for scientific intelligence and later as deputy director for research. He then spent six years as assistant director for science and technology of the U.S. Arms Control and Disarmament Agency before taking up his present work in 1969. Scoville is coauthor with Robert Osborn of *Missile Madness* and author of *Toward a Strategic Arms Limitation Agreement.*

SEYMOUR LEVINE ("Stress and Behavior") is professor of psychology in the department of psychiatry at the Stanford University School of Medicine. Born in New York, he was graduated from the University of Denver in 1948 and took his Ph.D. at New York University in 1952. From 1953 to 1956 he was at the Institute for Psychosomatic and Psychiatric Research of the Michael Reese Hospital in Chicago. He went to Stanford after four years at Ohio State University and two years at the Institute of Psychiatry of the University of London. Levine's interests are in developmental and behavioral neuroendocrinology and hormone behavioral relations. His previous articles in SCIENTIFIC AMERICAN were "Stimulation in Infancy" and "Sex Differences in the Brain."

REGINALD E. NEWELL ("The Global Circulation of Atmospheric Pollutants") is professor of meteorology at the Massachusetts Institute of Technology. He was born in England and received a bachelor's degree in physics from the University of Birmingham in 1954. He then moved to M.I.T. to study meteorology, receiving his master's degree in 1956 and his Sc.D. in 1960. Since 1961 he has taught a course on upper-atmosphere physics. Newell writes that he enjoys visits to nearby beaches with his four children, "preferably when the power-plant plumes and the smoke from the trash burned off Boston harbor are blowing away from the beach." He also enjoys debating pollution and political problems with his wife and others. Aside from the atmosphere his professional interests include the circulation of planetary atmospheres, auroras and theories of climatic change.

JEREMIAH P. OSTRIKER ("The Nature of Pulsars") is associate professor of astrophysical sciences at Princeton University. He has been at Princeton since 1965, a year after he received his Ph.D. in astrophysics at the University of Chicago. He spent the year as a postdoctoral fellow in England. Earlier he had received his bachelor's degree in physics and chemistry at Harvard University. Ostriker writes that he is "married to a poet and English professor (at Rutgers University), Alicia," and that they have three young children. He adds: "Among my entertainments are playing squash, bicycling, sitting on committees, partying, playing with my children, etc."

ERIC DENTON ("Reflectors in Fishes") is Royal Society Research Professor at the University of Bristol; he notes, however, that he spends most of his time in the laboratory of the Marine Biological Association in Plymouth. He obtained his degrees at the University of Cambridge and University College London and was elected a Fellow of the Royal Society in 1964. His original field was physics, and during World War II he worked on aircraft radar. "At the end of the war," he writes, "I had the good fortune to be one of three young physicists taken on by A. V. Hill, the physiologist who is one of England's kindest as well as greatest scientists. He at once sent me down to Plymouth 'to learn biology through the skin.' This period was followed by seven happy years at the University of Aberdeen and one year in Paris." Denton has been associated with the Marine Biological Association since 1956. He has worked mainly on problems of buoyancy in marine animals (he was the author of "The Buoyancy of Marine Animals" in the July 1960 issue of SCIENTIFIC AMERICAN) and on vision.

WERNER RIEDER ("Circuit Breakers") is with Brown, Boveri & Company Limited in Switzerland and also teaches plasma physics at the Institute of Technology of Vienna, where he was awarded the title of professor in 1963. Born in Vienna, he received his Ph.D. at the University of Vienna in 1949. For seven

years thereafter he worked on metal physics and later on switch gear at the Institute of Technology of Vienna. He writes that he "detests smoking and alcohol (believing my mood does not need chemical help), cocktail parties, all kinds of religion, including political parties (although politically interested)," because he wants to think independently and let others do the same. He says he is "keen on walking, especially at a level of about 10,000 feet and over long distances, watching landscape, flowers, game, Romanic and Gothic churches," and that he has "abandoned to learn proper English (after 40 years' efforts)."

BJÖRN SIGURBJÖRNSSON ("Induced Mutations in Plants") is deputy director of the Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture, operated in Vienna by the Food and Agriculture Organization of the United Nations and the International Atomic Energy Agency. "Although a city boy," he writes, "born in Reykjavik, Iceland, I spent all my summer periods on my brother's farm near Reykjavik and developed an interest in farming and agriculture. I even completed a farmers' school in Iceland before entering the University of Manitoba, where I soon got interested in genetics and plant breeding. I was graduated in 1956 and completed the master's degree in 1957. I then went to Cornell University and obtained a Ph.D. in 1960 with emphasis on plant breeding and cytology of forage crops." Sigurbjörnsson worked in Iceland until 1963, when he joined the staff of the IAEA, going to the joint division when it was formed a year later. "Living in Vienna I find delightful," he writes, "and on the basis of my location you can guess my two main hobbies: music and skiing."

NORMAN HOWARD-JONES ("The Origins of Hypodermic Medication") is a physician who retired last year after 22 years as director of the Division of Editorial and Reference Services of the World Health Organization. Before he went to Geneva to take up that work he was director of the medical department of the British Council in London, where he founded and was the first editor of the *British Medical Bulletin*. Medical history has been his hobby for many years; this year he is a visiting scientist in the history of medicine division of the U.S. National Library of Medicine. "I enjoy writing," he says, "and I enjoy even more criticizing the writings of others, but what I enjoy most is laughing immoderately at my own jokes."

Meet the most productive animal that ever lived.

Meet Dr. Lauren Donaldson and friend — a two-year-old, 18-pound supertrout that is the product of nearly 40 years of selective breeding at the University of Washington College of Fisheries. This one fish, at her second spawning, laid a record 23,487 eggs. Her surviving progeny, now mature, weigh approximately 100 tons!

In 1932, when Dr. Donaldson began his trout selection program, an average mature Rainbow trout (4 years old) weighed 1½ pounds and was capable of producing from 300 to 400 eggs. By 1944, the program had bred a trout that reached sexual maturity in only two years, by which time it weighed over 2 pounds, and would lay an average of 1600 eggs. In 1968, when the prolific lady pictured above reached sexual maturity, the average two-year-old female Rainbow in Dr. Donaldson's breeding ponds weighed about ten pounds, and could be expected to lay over nine thousand eggs!

An extension of this program, due in part to the rising cost of feeding each new crop of king-size select brood stock, was an inter-racial cross with the migratory Rainbow, or Steelhead. This has produced a vigorous hybrid fish that feeds in the open sea, returns to spawn in two years instead of the Steelhead's usual four, and is 50 to 90% bigger—up to 7 pounds. Beyond the Steelhead fisherman's wildest dreams!

Perhaps even more significant because of its projected effect on the world's food supply is the selective breeding of Chinook salmon, also being conducted by Dr. Donaldson. In the past ten years the program has increased the weight of the average selected salmon by four pounds, and its fecundity by 200 additional eggs each year. Every year up to 5 million eggs are carried to the hatchery by adult salmon, and since only 5 to 10 percent are selected for release, many eggs become available to develop fisheries elsewhere. Millions of eggs have been sent to initiate indigenous salmon runs in other countries.

Dr. Donaldson is cooperating with several Washington State and Federal agencies interested in developing a marine aquaculture project underway at the mouth of the Nooksak River in Puget Sound. This 750 acre underwater "farm" is raising both supertrout and salmon from eggs provided by the U of W, in addition to vast beds of clams and oysters, all under the management, and for the benefit of, the Lummi Indians.

"It's taken some years and some hard work," says Dr. Donaldson, "but I think we've helped prove that 'fish farming' can be a practical reality here in Washington, or anywhere in the world."

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Established 1845 SCIENTIFIC AMERICAN January 1971 Volume 224 Number 1

The Limitation of Offensive Weapons

It is argued that the best possible outcome that can be expected to emerge from the current strategic-arms-limitation talks (SALT) would be a freeze on the existing offensive forces of both sides

by Herbert Scoville, Jr.

Recent public debate in the U.S. on the control of strategic weapons has been mainly focused on antiballistic-missile (ABM) systems. Apart from the limited and so far unsuccessful effort to halt further testing by this country of multiple independently targeted reentry vehicles (MIRV's), there has been little open discussion of how offensive strategic weapons might also be controlled. It appears to have been generally assumed that reaching an international agreement to limit the deployment of offensive weapons systems would be a comparatively straightforward matter not requiring such extensive analysis.

In reality, however, a number of different approaches to the limitation of offensive weapons are possible, and these could have very different effects on the future course of the strategic-arms race. Certain approaches could raise serious issues of national security for one side or the other, whereas others could actually accelerate the arms race instead of curtailing it. The economic gains from the banning of certain activities could be completely nullified by rechanneling arms expenditures into new developments. Some types of agreement would be extremely difficult to verify and could even lead to increased tensions by arousing fears that the agreements were not being honored. Other possible agreements, although superficially attractive to one side or the other, would be extremely difficult to negotiate.

In any attempt to evaluate the various approaches to the problem of limiting offensive weapons it is important to bear in mind the stated objective of the U.S. strategic forces: to deter the initiation of nuclear war by maintaining a credible capacity to cause unacceptable destruction to the other side even after any conceivable surprise attack. In theory this "assured-destruction capacity" can be achieved by having enough offensive forces so that those that survive a "counterforce" strike are enough to penetrate the enemy's defenses. At present both the U.S. and the U.S.S.R. possess such forces in the form of a combination of submarine-launched ballistic missiles (SLBM's), fixed, land-based intercontinental ballistic missiles (ICBM's) and long-range strategic bombers. Neither side has an ABM system that can threaten the other's deterrent. The primary goal of any arms-control agreement is to provide greater confidence that this state of mutual deterrence is maintained and at the same time conserve scarce resources that both nations need for many other programs.

In general the methods of offensive-arms limitation that have been proposed so far can be grouped under three broad headings. First, an agreement could be reached setting a ceiling on the total number of delivery vehicles that would be allowed for each side. Such an agreement would not place any limitation on the mix of weapons that could be included in the total number. Thus replacement of an existing weapon with another type of weapon would be allowed. A variation of this approach would further restrict the number of weapons in specific categories, such as bombers or land-based ICBM's; alternatively, such an agreement might limit the replacement of an existing weapon by one of a radically different size.

The second general approach would be to limit the total useful payload deliverable by each side; payload in this case would include both warheads and penetration aids.

The third approach would be to freeze the strategic forces of both sides at their present levels, without formally stating any specific allowed numbers. Substitution of existing delivery vehicles or launchers by new types would not be permitted. A possible variation would be to allow only those replacements that did not alter the external configuration of the delivery vehicle or launcher.

It is important to analyze each of these approaches in detail in order to develop an understanding of the significance of any agreement that might be reached as a result of the current strategic-arms-limitation talks (SALT) between the U.S. and the U.S.S.R.

Before proceeding with such an evaluation, it is necessary to review the present levels of the deployed strategic forces on both sides and consider how these levels might change in the event that no arms-limitation agreement is reached [*see illustration on next page*].

For the purpose of this review a land-based delivery vehicle is considered strategic if it has the range to deliver a warhead to a substantial part of the territory of one nation from its deployed launching point on the territory of the other nation; in addition delivery vehicles launched from nuclear-powered submarines are regarded as strategic. Systems that are only capable of being fired between Siberia and Alaska are normally not considered to be part of this total. Similarly, manned aircraft that are only capable of one-way missions, short-range, medium-range and intermediate-range missiles that are capable of being used only against allied nations, and tactical aircraft that are based either overseas or on carriers are not included in the total. (The U.S. FB-111's, which have been classed as strategic bombers by Secretary of Defense Laird, are now being deployed in Britain, so that these are a somewhat marginal case.) Although any such definitions are of necessity somewhat arbitrary and would of course be the subject of negotiation, they help to simplify the analysis and do not alter the basic conclusions.

Since the U.S. and Russian missiles do not have identical characteristics, numbers alone are not sufficient to analyze the security implications of any potential agreement. The U.S. Minuteman I and Minuteman II missiles, which comprise most of our deployed ICBM force, can each carry a warhead with an explosive yield in the megaton range. Roughly half of these missiles, however, are in the process of being replaced with the Minuteman III, which will have approximately the same payload but will carry three MIRV's, each with a yield in the range of hundreds of kilotons. The 54 Titan missiles have a larger payload capacity: each can deliver more than five megatons on the U.S.S.R. No plans exist for modernizing these Titans. The Russian SS-11's and SS-13's have nearly the same payload capability as the Minuteman. Just recently Secretary Laird announced that the Russians were testing an SS-11 system with three multiple reentry vehicles (MRV's), which lack the capability for being independently targeted. The Russian SS-9, a much larger missile capable of delivering a 25-megaton warhead on the U.S., has been tested for a period of about two years with three MRV's, each of which might have a warhead yield of about five megatons.

The U.S. has no plans to deploy additional land-based missile launchers, although many design studies have been carried out for advanced systems that might be either mobile or in "superhardened" rock silos (or both). The U.S.S.R., on the other hand, is continuing to deploy SS-11's and SS-13's at the rate of about 100 per year and SS-9's at the rate of about 50 or fewer per year. Although there is some evidence that the rate of this deployment has decreased somewhat in the past year, it is not known at what point the Russians would unilaterally halt these programs in the absence of an arms-control agreement. There is some possibility that they are continuing the deployment of the SS-9 in order to emulate the U.S.'s example of being able to negotiate at SALT "from a position of strength."

The U.S. SLBM force consists of 41 submarines equipped with Polaris missiles, a large fraction of which are the A-3 model with three MRV's. Of the existing Polaris submarines 31 will be modified to carry the new Poseidon missile, which will be capable of delivering 10 MIRV's with yields of somewhat less than 100 kilotons each. At present eight submarines are undergoing such modification; the first will go to sea in January, 1971. The early Russian ballistic-missile submarines could handle only three missiles each, but the later versions, some 14 of which are now reported to be operational and 16 more to be under construction, are equipped to carry 16 missiles of the early Polaris type. No Russian testing of MRV's or MIRV's for this system has been reported. The Russians have the capability of increasing this fleet by approximately six or eight submarines per year and so could have a force with a numerical, but not qualitative, equivalence of the U.S. fleet before 1975. The U.S. has no firm plans for building new ballistic-missile submarines but has in the design stage a replacement for Polaris-Poseidon called the underwater long-range missile system (ULMS). Secretary Laird has stated that without an agreement at SALT a decision will have

U.S.

DELIVERY VEHICLES		NUMBER	APPROXIMATE EXPLOSIVE YIELD (MEGATONS)
ICBM'S	TITAN	54	5+
	MINUTEMAN	1,000	1
SLBM'S	POLARIS	656	1
BOMBERS	B-52, FB-111	550	
TOTAL		2,260	

U.S.S.R.

DELIVERY VEHICLES		APPROXIMATE NUMBER	APPROXIMATE EXPLOSIVE YIELD (MEGATONS)
ICBM'S	SS-9	270	25
	SS-11, SS-13	825	1
	OLD MODELS	220	1+
SLBM'S		254	1
BOMBERS	BISON, BEAR	150	
TOTAL		1,719	

STRATEGIC OFFENSIVE FORCES of the U.S. and the U.S.S.R. as of January 1, 1971, are listed in this table. The three major categories on both sides are fixed, land-based intercontinental ballistic missiles (ICBM's), submarine-launched ballistic missiles (SLBM's) and long-range bombers. The approximate explosive yield of each type of missile is given in equivalent megatons of TNT; megatonnage is not indicated for the bombers, since this value varies from mission to mission, but the U.S. is known to have a substantial advantage in this category. In addition to the figures shown the U.S.S.R. is believed to have under construction about 40 SS-9's, 100 SS-11's and SS-13's, and 16 submarines carrying 256 SLBM's. The SS-9 has been tested with three multiple reentry vehicles (MRV's), each with a yield of about five megatons. The SS-11 has also been tested with three MRV's, with a total yield of less than one megaton. About 50 percent of the Minutemen are currently being converted to carry three multiple independently targeted reentry vehicles (MIRV's), again with a total yield somewhat less than one megaton. Some Polaris SLBM's currently carry three MRV's with a total yield less than one megaton, and the U.S. is in the process of replacing the Polaris missiles on 31 of its submarines with Poseidon missiles capable of carrying 10 roughly 100-kiloton MIRV's. No additional bomber deployment is taking place on either side. The U.S. now has a total of more than 4,300 strategic nuclear weapons in the form of missile warheads and bombs, whereas the U.S.S.R. has about 2,000. With the completion of the MIRV program in the mid-1970's the U.S. total will rise to about 9,000.

to be made in 1971 on whether to proceed with the deployment of ULMS.

The U.S. currently has a force of 550 B-52 and FB-111 intercontinental bombers. Since there has been no new production of B-52 aircraft for many years, the size of this force is gradually decreasing, but it is estimated that it will still total several hundred aircraft into the 1980's. The B-52's are being modernized to carry air-to-surface missiles and improved penetration aids. Originally the nuclear weapons for these bombers had yields greater than 20 megatons, but it has been found more efficient to load them with several bombs having considerably smaller yields. The smaller Russian long-range bomber force is composed of a mix of turboprop Bears and jet Bisons. The U.S.S.R. has tested a nuclear device with a potential yield of 100 megatons deliverable by a Bear aircraft, but no information is available concerning whether or not such a weapon has been deployed. In all likelihood the majority of the bombs for the Russian aircraft are of much lower yield. The U.S. is in the early development stage of a new long-range intercontinental bomber, the B-1, but there is no known Russian program for the development of a replacement for the U.S.S.R.'s existing aircraft.

Perhaps the simplest type of arms agreement to limit offensive strategic weapons would be one in which both nations agreed to a common ceiling on the total number of deployed launchers or delivery vehicles without regard to what types would be included within the total. Replacement of existing weapons by new models of the same type or by substitution with a different type would be allowed provided that the total number of operational weapons at any given time did not exceed the agreed number. No restrictions would be placed on qualitative improvements or on the number of warheads or bombs that could be carried by any given delivery vehicle. In the case of missiles it would be assumed that each completed launcher contained one delivery vehicle, and no restrictions would be placed on missiles that were not associated with a launching platform. In the case of bombers each aircraft would be regarded as a single delivery vehicle.

There are several alternative ways such a ceiling on numbers might be selected. If the ceiling were very high, say 2,500, it would provide no limitation at all. If it were initially chosen to be very low, say 1,000, it would involve widespread scrapping of existing weapons and might raise questions in some minds as to the viability of the deterrent. Intermediate levels would satisfy the security requirements of both nations but, depending on the exact terms, might present negotiating problems.

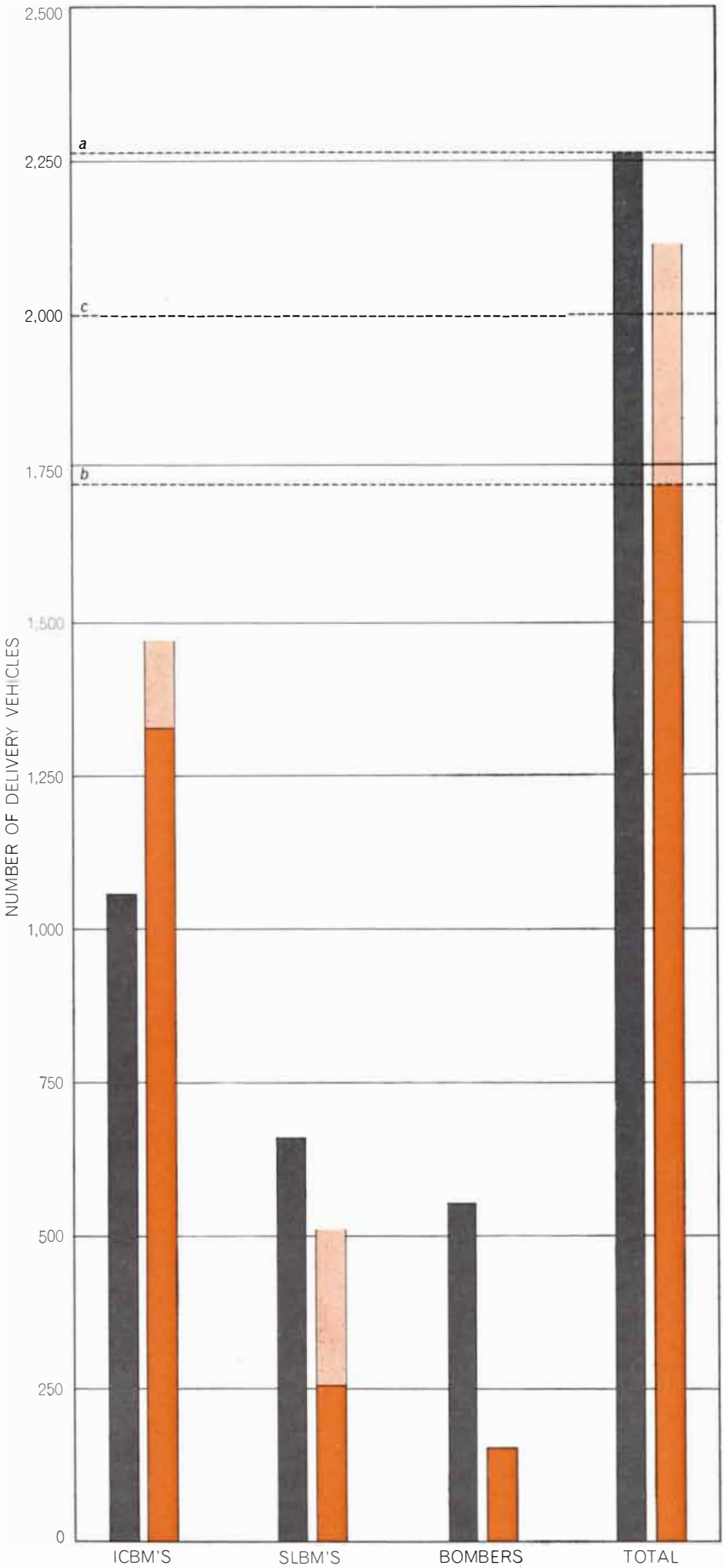
If such an agreement were reached with forces as of January 1, 1971, the U.S. would have a total operational force of 2,260 delivery vehicles and the U.S.S.R. about 1,720. This inequality results from the much larger U.S. bomber and SLBM forces, which outweigh the numerical advantage that the U.S.S.R. has in land-based ICBM's. The U.S.S.R. would also have approximately 400 additional missile launchers under construction. It is conceivable that the Russians might be willing to agree that the allowed numbers should be at the existing operational levels since a rough parity in force strength does exist. The larger payload capacity of the Russian land-based missiles (specifically the SS-9's) might be said to compensate for the U.S. advantage in number of SLBM's. The Russians might worry, however, that the number of their currently deployed sea-based missiles, the least vulnerable of all strategic systems, would be dangerously low in view of the fact that, with no restrictions on MIRV's, fixed land-based systems might at some time in the future be vulnerable to complete elimination by a U.S. counterforce strike. Furthermore, under such an agreement there would be nothing to prevent the U.S., if it chose, from replacing its present small missiles with those of larger payload.

On the other hand, the agreement could require that both nations have an equal number of delivery vehicles. Since the relative Russian inferiority in numbers would be largely alleviated if the U.S.S.R. were allowed to complete those launchers now under construction, a freeze on new starts might be the simplest way to achieve equality. The alternative to the U.S.'s reducing its force levels to those of the U.S.S.R. might be politically more difficult for the U.S. to accept and might leave the Russians feeling insecure because of their comparatively small number of SLBM's.

None of these approaches presents any real risk to U.S. security, particularly if ABM systems are simultaneously limited to low levels, since the U.S. would still have an adequate deterrent force. Even if the Russians developed MIRV's with sufficient accuracy to provide a high probability of eliminating U.S. land-based missiles, the U.S. would still be left with 656 submarine launchers, almost 500 of which would be capable of firing Poseidon missiles, each of which in turn could carry 10 warheads. Such a weapons system could be confident of wreaking completely unacceptable devastation on the U.S.S.R. in retaliation even if the Russians had deployed a very large ABM force. In addition the U.S. would have as a backup a large bomber force, which could not be destroyed simultaneously with the ICBM force. The deterrent should therefore remain secure, but if in time concern for security developed, the U.S. would always be in a position to replace its fixed land-based systems with less vulnerable mobile or sea-based ones.

An agreement along these lines, however, would have only minor effects in curbing the offensive-arms race and would only turn it in the direction of qualitative rather than quantitative developments. Since at present the U.S. has no plans for increasing the total number of its delivery vehicles, it would unilaterally affect the U.S.S.R. Although the U.S. is doing design studies on new systems in all categories, no decisions have been made for the deployment of any of these systems, and any deployments that might occur would probably serve to replace existing systems. On the other hand, such an agreement would have considerable effect on present Russian programs since the U.S.S.R. is continuing to deploy both land-based ICBM's and new submarines with SLBM's. In spite of this asymmetry the Russians might be willing to negotiate such a ceiling, since they may now be almost at the point of halting additional deployments. If the total number of Russian delivery vehicles were to be kept at the January 1971 level, it is likely that the Russians would decide to replace some of their 220 older ICBM's with SLBM's in order to remedy their present deficiency in this area. They could also substitute SS-9's for some of these old missiles, thus eliminating one of the chief U.S. aims at SALT.

The failure to place restrictions on qualitative improvements in the delivery systems or on the replacement of old missiles with new ones is likely to accelerate rather than restrict the arms race. We have had the experience of an arms-control agreement being used to justify technical programs that otherwise might not have been carried out. In 1963 one of the key elements in gaining acceptance of the Limited Test Ban Treaty by the Joint Chiefs of Staff and Congress was President Kennedy's undertaking that the U.S. would maintain a standby capability to resume atmospheric testing on short notice and would vigorously



prosecute those weapons-development and test programs that were still permitted under the treaty in order to be in the strongest position possible should the Russians abrogate or violate the treaty. Such programs have cost the U.S. hundreds of millions of dollars, have involved an increase in the total annual number of nuclear tests over the average for the preceding 10 years, and have in many cases been continued at a somewhat reduced level up to the present time even though many have little or no effect on national security. It is almost certain that similar requirements would be placed on the Administration in the event that an agreement were reached in SALT. The U.S.S.R. would probably be pressured to emulate such actions. Thus such a SALT agreement could become a stimulus to the arms program in the same way that SALT itself has already been used to justify continuing present programs in order to be able to negotiate from strength.

In the first place the U.S. would undoubtedly proceed with its present program to put MIRV's on a large fraction of the Minuteman and the Polaris systems. In fact, under the constrictions of a SALT agreement it is not at all unlikely that these forces would be completely MIRVed instead of only partially as now planned. The Russians, who do not yet have any MIRV systems tested, would undoubtedly feel impelled to proceed with similar programs. They probably would not be content with placing only three MIRV's on their SS-9's, the number that has been given in most threat calculations publicized by the Department of Defense, and they would undoubtedly attempt to take advantage of the larger payload of the SS-9 by plac-

POSSIBLE NEGOTIATED CEILINGS on the strategic offensive forces of the U.S. (*black bars*) and the U.S.S.R. (*colored bars*) are indicated by the broken lines at the top of this chart. An agreement that placed a ceiling on the total number of delivery vehicles at the present U.S. level (*a*) would have to allow the U.S.S.R. to add about 150 vehicles (presumably missiles) to its forces in addition to those now under construction. An agreed ceiling at the present Russian level (*b*) would require a corresponding cutback in U.S. forces. A compromise ceiling of, say, 2,000 delivery vehicles (*c*) would allow the Russians to finish some of the missiles they now have under construction (*light-colored bars*) and would require a small U.S. reduction in total delivery vehicles. A freeze at existing force levels would leave the strategic balance substantially as it appears here.

ing 10 or more warheads on each missile. In time these could have the accuracies required to virtually ensure destruction of all U.S. fixed land-based ICBM's. The race for increasingly effective MIRV systems would be given the sanction of an arms-control agreement.

The race, however, would not be restricted to the development of MIRV's. As the threat to the U.S. land-based forces increased, an ABM defense of the missile sites, if not already banned, would begin to appear inadequate. Since it would be allowed to do so under the terms of the agreement, the U.S. would feel forced to attempt to reduce this vulnerability by replacing fixed land-based systems up to the agreed ceiling even though the existing weapons would continue to provide an adequate deterrent. The most likely replacement would be less vulnerable but more expensive submarine systems. If land-based systems were eliminated entirely, however, it would create the difficult political problem of removing the Air Force from the strategic-missile picture. Substituting sea-based missiles for land-based ones would be argued as having the security disadvantage of placing reliance on a single type of missile deterrent system. This point has already been used to justify the Safeguard ABM system. It is most likely that at least some of the conversion would include replacement with new land-based systems involving superhardening and/or mobility. The expense of deploying such new systems would be staggering compared with that of present programs. The U.S. also might be tempted toward missiles with a larger payload in order to compensate for the Russian advantage in this area and to circumvent the restrictions imposed by the limit on the total number.

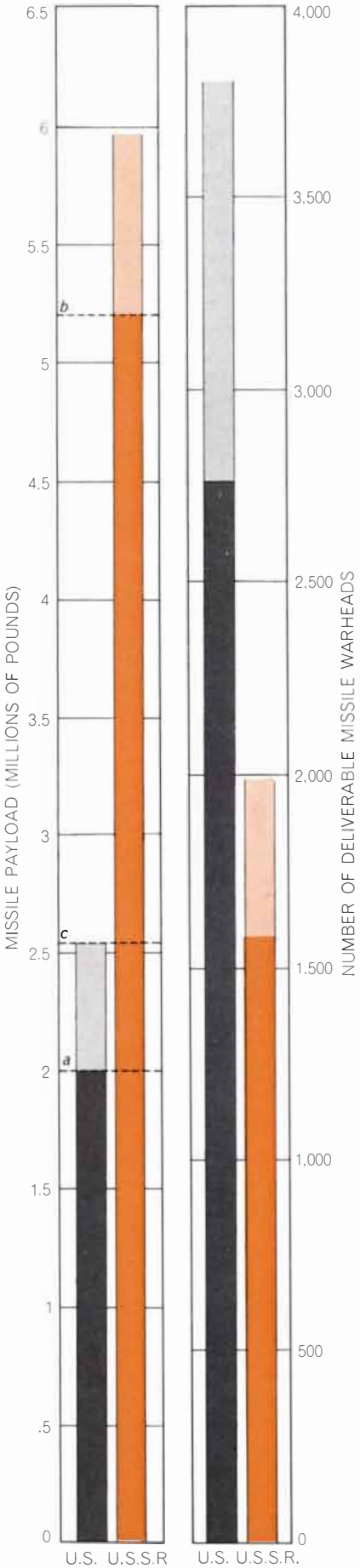
Within such an agreement the U.S.S.R. would also probably be led to deploy new systems. Certainly the Russians would be forced to take certain measures to decrease the vulnerability of their present land-based missile systems. This could be carried out by using up a larger fraction of their total number of allowed missiles in the form of submarine systems. Such a program could be quite expensive for the U.S.S.R. because submarines are costly vehicles and because the distance from ports to operating areas is considerably greater for the Russian submarines than it is for those of the U.S. From a geographical point of view alone, the U.S.S.R.'s submarines also are probably more vulnerable to anti-submarine-warfare measures than those of the U.S. since they must operate in deep-ocean areas that are surrounded by Western-controlled land masses and are more amenable to acoustic-detection techniques.

Finally, the Russians too would have the political problem of moving their deterrent from land to sea. The rocket forces are a powerful group within the Russian military hierarchy, and they are unlikely to forgo this mission. The U.S.S.R. is traditionally much more land-minded than the U.S. Therefore it is likely that the Russians would turn to a firing doctrine of "launch on warning" or to mobile land-based missile systems or to both. They have already tested some mobile missiles at short ranges and have boasted of the existence of mobile ICBM's. It would seem very likely that they would move into this area with extensive programs as they became concerned that their present forces might be threatened. Such deployment would increase the uncertainties in U.S. planning, since mobile missiles are hard to count accurately. It is also possible that the Russians would choose to increase the proportion of the large SS-9's in their missile force in order to ensure the maximum potential payload and penetration capability. This would still further increase U.S. fears of the Russian threat.

Although under this agreement both the U.S. and the U.S.S.R. would have the option of replacing their old bombers, it is not clear that either nation would choose to do so. As the present forces become obsolete or gradually become smaller because of accidents and deterioration, both nations might choose to deploy additional missiles in their place. Such a choice would be less costly than developing and deploying an entirely new bomber force, but it would in time eliminate one alternative form of deterrent. When bomber forces are no longer operational, the need for costly air-defense systems will be largely eliminated. The U.S. is already decreasing its air-defense efforts, whereas the Russian efforts in this area continue at a high level. The Russians would be faced with the decision on bomber replacement sooner than the U.S. in view of the fact that they have fewer long-range bombers. Their medium-bomber force has the range capable of attacking both Chinese and European targets, so that the U.S.S.R. does not need the very-long-range bombers for this purpose. On the other hand, the U.S. has only a small number of medium-range aircraft operational and, when the B-52's are gone, it would be forced to rely entirely on the FB-111's and carrier-based planes in the event that such aircraft were needed for lesser conflicts. The U.S., however, is known to be developing the B-1 as a replacement for its B-52's. As a result the U.S. might be less inclined to forgo bomber replacements than the U.S.S.R. would be.

Verification of an agreement limiting strategic delivery systems to a given fixed total would present a number of difficulties. Any new construction of missile launchers or of submarines carrying ballistic missiles could be observed by unilateral means (that is, without on-site inspection) well in advance of completion so that one could be confident of detecting any significant additions to the force. Nonetheless, an accurate count of the total number of operational missiles at a specific time would be harder to obtain if substitutions were allowed. This would be particularly difficult if mobile land-based missiles were deployed. Moreover, there would be some difficulty in ascertaining when a new missile system that was being constructed to replace an old one had reached operational status. If the replacement rate were very high, then concern might arise that the new facilities were being constructed without the intention of phasing out existing ones and that by so doing one side hoped to gain a temporary advantage. It is unlikely, however, that the new construction would be so extensive that such a violation could provide a real threat to anyone's security in view of the already large number of missiles available to both sides. Procedures for replacements could perhaps be negotiated to reduce the risks from a violation, but such a situation is likely to create a climate for accusations of bad faith and to increase tensions, which of course is the exact opposite of what a well-designed agreement should provide.

A final difficulty might arise in proving a violation. It would not be enough to point to a new site; it would also be necessary to present evidence that the total number of sites at a given time exceeded the agreed number. This might be very difficult to do and would open the way to charges and countercharges. The problem would be even more difficult if missiles were allowed to be substituted for bombers, since the operational status of the entire bomber force at any one time is difficult to determine. During the complete nuclear-test moratorium from 1958 to 1961, continued claims were made by certain groups that the Russians were violating the moratorium, and major efforts were necessary in order to provide the President with sufficient confidence that this was in-



deed not the case. An agreement such as the one proposed above would provide countless opportunities for misunderstandings.

In summary, an agreement that placed a ceiling on the total number of strategic delivery systems, although simple in concept and probably presenting little risk to the security of either nation, would have little if any value in controlling the strategic-arms race. In fact, the race might even be accelerated as it turned to qualitative as opposed to quantitative increases. There would clearly be little saving in funds, and in actuality new and expensive programs might be more easily justified under such an agreement than they would be without any agreement at all. At a minimum some additional restrictions on the replacement of existing systems should be added to this approach. It would be far better for both sides to agree to phase out their fixed, land-based missiles as they became vulnerable than to allow their replacement with new weapons. Although it is difficult to imagine any violation that could escape detection seriously affecting the security of either nation, it is likely that many misunderstandings and disputes would arise through misinterpretation of the programs allowed under the agreement.

In view of the numerous difficulties and risks that an agreement allowing complete freedom to shift strategic forces from one type to another presents, consideration could be given to agreeing not only on the total number of systems but also on the numbers within the various categories. The simplest such scheme would involve an agreement on specific numbers of aircraft and specific numbers of missiles; it would allow the option to vary the types of missiles or aircraft within the agreed numbers. This approach would represent a considerable improvement, since it would separate out the disparity in the numbers of aircraft, which is less significant, from the more critical missile problems. At present both nations have approximately the same number of missiles, the Russian advantage in land-based systems almost compensating for the U.S. advantage in sea-based systems. If closer equality were essential, the Russians could be allowed to complete the missile submarines now under construction until they had the same total number of missiles as the U.S. This separating of missiles and aircraft would avoid many of the difficulties in negotiating an agreed total number of delivery vehicles.

Such a variation would, however, still have many of the disadvantages of a simple agreement on total number. Strong pressures would still hold for replacing existing systems with more modern ones. With complete freedom to continue development and deployment of MIRV's, both sides would have strong incentives for revising their force structures to reduce the vulnerability of their land-based systems. The pressure would be particularly strong for the U.S.S.R. with its relatively weak SLBM forces. In addition there would be nothing to prevent the U.S.S.R. from continuing to build up its SS-9 force to the point where Secretary Laird's predictions about the vulnerability of the U.S. deterrent would become more credible. For this purpose the U.S.S.R. has more than 200 older missiles that could be phased out and replaced. There would then be strong pressures within the U.S. for the replacement of existing systems to neutralize this Russian threat. As in the previous approach, the arms race might only proceed faster on a new track.

Since such an agreement would freeze the U.S. with an overwhelming advantage in strategic bombers, it would certainly present the Russians with serious political difficulties even though they have no known plans to expand their present force. They would probably seek in some way to try to negotiate a reduction in the number of U.S. bombers to reduce this inequality. The U.S. in turn might be quite reluctant to do so and could use the argument that this U.S. advantage was compensated by the large Russian medium-range bomber force. Once this class of aircraft becomes a subject of negotiation, however, the Rus-

ALTERNATIVE CEILINGS on strategic offensive forces are shown in this pair of bar charts; systems currently under construction are indicated by the lighter gray and lighter colored bars. In terms of deliverable missile payload the Russians have a significant lead (*left*), but this is outweighed by the large U.S. advantage in bomber capacity (*not shown*). In terms of deliverable warheads the U.S. currently has about a 50 percent lead (*right*). An agreed ceiling on payload could require that the U.S.S.R. greatly reduce the size of its missile force (*a*), or that the U.S. greatly expand its force (*b*), or that some combination of these two approaches be put into effect (*c*). A freeze on warheads that put no restrictions on MIRV's would allow the U.S.S.R. to make more effective use of its payload advantage and would eventually enable it to surpass the U.S. in deliverable warheads as well.

sians are likely to press many complicating questions pertaining to U.S. carrier-based and European-based systems. Although the bomber discrepancy is likely to complicate the negotiation, it would probably not be an insuperable obstacle, since for both countries the bomber forces are less critical to the deterrent balance. It should not be forgotten, however, that the largest part of the total nuclear yield that can be delivered by the U.S. on the U.S.S.R. comes from the U.S. bomber force, and the Russians are extremely conscious of that fact. This undoubtedly accounts for their large concentration of effort on antiaircraft defenses even now when the major threat is from missiles.

An additional variation of this approach would be to limit the further deployment of very large missiles such as the SS-9. If the SS-9's could be kept at their present number, the threat to the U.S. Minuteman would be greatly reduced, since extensive MIRVing would be required before the present force could approach a first-strike capability. Certainly as long as the Russians could not deploy more than three MIRV's per missile an important fraction of the Minuteman force could not be threatened. On the other hand, a limitation on Russian SS-9 deployment is not easily balanced by any similar U.S. limitation. This country has no plans for deploying larger ICBM's, and the Russians are not likely to agree to any restrictions on their SS-9's without some parallel restriction on the part of the U.S. The most obvious limitation would be on the further replacement of the Polaris missile with the larger Poseidon missile or the possible eventual deployment of an underwater long-range missile system. Such a proposal, however, is likely to be strongly opposed by the U.S. since the Poseidon system is considered the most critical element in the U.S. deterrent. The ability of this missile to carry more than 10 MIRV's ensures penetration of any ABM system the U.S.S.R. would be able to construct for many years to come. If ABM's were also limited to low levels by the agreement, however, then the U.S. requirement for the Poseidon MIRV's to penetrate a Russian ABM system would be removed. Furthermore, if the SS-9's were limited, the Minuteman missiles could be relied on to supplement the sea-based deterrent. Thus from a strict security point of view the U.S. could afford an agreement that limited SS-9's and Poseidons simultaneously, even taking into account the risks from a possible clandestine ABM program. Nevertheless, there would be strong opposition in the U.S. from those groups that have insisted on the necessity for continued U.S. MIRV testing and deployment. This opposition would have to be overcome, because unless some limitations were imposed to prevent present missiles from being replaced by larger ones the arms race would continue almost unabated and U.S. security would not be improved.

One proposal that has been suggested in order to place some limitations on qualitative improvements on existing strategic systems would be to agree that each nation would be restricted to a total payload that could be delivered on the other nation. Payload, sometimes referred to as throw weight, is here defined as the total useful weight that can be delivered to a target area from a launcher. This can be in the form of nuclear warheads or penetration aids to overcome defenses. For a given missile there will be a tradeoff between range and payload (since the longer the range is, the lower will be the deliverable payload) so that the payload would have to be tied to some nominal range.

Such an agreement would have the advantage of preventing the replacement of existing small missiles with much larger ones. It would not, however, prevent the replacement of single-warhead missiles by MIRV's since this could be done without increasing the payload of existing missiles. In actuality the threat to the U.S. from the SS-9, which has created such concern on the part of Secretary Laird, results from the assumption that MIRV's will replace the existing reentry vehicles without requiring any increase in the total payload.

If the agreement were such that the U.S. and the Russian missile forces were frozen with the existing payloads, the U.S.S.R. would be left with an advantage of about two to one in the missile payload that could be delivered on the U.S. This disparity would be somewhat alleviated if the U.S. were allowed to complete the conversion program for 31 of its Polaris submarines from the present missiles to the larger Poseidon. It is highly unlikely that the U.S.S.R. would agree to the continued buildup on the part of the U.S. without being allowed some concession in return. This could take the form of allowing the U.S.S.R. to complete its present submarine construction program to the point where it approached the Polaris fleet in size, if not in payload capacity. This would involve a very significant addition to the total number of missiles available to the Russian forces, however, and would then provide a disparity in favor of the U.S.S.R. in total number of strategic delivery vehicles. Although none of these inequalities would present serious security problems—in fact, greater emphasis on submarine-based systems improves the reliability of the deterrent—they would certainly present serious political problems in the U.S. or the U.S.S.R. and might therefore be difficult if not impossible to negotiate.

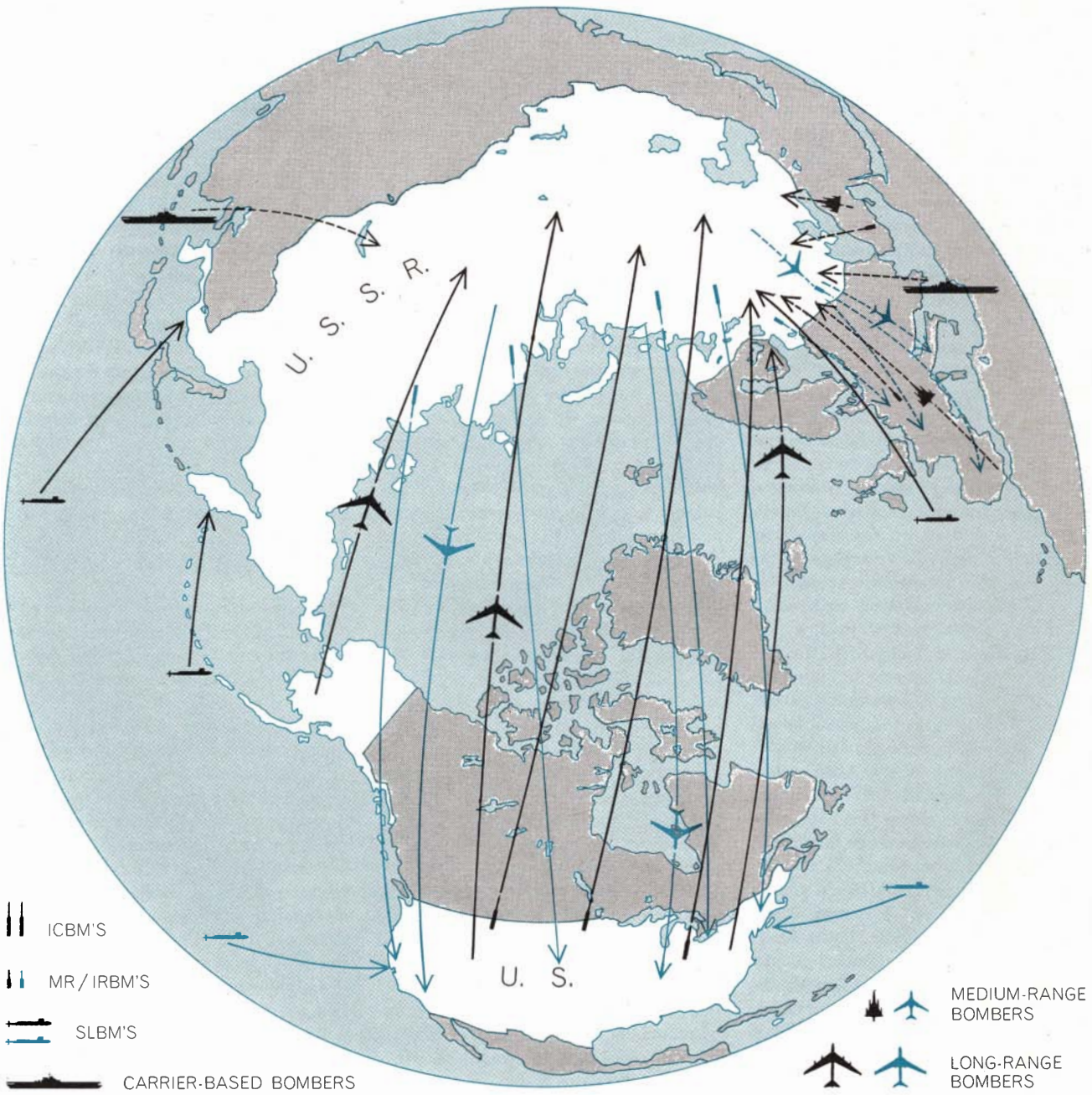
Another alternative might be to allow both nations to have the same total payloads without any restrictions on how this was divided among various missile systems. That, however, would either enable the U.S. to build up unilaterally to the present Russian level by doubling its present payload capacity or require the U.S.S.R. to reduce the size of its forces. Neither of these alternatives appears to be negotiable. If bomber load were included in the total payload for strategic systems, the tables would be turned and the U.S. would have an advantage. Perhaps the simplest solution would be to leave the Russians with their present advantage in missile payload and consider that this was compensated for by the present U.S. advantage in long-range bombers. Such an agreement would not threaten U.S. security even if the U.S.S.R. exploited its missile advantage by MIRVing its larger payload capacity. Provided that ABM defenses were simultaneously controlled at zero or very low levels, the Polaris fleet would by itself be able to provide an adequate deterrent even if the Poseidon conversion was not completed. The large U.S. bomber force would offer an additional safety factor, although this would not be vital.

If the limitation were restricted to payload only without any simultaneous restrictions on the number of delivery vehicles, then each nation would have the option of increasing the total number of its delivery vehicles, provided that it reduced the average payload of each individual vehicle. Such a conversion would not increase the threat and in fact might in some cases add a greater reliability to the deterrent. The more potential launch points and the greater the number of potential retaliatory warheads there are, the greater will be the certainty that the deterrent will not be eroded by a combination first strike and ABM defense. It does, however, mean that there would be few restrictions on the development of new missile systems to replace existing ones. Uncertainty would always be created during these transition periods concerning whether or not the limitation was being abided by.

Therefore a more satisfactory arrange-

ment might be to combine the payload limitation with one on total number. This would tend to freeze present forces at their existing strength and would provide fewer opportunities for misunderstanding. There would certainly be less excuse for a broad expansion of the arms race. In qualitative areas the most serious development that this type of agreement would not control is MIRV's. In fact, the result would probably be a race to develop the most efficient MIRV system within the agreed limitations on payload and number. Whether or not in the face of such a situation it will be possible to maintain a prolonged halt to other parts of the arms race is open to serious question. As mentioned above, it is likely that there would still be strong incentives for replacing existing systems with less vulnerable ones, for example the replacement of fixed land-based Minuteman or SS-11 missiles with sea-based systems or with mobile or superhardened land-based ones.

Finally, one should consider whether or not a limitation on payload can be adequately verified without requiring unacceptably intrusive inspection. Within a given missile silo, either on land or in a submarine, it would be possible to replace an existing missile with one having a somewhat greater payload capacity. This might be accomplished by increasing the energy available from the fuel, by better utilization of the launch-tube volume or by using different techniques for ejecting the missile from the launcher. None of these changes is particularly susceptible to observation by unilateral means, although evidence of wide-scale conversions that might significantly affect security might be difficult to conceal. If replacement of existing systems were allowed for other purposes,



STRATEGIC OFFENSIVE WEAPONS ARE DEFINED for the purpose of this article to include only those long-range nuclear weapons indicated by the solid black and colored arrows on this map. Various other medium-range, intermediate-range and tactical weapons systems, indicated by the broken arrows, are nevertheless available to both sides and could be discussed at SALT.

however, it might be almost impossible to detect those that involved an increase in payload capacity. Thus it would appear that for a deployment ban alone it would at a minimum be necessary to carry out rather extensive on-site inspections if one was to be certain that the agreement was being abided by. This verification problem has also been the major stumbling block in developing controls on MIRV deployment.

As in the case of MIRV's, however, there are opportunities for dealing with the problem by limiting the testing of missiles with larger payloads. At present the U.S. has a reasonably reliable estimate of the payload capacity of the Russian missiles. This has been obtained by observation of test programs over the years and is partially the basis for Secretary Laird's being able to announce that the Russian SS-9 is capable of delivering a payload of 13,500 pounds and a single warhead of 25 megatons on the U.S. Therefore, providing that the Russians did not change their test procedures, it is likely that the U.S. would be able to determine if they tested a new missile with a significantly increased payload.

On the other hand, it is possible that by changing its test procedures the U.S.S.R. could test a missile with a larger payload capacity without U.S. knowledge. Development testing could proceed under conditions where observations from outside the U.S.S.R. might not be able to determine that the payload of the operational system had been increased. Any new missile system on which the Russians intended to rely for a major part of their strategic power, however, would require testing under closely simulated operational conditions, and such tests might be more easily monitored and provide opportunities for detection of an increased payload capability. Such detection would be significantly more difficult than the detection of MRV and MIRV testing; yet the verification problem has been used by some as a justification for on-site inspection in order to control MIRV's. Therefore, if verification considerations are sufficient to prevent the achievement of a MIRV ban, such considerations should also militate against the negotiation of a ban that limited payload capacity.

Another approach to limiting the deployment of strategic arms would be an agreement that froze existing delivery systems at their current status. The levels of the agreed freeze need not be specified since the ban would be directed at changes in the existing balance rather than at limitations to agreed numbers. Ideally the prohibition should be all-inclusive, not only banning the substitution of one launcher by another of a different type but also preventing the replacement of the present missiles and aircraft. This would be most satisfactory from the point of view of security, of halting the arms race and of economic savings. It would, however, present serious problems of verification, since extraordinarily intrusive and almost certainly impractical inspection would be required to ensure that new weapons having some enhanced capabilities were not being substituted for those currently deployed. For example, to detect the deployment of an improved guidance system in a missile would require dismantling the missile and inspecting its interior. Even then one could not be sure that violations were not occurring. An agreement, however, could partially cope with the problem of qualitative improvements by restricting the launchers to those now in existence, by not allowing their replacement by new systems and by restricting any modifications to these launchers and their missiles to those that did not change their external configuration or that of the missiles they contained.

Under such a freeze it would be possible to replace single warheads by MIRV's in existing missiles, since this could be accomplished without any alteration in the external configuration of the launcher or missile; enlarging the missiles to still further improve MIRV capability would be constrained. Some other improvements in the missile systems might be possible, but these would also be restricted by the necessity of keeping the configuration of the launcher and the envelope of the missile unchanged. Since the replacement of old launchers by new ones would not be allowed, wholesale changes in the force structure would be prohibited. Fixed land-based missiles could not be replaced by submarine systems or by mobile ones. This might be considered a disadvantage, since in time such land-based systems would become vulnerable to highly accurate MIRV's, although this would be less likely with a freeze than without one. In any case, as long as ABM systems were simultaneously limited to low levels the deterrent would not be threatened. The U.S. would still have 656 SLBM's, supplemented by a large bomber force, which would be more than enough to produce unacceptable damage to the U.S.S.R. in a retaliatory strike. Since it is not possible to destroy either the bomber or the Minuteman forces without providing advance warning to the other, the combination of these two forces would still provide deterrence even if they were individually vulnerable. Pressures for new strategic systems could probably be contained. The conversion of the Polaris to the Poseidon would, however, be halted at the point it had reached at the time the agreement went into effect. The halt in submarine construction might be a more serious problem for the Russians, since their SLBM program lags considerably behind that of the U.S.

Such a freeze would leave both nations with a secure deterrent force (provided that ABM systems were simultaneously controlled). Furthermore, at the present time both nations have an approximate parity in overall force strengths in spite of inequalities within individual systems. Thus such an agreement should be politically acceptable to both sides. Any changes that would be allowed under the agreement or carried out clandestinely could not upset the present strategic balance.

From the point of view of controlling the arms race this proposal would be the most far-reaching. There would be greatly reduced opportunities or incentives for replacing existing missile systems with new ones. Although MIRV's would be allowed, the replacement of the fixed land-based system by a mobile or a sea-based one would be precluded, and there would be few incentives for increasing the payload capacity of the existing missiles within the agreed limitations. Such an agreement would therefore also be by far the most effective in terms of economic savings.

Verification of a freeze of this nature would also be relatively easy. New deployments of missile launchers or long-range aircraft are comparatively easy to observe by unilateral means, and since any change in visible characteristics would be banned, it would be relatively easy to determine if a violation had occurred. To determine a violation it would not be necessary to present evidence on the total number of deployed systems but only that a change had occurred from the situation that existed at the time the agreement went into effect. This would avoid the extensive disclosure of unilateral information available on the programs of the other side and would greatly simplify making a case for a violation before the world. Furthermore, sources of misunderstanding and confusion would be much reduced. Since no new missile-site construction would be allowed, there would be no question of whether a given activity was an allowed replacement or not. The

only possible source of confusion would be in connection with the external configuration of the missiles themselves. Once the missile was emplaced within the hole, it would be very difficult to determine whether or not it had the same external configuration as an older missile. There would, however, always be some risk of detection of such replacement during the emplacement phase; evidence that a new missile was available for this purpose could be obtained during testing. Furthermore, since the dimensions of the launcher would be kept constant, the opportunities and incentives for significant cheating would be kept to a minimum. Thus old Russian missiles could not be replaced by SS-9's. In sum, it would appear that such a freeze could be adequately verified without fears that security was being eroded.

None of the foregoing proposals for limiting the deployment of offensive strategic weapons provides any limitations on the deployment of MIRV's. The proposals for limiting payload or banning changes in the external configuration of missiles or launchers would still allow replacement of single warheads with MIRV's, although they would provide some limitations on the number of MIRV's that could be associated with any one missile, since the number is dependent on the payload available and the external configuration of the missile. The proposed Poseidon missile, however, is planned to carry 10 or more MIRV's, each one admittedly of low yield (although still several times greater than the Hiroshima bomb). The SS-9, which is much larger than the Poseidon, could be adapted to hold at least 10 MIRV's.

Analyses of the foregoing proposals also show that the most destabilizing element would in all cases be the ability to obtain a MIRV capability. MIRV's threaten the viability of the fixed land-based missile component of the strategic force and provide pressures for the development and deployment of new systems. A Russian MIRV capability presents a much greater potential threat to the U.S. than vice versa because of the greater payload of the Russian missiles. Therefore it should be an extremely important U.S. objective to see that MIRV's are controlled. The problems of MIRV's have been discussed in detail elsewhere [see "The Limitation of Strategic Arms," by G. W. Rathjens and G. B. Kistiakowsky; SCIENTIFIC AMERICAN, January, 1970]. Heretofore the major problem facing the U.S. in this connection has been fears that a MIRV ban could not be adequately verified. Clearly this is true for deployment of previously tested systems, since this would require at a minimum extremely extensive and probably impractical inspection. Nonetheless, it would take the Russians at least a year and probably several years before they could have a tested, deployable MIRV system that could threaten the Minutemen. Hence this provides an opportunity to extend the ban to include testing. Although there are differences of opinion on the adequacy of unilateral verification techniques, such techniques would certainly be much more satisfactory for verifying a ban on the testing of MRV's and MIRV's than they would be for verifying a limitation on total missile payload. A strong case can be made that it is technologically possible to verify a MIRV test ban adequately by unilateral means in order to protect U.S. security without on-site inspections. These means should clearly provide greater confidence against significant violations than would the on-site inspections that have been proposed for the detection of clandestine deployment of MIRV's, since it is not clear how any procedure could provide confidence that

POSSIBLE SALT AGREEMENT	EFFECT ON U.S. SECURITY	ECONOMIC SAVINGS FOR U.S.	EFFECT ON ARMS RACE	NEGOTIABILITY
1 CEILING ON NUMBERS OF DELIVERY VEHICLES				
a NO LIMITATION ON REPLACEMENT	LITTLE, IF ANY, IMPROVEMENT	NONE (MIGHT INCREASE MILITARY EXPENDITURES)	LITTLE, IF ANY (MIGHT ACCELERATE)	VERY EASY (VERIFICATION COMPLICATED)
b SEPARATE CEILINGS ON MISSILES AND BOMBERS	SLIGHTLY BETTER THAN 1a	LITTLE, IF ANY	SLIGHTLY BETTER THAN 1a	EASY (VERIFICATION COMPLICATED)
c LIMITATION ON LARGE ICBM'S	SOME IMPROVEMENT	LITTLE, IF ANY	BETTER THAN 1b BUT LIMITS ONLY ONE SYSTEM	HARD (UNLESS U.S. IS ALSO WILLING TO HALT POSEIDON)
2 FREEZE ON DEPLOYED PAYLOAD	NO IMPROVEMENT (FREEZES U.S. INFERIORITY)	SOME	GOOD BUT DOES NOT HALT MIRV'S	HARD (VERIFICATION HARD)
3 FREEZE ON DELIVERY VEHICLES				
a NO REPLACEMENT	SIGNIFICANT IMPROVEMENT	VERY LARGE	EXCELLENT	POSSIBLE (VERIFICATION MARGINAL)
b NO CHANGE IN EXTERNAL CHARACTERISTICS	SIGNIFICANT IMPROVEMENT (LESS THAN 3a)	LARGE (LESS THAN 3a)	VERY GOOD	EASIER THAN 3a (VERIFICATION EASY)
4 LIMITATION ON MIRV'S				
a BAN ON DEPLOYMENT	IMPROVEMENT	SIGNIFICANT	VERY GOOD	HARD (VERIFICATION ALMOST IMPOSSIBLE)
b BAN ON PRODUCTION TESTING AND DEPLOYMENT	GREAT IMPROVEMENT	SIGNIFICANT	VERY GOOD	EASIER THAN 4a (VERIFICATION POSSIBLE)

VARIOUS APPROACHES to a strategic-arms-limitation agreement are evaluated in this table in very general terms. The best agreement possible under the present circumstances would appear to be one in which the strategic forces of both sides would be frozen at their existing levels, ABM systems would be banned and further production, testing and deployment of MIRV's would be halted.

a single warhead was not substituted for a deployed MIRV warhead before the inspectors visited the launching site.

As time has passed, another obstacle has arisen to the success of achieving a MIRV limitation. The U.S. has now completed more than two years of testing on its first-generation MIRV system for the Minuteman III and Poseidon missiles. Beginning in June, 1970, the deployment of Minuteman III with MIRV's was begun at an operational site in North Dakota. Eight Polaris submarines are now in the yards being modified to fire the Poseidon missile, and the first of these will be going to sea in January, 1971. Even if the U.S. were willing to stop this program and actually withdraw these MIRV missiles from the inventory, it would seem highly unlikely that the Russians would be willing to accept an agreement that would leave them so far behind the U.S. in this particularly critical strategic area. Past experience has clearly shown that the Russians are unwilling to negotiate from a position of significant inferiority. They steadfastly refused to seriously discuss strategic-arms limitations until they had approached general parity with the U.S. Therefore there should be no optimism that it will be possible to reach an agreement on MIRV's until the Russian program is considerably more advanced. The clock on the U.S. development cannot be turned back. Unfortunately when the Russians have a capability equivalent to the present U.S. one, an agreement will still be extremely hard to achieve, since then they would be able to deploy an already tested system and the verification problems would be greatly compounded. Hence the U.S. should make an urgent, all-out effort to attempt to persuade the U.S.S.R. to accept a MIRV limitation at this time. Otherwise U.S. security could in the long run be reduced and the arms race would continue, while scarce funds would be expended on more advanced weapons systems. An agreement to ban the production, testing and deployment of MIRV's would be in the mutual interest of both sides; the U.S. could still verify such a ban in the testing phase and the Russians in the production and deployment phases.

Although it is not the purpose of this article to discuss limitations on ABM systems, it is clear in analyzing the various alternative methods of limiting offensive systems that their adequacy is strongly dependent on whether or not ABM systems are limited at the same time. In fact, ABM limitations would be desirable even if no controls could be placed on offensive weapons. Without controls on such defenses, fears could develop that an ABM system might be deployed that could successfully handle those residual offensive weapons that might survive a first strike. If this came to pass, the deterrent would be threatened. Thus without controls on ABM systems, and particularly without also having controls on MIRV's, strong pressures will exist for the deployment of new offensive systems that will be less vulnerable to a first strike: mobile land-based missiles and more SLBM's. There will also be increased pressures to deploy more MIRV's on the existing systems, particularly on the SLBM's. These would not be needed if ABM defenses were also limited to low levels.

From the point of view of arms control, a complete ban on ABM systems would be most satisfactory, but if these were limited to defense of capitals, then they should not require an escalation of the offensive-arms race. Whereas the present Moscow ABM system might be politically justifiable by the U.S.S.R., in view of its existence and in view of that city's role as the center of the Russian nation, it is harder to justify the large U.S. expenditure of funds for a future defense of Washington, which does not occupy the same position in American minds. Security considerations allow the U.S. to leave the Moscow ABM system as it is and to forgo the Washington ABM system and perhaps extract some parallel concession from the Russians in another area. If ABM defenses were limited to defense of Minuteman sites, they should, like capital defenses, not be destabilizing, since these would not provide significant protection of U.S. urban centers. Unfortunately the same would not be the case for a parallel Russian ICBM defense, because their ICBM deployment is relatively close to urban centers; hence such a system could provide nationwide coverage and could be viewed as a potential threat to the U.S. deterrent. If either nation built a thin area defense to handle even a small Chinese threat, this too would be destabilizing and militate against U.S.-U.S.S.R. controls on offensive weapons, since it could be viewed as being expandable into a system that could cope with a limited second-strike capability.

In summary, it appears that the ideal method of limiting offensive strategic weapons would be to freeze currently deployed forces at present levels and types of weapons. This would maintain the present security that exists in a stable strategic balance; it would have the greatest damping effect on the arms race, and it would provide the largest economic savings. On the other hand, such an agreement would present numerous problems of verification, since many qualitative improvements cannot be detected without very intrusive inspection.

The most immediately practical method of controlling offensive weapons would involve a freeze on existing systems, a ban on the construction of new launchers and a restriction on any changes in deployed systems to those that do not change their external characteristics. Such an agreement would provide some valuable limitations on qualitative improvements and would be adequately verifiable by unilateral means.

A limitation that restricted both the number of weapons and the payload they could deliver would also provide some useful restriction on qualitative improvements but would present certain verification problems. It might also prove difficult to find a mutually satisfactory negotiating formula for such a concept in view of the present large Russian lead in missile payload and the U.S. lead in bomber payload.

An agreement that limited strategic weapons to specific numbers without any restrictions on replacement or substitution would do little if anything to halt the arms race and in fact might provide strong incentives for accelerating it along new directions. Placing additional limitations on specific types of weapons might overcome some of these defects, but it would be difficult to achieve an arrangement that would satisfy both the security and the political requirements of both nations. Furthermore, this type of agreement would provide opportunities for misunderstandings concerning whether or not it was being abided by.

Although limitations on MIRV's may now be increasingly difficult to achieve both because of problems of verification and because of the present U.S. technological lead, the risks they present to the strategic balance and to almost any long-term arms-limitation agreement make it important that no opportunities be overlooked to attempt to reach some limitation on these weapons. The risks from no limitation would seem to far outweigh the risks from possible undetected violations of a ban on MIRV production, testing and deployment.

Finally, a prerequisite to any useful long-term limitation on offensive forces requires a simultaneous ban on ABM systems or at least a limitation that precludes rapid expansion to provide nationwide coverage.

STRESS AND BEHAVIOR

The chain of pituitary and adrenal hormones that regulates responses to stress plays a major role in learning and other behaviors. It may be that effective behavior depends on some optimum level of stress

by Seymour Levine

Hans Selye's concept of the general "stress syndrome" has surely been one of the fruitful ideas of this era in biological and medical research. He showed that in response to stress the body of a mammal mobilizes a system of defensive reactions involving the pituitary and adrenal glands. The discovery illuminated the causes and symptoms of a number of diseases and disorders. More than that, it has opened a new outlook on the functions of the pituitary-adrenal system. One can readily understand how the hormones of this system may defend the body against physiological insult, for example by suppressing inflammation and thus preventing tissue damage. It is a striking fact, however, that the system's activity can be evoked by all kinds of stresses, not only by severe somatic stresses such as disease, burns, bone fractures, temperature extremes, surgery and drugs but also by a wide range of psychological conditions: fear, apprehension, anxiety, a loud noise, crowding, even mere exposure to a novel environment. Indeed, most of the situations that activate the pituitary-adrenal system do not involve tissue damage. It appears, therefore, that these hormones in animals, including man, may have many functions in addition to the defense of tissue integrity, and as a psychologist I have been investigating possible roles of the pituitary-adrenal system in the regulation of behavior.

The essentials of the system's operation in response to stress are as follows. Information concerning the stress (coming either from external sources through the sensory system or from internal sources such as a change in body temperature or in the blood's composition) is received and integrated by the central nervous system and is presumably delivered to the hypothalamus, the basal area of the brain. The hypothalamus secretes a substance called the corticotropin-releasing factor (CRF), which stimulates the pituitary to secrete the hormone ACTH. This in turn stimulates the cortex of the adrenal gland to step up its synthesis and secretion of hormones, particularly those known as glucocorticoids. In man the glucocorticoid is predominantly hydrocortisone; in many lower animals such as the rat it is corticosterone.

The entire mechanism is exquisitely controlled by a feedback system. When the glucocorticoid level in the circulating blood is elevated, the central nervous system, receiving the message, shuts off the process that leads to secretion of the stimulating hormone ACTH. Two experimental demonstrations have most clearly verified the existence of this feedback process. If the adrenal gland is removed from an animal, the pituitary puts out abnormal amounts of ACTH, presumably because the absence of the adrenal hormone frees it from restriction of this secretion. On the other hand, if crystals of glucocorticoid are implanted in the hypothalamus, the animal's secretion of ACTH stops almost completely, just as if the adrenal cortex were releasing large quantities of the glucocorticoid.

Now, it is well known that a high level of either of these hormones (ACTH or glucocorticoid) in the circulating blood can have dramatic effects on the brain. Patients who have received glucocorticoids for treatment of an illness have on occasion suffered severe mental changes, sometimes leading to psychosis. And patients with a diseased condition of the adrenal gland that caused it to secrete an abnormal amount of cortical hormone have also shown effects on the brain, including changes in the pattern of electrical activity and convulsions.

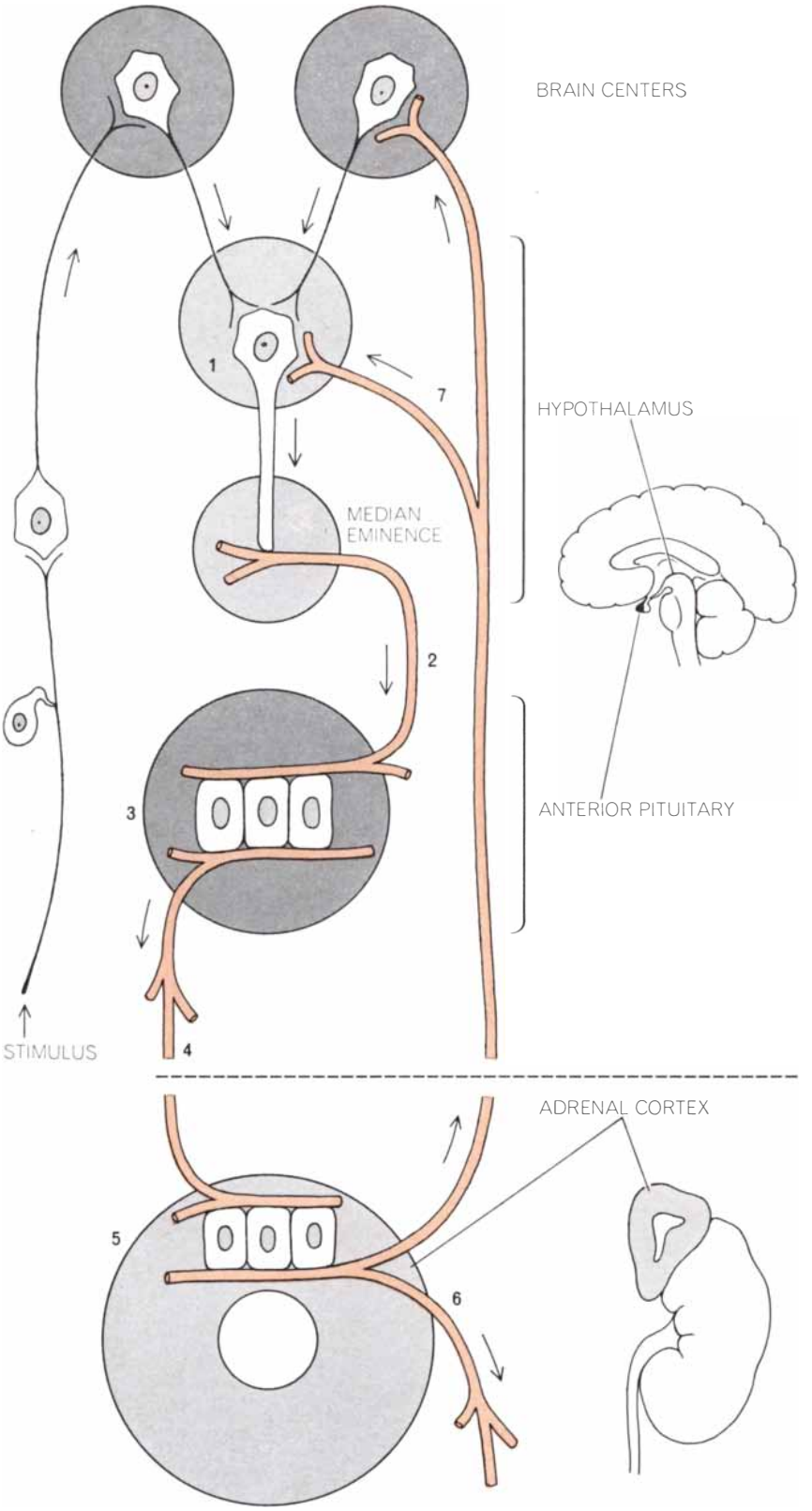
Two long-term studies of my own, previously reported in *Scientific American* [see "Stimulation in Infancy," May, 1960, and "Sex Differences in the Brain," April, 1966], strongly indicated that hormones play an important part in the development of behavior. One of these studies showed that rats subjected to shocks and other stresses in early life developed normally and were able to cope well with stresses later, whereas animals that received no stimulation in infancy grew up to be timid and deviant in behavior. At the adult stage the two groups differed sharply in the response of the pituitary-adrenal system to stress: the animals that had been stimulated in infancy showed a prompt and effective hormonal response; those that had not been stimulated responded slowly and ineffectively. The other study, based on the administration or deprivation of sex hormones at a critical early stage of development in male and female rats, indicated that these treatments markedly affected the animals' later behavior, nonsexual as well as sexual. It is noteworthy that the sex hormones are steroids rather similar to those produced by the adrenal cortex.

Direct evidence of the involvement of the pituitary-adrenal system in overt behavior was reported by two groups of experimenters some 15 years ago. Mortimer H. Appley, now at the University of Massachusetts, and his co-workers were investigating the learning of an avoidance response in rats. The animals were placed in a "shuttle box" divided into two compartments by a barrier. An electric shock was applied, and if the animals crossed the barrier, they could avoid or terminate the shock. The avoidance response consisted in making the move

across the barrier when a conditioned stimulus, a buzzer signaling the onset of the shock, was sounded. Appley found that when the pituitary gland was removed surgically from rats, their learning of the avoidance response was severely retarded. It turned out that an injection of ACTH in pituitary-deprived rats could restore the learning ability to normal. At about the same time Robert E. Miller and Robert Murphy of the University of Pittsburgh reported experiments showing that ACTH could affect extinction of the avoidance response. Normally if the shocks are discontinued, so that the animal receives no shock when it fails to react to the conditioned stimulus (the buzzer in this case), the avoidance response to the buzzer is gradually extinguished. Miller and Murphy found that when they injected ACTH in animals during the learning period, the animals continued to make the avoidance response anyway, long after it was extinguished in animals that had not received the ACTH injection. In short, ACTH inhibited the extinction process.

These findings were not immediately followed up, perhaps mainly because little was known at the time about the details of the pituitary-adrenal system and only rudimentary techniques were available for studying it. Since then purified preparations of the hormones involved and new techniques for accurate measurement of these substances in the circulating blood have been developed, and the system is now under intensive study. Most of the experimental investigation is being conducted at three centers: in the Institute of Pharmacology at the University of Utrecht under David de Wied, in the Institute of Physiology at the University of Pecs in Hungary under Elemér Endroczi and in our own laboratories in the department of psychiatry at Stanford University.

The new explorations of the pituitary-adrenal system began where the ground had already been broken: in studies of the learning and extinction of the avoidance response, primarily by use of the shuttle box. De Wied verified the role of ACTH both in avoidance learning and in inhibiting extinction of the response. He did this in physiological terms by means of several experiments. He verified the fact that removal of the pituitary gland severely retards the learning of a conditioned avoidance response. He also removed the adrenal gland from rats and found that the response was then not extinguished, presumably because adrenal hormones were no longer present to re-



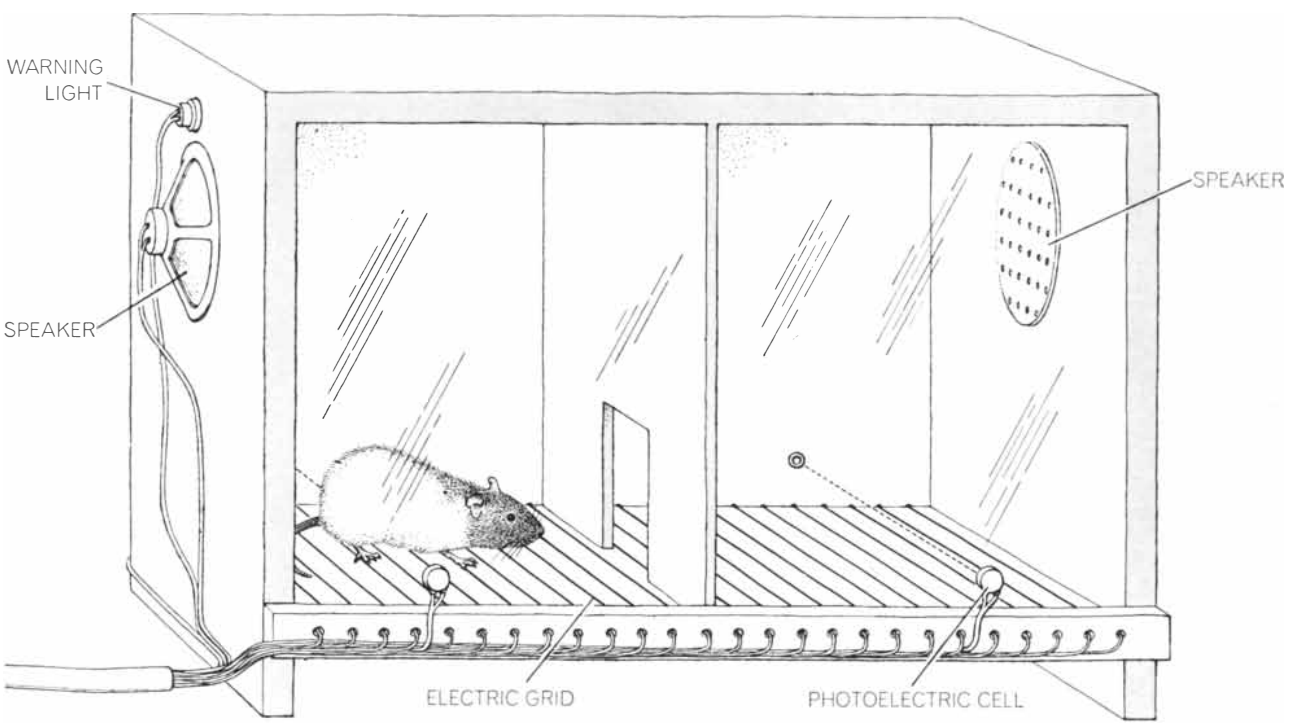
PITUITARY-ADRENAL SYSTEM involves nerve cells and hormones in a feedback loop. A stress stimulus reaching neurosecretory cells of the hypothalamus in the base of the brain (*1*) stimulates them to release corticotropin-releasing factor (CRF), which moves through short blood vessels (*2*) to the anterior lobe of the pituitary gland (*3*). Pituitary cells thereupon release adrenocorticotrophic hormone (ACTH) into the circulation (*4*). The ACTH stimulates cells of the adrenal cortex (*5*) to secrete glucocorticoid hormones (primarily hydrocortisone in man) into the circulation (*6*). When glucocorticoids reach neurosecretory cells or other brain cells (it is not clear which), they modulate CRF production (*7*).

strict the pituitary's output of ACTH. When he excised the pituitary, thus eliminating the secretion of ACTH, the animals returned to near-normal behavior in the extinction of the avoidance response.

In further experiments De Wied injected glucocorticoids, including corticosterone, the principal steroid hormone of the rat's adrenal cortex, into animals that had had the adrenal gland, but not the pituitary, removed; as expected, this had the effect of speeding up the extinction of the avoidance response. Similarly, the administration to such animals of dexamethasone, a synthetic glucocorticoid that is known to be a potent inhibitor of ACTH, resulted in rapid extinction of the avoidance response; the larger the dose, the more rapid the extinction. Curiously, De Wied found that corticosterone and dexamethasone promoted extinction even in animals that lacked the pituitary gland, the source of ACTH. This indicated that the glucocorticoid can produce its effect not only through suppression of ACTH but also, in some way, by acting directly on the central nervous system. It has recently been found, on the other hand, that there may be secretions from the pituitary other than ACTH that can affect learning and inhibit extinction of the avoidance response. The inhibition can be produced, for example, by a truncated portion of the ACTH molecule consisting of the first 10 amino acids in the sequence of 39 in the rat's ACTH—a molecular fragment that has no influence on the adrenal cortex. The same fragment, along with other smaller peptides recently isolated by De Wied, can also overcome the deficit in avoidance learning that is produced by ablation of the pituitary.

With an apparatus somewhat different from the shuttle box we obtained further light in our laboratory on ACTH's effects on behavior. We first train the animals to press a bar to obtain water. After this learning has been established the animal is given an electric shock on pressing the bar. This causes the animal to avoid approaching the bar (called "passive avoidance") for a time, but after several days the animal will usually return to it in the effort to get water and then will quickly lose its fear of the bar if it is not shocked. We found, however, that if the animal was given doses of ACTH after the shock, it generally failed to return to the bar at all, even though it was very thirsty. That is to say, ACTH suppressed the bar-pressing response, or, to put it another way, it strengthened the passive-avoidance response. In animals with the pituitary gland removed, injections of ACTH suppressed a return to bar-pressing after a shock but injections of hydrocortisone did not have this effect.

The experiments I have described so far have involved behavior under the stress of fear and anxiety. Our investigations with the bar-pressing device go on to reveal that the pituitary-adrenal system also comes into play in the regulation of behavior based on "appetitive" responses (as opposed to avoidance responses). Suppose we eliminate the electric shock factor and simply arrange that after the animal has learned to press the bar for water it fails to obtain water on later trials. Normally the animal's bar-pressing behavior is then quickly extinguished. We found, however, that when we injected ACTH in the animals in these circumstances, the extinction of bar-pressing was delayed; the rats went on pressing the bar for some time although they received no water as reinforcement. Following up this finding, we measured the corticosterone levels in the blood of normal, untreated rats both when they were reinforced and when they were not reinforced on pressing the



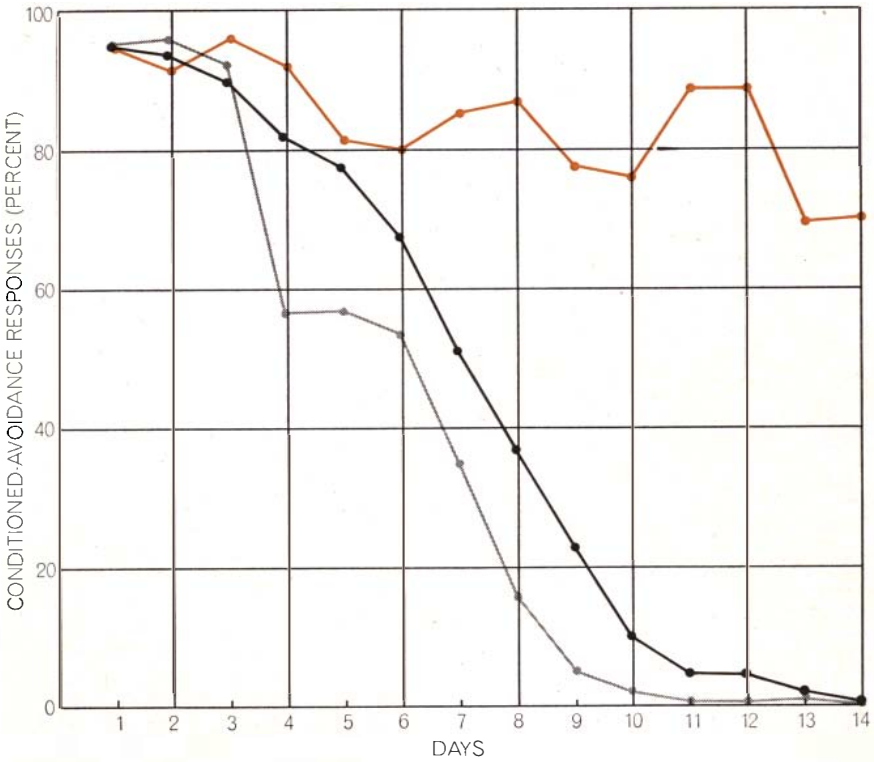
"SHUTTLE BOX" used for studying avoidance behavior is a two-compartment cage. The floor can be electrically charged. A shock is delivered on the side occupied by the rat (detected by the photocell). The rat can avoid the shock by learning to respond to the conditioned stimulus: a light and noise delivered briefly before the shock. The avoidance response, once learned, is slowly "extinguished" if the conditioned stimulus is no longer accompanied by a shock. Injections of ACTH inhibited the extinction process.

bar. The animals that received no water reinforcement, with the result of rapid extinction of bar-pressing, showed a marked rise in activity of the pituitary-adrenal system during this period, whereas in animals that received water each time they pressed the bar there was no change in the hormonal output. In short, the extinction of appetitive behavior in this case clearly involved the pituitary-adrenal system.

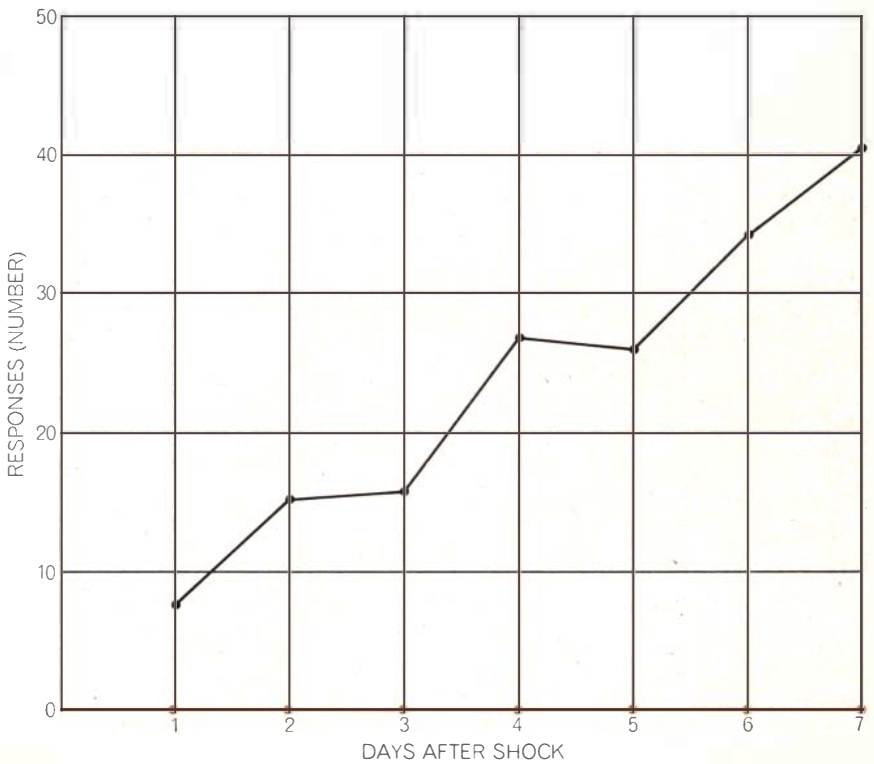
Further investigations have now shown that the system affects a much wider range of behavior than learning and extinction. One of the areas that has been studied is habituation: the gradual subsidence of reactions that had appeared on first exposure to a novel stimulus when the stimulus is repeated. An organism presented with an unexpected stimulus usually exhibits what Ivan Pavlov called an orientation reflex, which includes increased electrical activity in the brain, a reduction of blood flow to the extremities, changes in the electrical resistance of the skin, a rise in the level of adrenal-steroid hormones in the blood and some overt motor activity of the body.

If the stimulus is repeated frequently, these reactions eventually disappear; the organism is then said to be habituated to the stimulus. Endroczi and his co-workers recently examined the influence of ACTH on habituation of one of the reactions in human subjects—the increase of electrical activity in the brain, as indicated by electroencephalography. The electrical activity evoked in the human brain by a novel sound or a flickering light generally subsides, after repetition of the stimulus, into a pattern known as electroencephalogram (EEG) synchronization, which is taken to be a sign of habituation. Endroczi's group found that treatment of their subjects with ACTH or the 10-amino-acid fragment of ACTH produced a marked delay in the appearance of the synchronization pattern, indicating that the hormone inhibits the process of habituation.

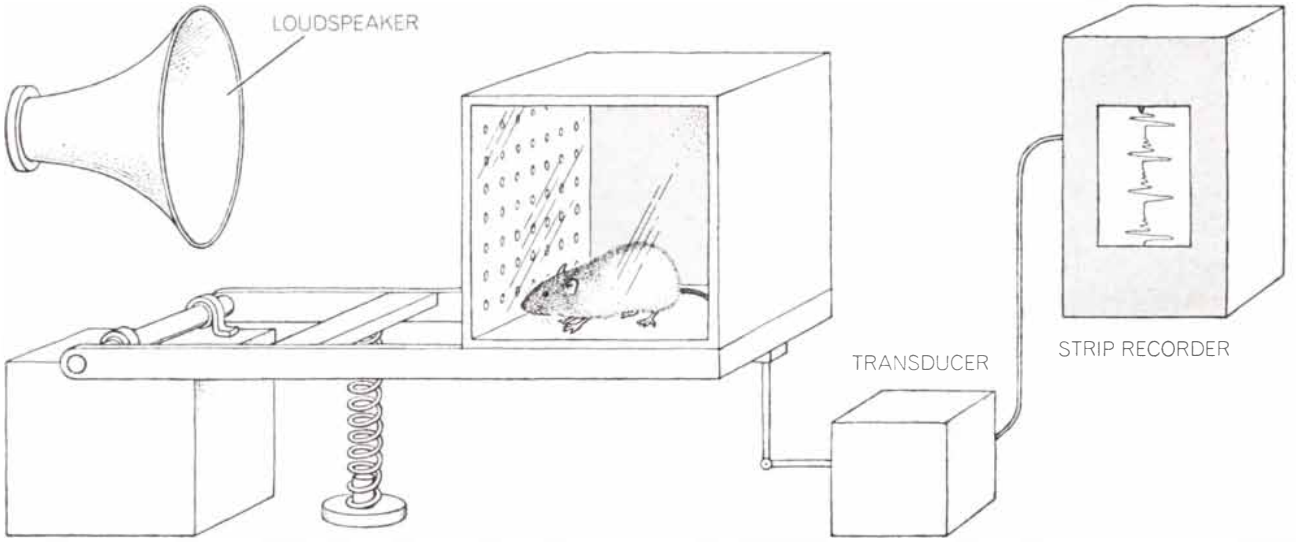
Experiments with animals in our laboratory support that finding. The stimulus we used was a sudden sound that produces a "startle" response in rats, which is evidenced by vigorous body movements. After a number of repetitions of the sound stimulus the startle response fades. It turned out that rats deprived of the adrenal gland (and consequently with a high level of ACTH in their circulation) took significantly longer than intact animals to habituate to the sound stimulus. An implant of the adrenal hormone hydrocortisone in the hy-



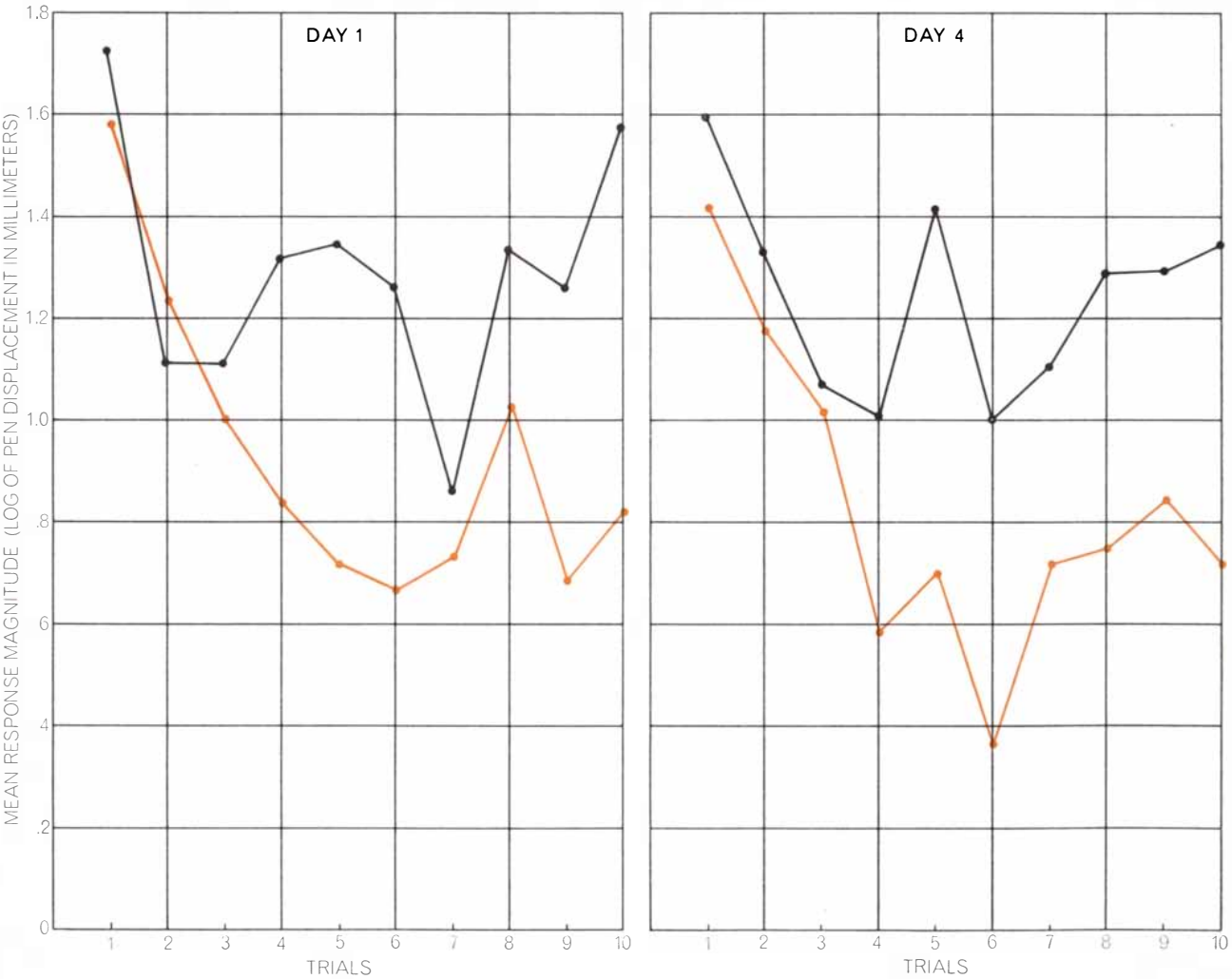
EXTINCTION of the avoidance response was studied by David de Wied of the University of Utrecht. Removal of the adrenal gland inhibited extinction (*color*); the rats responded to the conditioned stimulus in the absence of shock, presumably because adrenal hormones were not available to restrict ACTH output. When the pituitary was removed, the rate of extinction (*gray*) was about the same as in rats given only a sham operation (*black*).



PASSIVE AVOIDANCE BEHAVIOR is studied by observing how rats, trained to press a bar for water, avoid the bar after they get a shock on pressing it. Before being shocked rats pressed the bar about 75 times a day. After the shock the control animals returned to the bar and, finding they were not shocked, gradually increased their responses (*black curve*). Rats injected with ACTH stayed away (*color*): ACTH strengthens the avoidance response.



"STARTLE" RESPONSE is measured by placing a rat in a cage with a movable floor and exposing it to a sudden, loud noise. The rat tenses or jumps, and the resulting movement of the floor is transduced into movement of a pen on recording paper. After a number of repetitions of the noise the rat becomes habituated to it and the magnitude of the animal's startle response diminishes.



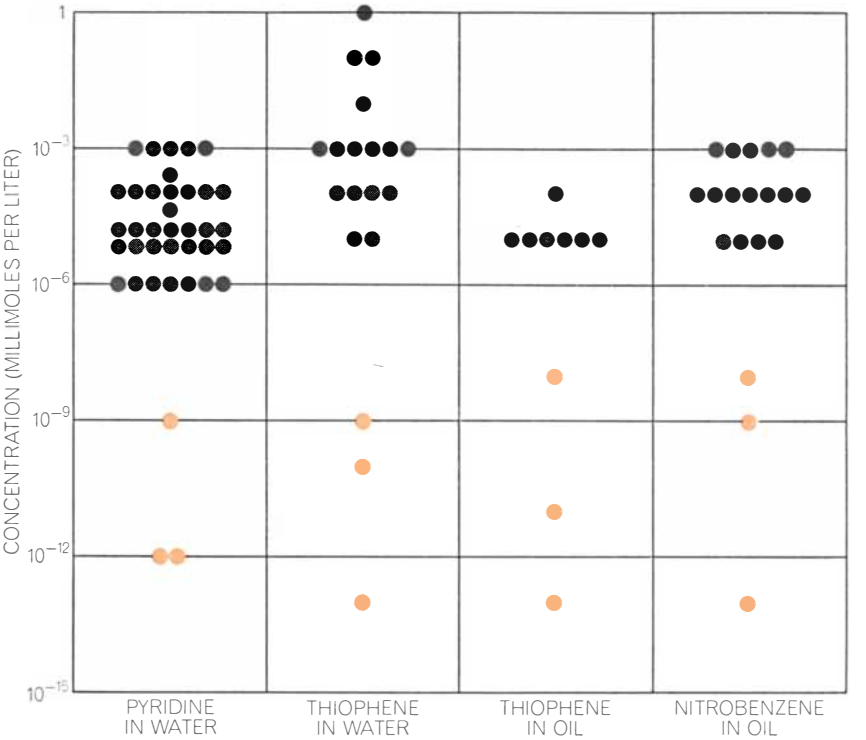
HABITUATION is affected by the pituitary-adrenal system. If a crystal of the adrenal hormone hydrocortisone is implanted in a rat's hypothalamus, preventing ACTH secretion, habituation is speeded up, as shown here. The mean startle response (shown as the logarithm of the recording pen's movement) falls away more rapidly in implanted rats (*color*) than in control animals (*black*).

pothalamus, on the other hand, speeded up habituation.

A series of studies by Robert I. Henkin of the National Heart Institute has demonstrated that hormones of the adrenal cortex play a crucial role in the sensory functions in man. Patients whose adrenal gland has been removed surgically or is functioning poorly show a marked increase in the ability to detect sensory signals, particularly in the senses of taste, smell, hearing and proprioception (sensing of internal signals). On the other hand, patients with Cushing's syndrome, marked by excessive secretion from the adrenal cortex, suffer a considerable dulling of the senses. Henkin showed that sensory detection and the integration of sensory signals are regulated by a complex feedback system involving interactions of the endocrine system and the nervous system. Although patients with a deficiency of adrenal cortex hormones are extraordinarily sensitive in the detection of sensory signals, they have difficulty integrating the signals, so that they cannot evaluate variations in properties such as loudness and tonal qualities and have some difficulty understanding speech. Proper treatment with steroid hormones of the adrenal gland can restore normal sensory detection and perception in such patients.

Henkin has been able to detect the effects of the adrenal corticosteroids on sensory perception even in normal subjects. There is a daily cycle of secretion of these steroid hormones by the adrenal cortex. Henkin finds that when adrenocortical secretion is at its highest level, taste detection and recognition is at its lowest, and vice versa.

In our laboratory we have found that the adrenal's steroid hormones can have a truly remarkable effect on the ability of animals to judge the passage of time. Some years ago Murray Sidman of the Harvard Medical School devised an experiment to test this capability. The animal is placed in an experimental chamber and every 20 seconds an electric shock is applied. By pressing a bar in the chamber the animal can prevent the shock from occurring, because the bar resets the triggering clock to postpone the shock for another 20 seconds. Thus the animal can avoid the shock altogether by appropriate timing of its presses on the bar. Adopting this device, we found that rats learned to press the bar at intervals averaging between 12 and 15 seconds. This prevented a majority of the shocks. We then gave the animals glucocorticoids and found that they became significantly more efficient!



SENSORY FUNCTION is also affected by adrenocortical hormones. Robert I. Henkin of the National Heart Institute found that patients whose adrenal-hormone function is poor are much more sensitive to odor. Placing various chemicals in solution, he measured the detection threshold: the concentration at which an odor could be detected in the vapor. The threshold was much lower in the patients (*color*) than in normal volunteers (*black*).

They lengthened the interval between bar presses and took fewer shocks. Evidently under the influence of the hormones the rats were able to make finer discriminations concerning the passage of time. Monkeys also showed improvement in timing performance in response to treatment with ACTH.

The mechanism by which the pituitary-adrenal hormones act to regulate or influence behavior is still almost completely unknown. Obviously they must do so by acting on the brain. It is well known that hormones in general are targeted to specific sites and that the body tissues have a remarkable selectivity for them. The uterus, for instance, picks up and responds selectively to estrogen and progesterone among all the hormones circulating in the blood, and the seminal vesicles and prostate gland of the male select testosterone. There is now much evidence that organs of the brain may be similarly selective. Bruce Sherman McEwen of Rockefeller University has recently reported that the hippocampus, just below the cerebral cortex, appears to be a specific receptor site for hormones of the adrenal cortex, and other studies indicate that the lateral portion of the hypothalamus may be a receptor site for gonadal hormones. We have the inviting prospect, therefore, that exploration of the brain to locate the receptor sites for the hormones of the pituitary-adrenal system, and studies of the hormones' action on the cells of these sites, may yield important information on how the system regulates behavior. Bela Bohun in Hungary has already demonstrated that implantation of small quantities of glucocorticoids in the reticular formation in the brain stem facilitates extinction of an avoidance response.

Since this system plays a key role in learning, habituation to novel stimuli, sensing and perception, it obviously has a high adaptive significance for mammals, including man. Its reactions to moderate stress may contribute greatly to the behavioral effectiveness and stability of the organism. Just as the studies of young animals showed, contrary to expectations, that some degree of stress in infancy is necessary for the development of normal, adaptive behavior, so the information we now have on the operations of the pituitary-adrenal system indicates that in many situations effective behavior in adult life may depend on exposure to some optimum level of stress.

The Global Circulation of Atmospheric Pollutants

Worldwide wind and temperature patterns and the behavior of trace substances are studied in an effort to learn what effect changes in the atmosphere caused by man may have on the earth's climate

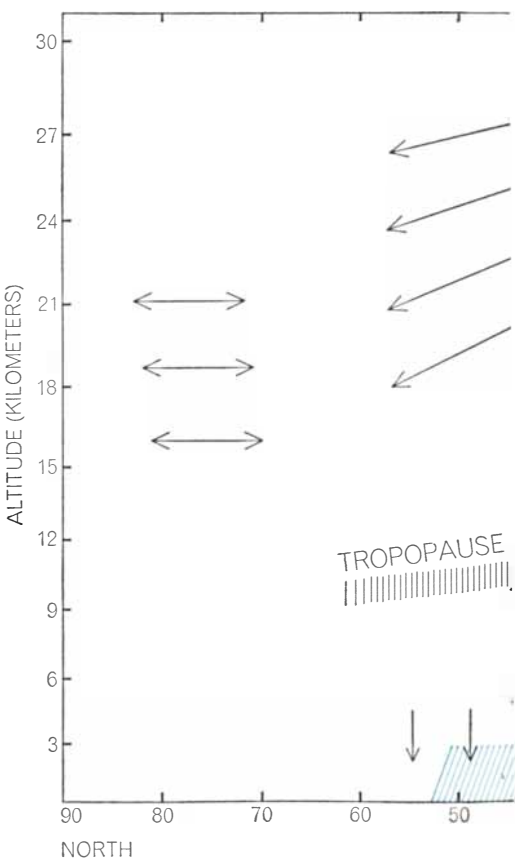
by Reginald E. Newell

Pollution is more than a plume of smoke rising above a factory or a yellowish haze hanging over a city. The foreign substances man introduces into the air spread all over the globe and rise into the upper atmosphere. It is therefore important to learn how each of the major pollutants enters the atmosphere, the speed and extent of its spread and the ways in which it may alter the atmosphere and thus affect temperature and precipitation both locally and worldwide. In this article I shall discuss the movement of the various pollutants and review what is known about the effect on temperature of foreign substances in the atmosphere.

Of the total of 164 million metric tons of pollutants emitted each year in the U.S., about half comes from automobiles. Of the main component, carbon monoxide, 77 percent is from automobiles; so are most of the hydrocarbons and much of the oxides of nitrogen. The oxides of sulfur come mainly from electric power plants, small particles mainly from power plants and industry. In addition to these more obvious pollutants, vast quantities of water and carbon dioxide are produced by the burning of fossil fuels. Other pollutants are lead from automotive gasoline and ozone, which is produced by the action of sunlight on automobile exhaust. Radioactive substances introduced by man's activity include fission products from weapons tests, such as strontium 90, cesium 137 and iodine 131, and neutron-activated casing materials, such as tungsten 185, manganese 54, iron 55, rhodium 102 and cadmium 109. A satellite carrying a portable power plant using plutonium 238 as fuel accidentally burned up in the atmosphere over the southern Indian Ocean in April, 1964, at a height of from 40 to 50 kilometers instead of going into orbit, and the radioactivity from that point source has been tracked over the globe. The reprocessing of nuclear-fuel elements from power plants releases krypton 85, a radioactive gas with a half-life of about 10 years, which is gradually accumulating in the atmosphere.

Trace substances are, of course, present in nature. Carbon dioxide is taken up by plants during their growth cycle and released by the decay of plant material. Sulfur is also involved in plant processes and is abundant in the ocean, from which it is released by sea spray; it is sometimes injected high into the atmosphere in large amounts during volcanic eruptions. Ozone is produced in the upper atmosphere and carried downward toward the earth's surface, where it is destroyed [see "The Circulation of the Upper Atmosphere," by Reginald E. Newell; SCIENTIFIC AMERICAN, March, 1964]. As for radioactivity, radon and thoron gas emanate from the soil and decay in the atmosphere, giving rise to a chain of radioactive substances; some of the end products, such as lead 210, are transported up into the stratosphere. Cosmic rays entering the atmosphere collide with air molecules, usually in the stratosphere, to form radioactive nuclides such as beryllium 7, sodium 22 and carbon 14, some of which live long enough to find their way down to the surface.

Whether natural or man-made, some of these trace substances occur as gases, others as aerosols: finely divided liquid droplets or solid particles. Many are involved in phase transformations. For example, water vapor (gas) may be cooled to the point where it changes to water droplets or to ice crystals, forming clouds; sulfur dioxide gas may change in moist air to droplets of sulfuric acid. The gases diffuse and mix quite easily but the aerosols are governed by a number of factors that limit their spread. Large particles with radii of 10 microns (thou-



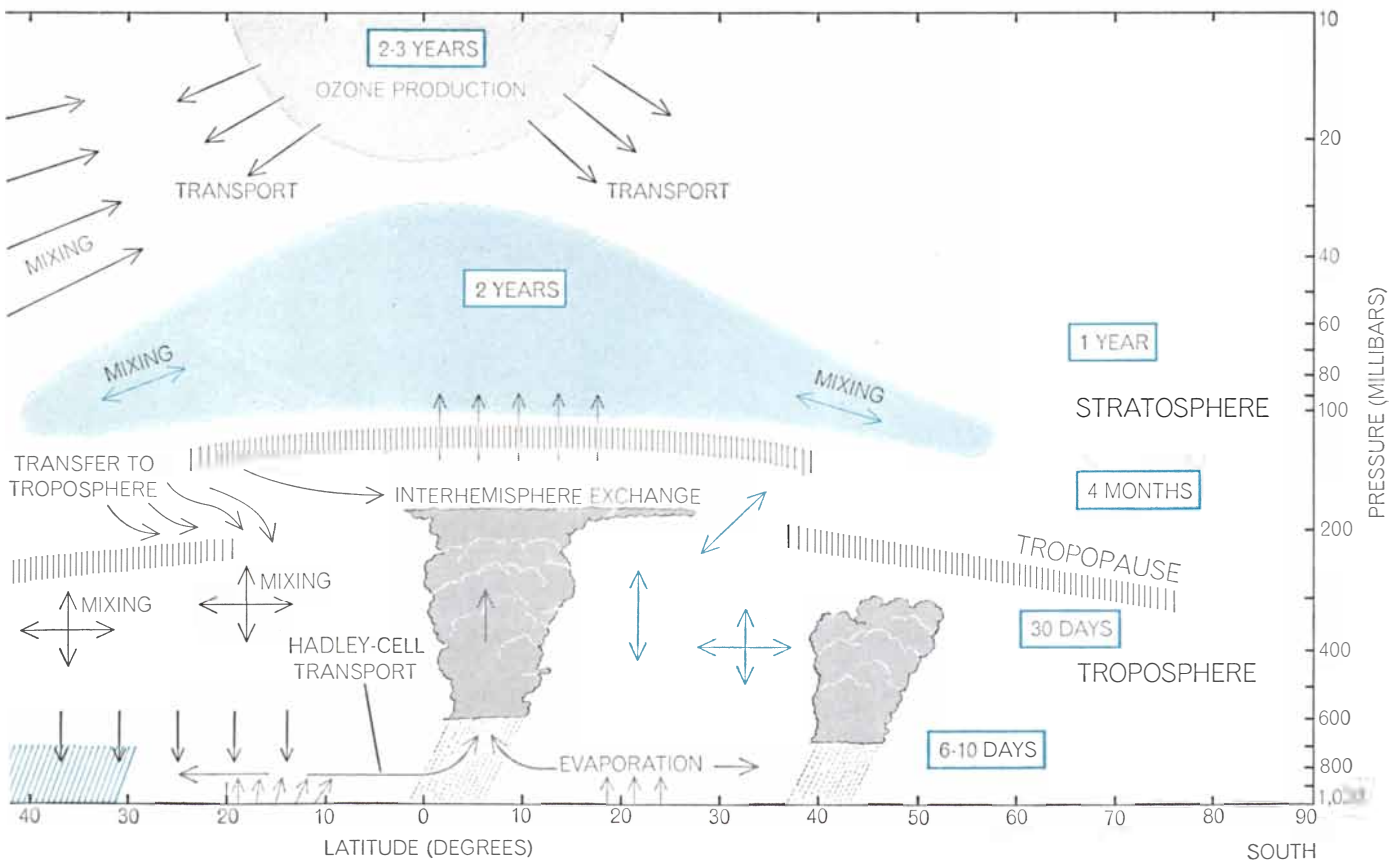
DISTRIBUTION AND MOVEMENTS of ozone (*black*); water (*gray*) and aerosols, or small solid and liquid particles (*color*), are

sandths of a millimeter) or more can be washed out of the air by raindrops or fall out directly. Very small particles can grow by coagulation until they too can be trapped in clouds and be washed out. Particles larger than about .3 micron cannot reach the upper atmosphere under normal circumstances because their fall velocities are greater than the average updraft speeds. Larger particles are nevertheless found in the upper atmosphere, some being introduced directly by volcanic eruptions, others growing there from smaller particles and gases introduced by the air motion. (Incidentally, the electrostatic precipitators on smokestacks are good for trapping particles with radii larger than about a micron; so is the human nose. Smaller particles can penetrate into the lungs, however, and so it is not always the larger particles one sees pouring from chimneys that are the most hazardous to health.)

Trace substances are moved over the globe by wind systems that fluctuate in strength and direction from day to day as cyclones and anticyclones move around the globe. The lowest 10 to 15 kilometers (six to nine miles) of the atmosphere, where the temperature decreases with height, is called the troposphere; above it to about 50 kilometers is the stratosphere, which in some respects resembles a series of stratified layers. Air parcels in both the troposphere and the stratosphere can be tabbed and tracked from one day to another [*see illustration on next page*]. The prevailing, or mean, wind, which is revealed by averaging over a long time period, blows from west to east over much of the middle latitudes in both hemispheres, but at low latitudes (and in the upper regions in general in summer) the prevailing wind is from the east. The mean wind transfers trace substances fairly rapidly round the globe; for example, the 35-meter-per-second west to east flow at 30 degrees north latitude gives a transit time of about 12 days. Clouds of debris from a nuclear explosion or volcanic eruption can often be identified as they make several circuits of the globe.

While the prevailing wind is along lines of latitude, north-south oscillations occur at the same time; the resulting north-south drift and an accompanying up-and-down motion give rise to an overturning pattern at low latitudes called the Hadley-cell circulation [*see illustration on page 36*]. In the Tropics this large cell is a dominant feature of the circulation, whereas at middle latitudes north-south eddies in the prevailing-wind systems overshadow the mean north-south drifts. Air can be exchanged between the hemispheres by both the mean Hadley circulation and eddies in the upper tropical troposphere. As for vertical exchange, air passes into the stratosphere from the troposphere at low latitudes in the Hadley-cell circulation. Most of the transfer back into the troposphere is thought to occur close to the tropopause level near the middle-latitude jet stream [*see illustration on these two pages*], and some transfer back into the stratosphere may also occur there.

In the troposphere clouds, rain and thunderstorms are evidence of considerable vertical motion. Vertical velocities may reach 10 to 20 meters per second in thunderstorms but are generally no more than 10 centimeters per second in normal middle-latitude cyclones and anticyclones. In the stratosphere it is much harder to push an air parcel up or down



indicated on a schematic diagram drawn along a line of longitude. Effects illustrated for one hemisphere occur in both hemispheres. Boxed figures are residence times for aerosols. Pressure, measured in millibars, is often used by meteorologists as a measure of altitude. The tropopause is the boundary between the troposphere and the stratosphere; its altitude varies with latitude as indicated.

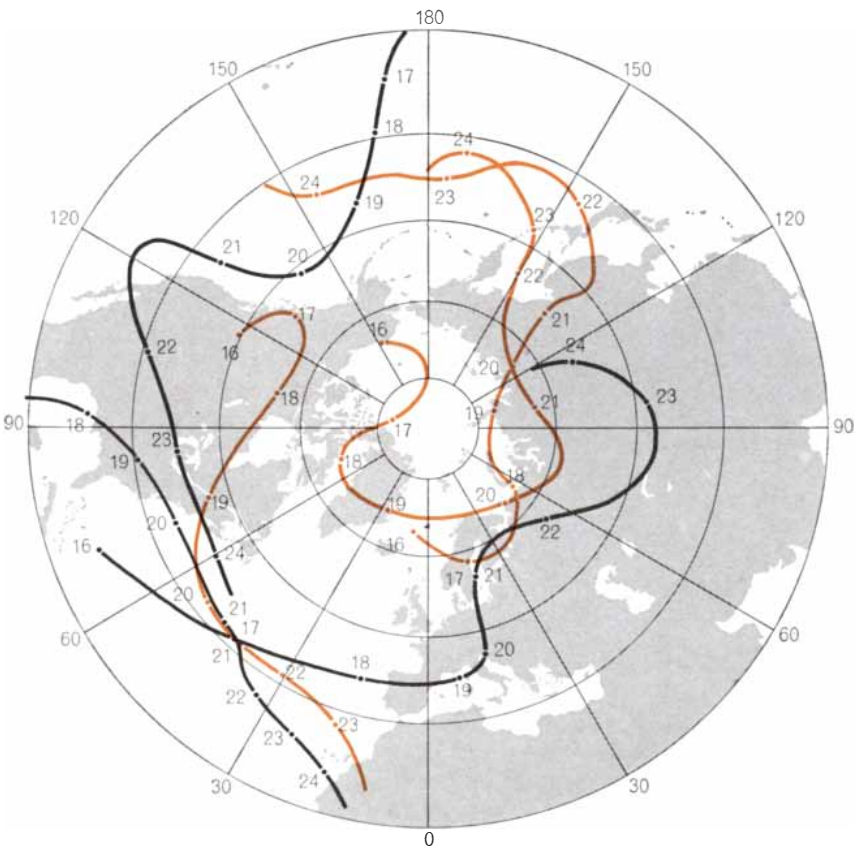
because the temperature increases with height, and so vertical motions rarely exceed a few centimeters per second and are often much smaller. The vertical spread of a trace substance in the stratosphere is therefore rather slow, like the downward migration of a card in a pack of cards that is being shuffled. There is much less shuffling at low latitudes than there is over the polar regions, so that trace constituents can stay in the equatorial stratosphere for several years.

Once the material reaches the bottom of the pack and enters the troposphere it can be mixed vertically rather rapidly. Small particles spend about 30 days in the troposphere before being washed out by rain. Gases spend varying periods there depending on the "sinks" by which each is removed from the atmosphere: incorporation into cloud droplets, reactions with other gases, loss to finely divided liquid or solid particles or the earth's surface and so on. Generally the tropospheric residence times of gases are from about two to four months—provided that there *is* a sink. (Krypton 85, for example, has no known sink and disappears only by radioactive decay.)

The global temperature pattern shows that the coldest air is over the Equator near the tropical tropopause at all seasons and over the winter pole in the stratosphere. The lowest temperatures over the Equator occur in January. Notice that temperature increases with latitude in the lower stratosphere. The temperature pattern is maintained by the liberation of latent heat, by radiation and by the motion of air masses, the sum of which is roughly in balance. When more water is rained out of a given air column than is evaporated into it from the surface, the column gains the latent heat that is liberated. The net effect of latent-heat liberation and radiative processes is that tropospheric air is heated at low latitudes and cooled at high latitudes, generating energy. In the troposphere the net effect of the radiative processes by themselves is to cool the air at all latitudes. Contributions come from absorption of incoming solar radiation, and from absorption and reemission of terrestrial long-wave radiation, by carbon dioxide, water vapor and ozone. Water vapor dominates in the lower layers, producing cooling of up to two degrees per day, with carbon dioxide of secondary importance; in the stratosphere carbon dioxide and ozone dominate [*see top illustration on page 39*]. Horizontal and vertical motions can also produce temperature changes. If air is forced to rise, it cools as it expands; if it is forced to sink, it contracts and becomes warmer, as in a bicycle pump. The former effect is thought to maintain the low temperatures over the tropical tropopause, the upward motion being forced from below, where the latent heat is liberated. On the other hand, compression is responsible for the inversion over the Los Angeles basin during a good fraction of the year—the increase of temperature with altitude that inhibits vertical mixing and traps pollutants near the surface.

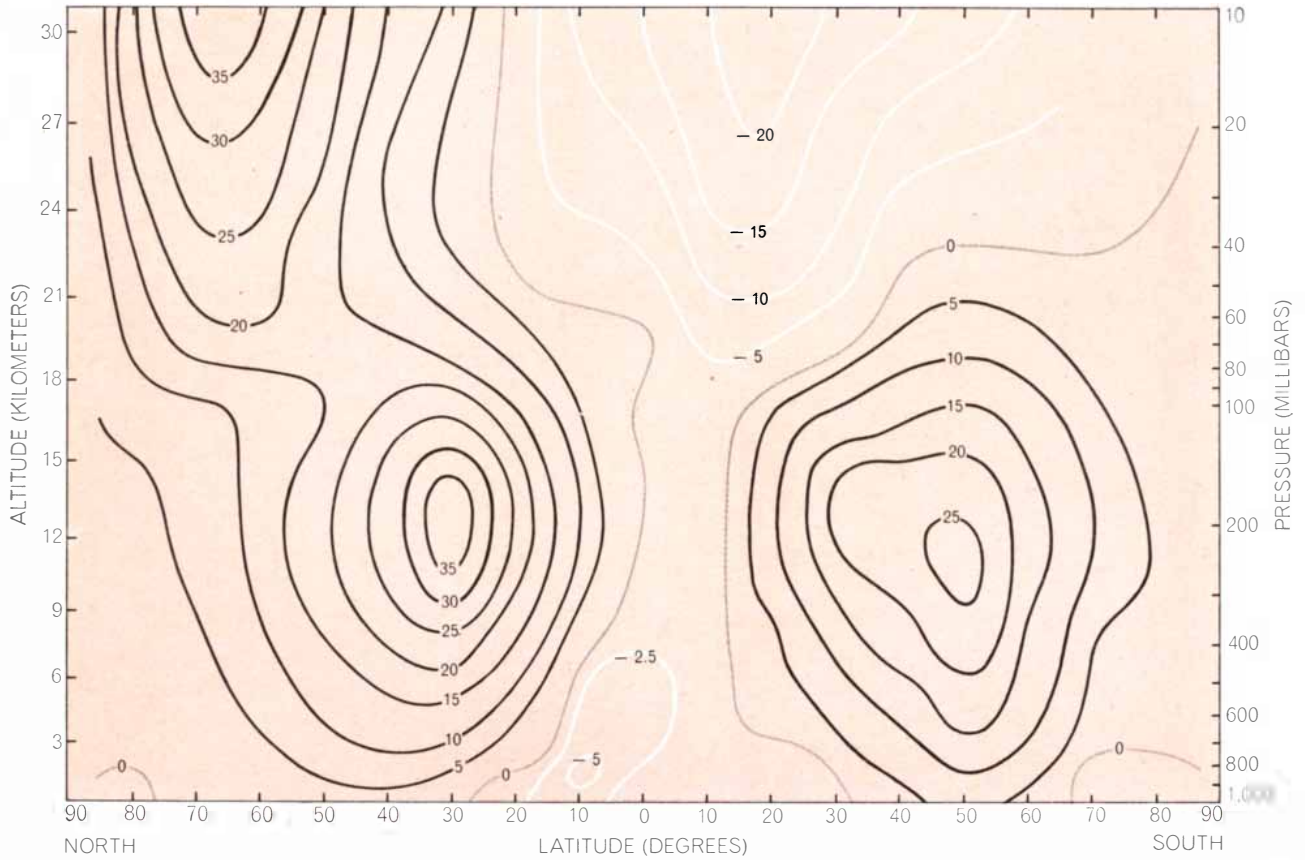
Carbon dioxide is quite well mixed vertically, whereas water-vapor concentrations decrease with distance from the source (the earth's surface) and ozone decreases away from its source in the middle stratosphere [*see bottom illustration on page 39*]. Aerosols show two regions of high concentration. One is at the source (ground level). The other, in the lower stratosphere, is due to the direct injection of particles and the injection of gases from which particles form, together with a very slow removal rate.

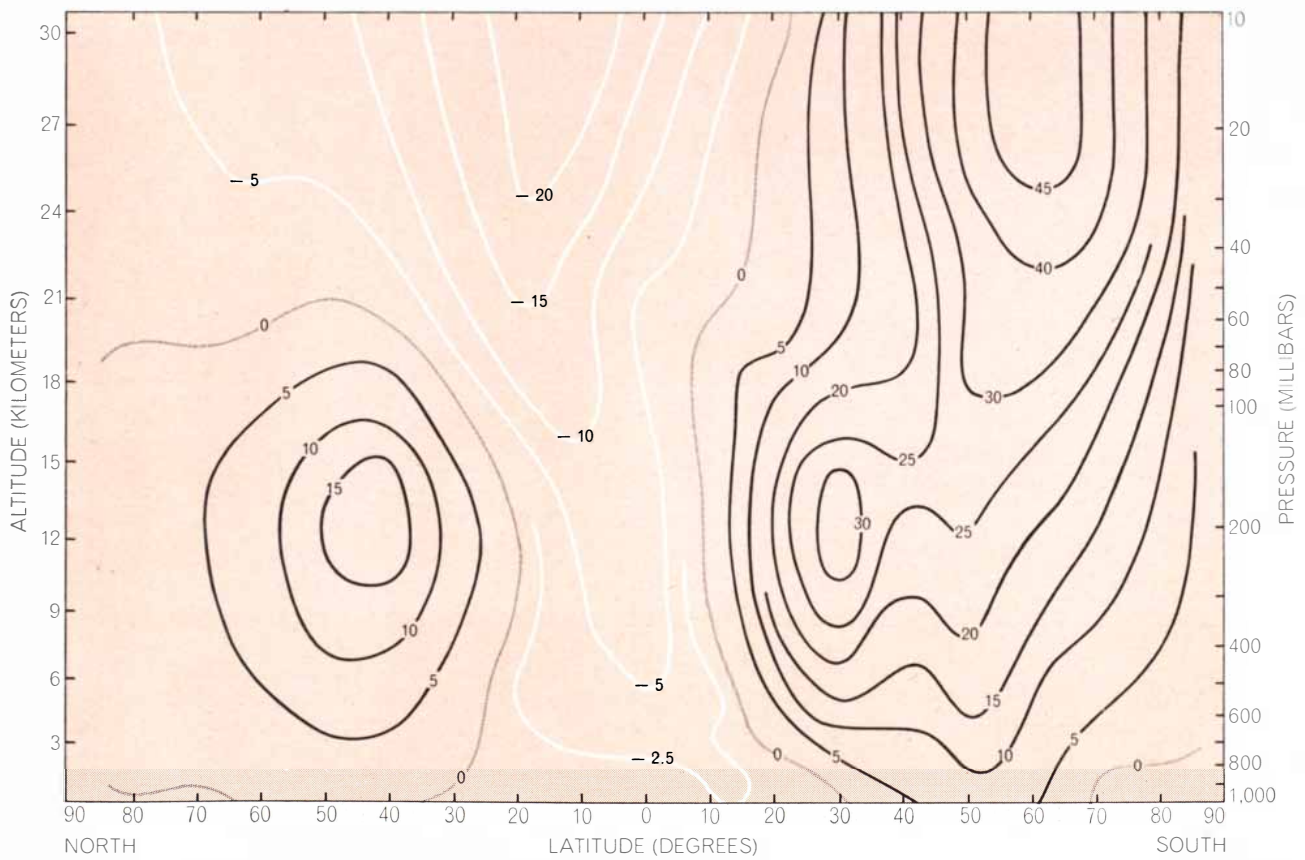
It is fairly clear that if the present atmospheric temperature structure is maintained by a combination of air motions and effects that involve trace substances, it can be altered by changes in the concentration of trace substances. One therefore needs to know the natural cycles of the atmospheric trace constituents that are important in this context and the changes in the cycles that are being or may in the future be brought about by man.



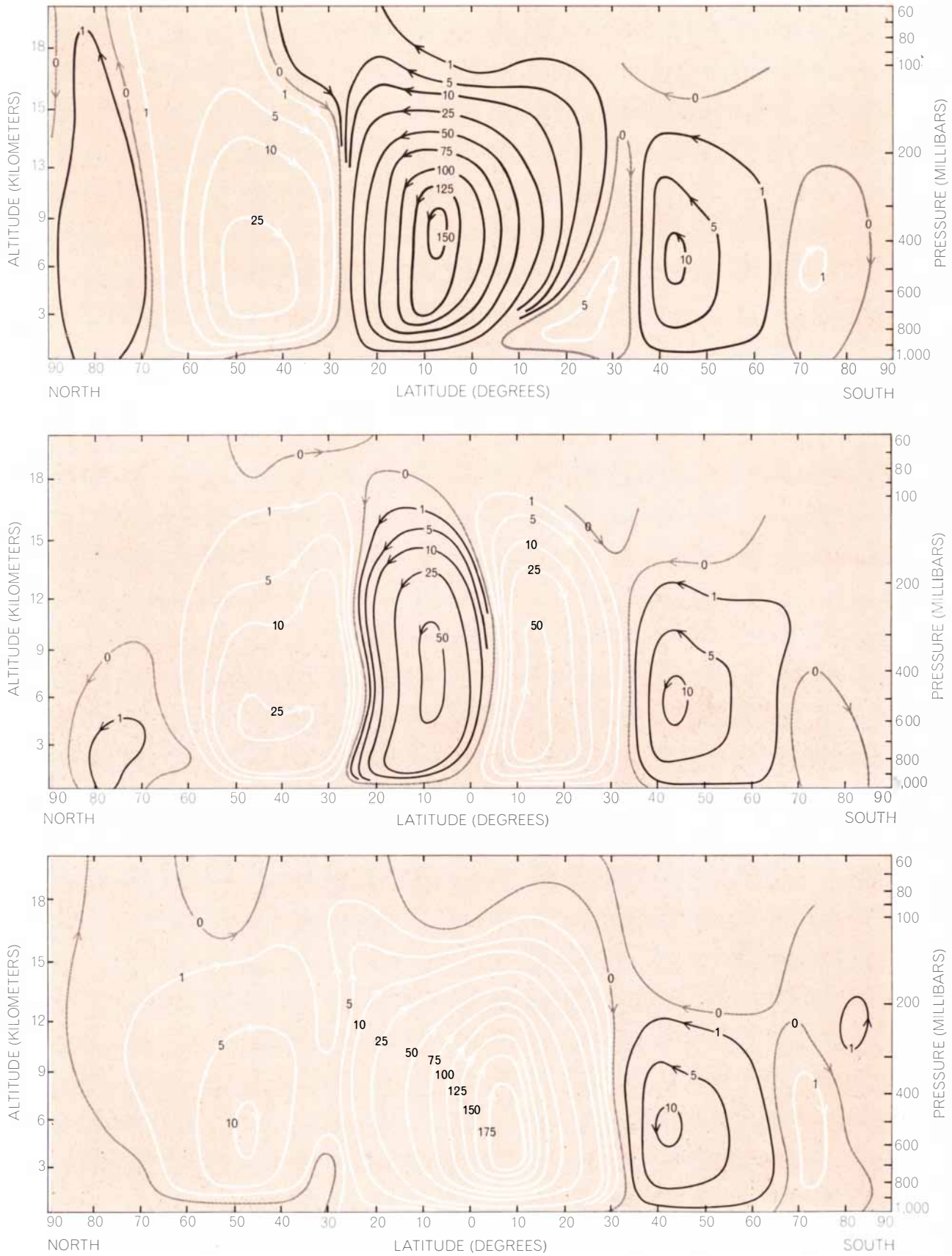
MOVEMENT OF AIR around the world is determined by identifying specific air parcels and tracking them. These tracks were worked out by Edwin Danielsen of the National Center for Atmospheric Research, who identified parcels in the troposphere (*black*) and stratosphere (*color*) and tracked them. The numbers represent successive days in April, 1964.

Ozone (O_3) is produced by the photodissociation of molecular oxygen and the recombination of molecular with atomic oxygen, primarily above about 22 kilometers and at low latitudes. Ozone is transported toward the poles and downward by atmospheric motions between the subtropics and the high latitudes. From the lower stratosphere in the middle latitudes the ozone seeps into the troposphere, and it is eventually destroyed at the earth's surface or in reactions with aerosols in the surface layer. There is a maximum of ozone in the lower stratosphere in the spring and in the troposphere in the late spring; it is caused by an increase in the supply of energy to the stratosphere from the troposphere in this season and a concomitant increase in the large-scale mixing motions. Ozone stays for about four months in the middle-latitude lower





PREVAILING WINDS are revealed by averaging observations over a period of time. Here the mean east-west wind speed is shown as computed for two three-month periods: December–February (*top*) and June–August (*bottom*). The speed is given in meters per second, with positive numbers indicating winds blowing from west to east (*black contour lines*) and negative numbers for east-to-west winds (*white lines*). Note that seasonal changes in the lower atmosphere are larger in Northern Hemisphere than in Southern.



MASS FLUX IN THE TROPICS takes the form of Hadley-cell circulation, the result of a combination of north-south and up-and-down motions. It is shown here for three seasons; December–February (*top*), March–May (middle) and June–August (*bottom*). The difference between adjacent contour values gives the flux in millions of metric tons per second based on average values from all longitudes; actually the pattern varies with longitude. The charts are based on work of Dayton G. Vincent and John W. Kidson.

stratosphere and from two to three months in the troposphere.

Most of the steps of the cycle have been verified in detail by a "dynamical-numerical" model that was developed at the Environmental Science Services Administration's Geophysical Fluid Dynamics Laboratory at Princeton University and has been applied to the ozone problem by Syukuro Manabe and B. G. Hunt. In such a model equations governing temperature, wind speeds and ozone concentration are solved with a computer to trace the evolution of the fields over a period of time. The models have been developed to help in weather forecasting and in understanding the general circulation of the global atmosphere and theories of climatic change. Radiative effects, the earth's surface properties, clouds and even ocean temperatures all have to be included to achieve a good representation of the atmosphere, and the necessary degree of resolution in space and time can only be obtained with the largest computers. As far as can be seen, the influence of man-made ozone (in city smog) is small compared with the natural cycle of production, transport and loss, which totals about two billion tons per year. (This is on a global scale, of course, and is of small comfort to people whose smarting eyes make them quite aware of the ozone in the smog they live with.)

The water-vapor cycle in the troposphere depends on the difference between precipitation and evaporation in a given air column [*see illustration on page 40*]. In the subtropics there is an excess of evaporation over precipitation, so that these latitudes can be regarded as source regions; the opposite situation occurs over the middle and low latitudes. Water vapor is therefore transported from subtropical latitudes toward the Pole and toward the Equator. Large-scale eddy processes govern the movement toward the Pole and the mean Hadley-cell circulation governs the movement toward the Equator. The average rainfall at a point on the globe is about 100 centimeters per year and the average residence time of a water-vapor molecule in the troposphere is about 10 days.

The water vapor produced by man—by fuel combustion, for example—is not a significant fraction of the natural tropospheric cycle. (Again, people who live near power-plant cooling towers will think otherwise.) Nevertheless, more subtle effects could well be produced by interference with the evaporation-precipitation cycle. (Efforts have already been made to do this on a small scale by spreading a thin film on the water surface of some reservoirs in Australia to prevent excessive evaporation.) One would need a complete dynamical-numerical model to see what effect a given change would have if extensive regions were altered. Less water vapor evaporated would lead to less liberation of latent heat—but also to less cooling by the radiative effect; only a full model can give a proper idea of the interlocking feedbacks and their net effect.

	PARTIC-ULATES	SULFUR OXIDES	NITROGEN OXIDES	CARBON MONOXIDE	HYDRO-CARBONS
POWER AND HEATING	8.1	22.1	9.1	1.7	.6
VEHICLES	1.1	.7	7.3	57.9	15.1
REFUSE DISPOSAL	.9	.1	.5	7.1	1.5
INDUSTRY	6.8	6.6	2	8.8	4.2
SOLVENT EVAPORATION					3.9
TOTAL	16.9	29.5	17.1	75.5	25.3

POLLUTANTS emitted in U.S. in 1968 are shown. Estimates, in millions of metric tons, are by George B. Morgan and colleagues of National Air Pollution Control Administration.

The water-vapor balance of the stratosphere is much more delicate. Alan W. Brewer of the University of Toronto has suggested that most of the water vapor in the stratosphere enters through the region near the tropical tropopause in the rising branch of the Hadley-cell circulation. The temperature is close to −80 degrees Celsius in that region, and so the air can hold only minute amounts of moisture; in the process of passing through, most of the moisture from the troposphere is frozen out and precipitates, staying in the troposphere as cirrus clouds. (The fact that the frost point throughout the lower atmosphere even at middle latitudes is close to the temperature near the tropical tropopause forms the observational basis for Brewer's suggestion.) Henry Mastenbrook of the Naval Research Laboratory has been monitoring the water vapor in the stratosphere since 1964, flying a frost-point device (developed by Brewer) on high-altitude balloons. He finds that the content in the lower stratosphere varies seasonally in phase with the temperature at the tropical tropopause, whereas the content at 30 kilometers varies only slightly, with average values throughout of only two to three micrograms of water vapor per gram of air.

From the mean rising motion and the water-vapor content near the tropical tropopause one can calculate the mass of water entering the stratosphere; it is about seven million grams per second. Now, 500 supersonic transport planes flying at 21 kilometers (70,000 feet) would inject about two million grams of water vapor per second directly into the stratosphere. Since this water is introduced above the cold trap, and since it is introduced at a rate that is of the same order of magnitude as the natural rate, it is clearly going to lead to a significant increase in the water-vapor content at high levels. Wherever rising motion and low temperatures exist together in the stratosphere, clouds may form as expansion and concomitant cooling allow the air to reach the local frost point. Such clouds are occasionally observed near 25 kilometers over Norway and Iceland and over the Antarctic in winter, and also near 80 kilometers at high latitudes in summer and near the tropical tropopause —regions in which temperatures become very low. Increased water-vapor content in the stratosphere, then, would be expected to produce increased cloudiness and therefore a change in the albedo, or reflectivity, of the earth. Again, however, a full dynamical-numerical model

	NATURAL	MAN-MADE
OZONE	2×10^9	SMALL
CARBON DIOXIDE	7×10^{10}	1.5×10^{10}
WATER	5×10^{14}	1×10^{10}
CARBON MONOXIDE	?	2×10^8
SULFUR	1.42×10^8	7.3×10^7
NITROGEN	1.4×10^9	1.5×10^7

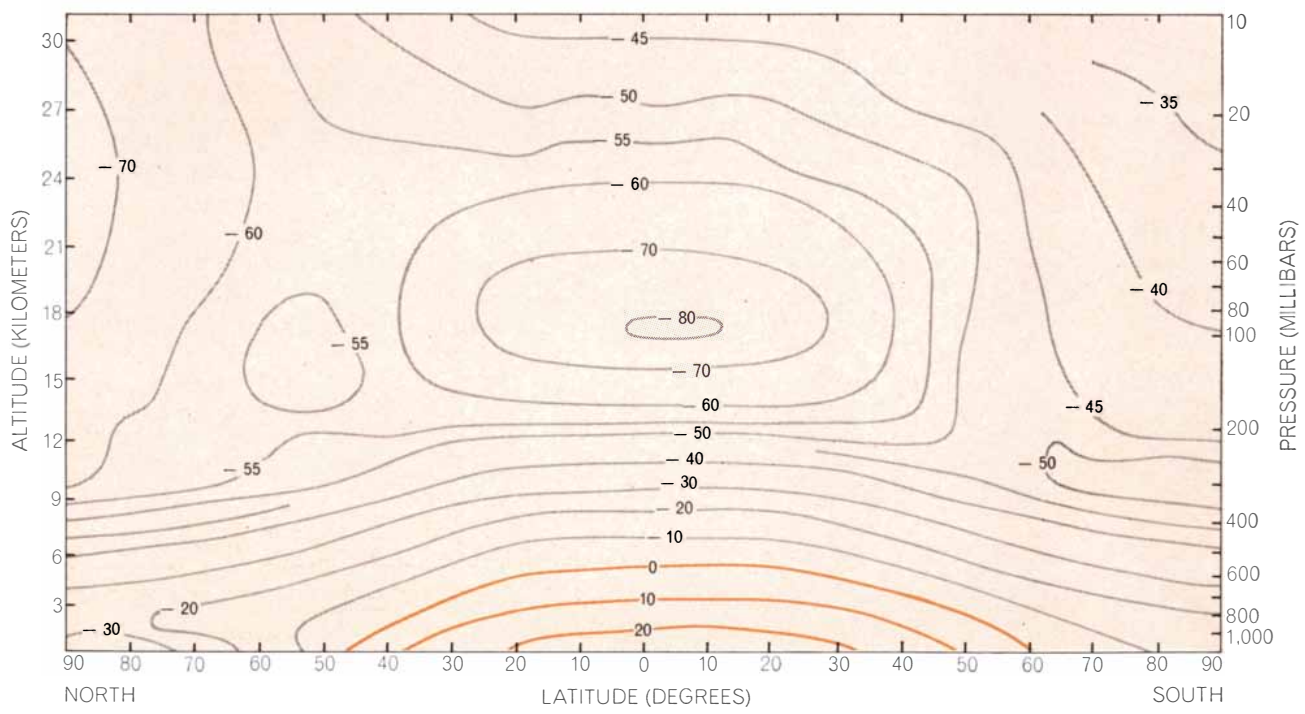
NATURAL AND MAN-MADE trace-gas cycles are compared (in metric tons). Sulfur and nitrogen data are from E. Robinson and R. C. Robbins of the Stanford Research Institute. (The man-made carbon dioxide input is not really a cycle; some remains in the atmosphere.)

is required in order to study the possible changes.

The largest pollutant by mass is carbon dioxide, and here there is evidence that man's activities are indeed altering the concentrations formerly controlled by nature. Some 70,000 million tons per year are involved in the natural cycle, corresponding to a fluctuation of nine parts per million by volume in the carbon dioxide concentration of 320 parts per million. Plants and trees start taking up carbon dioxide in the spring and continue to do so until the fall; then the leaves drop, vegetable matter begins to decay and the direction of the net transfer is from matter to air. This seasonal cycle can be monitored on the ground or in the lower troposphere. Superimposed on the seasonal cycle is a long-term increase, produced by the burning of fossil fuels. The carbon dioxide increase expected from the fuel that has been burned is about 1.8 parts per million per year, yet the observations show an increase of only about .7 part per million per year [see "The Carbon Cycle," by Bert Bolin; SCIENTIFIC AMERICAN, September, 1970]. Where does the rest of the carbon dioxide go? Some of it may be incorporated in the biosphere, but it is thought that the largest fraction is dissolved in the oceans, which all together contain about 60 times as much carbon dioxide as the atmosphere does. The solubility diminishes as the temperature of the water increases. There has been some concern that as carbon dioxide in the air increases, presumably raising the air temperature through the "greenhouse effect," the water temperature will rise also, releasing some of the carbon dioxide from the ocean back into the air. Proponents of this view argue that a runaway effect will occur, with the additional carbon dioxide producing still more atmospheric heating.

It is well to bear in mind, however, that the net radiative contribution of carbon dioxide is to cool the atmosphere. With computer programs developed by Thomas G. Dopplick, my colleagues at the Massachusetts Institute of Technology and I have rerun the radiative-heating computations, assuming a tripled carbon dioxide concentration of 1,000 parts per million and the same temperature and cloudiness distributions. We find that the cooling rate diminishes by only a small fraction of a degree per day in the lower levels and actually increases in the stratosphere. Other things being equal, one could interpret a smaller cooling rate as effective heating in the troposphere. The outgoing infrared flux emitted by carbon dioxide is smaller for higher concentrations; for the atmosphere to radiate the original amount of infrared radiation back to space it would have to radiate at a higher effective temperature. Other things are not equal, however. If the temperature distribution changed, it is likely that the clouds, albedo and therefore the radiation-stream balance would change also. For example, a slightly higher temperature would mean more evaporation and hence more water-vapor radiative cooling. Although it is tempting to argue from our results that little net temperature change should be expected, it is again clear that the proper way to proceed is to run a complete dynamical-numerical model with higher carbon dioxide levels and see what happens.

Another substance that is copiously produced by combustion is carbon monoxide. Levels of 50 parts per million are not uncommon in city streets, with values up to several hundred parts per million in traffic tunnels and underground garages; weekly average levels of 20 parts per million are sometimes found in the Los Angeles basin. The toxic effect is proportional to the ambient-air concentration and the time of exposure. Carbon monoxide that enters the bloodstream combines with hemoglobin, forming carboxyhemoglobin, and thus reduces its capacity to carry oxygen. Impairment of mental function, as measured by visual performance and ability to discriminate time intervals, occurs when carboxyhemoglobin in the blood



TEMPERATURE PATTERN is given for a north-south cross section of the atmosphere for the three-month period December–February. The isotherms, or contour lines of equal temperature, indicate the temperature in degrees Celsius. The coldest air is over the Equator and near the winter pole. In the latter region the temperature sometimes reaches —85 degrees C. at certain longitudes.

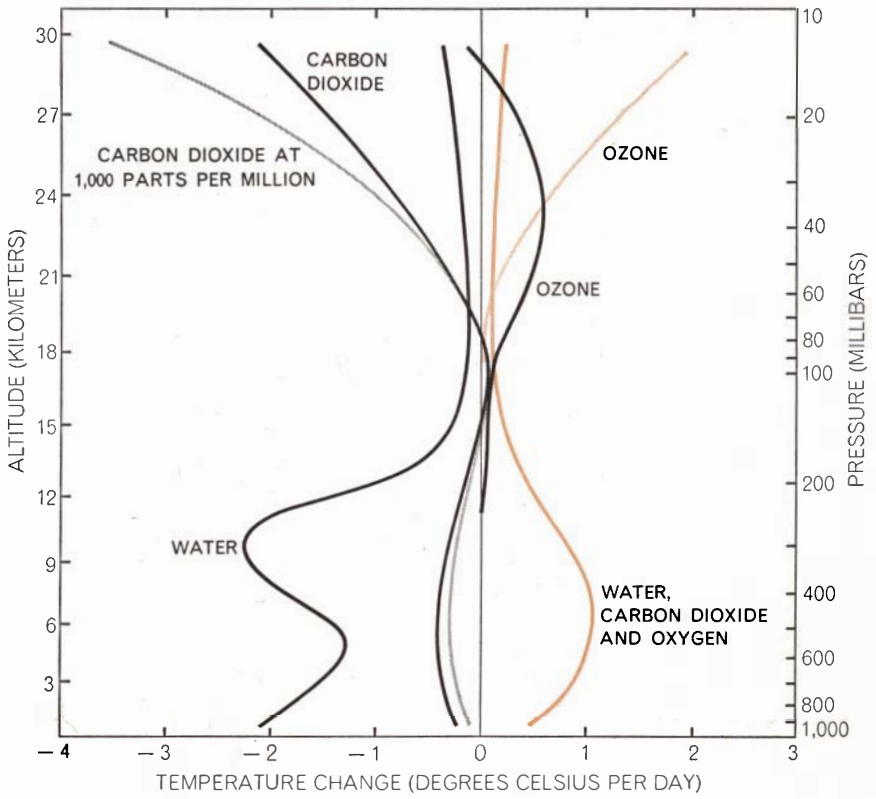
goes above about 2.5 percent (compared with a normal level of about .5 percent). Such values accompany exposure to 200 parts per million for about 15 minutes or 50 parts per million for about two hours.

The 200 million tons injected each year would correspond to an increase of .03 part per million per year. No such increase has been observed, and so a search for sinks of carbon monoxide is under way.

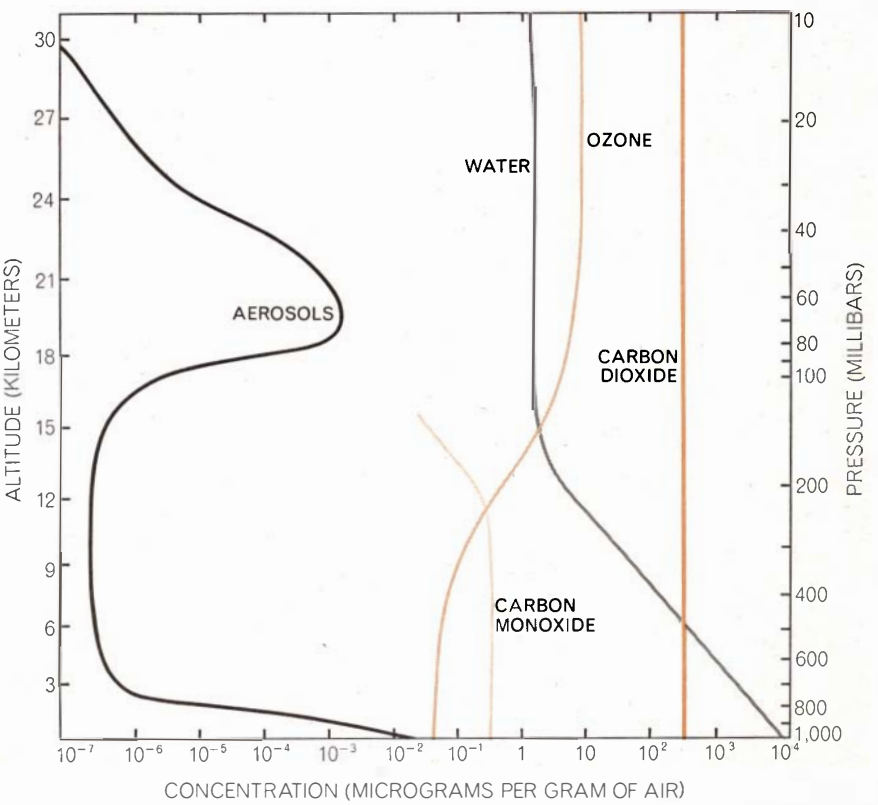
Christian E. Junge of the University of Mainz and his student Walter Seiler have reported that near sea level there is a boundary close to the Equator with high carbon monoxide values to the north and low values to the south; in the upper troposphere aircraft measurements show no such boundary [*see bottom illustration on page 41*]. Such a carbon monoxide discontinuity is compatible with the fact that there are more automobiles in the Northern Hemisphere and with what is known of the Hadley-cell circulation. At low levels the air just north of the discontinuity is streaming toward the Equator, whereas the air to the south has come from the Southern Hemisphere, with a much smaller population of automobiles. (A similar boundary was frequently revealed by surface-air measurements of strontium 90 when nuclear tests were being held in the Northern Hemisphere.) Higher up in the troposphere eddy mixing eliminates the interhemisphere gradients.

There is still much to be learned about the carbon monoxide sink. Junge's data show a decrease in the stratosphere, and it has been suggested that carbon monoxide combines above the tropopause with hydroxyl radicals (OH) to produce carbon dioxide and hydrogen. There are no direct measurements of the hydroxyl radical in the lower stratosphere and the computed amounts, together with the reaction rate, are just barely sufficient to account for the loss of 200 million tons per year. Furthermore, the rate at which air is transferred from the upper troposphere to the lower stratosphere also seems a shade too low to ascribe the entire loss to this path. The ocean, which has been found to contain carbon monoxide, has been suggested as both a sink and a source; so little is known that it is difficult to say which! Clearly many more observations are needed all over the atmosphere and in the ocean at different latitudes.

Nitrogen constitutes the largest fraction of the atmosphere and is involved in a variety of reactions, including plant growth. The total atmospheric turnover in all forms is about 10 billion tons per



RADIATIVE TEMPERATURE CHANGE is brought about by the absorption of solar visible and ultraviolet (*light color*) and near-infrared (*dark color*) radiation and the absorption and reemission of thermal radiation from the earth (*black*) by various atmospheric gases. The direction and magnitude of each effect vary with altitude, as shown for at the Equator in January. If the carbon dioxide concentration were tripled to 1,000 parts per million, its effects would change as shown (*gray*), according to computations by author's group.



MIXING RATIO, or concentration, of the trace constituents of the atmosphere varies with altitude, decreasing with distance from their sources, except in the case of carbon dioxide.

year, whereas the amount introduced by man is only about 50 million tons. While this much pollution is very important in some regions (city smogs are produced by the action of sunlight on oxides of nitrogen from automobiles), on a global scale it seems that nature's contributions dominate.

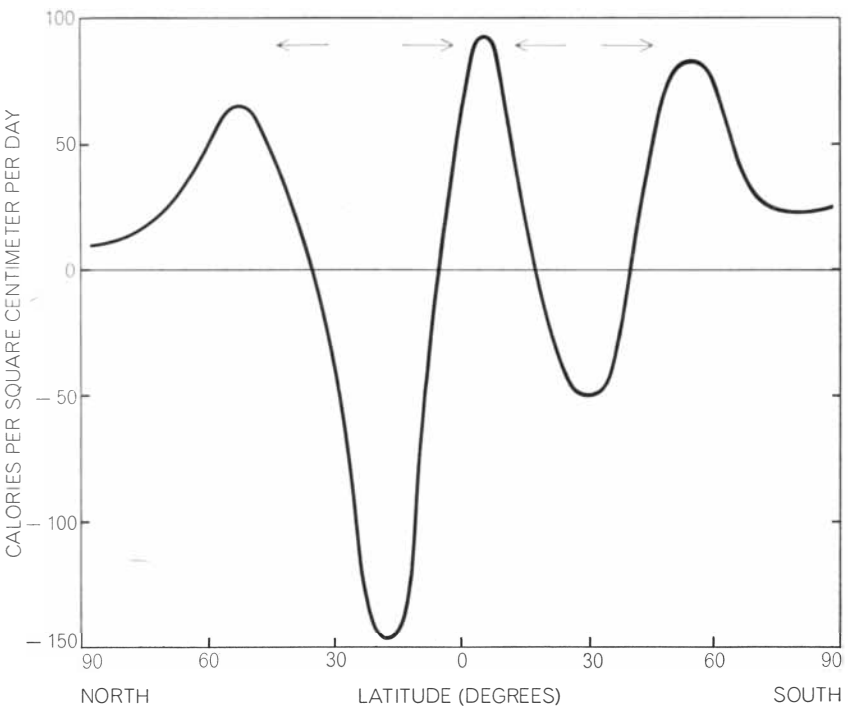
There is no such clear distinction for the sulfur compounds. Sulfur is an abundant constituent of ocean water and is released to the atmosphere by sea spray and by biological decay; it is removed by precipitation, intake by vegetation and direct deposition. The total amount involved in the natural cycle is about 142 million tons per year; the 73 million tons injected by man as a pollutant is therefore a very significant amount. This additional sulfur is thought to end up in the ocean and, as Erik Eriksson of the University of Stockholm has stressed, increases the acidity of terrestrial waters. (Fish cannot live in waters of high acidity, and they already shun some inland waterways in Sweden; man has been given a warning.) Sulfur dioxide and particles together in the air seem to produce respiratory ailments.

A considerable amount—no one knows exactly how much—of sulfur dioxide emitted to the atmosphere ends up as sulfate ions or as ammonium sulfate particles. The time necessary for the sulfur dioxide to disappear as a gas and become incorporated into particles varies from about half an hour to a few days, depending on the air's moisture content and other factors. Measurements made by Junge show that the very small particles called Aitken nuclei (radius about .03 micron) decrease in concentration above the tropopause in a manner consistent with the view that their source is the troposphere. Their composition is unknown. In addition there is a layer of somewhat larger particles (mean radius about .3 micron, with some radii of a micron or more) in the lower stratosphere, composed of ammonium sulfate or sulfuric acid. James P. Friend of New York University and Richard D. Cadle of the National Center for Atmospheric Research have independently verified Junge's finding of this layer of larger particles. Junge has suggested that the large particles in the lower stratosphere may grow on the Aitken nuclei from the gases injected there, and gradually coagulate to form larger particles before they fall, or are transported by exchange, into the troposphere.

When the distribution of sizes of particles of various kinds in the lower troposphere is measured, it is found that most of the mass is accounted for by particles whose radius is between .1 micron and 10 microns. Observations over land away from major cities have shown an increase in worldwide particle mass in the past 10 years, even though over some city areas there has been a decrease. There has been considerable speculation that an increase in the concentration of particles in the troposphere would cause more solar radiation to be scattered back to space and thus contribute to the lowering of terrestrial temperatures. There are no measurements to support this speculation. In fact, George Robinson of the British Meteorological Office has found that solar radiation is absorbed, rather than scattered, by tropospheric aerosols.

The efforts now being made to reduce particulate pollution, coupled with the relatively short washout time for aerosols, provide reason to hope the long-term effect of large man-made aerosols may be small. If particulate material is not removed but is simply more finely divided, however, more will find its way into the stratospheric regions where the residence times are long and the influence of aerosols generated at the surface could be appreciable.

In the case of hydrocarbons, very little is known about the natural cycle and consequently about the worldwide effect of man's interference. Methane (marsh gas) is abundantly produced by nature and finds its way to the stratosphere, but there are no global-scale measurements. Yet hydrocarbons do appear to play a role in smog formation and cannot be ignored at the local level.



DIFFERENCE between precipitation and evaporation at each latitude is given in terms of the amount of heat lost through evaporation or gained through precipitation in each column of air. (About 600 calories are required to evaporate a column of water one centimeter high covering one square centimeter.) The curve, for December–February, is based on three sets of data. Imbalances of precipitation (*top*) and evaporation (*bottom*) are redressed by air motions that transport water toward Equator and toward poles (*arrows*).

Great volcanic eruptions, such as that of Krakatoa in 1883 or Mount Agung on Bali in 1963, increase the layer of stratospheric aerosols, so that colorful sunsets are produced all around the world. After Krakatoa, investigators suggested that the sunsets were due to the injection of sulfuric acid as well as volcanic dust, basing this suggestion on the fact that there is a strong odor of sulfur near active volcanoes. Samples taken in the lower stratosphere over Australia after the Bali eruption showed that this was indeed the case.

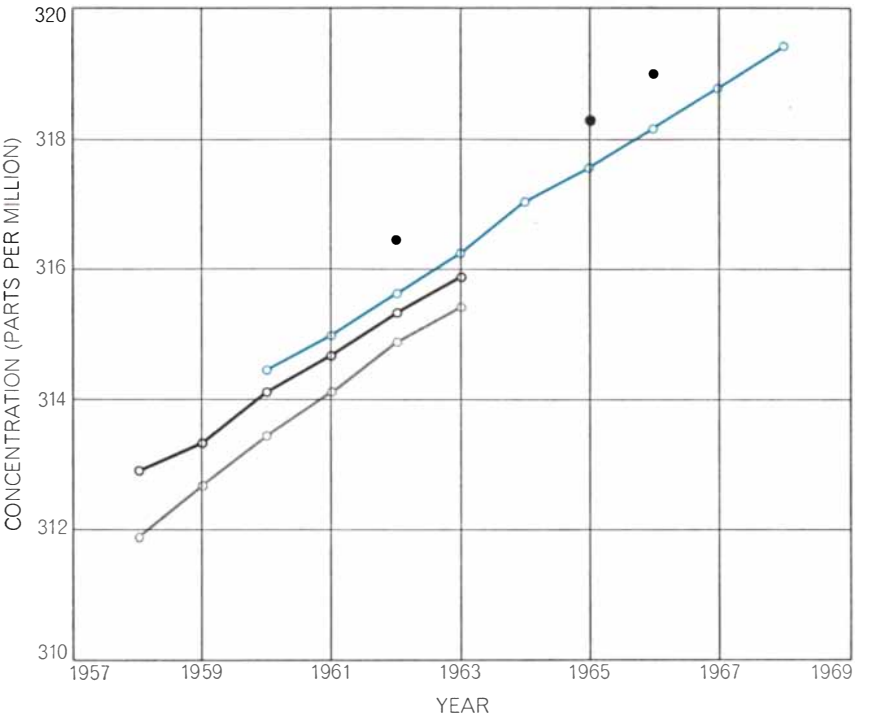
As the concentration of particles (and perhaps their size too) increases, solar radiation is intercepted and less arrives at the ground. Such blocking has often been proposed as a major cause of climatic change [see "Volcanoes and World Climate," by Harry Wexler; SCIENTIFIC AMERICAN, April, 1952]. We examined stratospheric temperature patterns after the Bali eruption in March, 1963, and found there was an immediate rise in stratospheric temperatures, with values

as high as eight degrees C. above average being recorded; the rise was global in extent [*see illustrations on next page*]. It was mainly concentrated in the region above 15 kilometers and there were concomitant changes in the wind field. Presumably the small particles intercepted and absorbed solar radiation. (Their size is of the same order as the wavelength of light.)

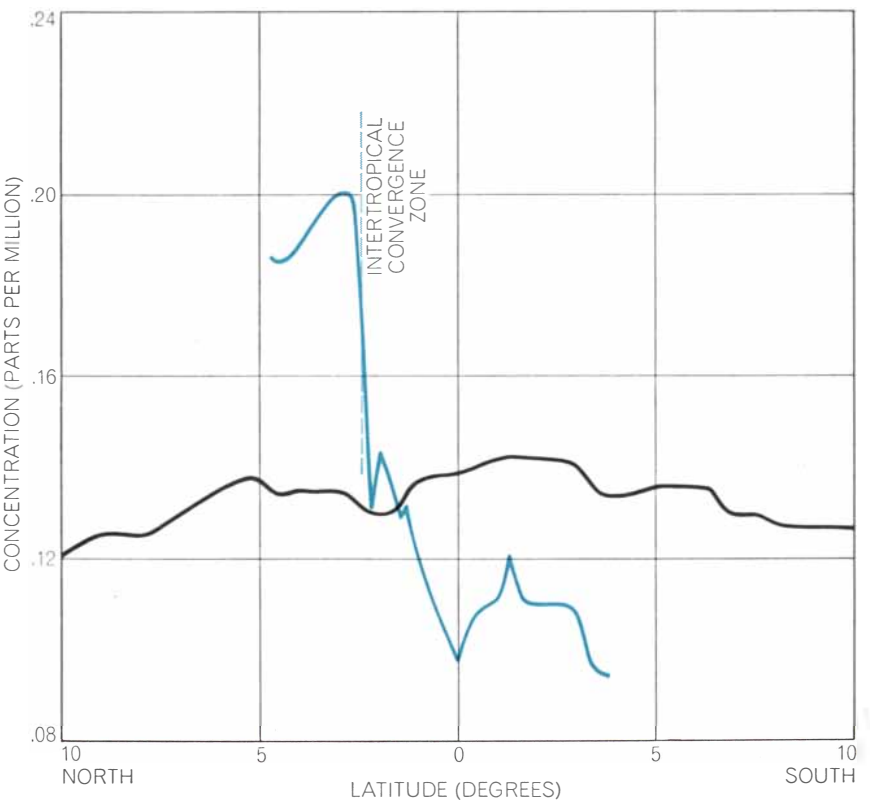
The variation of the temperature change with latitude and height was very similar to the patterns that have been found for clouds of radioactive debris in the stratosphere. Such clouds persist longest over the Equator and slope downward toward the poles. The volcanic cloud from Bali did likewise—and the same slope was discussed in a report on Krakatoa published in 1888. The 1963 temperature increase is the largest climatic change ever observed by man. (There were no balloon observations of the stratosphere after Krakatoa.) It serves to warn us that we should watch the sulfur cycle carefully and try to learn soon whether the increased amounts injected into the troposphere by man can find their way into the stratosphere.

Investigators are able to base deductions about atmospheric motions on a network of 800 balloon sounding stations, at many of which temperature is also measured; global maps of temperature constructed from satellite observations are also becoming available. Yet the pollutants in the air we breathe are measured at very few places, and there are no systematic measurements above the surface layers. Moreover, most of the surface measurements are made near cities. It is perfectly well established that if a city has oil-fired or coal-fired power plants, there will be sulfur in the air; if it has automobiles on crowded streets, there will be carbon monoxide and oxides of nitrogen. The most intensive monitoring efforts near cities cannot provide information concerning the global buildup of pollutants.

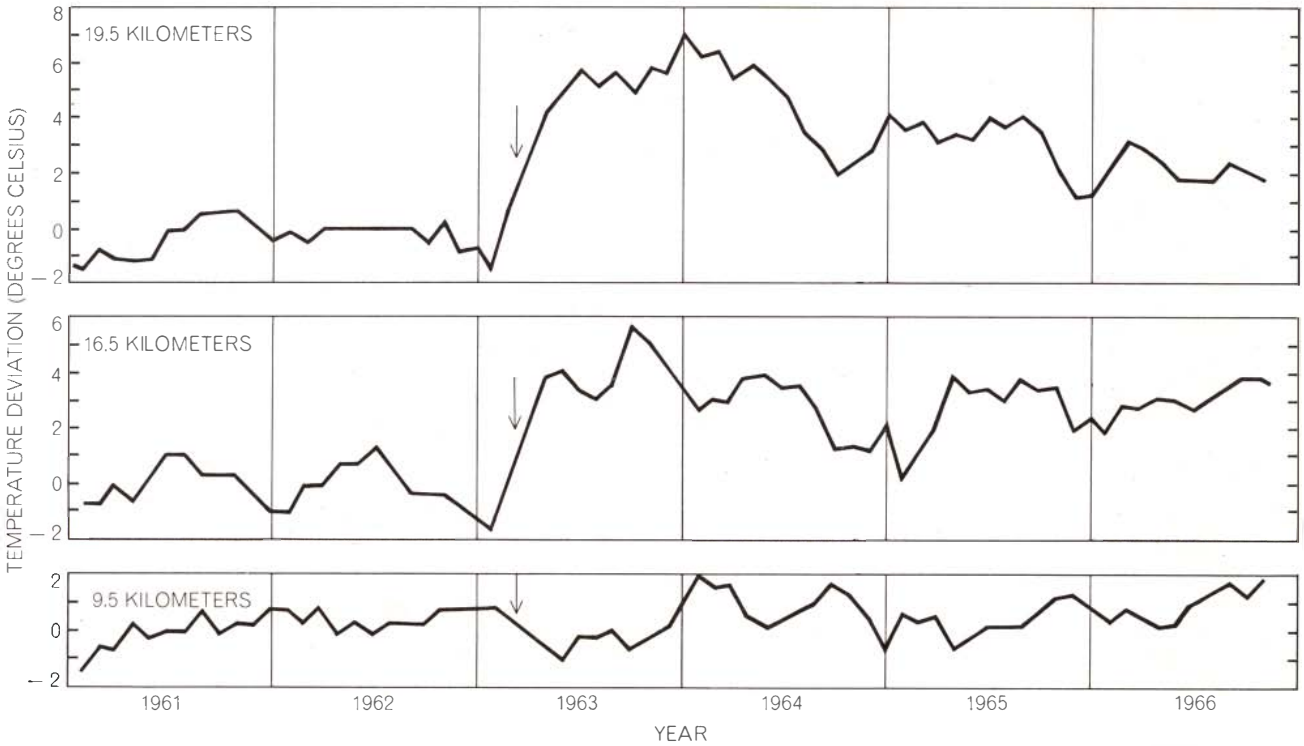
Water vapor and ozone have been measured above the surface because of their interest as natural trace substances. Moisture sensors are included on the same balloon flights that collect wind and temperature information, but the sensors only operate up to about six to eight kilometers. Mastenbrook's special frost-point hygrometer, which records moisture content up to about 30 kilometers, makes only one flight a month from Washington, D.C.—pitifully inadequate for a study of the global distribution of stratospheric moisture. About six balloon stations measure ozone up to about



LONG-TERM INCREASE in atmospheric carbon dioxide is revealed by four investigations. The data are from measurements at Barrow, Alaska, by John Kelley of the University of Washington (*black dots*), aircraft observations by Bert Bolin and Walter Bischof of the University of Stockholm (*color*) and measurements at Mauna Loa in Hawaii (*black curve*) and in the Antarctic (*gray*) by Charles Keeling of the Scripps Institution of Oceanography.



CARBON MONOXIDE measurements made from a ship at sea (*color*) and from an aircraft at 10 kilometers (*black*) by Christian E. Junge and Walter Seiler of the University of Mainz reveal a change in concentration at sea level but not in the upper troposphere. The boundary is explained by the larger number of automobiles in the Northern Hemisphere and the rising motion of the Hadley-cell circulation at the Intertropical Convergence Zone (*broken line*). Higher up eddy currents mix the air, eliminating the interhemisphere gradient.

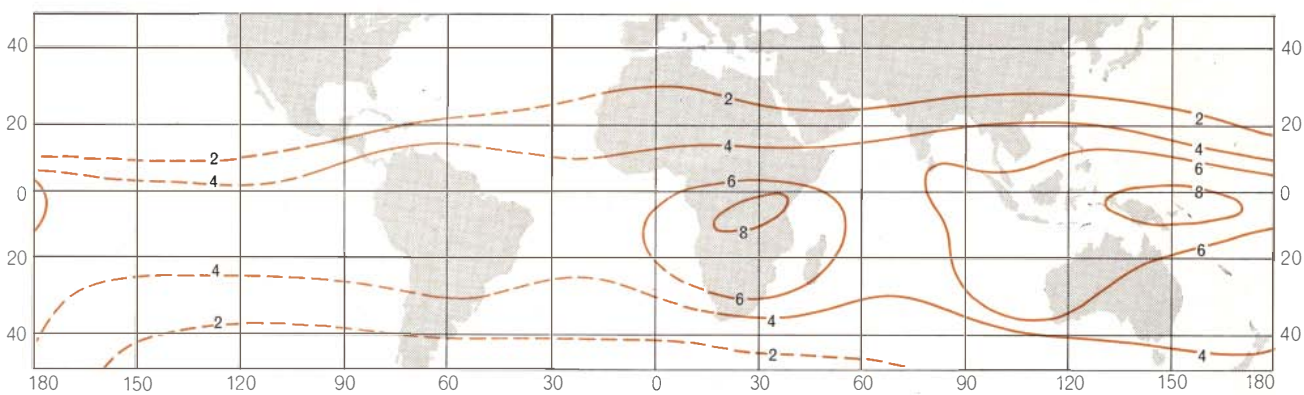


TEMPERATURE CHANGES above Port Hedland, Australia, show the heating effect (first noted by James G. Sparrow of the University of Adelaide) of particles from the 1963 eruption of Mount Agung on Bali. Monthly means were calculated for five years before the eruption (*arrows*); deviations from the means were computed and three-month running averages were plotted.

30 kilometers once a week. The Atomic Energy Commission launches balloons from four sites to obtain samples from up to 35 kilometers, mainly for analysis of radionuclides, although carbon dioxide has sometimes been included. High-altitude sampling aircraft such as the U-2 have also been used, but as nuclear tests in the atmosphere have decreased these sampling programs have naturally been pared. Practically all the published data on carbon monoxide measured away from the surface is represented in Junge's results. (The instrument he used was made portable and carried on a commercial jet flight; it occupied one seat, the observer another.) A few spot measurements of sulfur dioxide and sulfate above the surface layers have been made by Hans Georgii of the University of Frankfurt; again no extensive coverage is available.

There are many opportunities to collect data on atmospheric trace substances by taking advantage of commercial airline flights and regular ocean voyages as well as special oceanographic cruises, the unique AEC balloon network, the surface-air sampling networks established to monitor global radioactivity levels, mountaintop observatories and so on. Now that some important trace substances are being introduced into the atmosphere by man at rates comparable to those in the natural cycle, it seems appropriate to start making these measurements.

I must mention in closing that one cannot take the global view of pollutants without feeling some concern about the rate of use of natural resources and the rate of generation of pollutants. Both could be slowed considerably by a serious effort to use every pound of fuel in the most efficient manner possible.



HEATING EFFECT after Mount Agung is mapped. The isotherms give the increase in mean temperature at about 19 kilometers, in degrees Celsius, from January before the eruption to one year later. (Broken lines indicate uncertainty due to scarcity of observations.)

We want to be useful ...and even interesting

Kodak

Planning a talk with slides?

We get just as much for film that turns into good slides as poor ones. For some obscure reason, we prefer that you show good ones. Accordingly, we have put out a new Kodak publication. Don't bother with it if you just want to do a snow job with your data. If you want to communicate with your audience—whatever their level—and would like suggestions, send for a copy of "Slides with a Purpose" from Department 640, Eastman Kodak Company, Rochester, N.Y. 14650.

Warning

Get ready for the time when engineers commonly draw up their brainchildren roughly with their light pens. The computer does more than neaten up the drawing. It 1) figures costs, 2) sets up inventory control for components and materials, 3) runs the equipment that fabricates the finished item as drawn, 4) sets up inventory control for the item, 5) fits it into a PERT system. It does *not* enjoy the ultimate product. Computers can't enjoy anything.

When *people* perform the abovementioned functions they need prints of drawings. Therefore we have long made films and papers for conserving, preserving, and restoring the work of draftsmen. What of that business?

We'll see.

Laser dyes, complete with motivation

"The Laser Dye Report" should be requested from Eastman Organic Chemicals, Eastman Kodak Company, Rochester, N.Y. 14650 by those bent on exploiting the broad-range tunability of dye lasers. The report was prepared by one of the three Kodak physicists who recently achieved the first CW dye laser with Rhodamine 6G (EASTMAN 10724).* He has selected several other good laser dyes and has supervised the testing in an actual laser system of the production lots we now offer in solution form. For each of them he gives tuning coefficients, threshold data, absorption and emission peaks, literature references.

If a laser beam were pointed over a suffering city and swept over an appropriate frequency range, it should call forth a fluorescence signature from each species of polluting molecule in the air. And if our peddling of EASTMAN Organic Chemicals were to stimulate someone to build successful instrumentation for chemistry-at-a-distance, we would be very proud.

*Peterson, Tuccio, Snavely, *Applied Physics Letters*, 17:245 (1970).

The power of used water

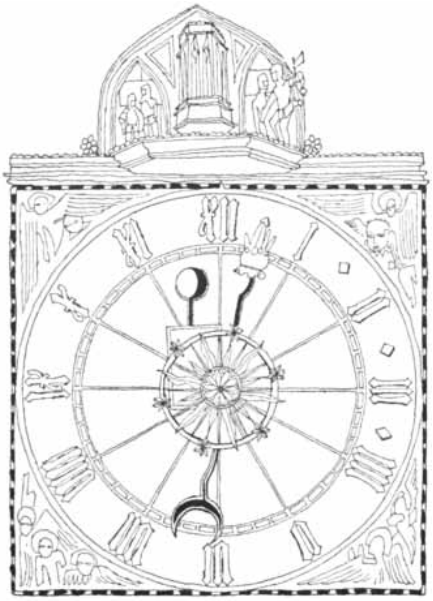
Of our plants in various places, the one in Rochester, N.Y. still turns out by far the most photographic materials. Under the doctrine that product quality, quantity, and price must not outweigh in importance the preservation of environmental quality, permit us to brag a bit about the engineering behind this pipe.

We're looking up here from the Genesee River gorge, some 150 feet below the manufacturing plant and some three miles from the river's mouth on Lake Ontario. Some 36 million gallons of used water come down this pipe a day, bearing kinetic energy we paid for when we pumped it up from Lake Ontario. It is on its way to a primary settling tank and thence through trickling filters, where dwell organisms that break down waste compounds, to an activated sludge tank where other microorganisms continue the oxidation. The activation could be accomplished by surface aeration. Instead, at the expense of doubling the electrical power requirement, we quietly inject the oxygen 20 feet beneath the surface. Surface aeration, we estimate, would bring forth a sound "about equivalent to a medium surf." Rochester is too far from the ocean for the neighbors to be fooled into accepting noise pollution as a tradeoff for water pollution.

So, instead of letting the kinetic energy generate a 6-inch froth on the primary tank, it's merely smart engineering to use it hydroelectrically in the interests of tranquillity for the neighborhood and the health of fish.

For a mere $10 million investment in this new secondary treatment plant, we remove 95% of the 5-Day Biochemical Oxygen Demand from our effluent. That's not the last word, merely a good beginning.

SCIENCE AND



Small Steps for Mankind

As the U.S. and the U.S.S.R. have continued their negotiations on the limitation of nuclear weapons, the United Nations has successfully completed a small but significant step in the same direction. In November the Political Committee of the UN General Assembly approved a treaty prohibiting the emplacement of nuclear weapons on the seabed outside a 12-mile offshore zone. The treaty, which will take effect on ratification by 22 governments, originated with an agreement between the U.S. and the U.S.S.R., although compromises were made during two years of drafting work to meet the views of other nations, notably coastal ones.

The treaty, if ratified, will presumably serve to forestall an arms race to station nuclear missiles on the ocean floor or to emplace nuclear mines for defense against missile-carrying submarines. It is the sixth such treaty the UN has achieved in 11 years. Its predecessors demilitarized Antarctica (1959), put controls on tests of nuclear weapons (1963), prohibited nuclear weapons in space (1967), made Latin America a nonnuclear zone (1967) and barred the proliferation of nuclear weapons beyond the nations that already had them (1968).

Nonnuclear Zone

The way to overcome the obsolescence of the Panama Canal is to dig another canal, but not with nuclear explosives, according to a commission that has studied the canal situation for the past six years. The Atlantic-Pacific Interoceanic Canal Study Commission, which was appointed by President Johnson in 1964, submitted its report to President Nixon last month. Although nuclear excavation had been considered a possibility, the commission ruled it out on grounds that included possible conflict with the nuclear-test treaty and the danger of radioactivity in the atmosphere.

The problem with the existing canal is that many modern ships, including supertankers, are too big for it. The commission, which investigated a number of routes for a larger new canal, recommended two routes as being the most promising. One would run through the present Canal Zone; the other would be about 10 miles west of the canal and outside the zone. A sea-level canal along one of these routes, dug with conventional explosives and made big enough to handle vessels up to 250,000 tons, would cost about $2.9 billion, the commission estimated. A cheaper option offered by the commission is the construction of a new lane of locks along the two existing lanes; this would cost about $1.5 billion if the design were for ships up to 150,000 tons.

Lunar Rock No. 12013

The igneous rocks of the earth's crust fall into two broad classes. Sialic rocks such as granite are rich in silicon and aluminum. Mafic rocks such as basalt are rich in magnesium and iron. The basaltic rocks comprise the lava flows and bedrock of the ocean floor and are considered to be derived from the even more mafic rocks that constitute the bulk of the earth's mantle; granitic rocks are found almost without exception on continents and in association with rocks of sedimentary origin. Investigation of the surface of the moon, first by unmanned, instrumented Surveyor missions and then by the astronauts of *Apollo 11*, indicated a generally basaltic composition of rocks and loose soil. The rocks did, however, show microscopic areas of glassy material of near-granitic composition. Now intensive study of a single unusual rock brought back by the astronauts of *Apollo 12* provides evidence for a major source of granitic rock. The study was

undertaken in a number of laboratories; their reports, brought together in a single issue of *Earth and Planetary Science Letters,* illustrate the combined analytical power of a variety of techniques brought to bear on a single sample.

Lunar sample 12013 was a generally light gray rock that measured about four by three by two centimeters and weighed 82.3 grams (about .18 pound). The first indication that the rock was peculiar came during preliminary examination at the Lunar Receiving Laboratory in Houston, which showed a concentration of potassium, thorium and uranium some 40 times higher than the concentration in other *Apollo 12* rocks. Moreover, sample 12013 was an exceedingly complex rock, threaded with veins and quite obviously an aggregate of different rock fragments welded together. Because of the sample's small size, unusual composition and heterogeneity, it was carefully subdivided. Thin sections were prepared for microscopic and electron-probe analysis. Then in the laboratory of Gerald J. Wasserburg at the California Institute of Technology a four-millimeter slab was divided into 46 small pieces for mineralogical, chemical and isotopic analysis at Cal Tech and in other laboratories in the U.S. and abroad. (Wasserburg and his colleagues sign their paper in *Earth and Planetary Science Letters* "Lunatic Asylum, The Charles Arms Laboratory of the Geological Sciences.")

The results of the various investigations are reported in detail in individual papers. The general story that emerges is as follows. Sample 12013 is an agglomeration of irregular fragments and veins of disparate mineralogical types. The dominant material, which apparently serves as the "cementing agent," is a light-colored granitic component that is extremely rich in potassium, thorium and uranium. The remainder of the material, ranging from black through shades of gray, is of a generally basic nature like most of the lunar mare material examined to date. Various dating methods, including the rubidium-strontium technique and the potassium-argon technique, clearly establish that the rock was formed as it is now 4.0 billion years ago. Its components, however, existed in different forms some hundreds of millions of years earlier; the granitic component

is about 4.5 billion years old and the basaltic rock must be slightly older. It appears, therefore, that very early in the moon's existence there was a reservoir of granitic material somewhere on the moon. It was somehow remelted and "squeezed out" of its original site to invade the basaltic minerals four billion years ago.

One major question that remains to be answered is the nature of the remelting event. Was the heat provided by the impact of meteorites or of a larger celestial body, or by the collision of "moonlets" to form the present moon? Or was it provided by some internal heat source such as moon-rock radioactivity? Whatever the source of the heat that caused melting and differentiation, they must have "shut off," since there is as yet no evidence of lava formation after 3.3 billion years ago. Another question is the source of rock 12013 itself. It could have come from the lunar highlands, which have not yet been directly sampled by Apollo missions. It could have been ejected by a major impact crater from a deep stratum under a mare. Or it could have come from a local source in the Sea of Storms as a result of some kind of filtering or other differentiation process in one of the older underlying lava flows.

Two Genes, One Enzyme

Two bacterial enzymes that normally occur in the form of independent protein molecules have been fused into one large protein molecule by mutations that have the effect of erasing the chemical "punctuation mark" that ordinarily separates the two genes directing the synthesis of the enzymes. The fused molecule combines the distinctive chemical functions of the two original enzymes, both of which participate in the synthesis of histidine, one of the 20 amino acids found in proteins. The laboratory demonstration that gene fusion can lead to the fusion of separate protein molecules suggests how large enzymes with several functions may have arisen in the course of evolution.

The gene-fusion experiment, which is described in *Nature,* was performed by John R. Roth of the University of California at Berkeley in collaboration with Joseph Yourno and Tadahiko Kohno of the Brookhaven National Laboratory. The two genes fused in the experiment were the second and third genes ("*hisD*" and "*hisC*") in a sequence of nine genes whose enzyme products enable *Salmonella typhimurium* to synthesize histidine. The nine-gene sequence is known as the histidine operon. Each gene is specified by a particular sequence of bases in the linear molecule of deoxyribonucleic acid (DNA) that embodies the total genetic message of the bacterium. The message contains instructions for synthesizing the more than 4,000 enzymes the cell requires in order to survive and replicate.

The genetic message can be parsed into the sequences of three bases called codons, the great majority of which stand for a particular amino acid when the gene is subsequently translated into a protein. A few codons, however, provide the punctuation that divides the genetic message into separate genes, thus informing the cell's machinery for making proteins where one molecule ends and another begins.

It appears that the *hisD* and *hisC* genes were fused as a consequence of two closely spaced mutations, one on each side of the punctuation mark separating the two genes. The first mutation was a deletion that removed a "letter" from the genetic message; the second mutation inserted an extraneous letter. Such mutations are called "frame-shift" mutations since they cause succeeding bases to be "read" in incorrect groups of three.

In this case the first mutation caused the punctuation mark to be misread and thus to go unrecognized. The second mutation restored the proper reading frame immediately after the unrecognized punctuation mark. As a result all of the *hisD* gene up to the first mutation was read correctly, as was all of the *hisC* gene beyond the second mutation. The intervening codons were evidently translated into a short sequence of amino acids capable of acting as a bridge to join the two enzymes, each essentially complete and therefore still functionally active.

Creationism

In recent months the teaching of evolution has come under attack in a number of states. The revival of fundamentalism in biology takes a somewhat new form: the emphasis is on opposition to current theories of the origin of life and the diversity of species not by theologians but by scientists. The movement is led by the Creation Research Society, whose members have appeared before state boards of education and textbook committees in California, Texas, Arkansas and Tennessee. The society's credo says that it is "committed to full belief in the Biblical record of creation and early history" and that its goal is "the realignment of science based on theistic creation concepts." The society's 300 or so members have master's degrees or doctorates in various fields of natural science. Its current president is Henry Morris of Christian Heritage College in San Diego, Calif.

The society's major success to date has been the inclusion of language it favored in a new "science framework," or guidelines, adopted in late 1969 by the California State Board of Education. What the board did was to substitute new wording for two paragraphs in the proposed guidelines prepared by the state advisory committee on science education. The proposed paragraphs had indicated that life probably arose from "a soup of amino-acid-like molecules" some three billion years ago and that the diversity among present species is the result of evolution through natural selection from effective adaptation to changing environments. That language was attacked by representatives of the creationist point of view, led by members of the Creation Research Society, according to an article in *BioScience* by Walter G. Peter III. They argued that the doctrine of special divine creation deserves equal status with other explanations of the origin of man since it is not only a theistic belief but also a scientifically valid doctrine, defensible by the society's professional members; that it is illegal to present merely a humanistic viewpoint, as in the proposed guidelines, and that the rights of Christian children would be violated by what would be in effect the teaching of the absence of God.

Several members of the society testified against the original guideline language. George F. Howe of Los Angeles Baptist College in Newhall, Calif., held that creationism is no less "scientific" and no more "religious" than the general theory of evolution. Indeed, creationism solves what he called a problem for evolutionists: the large odds that a living protocell—or even a specific protein molecule—could have formed merely through the accretion of various substances in an ancient ocean. The evolutionist's reliance on mutation as the mechanism for evolution, he said, is contradicted by evidence that the vast majority of mutations are harmful; creationists maintain that cells of each living "kind" were formed rapidly by the Creator. Moreover, the manner in which species appear in the fossil record in a "now you don't see them, now you do" manner fits the creationist—not the evolutionist—view. Dennis S. McCurdie, a geologist, argued that wrong conclusions have been drawn from carbon-14 dating of fossil-bearing materials and that carbon-

14 studies actually demonstrate that the earth was created recently—perhaps 10,000 years ago.

The board removed the two disputed paragraphs. It substituted a statement that "all scientific evidence to date concerning the origin of life implies at least a dualism or the necessity to use several theories.... Creation in scientific terms is not a religious or philosophic belief.... Creation and evolutionary theories are not necessarily mutual exclusives.... Aristotle proposed a theory of spontaneous generation. In the nineteenth century, a concept of natural selection was proposed.... More recently efforts have been made to explain the origin of life in biochemical terms."

The effect of the new science framework is still not clear. California's state board does not actually adopt textbooks beyond the eighth-grade level; local boards are free to adopt their own high school texts. As for elementary and junior high school science books, the first call for new adoptions since the 1969 guidelines were approved is not due until March. At that time the new point of view will presumably have to be taken into account.

The Antiquity of Quasars

A study of the distribution of quasi-stellar objects (quasars) carried out by Maarten Schmidt of the California Institute of Technology indicates that these puzzling objects were much more plentiful five billion to eight billion years ago than they are today. His study suggests that a complete survey of the sky with large telescopes would reveal as many as 14 million quasars, but since they are such short-lived objects all but 35,000 or so must have burned themselves out in the time it has taken their light to reach us. Schmidt's observations provide a strong argument against the steady-state hypothesis, which holds that the universe has always looked just as it does now.

Eight years ago Schmidt was the first to interpret the spectrum of a quasar and show that its light was strongly shifted to the red end of the spectrum. As a result an object that had seemed to be just another 13th-magnitude star in our own galaxy was shown to be receding at a sixth the velocity of light and therefore was about two billion light-years away, assuming that its recession was due to the general expansion of the universe. Since 1963 more than 200 quasars have been identified, some receding at more than 80 percent of the speed of light. Evidently many quasars are up to 100 times more luminous than ordinary galaxies, which are much too dim to be seen at the immense distances at which one can detect quasars.

Schmidt's conclusion that quasars were more plentiful in earlier epochs results from a study of all the quasar-like objects in a limited region of the sky selected as being representative of the entire celestial sphere. Working with the 200-inch Hale telescope, he identified 23 quasars in the small region. When he classified the quasars according to their luminosity and red shift (distance), he found that their total number increases with distance significantly faster than it would if their distribution in space were uniform. If the quasars were uniformly distributed, their number would increase simply as the cube of the distance. This confirms earlier distribution counts of radio sources, including radio galaxies as well as quasars.

Perhaps the most provocative aspect of Schmidt's statistical study is that the increase in the number of quasars seems to stop about 8.5 billion light-years out. At the corresponding time the universe evidently contained 1,000 times more quasars than survive today. This suggests that quasars were born in the greatest number no more than one or two billion years after the "big bang" that created the universe.

Ring Records

Thirty million million protons, stacked in bunches and traveling close to the speed of light, have been observed outside a small town in Switzerland. That is the essence of a recent announcement from the laboratories of the European Organization for Nuclear Research (CERN) near Meyrin, Switzerland, where the first successful tests of the Organization's still unfinished intersecting-storage-ring (ISR) complex have just been completed.

The most notable accomplishment of these trial runs was confirmation of the validity of the "proton-stacking" procedure as an effective method for storing many successive bunches of high-energy protons accelerated by the CERN proton synchrotron. The object is to build up a high current of charged particles traveling in opposite directions inside the two large concentric storage rings of the ISR complex. After being stored for periods of as much as a day, the beams are to be brought together in head-on collisions to produce subnuclear events unobservable by any other means. The trick is to add the successive accelerated beams together inside each vacuum ring without having them interfere with one another. Before a new string of bunches is accepted from the accelerator, the previous string must be trapped by the ring's precision magnet system and eased out of the way by accelerating it to a slightly wider orbit. At the same time the bunches must be "squeezed" into the optimum shape by varying the accelerating voltage.

The approach worked in the initial trial of Storage Ring No. 1, producing the highest current of high-energy protons ever recorded. The peak current reached was 1.5 amperes, the equivalent of a circulating beam containing 30 million million protons. This is 15 times the maximum current attainable in the CERN accelerator.

It is expected that Storage Ring No. 2 will be completed in about a year. The two rings will then be operated together for the first time.

Status and Disease Research

Research on human diseases in the U.S. is largely supported by grants from the Government and from private organizations that raise funds by public subscription. Is there any relation between these grants and the incidence of a disease in a given population group? According to Robert B. Scott of Virginia Commonwealth University, there is such a relation in the case of certain diseases that affect black children more frequently than white children.

Writing in *The Journal of the American Medical Association*, Scott considers four diseases: phenylketonuria (estimated new cases per year, 350), muscular dystrophy (estimated new cases, 813), cystic fibrosis (estimated new cases, 1,206) and sickle-cell anemia (estimated new cases, 1,155). The first three are diseases primarily or exclusively of white children. Sickle-cell anemia is almost exclusively a disease of black children.

Grants by the National Institutes of Health in 1968 for research in the three diseases of white children, writes Scott, totaled 172. There were 22 grants for studies of sickle-cell anemia. In the same year private fund drives collected more than $7 million for research on muscular dystrophy and nearly $2 million for research on cystic fibrosis. Groups in Los Angeles, New York, Washington, Richmond and Memphis soliciting funds for work on sickle-cell anemia were able to raise some $50,000. Commenting on Scott's findings, the editor of *The Journal* states: "The facts are clear. Hopefully, the clarion call has been sounded for action."

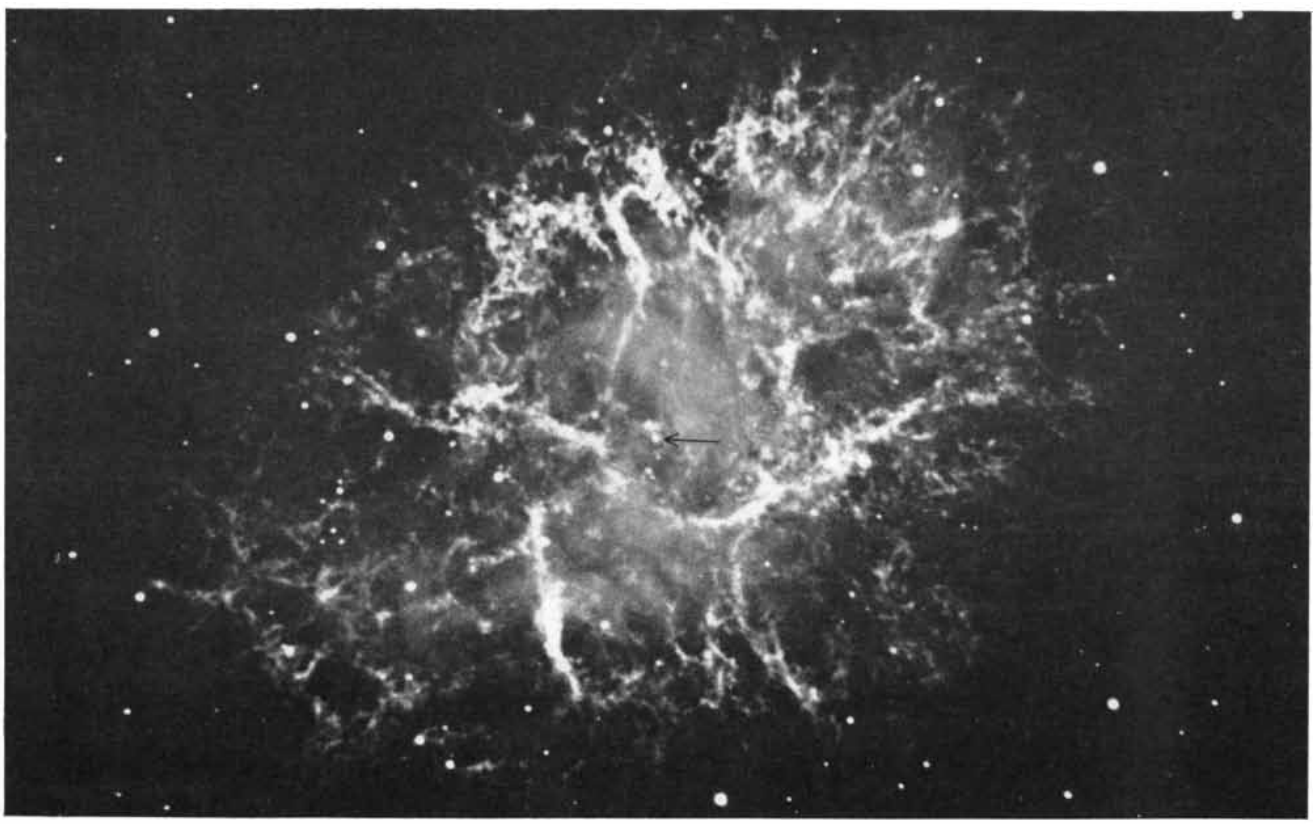
THE NATURE OF PULSARS

It is generally agreed that these flickering objects are neutron stars in rapid rotation. What seems to be such a star in the Crab Nebula may well account for some of the nebula's puzzling features

by Jeremiah P. Ostriker

In February, 1968, a group of radio astronomers at the University of Cambridge announced that a strange new class of radio-emitting objects had been found. The objects were pointlike sources that showed negligible transverse motion and hence were definitely outside the solar system. What was strange about them was that they emitted periodic bursts of radio "noise" in our direction. As a result they were quickly nicknamed "pulsars" and, although the name misleadingly connotes a pulsating (expanding and contracting) object, it has become the standard term [see "Pulsars," by Antony Hewish; SCIENTIFIC AMERICAN, October, 1968].

The bursts of radio waves from these sources were so accurately timed that any of the four originally discovered pulsars could have been used as a clock accurate to one part per 100 million. This in itself was not so surprising, since terrestrial time has been kept for millenniums by means of comparably accurate astronomical clocks based on the spin and orbital motions of the earth. The "tick" periods for the first pulsars discovered, however, ranged from .25 second to 1.3 seconds, far shorter than for



CRAB NEBULA, the gaseous debris of a supernova explosion observed by Oriental astronomers in A.D. 1054, is the site of the pulsar with the shortest period discovered so far. The observed radiation from the pulsar, originally named the south preceding star (*arrow*), turns on and off 30 times per second. This fact, first determined by radio astronomers, had never been noticed before by optical astronomers because photographs of the Crab complex are normally long exposures intended to reveal the filamentary outer structure of the nebula. Filaments appear white in this photograph, made by red light with the 120-inch reflecting telescope at the Lick Observatory. Amorphous gray areas result from synchrotron radiation emitted by very-high-energy electrons moving in nebula's magnetic field.

any known periodic astronomical phenomenon. What were the objects? The newspapers carried speculations that "little green men" might be trying to communicate with us by means of a radar-like code.

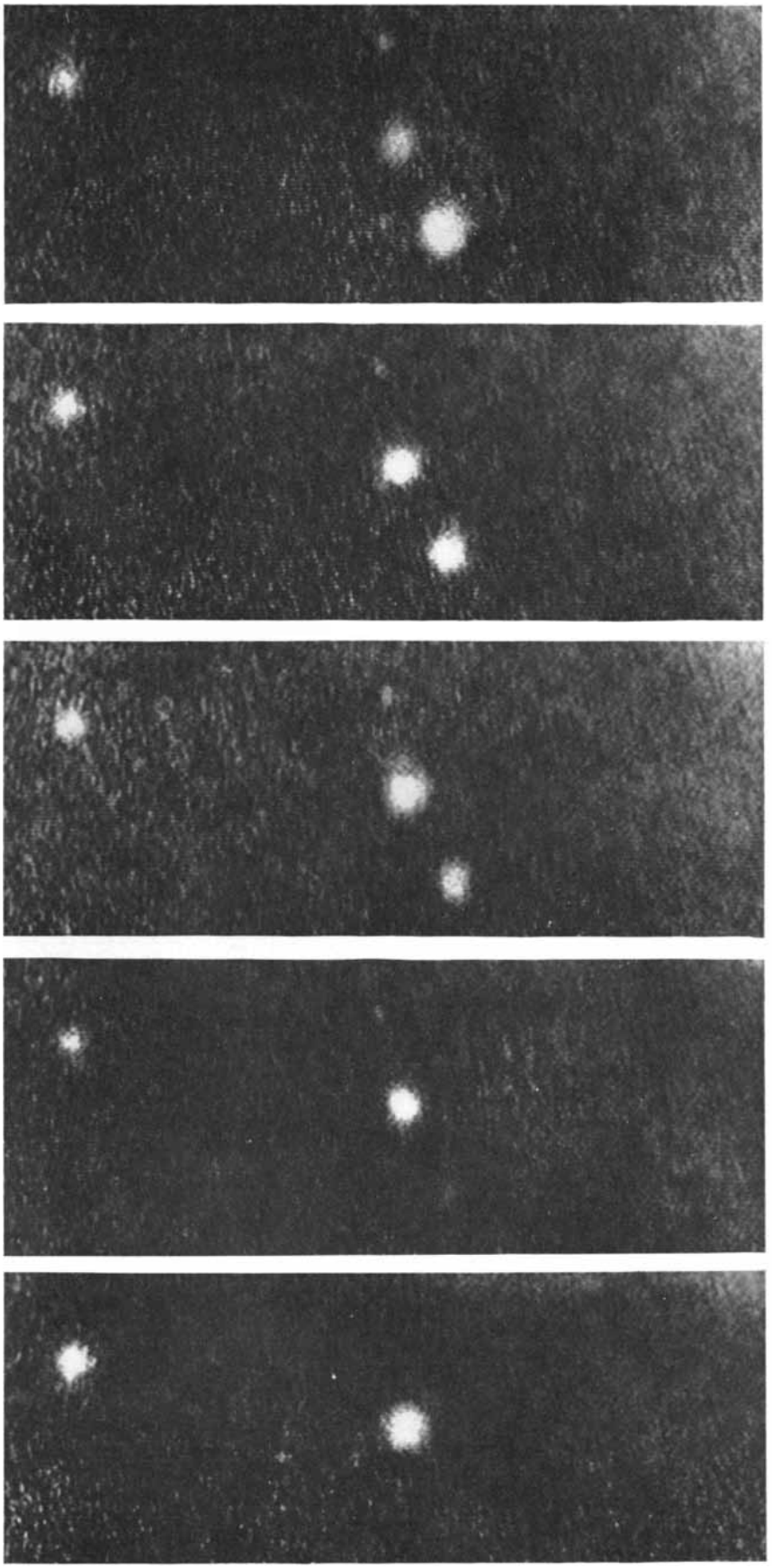
In the next two years new observations and new theories followed one another in rapid succession. The pace has slowed somewhat, and astrophysicists now largely agree on the nature of pulsars; they appear to be neutron stars.

The discovery of these strange stars illustrates beautifully what has come to be known as the "totalitarian principle of physics." This rule (originally formulated by the late British novelist T. H. White as the governing principle for a colony of ants) states that "anything not forbidden is compulsory." It has been cited repeatedly by physicists in recent years to defend the reality of improbable objects—from tachyons to quarks. In the subatomic realm the existence of some fundamental particles (notably neutrinos) has been correctly predicted on the basis of the totalitarian principle. The belated discovery of pulsars similarly confirms the reality of a hitherto hypothetical entity on the astronomical scale. The possible existence of neutron stars had been predicted as early as the 1930's, but before they were actually observed they had seemed almost too strange to be credible.

The Initial Observations

The first signs of something unusual about the radio sources in question were noticed in late 1967 by Jocelyn Bell, a graduate student at Cambridge, who at the time was engaged in an analysis of the records of certain small radio sources. The purpose of the project had been to study the effects on radio observations of the irregular clouds of plasma, or ionized gas, that stream outward from the sun through interplanetary space. Small radio sources are known to scintillate, or twinkle, characteristically as a result of the passage of their rays through this "solar wind." One such scintillating object, however, was observed to cross overhead near midnight, when the effects of the solar wind should have been negligible. Further examination showed that the variations in the radio waves were not caused by passage through the solar wind but were periodic and hence intrinsic to the source itself.

Efforts to find evidence of more such objects were rewarded almost immediately. Of the first four pulsars found one, designated CP0950 (Cambridge pulsar at 09 hours 50 minutes right ascension),



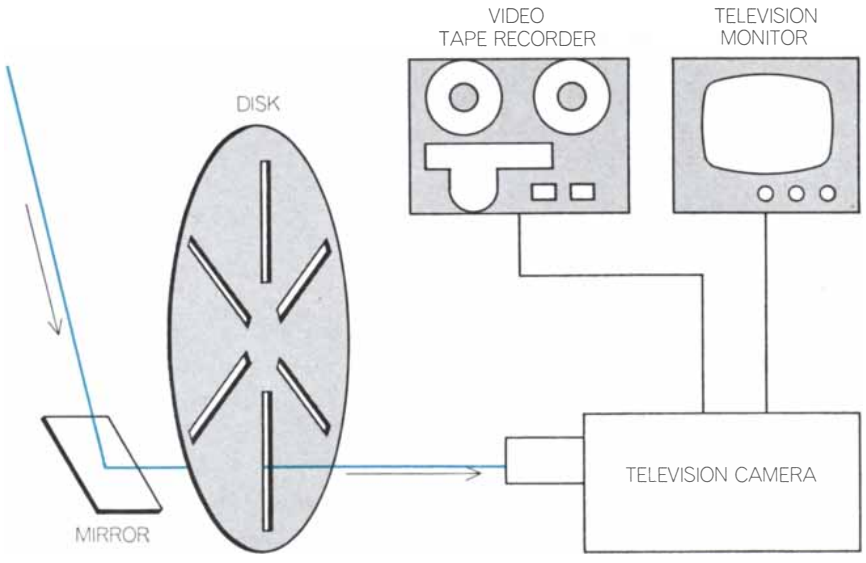
CRAB PULSAR FADES from maximum luminosity (*top*) to zero luminosity (*bottom*) in a few thousandths of a second, as shown in this sequence of photographs made by E. Joseph Wampler and Joseph S. Miller at Lick. The spottiness of the background is the result of electronic interference in the television system used to record the images.

had a period of only .25 second and a pulse width of only 20 milliseconds. The amplitude of the pulses from the objects was observed to be very uneven, but the interpulse spacing was quite regular. When a large number of successive periods of one of these pulsars are stacked on top of one another [*see illustration on page 53*], it can be seen that although the leading edges of the pulses occur within a few thousandths of a second of the predicted times, the shape of the pulses is quite irregular. Some of this irregularity must result from variations in the source itself, but much of it is undoubtedly caused by the effects of transmission through the interstellar medium.

The transmission medium in this case affects a radio signal in a special way. Radio signals do not travel through interstellar space at exactly the speed of light in a vacuum but rather at a slightly lower speed, for the simple reason that space is not quite a vacuum. The amount by which the signals are slowed is proportional to the density of electrons in space and is greater for longer wavelengths. As a consequence a pulse may be emitted at many different wavelengths simultaneously, but it will be dispersed by its passage through the interstellar medium and will arrive at the earth with its longer-wavelength components taking as much as several seconds longer to make the trip. From the time lag radio astronomers calculate a "dispersion measure," which is the product of the length of the trip times the average electron density of interstellar space (approximately .1 to .01 electron per cubic centimeter).

With this information the distances of the first pulsars were estimated to be in the range of tens to hundreds of light-years from the earth, roughly the distance range of the visually brightest stars. Given the observed radio fluxes and the estimated distances, the radio luminosities of the pulsars could be calculated. They were found to be modest, the average being only between a ten-thousandth and a millionth of the total luminosity of the sun.

The sun, however, emits the bulk of its energy output at optical wavelengths. It was natural to check if this is true for the pulsars as well, so that as soon as accurate positions were obtained by the radio technique the standard optical sky-survey plates were searched to see if visible stars could be found at the pulsar positions. The results were negative; no stars were found to the limits of the survey plates, which reveal stars to about the 21st magnitude. Since the objects were comparatively nearby, these brightness limits implied they must be intrinsically very faint in the optical region; the optical luminosity of CP0950, for example, had to be less than a hundred-thousandth of the optical luminosity of the sun. Nevertheless, the objects are intrinsically much brighter radio sources than the sun! At this point the first rudimentary requirements of a theory could be perceived, and it was already possible to say that no known type of astronomical object was likely to be the source of the observed radio emissions.



ROTATING SHUTTER with a period nearly equal to the period of the Crab pulsar was placed in the optical beam of the Lick telescope by Wampler and Miller in order to record the pulsar's flickering. The resulting signal was transmitted by means of television to the University of California at Santa Cruz. Since the pulsar and the shutter would be in phase and then out of phase for many seconds, still pictures could be made of the televised images.

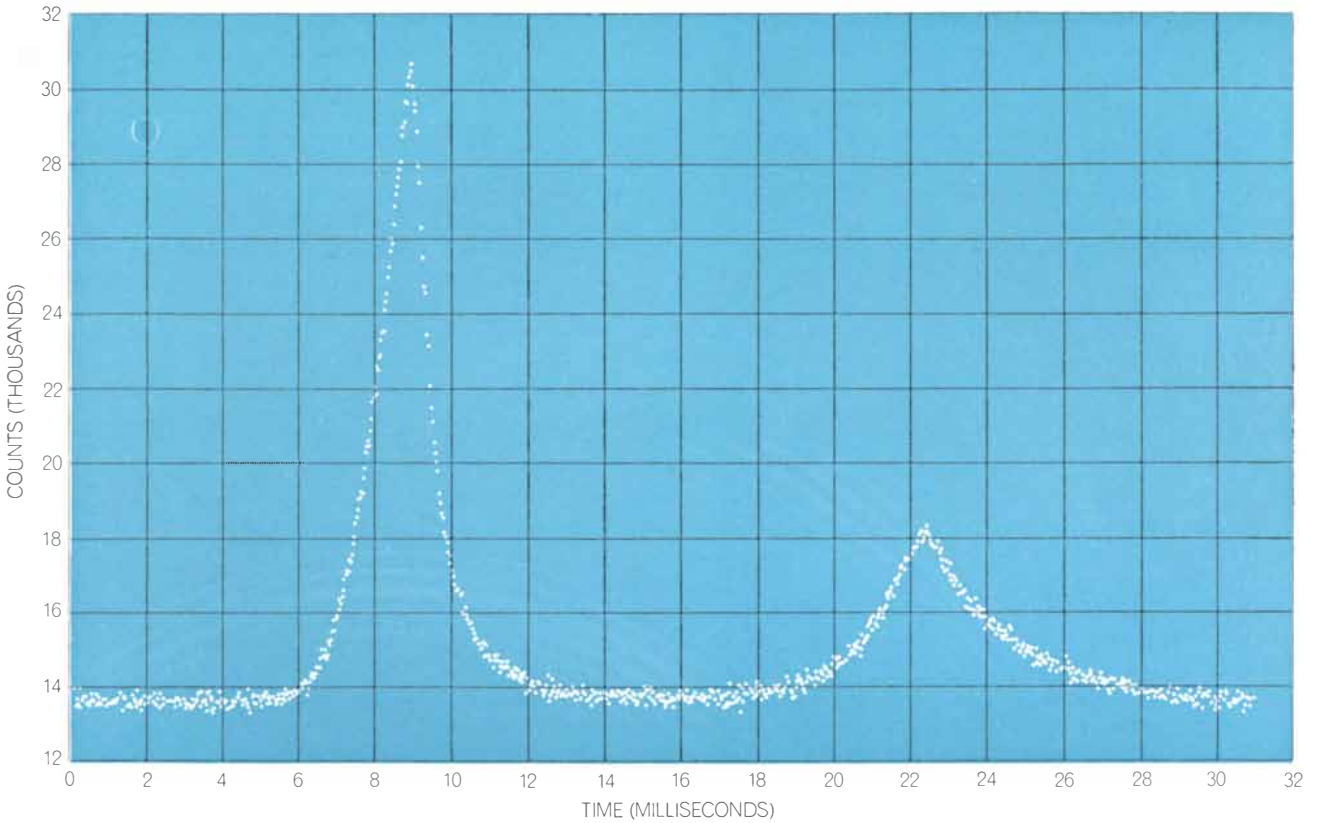
Theorizing by Elimination

Before considering the elimination process that was used to screen possible candidates for pulsars it will be useful to catalogue the small number of theoretically possible types of star. Only three broad categories are known to be possible, the classification being based on the origin of the outward force that must exist to balance the gravitational self-attraction within the star if it is to be in equilibrium. In ordinary stars (including all the unaided-eye stars) this outward pressure is provided by the thermal motions of electrons and ions in the hot gas that comprises the star. These stars must be hot to exist, and typically they have densities in the range from 10^{-4} gram to 10 grams per cubic centimeter.

The second category consists of the "degenerate" cold stars commonly called white dwarfs because the brightest and first-discovered members of the class were blue-white. They have mean densities in the range from 10^{4} to 10^{8} grams per cubic centimeter and can exist at an absolute temperature of zero degrees Kelvin. Thus thermal motions are unimportant, but the electrons are packed together so tightly that the quantum-mechanical Pauli exclusion principle does not allow all the electron velocities to be small even if the temperature is low. The residual electron motions provide the pressure to oppose gravity. In many respects white dwarfs are like giant atoms.

Finally, a number of theorists (including L. D. Landau, Fritz Zwicky, J. Robert Oppenheimer and G. M. Volkoff) had noted as early as the 1930's that, if ordinary matter were sufficiently compressed, the electrons would "tunnel" into the nuclei and a "neutron gas" would result. At a high enough density the repulsive forces among neutrons would become large enough to balance self-gravitation for objects of about one solar mass so that equilibrium would again be possible.

If white dwarfs resemble giant atoms, neutron stars (if they exist) would be more like giant atomic nuclei. They could exist at a temperature of absolute zero and would have mean densities in the range from 10^{11} to 10^{15} grams per cubic centimeter. In other words, the mean density in a neutron star would be on the order of a billion tons per cubic



LIGHT CURVE of the Crab pulsar, recorded by means of a photoelectric detector, reveals that there are actually two pulses in each period. The smaller pulse is the same color as the main pulse but has only half the luminous output. Unlike the radio pulses from the same source, the optical pulses, which are very steady and very sharp, are not affected by transmission through the interstellar medium. The light curve was obtained at the Smithsonian Astrophysical Observatory in Cambridge, Mass., by C. D. Papaliolios, N. P. Carleton and P. Horowitz of Harvard University. The interval between the points that comprise the curve is 32 millionths of a second.

inch! The mass-radius ranges of the theoretically possible white dwarfs and neutron stars are shown in the illustration on page 54.

The gravitational forces associated with a neutron star would be so large that Newtonian physics is inadequate to describe them; general relativity must be used, and the relativistic effects are large. For example, general relativity predicts that a light ray will be bent as it passes by a massive object. This effect, a deflection of a few ten-thousandths of a degree for a ray passing our sun, has been measured and provides one of the principal experimental tests of Einstein's theory. In contrast, a light ray following a "straight line" as it passed through relativistically curved space on a path grazing a neutron star with a mass equal to that of the sun would be deflected by about 30 degrees as seen by a distant observer. More spectacularly, a mass m falling to the surface of the same star would liberate an amount of energy equal to about .1 mc^2, regardless of the falling material; hence a falling marshmallow, which weighs about 10 grams, would explode with the power of a World War II atomic bomb. Fortunately for mankind neutron stars seem safely unharnessable.

Neutron stars were known to be theoretically possible in the sense that they were not "forbidden." Furthermore, it seemed possible for them to be formed under astronomical circumstances; the most plausible arguments associated their birth with supernova events. Extensive calculations of their properties had been done by a number of workers, including J. A. Wheeler of Princeton University and A. G. W. Cameron of Yeshiva University. However, although everyone agreed that neutron stars would be fascinating objects if they existed, nothing had been seen (until the Cambridge observations) that had properties resembling the hypothetical objects. Were pulsars neutron stars?

The initial observations contained important hints. First, there was a strong constraint on the possible size of the pulsars. Electromagnetic waves, whether light or radio waves, can travel only about 6,000 kilometers in 20 milliseconds (the pulse width of CP0950). If the pulse were emitted from a surface with the largest dimension much larger than this size, then because of the finite speed of light it would be received on the earth over an interval longer than the observed 20 milliseconds, even if each element of the surface radiated simultaneously. (Although the pulse could be emitted at various times over the emitting surface in such a way that each pulse from each element reached the earth at the same time, this expedient is artificial; furthermore, it is unlikely that the earth would find itself in such a privileged position for all the sources.) Thus the narrow pulse widths implied a small source for the radio signal—smaller than any stars except the common white dwarfs and the hypothetical neutron stars.

Second, since observations showed that the pulsars were intrinsically very faint, they had to be either small or cold or both. This constraint again left only white dwarfs and neutron stars as possible candidates. Even planets could be excluded if it is assumed that they do not exist without a parent ordinary star such as our sun.

Attention next focused on the origin of the precise clocklike timing of the

pulses. Some stellar behavior had to be conceived of that repeated periodically at intervals of about one second. In astronomy periodic behavior has been found in three settings. A single star can expand and contract regularly, a pair of stars can orbit around each other causing periodic eclipses, and a spinning star can be seen by a distant observer to vary regularly if its surface is not uniformly bright.

Genuinely pulsating stars are comparatively common and their periods are sometimes very stable, so that perhaps the pulsars were pulsating white dwarfs or neutron stars. White-dwarf pulsations were unlikely for a variety of reasons. The fundamental period of radial oscillation of a star is proportional to the inverse square root of the mean density and, although white dwarfs are very dense, none of the observed (or theoretically possible) white dwarfs could have periods as short as .25 second. The possible calculated pulsation periods might be reduced by rapid rotation or a preference for overtone modes. Even these somewhat artificial expedients are just barely able to allow a quarter-second pulsation period, and they turned out to be quite inadequate when pulsars with much shorter periods were ultimately found. Furthermore, in order to excite the hypothetical oscillations white dwarfs would have to be so hot that they would have been seen by optical telescopes; moreover, they would have evolved at a rate incompatible with the observed period stability.

Neutron-star pulsations were excluded on the opposite grounds. All stable neutron-star models have calculated pulsation periods too short to be identified with the pulsars. Neutron stars would be too dense for this purpose, and consideration of overtones or the effect of rotation on the radial pulsation periods would not help. The pulsars were clearly not pulsating stars.

Could periodic orbits of stars in a binary system somehow cause periodic pulses? Orbiting white dwarfs were excluded since the minimum period (for a pair of very dense stars in a grazing circular orbit) was calculated to be 1.7 seconds, too long to be the origin of the pulsar clockwork. Pairs of neutron stars could be imagined with the desired orbital periods, but this solution was prohibited for a rather interesting reason. In classical electrodynamics an accelerated charged particle will radiate electromagnetic waves. There is an analogue of this in general-relativity theory, in which an accelerated mass point can be shown to radiate gravitational waves. Since the star in orbit is continuously accelerated about its companion, the general-relativistic gravitational radiation must occur and is easily calculated. A pair of neutron stars with a one-second orbital period would slowly spiral closer and closer together as the system radiated away gravitational energy. This would cause the orbital periods to decrease at rates much higher than those allowed by the pulsar observations.

This left only rotation. Of course arguing by elimination is always a dangerous undertaking. The pulsars might have been a totally new phenomenon, but scientists are conservative and prefer to explore familiar territory (if neutron stars can be considered familiar) before venturing into the unknown. It was possible to consider a white dwarf or a neutron star with some type of searchlight beam fixed to its surface. Once each period the beam would sweep by the observer, who would see a "pulse." If the beam were circular in cross section, it could easily miss a randomly placed observer, so that, if this "lighthouse theory" were correct, there would be many more pulsars emitting than terrestrial viewers could ever observe.

On the basis of these arguments I suggested in mid-1968 a version of the lighthouse theory with a white dwarf as the seat of the phenomenon, arguing on the too conservative grounds that white dwarfs were common (although rapidly rotating white dwarfs were not), whereas the neutron star was, like Thurber's Unicorn, a "mythical beast." Rotational forces cannot exceed gravity in a stable star, however, and white dwarfs cannot rotate much faster than about a quarter-second. Thus, if very-short-period pulsars were found, white dwarfs could be ruled out entirely. Then Thomas Gold of Cornell University suggested the neutron-star version of the lighthouse model. He further noted that the objects might have strong magnetic fields and might emit high-energy charged particles; as a result they would tend to lose angular momentum and slow down. His predictions have turned out to be correct.

Neutron-Star Hypothesis Confirmed

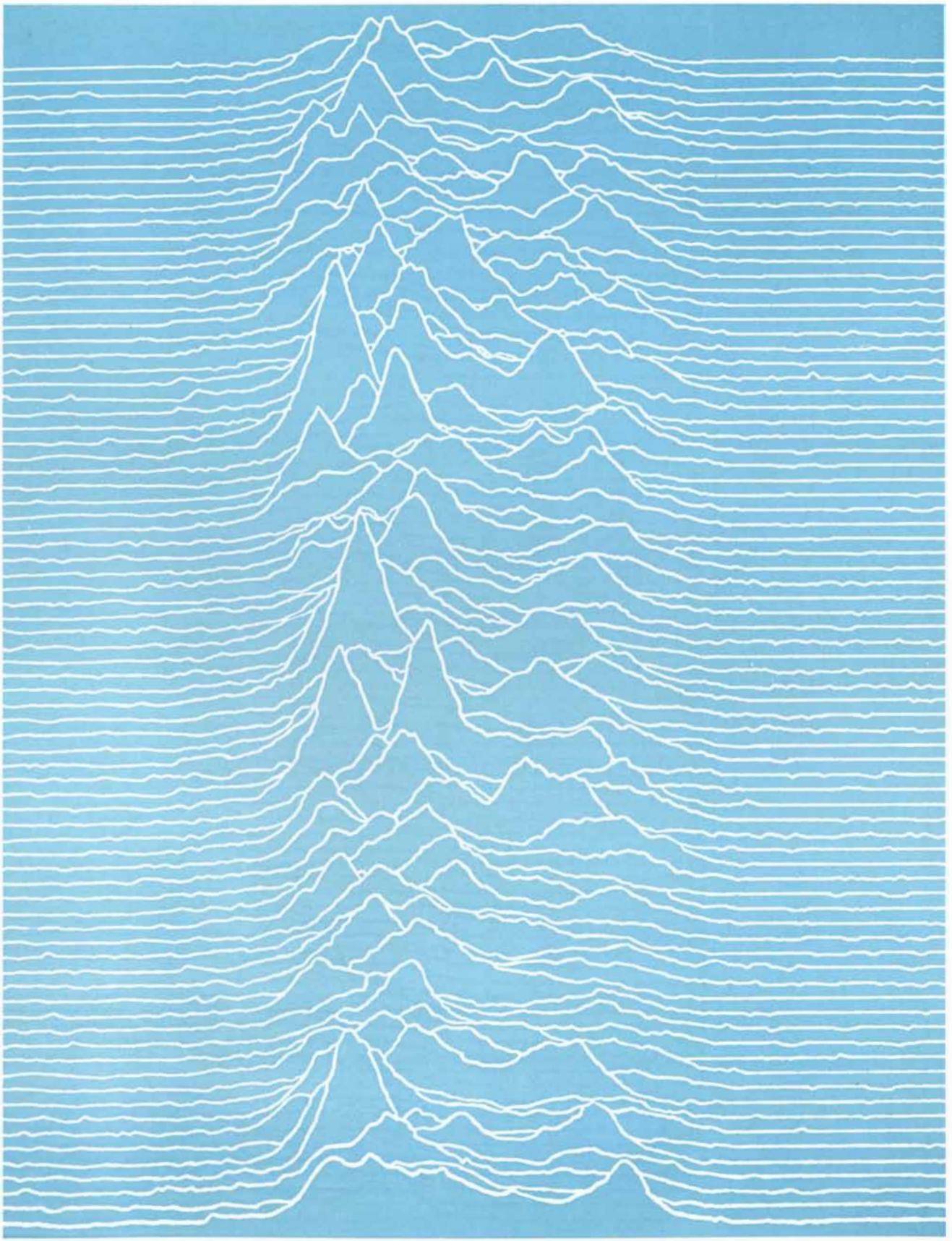
The case was broken in November, 1968. First, on November 6, D. H. Staelin and E. C. Reifenstein III at the National Radio Astronomy Observatory in Green Bank, W.Va., announced the discovery of two sources of pulsed radio signals in the vicinity of the Crab Nebula, the gaseous debris from an exploded star [*see illustration on page 48*]. Then on November 18 a group at the Arecibo Radio Observatory in Puerto Rico identified one of these sources with a pulsar in the center of the Crab Nebula. The pulsar had an astonishingly short period: one thirtieth of a second! Only neutron stars can rotate this rapidly. By November 25 the Arecibo group had already noticed that the period was gradually but definitely lengthening at the rate of 38 nanoseconds (billionths of a second) per day.

A rotating star, like a flywheel, must lose energy if its rotation rate decreases. From the period, rate of change of period and the calculated moment of inertia of a neutron star, the energy-loss rate was computed and a number of astronomers noted that the rate was just about sufficient to keep the nebula glowing. The origin of the energy input to the Crab Nebula had been a puzzle that had long defied attempts at solution. Among the various possibilities considered, Wheeler at Princeton in 1966 and Franco Pacini at Cornell in 1967 had independently put forward the apparently farfetched idea that a rotating neutron star might be the energy source. Now, after the fact, it is possible to use the observations of the Crab Nebula and its pulsar (NP0531) to invert the problem and show that if the pulsar is a rotating star, it must have the mass and radius of a neutron star [*see illustration on page 58*]. In other words, even without the theory developed over the past 40 years, it is possible to assert that stars of approximately one solar mass and radii on the order of 10 kilometers must exist since the pulsar in the Crab Nebula is such a star.

The fact that the Crab Nebula is well known to be the remnant of a supernova seen in A.D. 1054 by Oriental observers (while Europe slept) is also consistent with the neutron-star hypothesis; this connection was first recognized in the 1930's by Zwicky and Walter Baade, who calculated that much of the energy seen in a supernova explosion may be liberated when the core of a star collapses rapidly to a neutron star.

Why, then, had no one looked for a neutron star in such a well-studied object as the Crab Nebula? The answer is that people had looked, but no one knew what a neutron star should look like, and since none of the stars that are seen projected on the nebula appeared exceptional, the matter rested. Nonetheless, one centrally located, very blue star, termed the south preceding star, had been considered somewhat suspicious.

After the November discovery of a radio pulsar in the Crab Nebula observers pursued the search for an optical



EIGHTY SUCCESSIVE PERIODS of the first pulsar observed, CP1919 (Cambridge pulsar at 19 hours 19 minutes right ascension), are stacked on top of one another using the average period of 1.33730 seconds in this computer-generated illustration produced at the Arecibo Radio Observatory in Puerto Rico. Although the leading edges of the radio pulses occur within a few thousandths of a second of the predicted times, the shape of the pulses is quite irregular. Some of this irregularity in radio reception is caused by the effects of transmission through the interstellar medium. The average pulse width is less than 50 thousandths of a second.

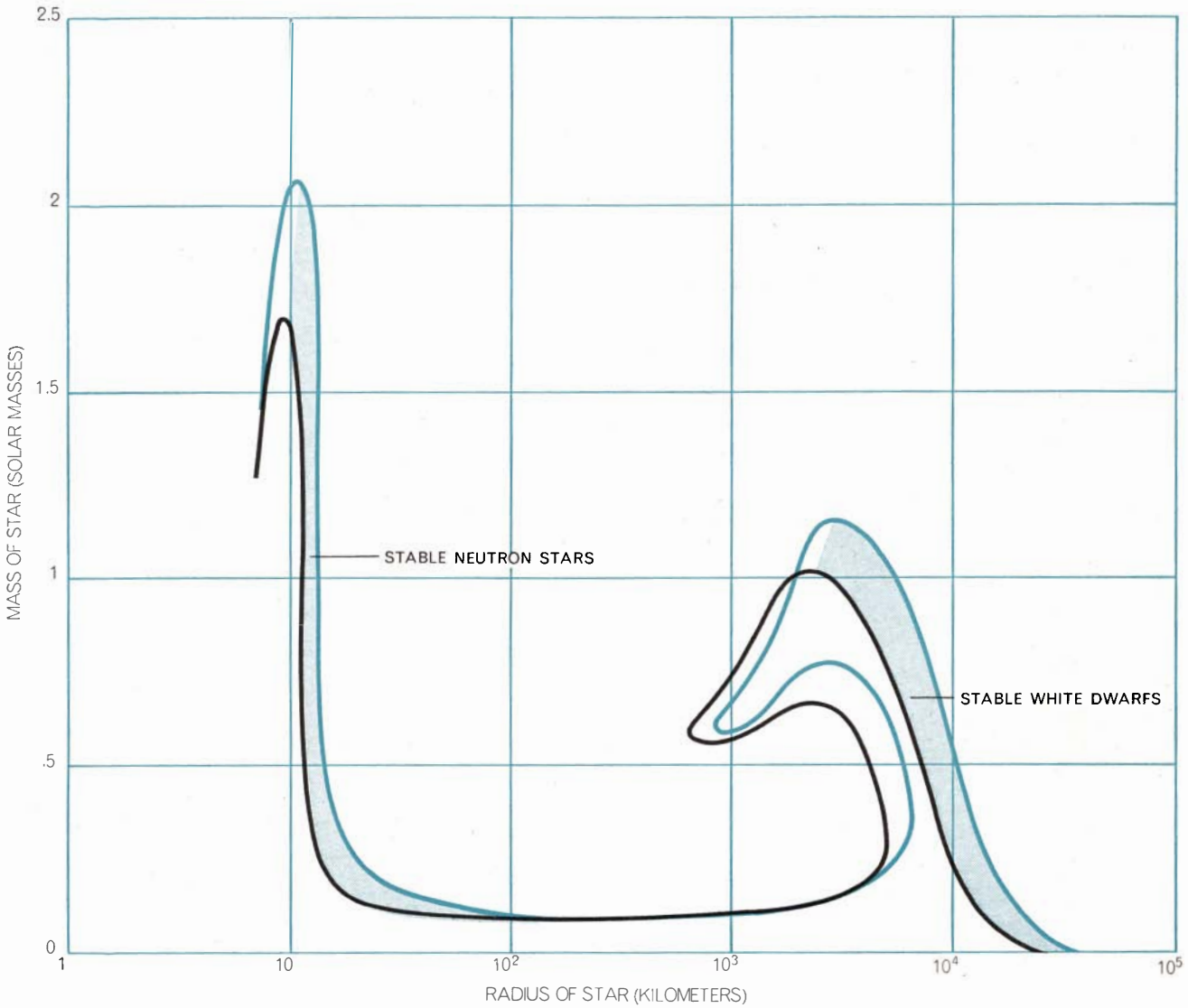
counterpart with renewed vigor. Now the period of the sought-after optical signal was accurately known, however, and the search was easier. On January 16, 1969, W. J. Cocke, M. J. Disney and D. J. Taylor at the Steward Observatory in Arizona found an optical image; the probable position was given as 6 ± 5 seconds of arc northeast of the south preceding star. By the end of the month groups at the Kitt Peak National Observatory and the Lick Observatory had determined that the south preceding star was indeed the pulsar. The extraordinary fact that the star turned on and off 30 times per second had simply never been noticed.

Soon afterward E. Joseph Wampler and Joseph S. Miller at Lick were able to display the flickering by a simple device [*see illustration on page 50*]. A rotating shutter with a period nearly equal to the period of the pulsar was placed in the optical beam of the 120-inch telescope on Mount Hamilton, and the resulting signal was transmitted by means of television to the University of California at Santa Cruz. As in other stroboscopic techniques, the pulsar and the shutter would be in phase and then out of phase for intervals of many seconds so that still pictures could be made of the televised images. A selected sequence of these pictures clearly showed the star changing from "on" to "off" states [*see illustration on page 49*].

Actually the light curve is somewhat more complicated. There are two pulses in each period; the smaller pulse is the same color as the main pulse but has only half the luminous output. The optical pulses are not affected by transmission through the interstellar medium. They are very steady and very sharp [*see illustration on page 51*]. Both optical and radio pulses show significant linear polarization, with the plane of polarization rotating through a definite angle as each pulse passes the observer. In order to produce this polarization there must be some mechanism at the source for aligning the emitting particles. A possible agent might be a strong magnetic field, which can have a determining effect on the motion of charged particles.

The Properties of Neutron Stars

By mid-1969 the period of rapid discovery had more or less ended and the-



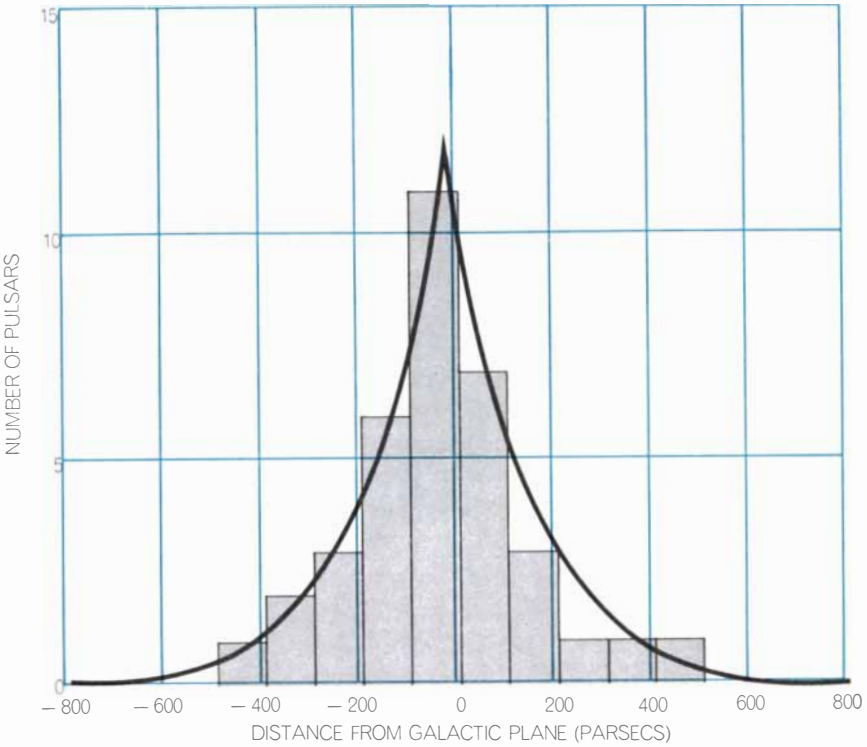
MASS-RADIUS GRAPH for stars at high densities shows two "stability regions" corresponding to the two theoretically possible classes of condensed stars: white dwarfs and neutron stars. The black curve represents nonrotating stars; the colored curve represents uniformly rotating stars at a very high rotational rate. The light-colored area indicates the regions where stable, uniformly rotating stars can exist. The graph is taken from the work of Kip S. Thorne and his associates at the California Institute of Technology.

orists were focusing on a fairly specific problem: the character of a rotating, magnetic neutron star. The physics problems encountered were and are formidable. For example, an accurate description of the interior of a neutron star will require new developments in elementary-particle physics, "applied" general relativity, solid-state physics and hydrodynamics. Many other questions remained to be answered: How strong a magnetic field would a neutron star be expected to have? How fast might it rotate? Exactly how is a rotating magnetic neutron star formed during a supernova explosion? By what mechanism are the pulsars losing energy and slowing down? Where does the energy go? What makes the observed radio pulses? Finally, how does all of this fit into the larger scheme of things—to nonpulsar astrophysics? All the answers that follow are tentative.

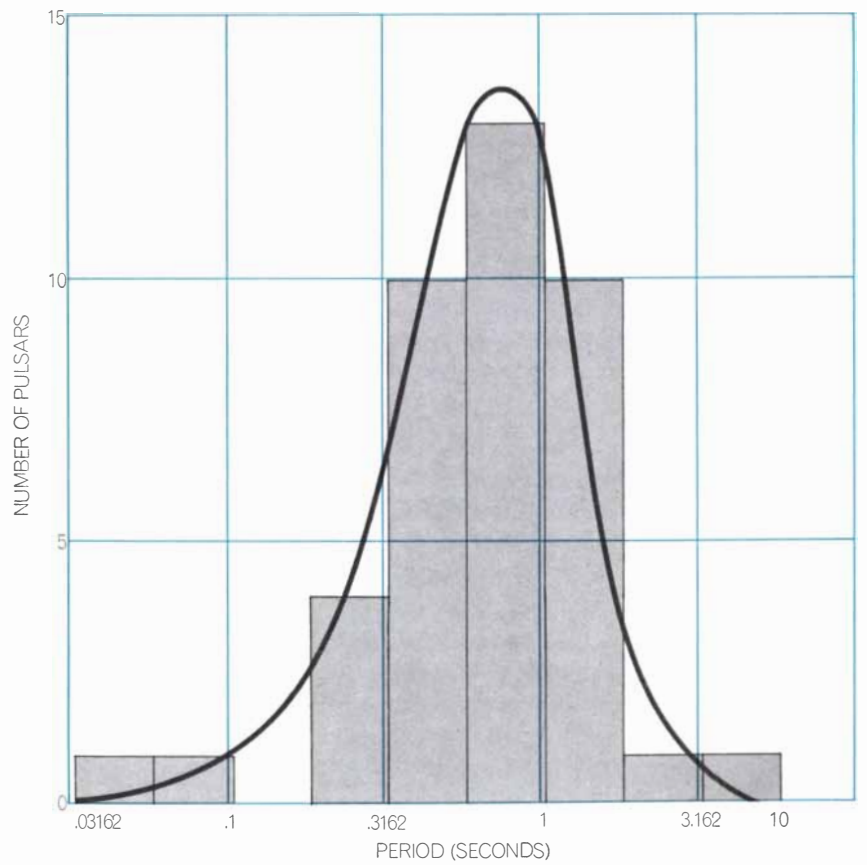
First let us consider whether neutron stars would be expected to have magnetic fields. The sun, in addition to the strong local fields observed in sunspots, has an overall dipole field of about one gauss. (By coincidence this is about the same as the earth's field.) On the other hand, more massive stars—the likely parents of pulsars—often have surface fields ranging from 100 to 10,000 gauss. The strength of the magnetic field inside a star cannot be measured directly, but on theoretical grounds one would expect the interior field to be much stronger than the observed surface field.

Consider now what would happen to the field within a star if the star's central regions should collapse. The magnetic lines of force would be effectively frozen into the highly conducting stellar material. Thus the field strength, which is proportional to the number of lines of force crossing a unit area, would increase as the inverse square of the shrinking stellar radius. Since neutron stars are 100,000 times smaller than ordinary stars, they should have fields 10^{10} times greater, or 10^{12} to 10^{13} gauss. The same principle has been used to generate large magnetic fields in the laboratory. An open tube made of a good conductor and surrounded by explosives is put in a strong magnetic field. When the explosives are detonated, the tube collapses and the field lines threading the tube are squeezed together. Transient fields as high as a million gauss have been produced in this way [see "Ultrastrong Magnetic Fields," by Francis Bitter; SCIENTIFIC AMERICAN, July, 1965].

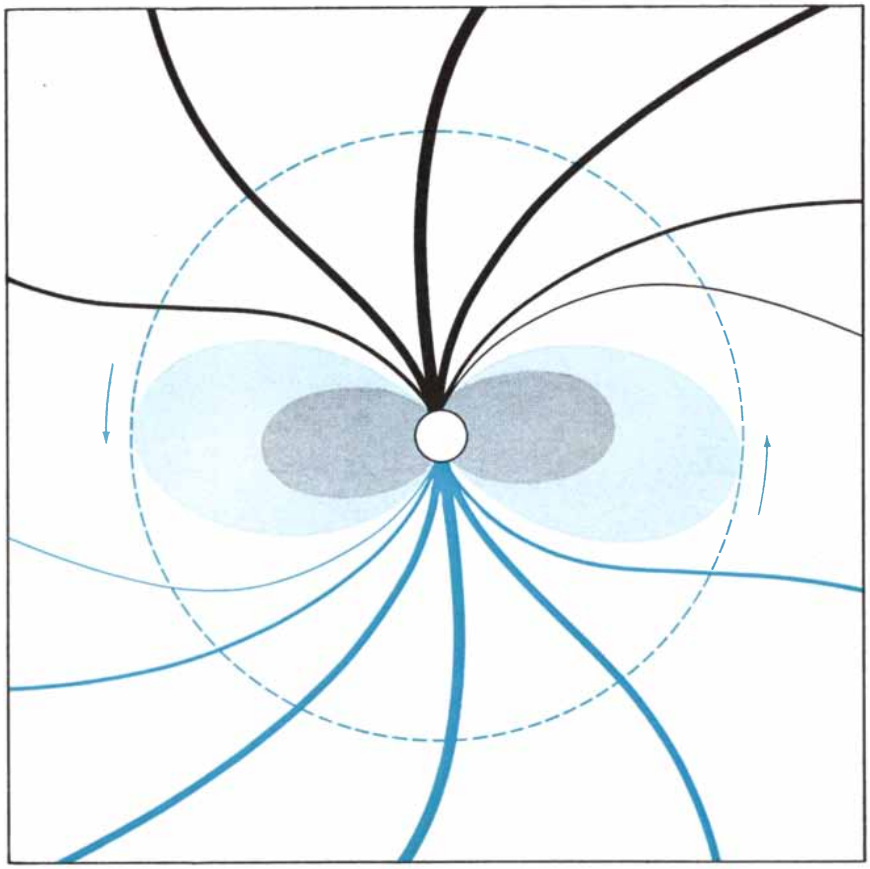
The parent stars of pulsars are thought to be relatively massive bright blue stars, in part because both appear to lie close



DISTRIBUTION OF PULSARS with respect to their perpendicular distance from the plane of the galaxy is given in this bar chart; the curve shows the distribution predicted on the assumption that the parent stars of pulsars are relatively massive bright blue stars. The parsec is an astronomical unit of distance equal to 3.26 light-years, or 19.2 trillion miles.



DISTRIBUTION OF PULSAR PERIODS is represented in this bar chart, which indicates that the average period for the first 41 pulsars discovered is less than one second. The curve shows the predicted distribution, assuming that pulsars live for about four million years.



NEAR MAGNETIC FIELD of a neutron star rotating in a vacuum would have the customary dipole pattern. The magnetic lines of force would rotate with the star at a velocity proportional to their distance from the rotation axis. This velocity would become equal to the speed of light at a distance that defines the "speed-of-light cylinder" (*broken circle*). The lines emanating from the north and south polar regions of the star are shown in black and color respectively for clarity; in both cases the thicker the line, the stronger the field. Within the speed-of-light cylinder the lines can form closed loops (*light-colored areas*).

to the plane of the galaxy [*see top illustration on preceding page*]. These parent-star candidates rotate rapidly, typically with a period shorter than 10 days, or 10^5 seconds. Assuming that angular momentum is conserved during collapse, the expected rotation period of a neutron star would be 10^{-5} second. Actually this is faster than a neutron star could rotate without breaking apart, so that some loss of angular momentum must occur during collapse. There are theoretical grounds for expecting gravitational radiation to carry away the excess, leaving the star rotating with a period of about 10^{-2} second.

Hence at birth a neutron star might be expected to have a magnetic field of 10^{12} gauss rotating at a rate of 100 revolutions per second. What would happen next? Obviously no laboratory experiments have any direct application to this exotic situation, but the laws of physics, derived from laboratory phenomena, are clear: An otherwise empty region in which there are oscillating electric or magnetic fields will emit electromagnetic waves.

The radiation emitted by a rotating magnet is called magnetic-dipole radiation and is fairly easy to visualize. Near the magnet the field lines have the customary dipole pattern, such as that seen when iron filings are shaken over a piece of paper covering a small toy magnet [*see illustration above*]. The lines rotate with the star and so have a velocity proportional to their distance from the rotation axis. This velocity becomes equal to the speed of light at the distance that defines a surface sometimes called the speed-of-light cylinder. As this surface is approached, the field lines depart from a simple dipole configuration; the lines crossing the surface are increasingly swept back into a spiral pattern [*see illustration on opposite page*]. Far from the spinning magnet, the magnetic field, which is at this point accompanied by an equal electric field, has assumed the character of an electromagnetic wave.

The waves of magnetic-dipole radiation satisfy the same equations that ordinary light or radio waves do, but for pulsars they have wavelengths 10^{14} times longer. This radiation, if emitted by neutron stars, would differ from ordinary light in another respect. The strength of the electromagnetic field in the wave would also be enormously greater than is found in the radiation from common optical sources (although lasers are beginning to be made that can reach a comparable field strength). It can easily be shown that such waves would carry off energy and angular momentum from the spinning star. Turning the problem around, the period and rate of slowdown observed in the Crab pulsar could be used to determine the hypothetical field at the surface of the star. The fact that the calculated number, 2.6×10^{12} gauss, was in the range anticipated earlier strengthened the belief that magnetic-dipole radiation was indeed responsible for the energy loss from the pulsars.

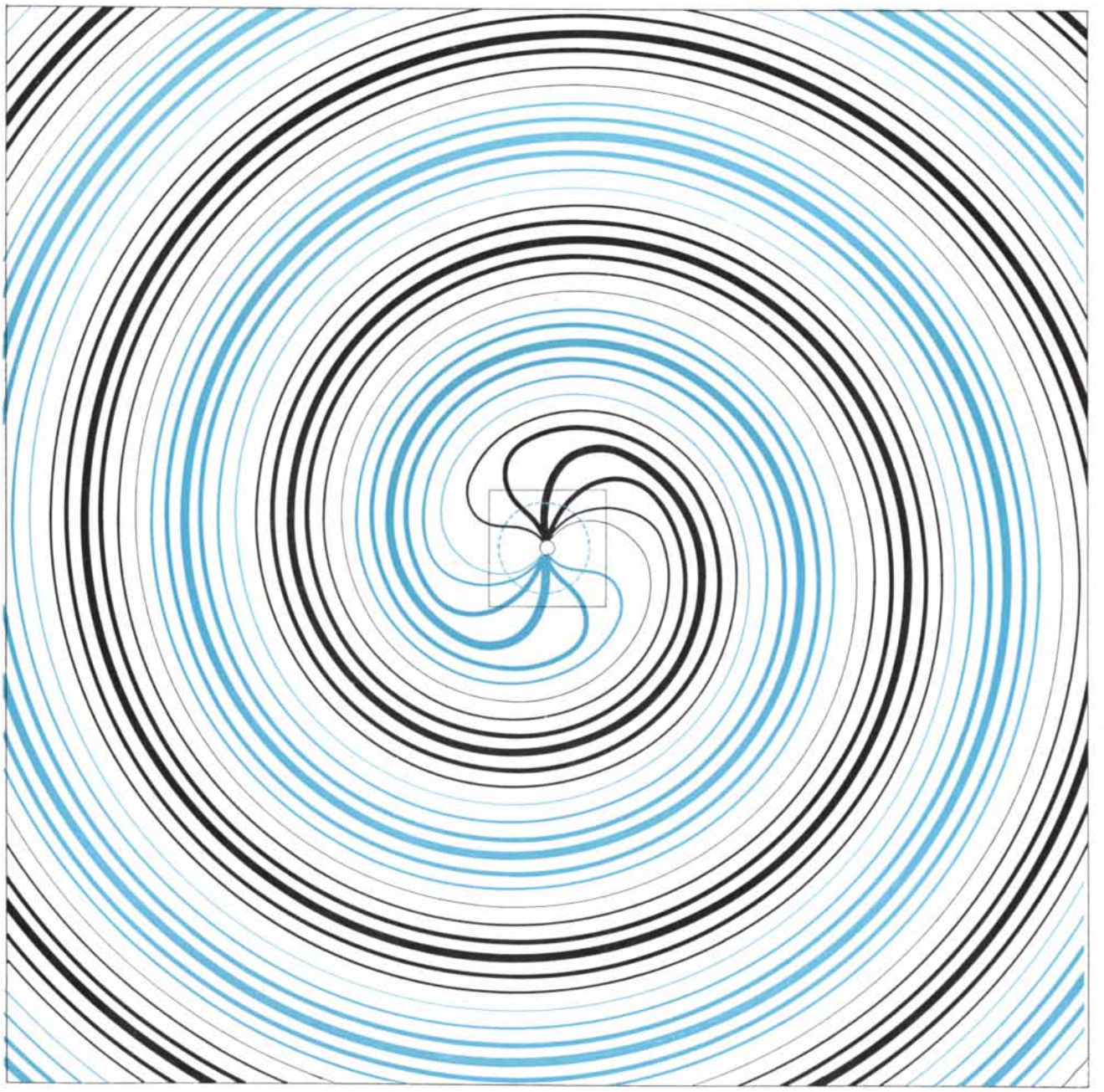
This low-frequency electromagnetic radiation, which was suggested first by Pacini and later by James E. Gunn and myself at Princeton, is inevitable if the pulsars are magnetic neutron stars spinning in a vacuum. Peter Goldreich and William Julian at the California Institute of Technology have shown, however, that such a star must have a magnetosphere, a plasma-filled region surrounding the star. Would electric currents in the plasma "short circuit" the displacement currents necessary to produce magnetic-dipole radiation? The problem is complex and debate on this point continues. It is interesting to note, however, that the "plasma solution" of Goldreich and Julian has exactly the same properties with respect to the emission of electromagnetic energy and angular momentum as the "vacuum solution." At present it appears that the plasma solution applies near the star but that at distances far from the speed-of-light cylinder the situation approximates the vacuum solution.

Let us accept either of these two electromagnetic theories and explore the consequences. In particular, how do they enable us to interpret the accumulated pulsar observations? First consider period changes. The periods of many more pulsars have now been found to be gradually increasing. Applying the theoretical model, one can calculate a pulsar's magnetic-field strength at its surface. These calculated values vary surprisingly little from object to object, with most fields being within a factor of two of the

value found for the Crab pulsar. The period distribution of the observed pulsars can also be roughly understood on the basis of the electromagnetic models. In these the rate at which a star's period changes with fixed magnetic field is inversely proportional to the period. Thus the star slows down at a lower and lower rate. If pulsars are being born at a roughly constant rate in the vicinity of the sun, then there would be an increasing number of them at longer and longer periods.

The pulsars with the shortest periods are in this view the youngest and consequently the rarest. NP0531 (in the Crab Nebula) is still the pulsar with the shortest period known; the one with the second-shortest, designated PSR0833, has a period of .089 second and lies near the center of the large and fairly old Vela supernova remnant. The longer-period pulsars may have been formed in supernovas but are so old that gaseous remnants would have been dissipated by now. The electromagnetic theories also enable one to date the observed sample from periods and rates of change of periods, yielding a mean age of about 10 million years. Unless by an unlikely coincidence pulsar production began just in time for us to see it, something must "turn them off" (make them unobservable) when they reach an age of about 10^7 years.

So far 14 pulsars have been found with periods of between one second and two seconds [*see bottom illustration on page 55*]. These periods are currently



FAR MAGNETIC FIELD of a rotating neutron star would depart drastically from the simple dipole configuration on the opposite page, with the lines of force becoming increasingly swept back into a spiral pattern as they crossed the speed-of-light cylinder. At great distances from the star the magnetic field, at this point accompanied by an equal perpendicular electric field, would assume the character of an electromagnetic wave with a constant wavelength equal to the distance between corresponding magnetic-field lines.

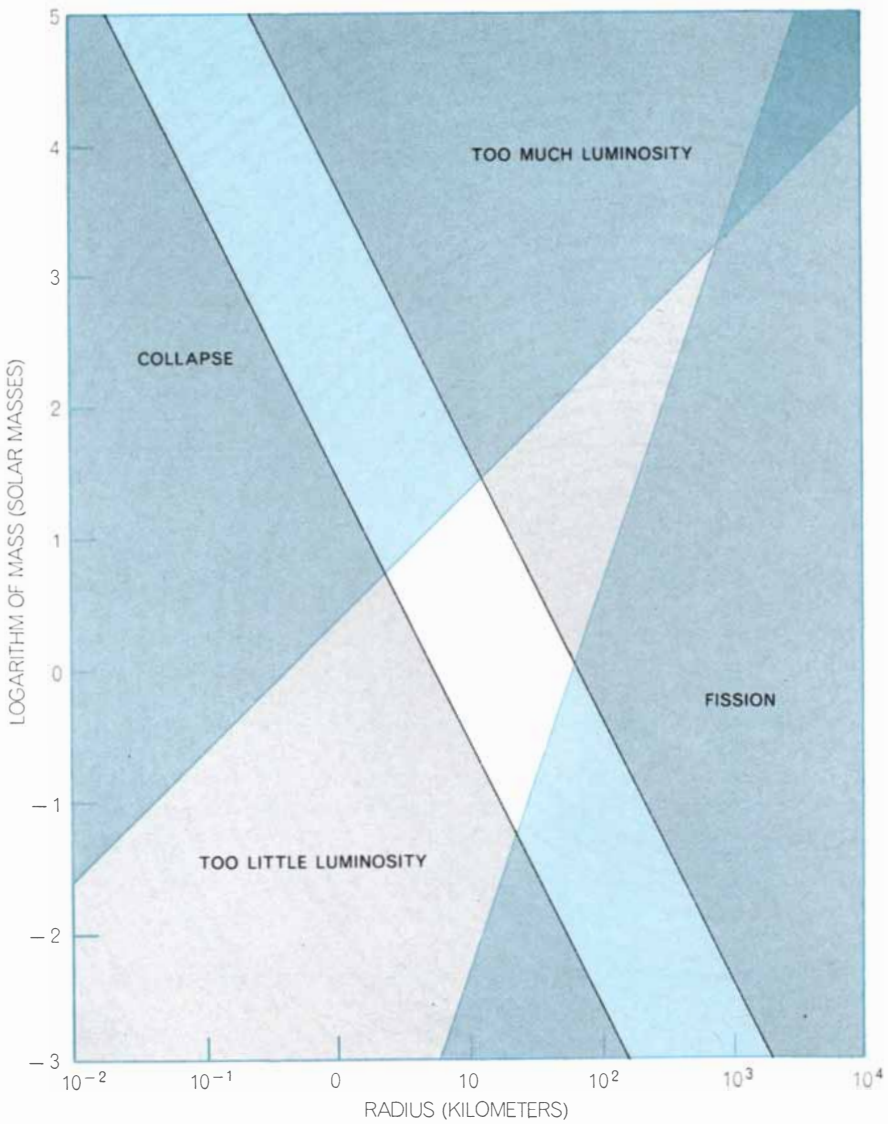
lengthening at a rate such that they will characteristically double in a few million years. Only three known pulsars, however, have periods of from two to four seconds. What became of the pulsars formerly with periods of between one second and two seconds? Again, unless we live at an anomalous point of time (a possibility astronomers are reluctant to consider), something of an as yet undetermined nature must make such pulsars difficult to detect after about 10^7 years. This means that there may be 10^3 to 10^4 times as many defunct pulsars as live ones; in fact, the nearest "dead" neutron star may be very close to us, perhaps less than 10 light-years away.

The Origin of the Pulses

What about the origin of the pulsed radio output? The total energy output of pulsars in our galaxy may be prodigious if they are rotating neutron stars. This luminosity, which depends on the initial, highly uncertain rate of rotation and the birthrate of pulsars in the galaxy, is estimated at 2×10^8 solar luminosities. The pulsed output, however, is much less than that. For the typical one-second pulsar the observed radio-energy output is only a tenth of a percent of the total energy-loss rate calculated from period and rate of slowdown. At present there are no widely accepted theories for the physical origin of the pulses. Most theoretical models have adopted the lighthouse geometrical picture with the beam of light generated by charged particles streaming from the magnetic poles. The pulse width is taken as a measure of the beam width, which characteristically has a cone angle of about five degrees of arc. For contrast, the earth's magnetic-dipole moment makes an angle of about 75 degrees with the equatorial plane. Thus if the earth were a pulsar, its pulses could be seen by distant observers in two parallel bands on the celestial sphere: at latitudes 75 degrees north and 75 degrees south, each with a width of several degrees.

One further characteristic is shared by a large class of theories intended to explain the pulses. In these theories a stream of charged particles emitted by the star is assumed to be accelerated by the ambient changing electric and magnetic fields. These particles then radiate by any one of a variety of mechanisms. The beaming of the emitted radiation is a simple consequence of special relativity: Even if a particle radiates isotropically in its own frame of reference (as seen by an observer moving with it), in the laboratory frame of reference the emission will be predominantly in the direction of motion if the particle is moving with a velocity near the speed of light. Thus if the motions of the particles are collimated, the emitted light beam will be collimated as well, no matter what process gives rise to the emission. Charged particles can move much more easily along magnetic-field lines than across them, so that the dipole field can act as a collimator for the particle beams, thereby producing the "searchlight."

That much is known, or surmised, concerning the origin of the pulses. Since 99.9 percent of the energy output is typically not pulsed, however, the disposition of most of the huge energy store is in doubt. Again the Crab Nebula provides the crucial clues. The Russian astrophysicist I. S. Shklovsky has long argued (and almost all investigators are now convinced he is right) that the amorphous central part of the nebula is a nonthermal source. Radiation from the filaments can be understood as coming from a dilute hot gas, but the central regions must radiate by a more esoteric process. The radiation is polarized, it shows no emission or absorption lines in its spectrum, and most peculiarly it is



LIMITS on the possible mass and radius of the pulsar in the Crab Nebula, derived from the pulsar's period, the rate of change of its period and the luminosity of the nebula, are given in this graph. Above the upper diagonal colored line a star would collapse as a result of a general-relativistic instability. Below the lower diagonal colored line the rotational forces in a star would exceed the gravitational forces and the star would break into pieces. Only within the open diagonal band defined by the adjacent gray areas would the energy loss of the rotating star equal the observed energy output of the nebula; the width of this band is determined by uncertainties in the observations. These constraints leave a small trapezoidal area (*white*) in the mass-radius plane. A neutron star with a mass equal to one solar mass and a radius of approximately 10 kilometers fits neatly in the allowed region.

emitted at measurable levels over an immense wavelength range from the shortest X rays to the longest radio waves. No thermal source could have these properties. Accordingly Shklovsky suggested in 1953 that the radiation arises from electrons moving at relativistic speeds (that is, speeds near the speed of light) in a magnetic field inside the nebula; this type of radiation is called synchrotron radiation. The electron energies required range from 10^{14} electron volts for X-ray production to 10^{9} electron volts for the long-wavelength radio emission. The nebular field was estimated to be about 10^{-4} gauss, which is from 10 to 100 times greater than typical values of the field in interstellar space. No really satisfactory explanations had ever been found for the origin of either the energetic particles or the nebular magnetic field before the discovery of pulsars. Nevertheless, the nebular spectrum was so unusual and fitted so well the predicted properties of a synchrotron spectrum that the explanation was widely accepted.

Perhaps most of a pulsar's energy is emitted as energetic particles and fields. This must be the case for the Crab pulsar or the coincidence between the total energy-loss rate of the pulsar and the energy requirement of the nebula has no significance. A number of specific mechanisms have been proposed for bringing about the energy transfer from rotation to particles and fields. In our approach, for example, Gunn and I accept the reality of the magnetic-dipole radiation and study the fate of a charged particle emitted by the neutron star that finds itself in these strong waves. The mathematical solution is complicated in detail but simple in principle. The energy flow in the waves is perpendicular to the wave fronts. Particles absorb some of this energy. Whatever their initial direction, they will soon be moving perpendicularly to the wave fronts. They are then moving with the outgoing waves; like surfers, they catch a piece of the wave and ride it out into the nebula.

The wave fronts, which enclose the neutron star, get bigger and bigger as they run at the velocity of light away from the star. Correspondingly they get weaker and weaker, their grip on the riding particles loosens and at some point the particles become uncoupled from the wave. For the Crab pulsar the energetic electrons produced in this way have energies of 10^{14} electron volts, just right to produce the observed X-radiation from the nebula. The particles of course need a magnetic field to bend their motions and to cause them to radi-

ate. Production of *both* particles and fields is required to explain the synchrotron-radiation spectrum of the Crab Nebula. The pulsar provides the fields as well. Once the particles are unlocked from the driving wave and their motions become random, motions in the wave field will cause them to radiate. Again there is quantitative agreement. The strength of the wave field in the nebula would be approximately 10^{-4} gauss, just about the value required earlier to explain the synchrotron spectrum.

The Archetypal Crab

The reader may wonder why such great stress is being given to a detailed understanding of the Crab Nebula. The hope is that the Crab complex is an archetypal example of a kind of object important throughout the universe. It is a reasonably nearby (6,000 light-years away) and easily observed object that many astrophysicists have felt contains keys to understanding the origin of cosmic rays and perhaps even quasars.

Taking the last point first, the spectra of the known extragalactic point sources, such as quasars, often bear a superficial resemblance to the spectrum of the Crab Nebula. In addition to the radiation these objects emit in the form of characteristic spectral lines, they emit enormous amounts of nonthermal radiation, which often ranges from very blue light to the far radio region and has a measurable polarization. In addition the light from quasars tends to fluctuate over a period of months.

Could a quasar be a collection of Crab-like supernova remnants, each one driven by its own pulsar? It has long been known that to understand quasars it would be necessary to find an efficient source for generating relativistic particles and magnetic fields. A pulsar is producing these in the Crab Nebula, so that perhaps a collection of pulsars is doing it in the quasars. Each upward fluctuation would then signal a supernova explosion and the birth of a new pulsar and supernova remnant. The idea is not really new. Many astronomers have suggested that a quasar may be the result of a series of supernova explosions in the center of a distant galaxy. What is new is the focus on the supernova remnant and on the pulsar as a source of particles and fields. At present this line of reasoning remains speculative. Nonetheless, work is proceeding and in a few years it may be possible to say that solution of one new astronomical mystery helped to solve a slightly older one. It would be gratifying to feel that the backlog of cosmic puzzles is not accumulating at a hopelessly rapid rate.

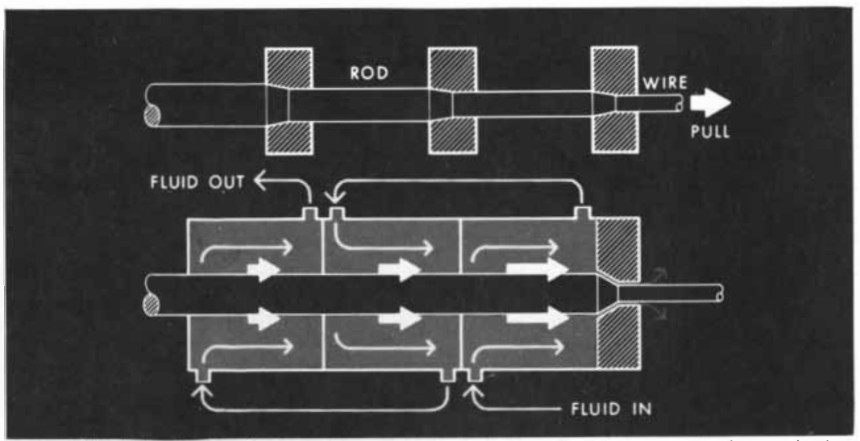
The origin of high-energy cosmic rays is an even older mystery. These charged particles, mostly atomic nuclei, bombard the earth from all directions with energies of up to 10^{20} electron volts. A few of the most energetic cosmic rays have energies more than a billion times greater than particles that can be produced in any man-made accelerator, either existing or planned. Various "cosmic accelerators" had been conceived for producing the particles but each had its own inadequacies and none was capable of producing the particles of highest energy.

In the Crab Nebula, however, something is obviously producing relativistic electrons since we see the radiation from the electrons. Whatever accelerates the electrons would be expected to accelerate atomic nuclei as well if they were present, so that perhaps the Crab Nebula is a source of cosmic rays. This much could have been said before the discovery of pulsars. Now the point can be made more definitively. A specific mechanism ("riding the waves") has been found for accelerating the electrons. Would this accelerate ions as well? The answer is yes. Protons (hydrogen nuclei) would reach an energy of about 10^{15} electron volts if they accompanied the electrons on the ride out from the neutron star. If as many protons were emitted as electrons (which seems likely), the Crab Nebula would now be a significant source of high-energy cosmic rays. Calculation shows that in the past it would have produced more cosmic rays per unit time and that each would have had an even higher energy. The maximum-energy particle that can be produced by this process is about 10^{21} electron volts, somewhat higher than the maximum-energy cosmic rays so far observed. Thus pulsars may be able to produce the super-high-energy particles whose origin has been so puzzling. The argument is too new and contains too many "maybes" to be relied on, but the possibilities are there.

This situation has become almost typical in astronomy. The discovery of pulsars has opened new fields and illuminated old ones. An extraordinary new meeting ground of astrophysics, general relativity and elementary-particle physics has been found. In spite of all the excitement it is still too early to know whether we have achieved any new understanding of nature. It will take at least a decade before the dust settles, but the earliest attempts at comprehending pulsars have been so fruitful that optimism is hard to suppress.

The big push to replace the long pull

Medieval German "schockenzieher" (shock drawer) pulled wire through die by swinging back and forth.

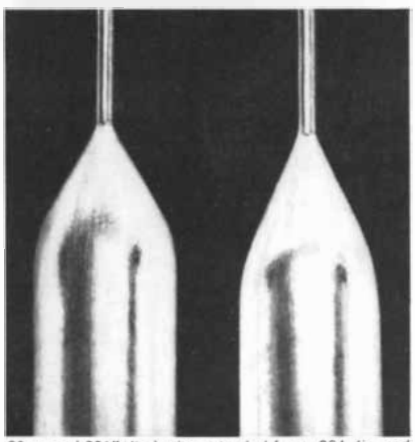


In conventional wire drawing (top), rod has to be pulled through series of dies for significant reduction. Hydro-dynamic extrusion (bottom) achieves the same reduction in one operation.

For at least 2000 years people have been making wire by pulling thin rods through small holes. The pulling force has been progressively human, animal, water, steam, and electricity, but the essentials remain.

But the process has limitations. You can get just so much reduction on one draw, so fine wire requires a series of draws. High speeds (modern wire drawing goes at speeds up to 12,000 feet per minute) wear out even diamond dies. And severe working and high tension drawing cause metal to become brittle, requiring annealing.

At Western Electric we probably make more wire than anyone else in the world. So we've been looking for a method that doesn't have these drawbacks, and a group at our Engineering Research Center in Princeton, N.J., has found one. This group has been working with metal under enormous hydraulic pressures—thousands of pounds per square inch—that enable it to flow like taffy into otherwise impossible shapes without getting brittle.



20 gage (.031" dia.) wire extruded from .364 dia. rod —a 99.2% reduction.

How could such enormous pressures be used to form wire? The simplest way would be to put a pointed rod in a chamber with a hole at one end that tapered down to a size just a shade larger than the wire you want; fill the chamber with liquid; raise the pressure. Two things would happen: pressure against the flat end of the rod would push the point against the hole; and pressure inside the hole would squeeze the rod as much as 24 successive draws did by the old method. Since it was the liquid that did the squeezing, rather than the material of the die, there would be virtually no wear on the die. And the wire would be soft and pliable, requiring no heat treatment.

So far so good. But the process would not be continuous. The rod would have to fit inside the chamber.

However: suppose the liquid were forced into an opening at one end of the chamber, and out of an opening at the other. It would then be moving continuously through the chamber, and would push the rod along. The rod could be continuously fed into one end of the chamber; and wire would be extruded continuously from the other.

Actually our engineers found that three successive chambers, with liquid flowing into and out of each (as in the above diagram) helps the wire move along better. And incidentally, while they are still searching for the right liquid, they have found that beeswax is close to ideal.

A prototype continuous hydrodynamic extrusion machine is now being built in Atlanta, Georgia. It is expected to produce aluminum wire, at a rate of 4000 feet per minute, at considerably less investment and operating costs than conventional wire-drawing machines.

Western Electric

Although the cathode ray tube terminal has become commonplace in computer systems, the problem of getting hard copies of the readouts has persisted.

Until now, available devices have been too costly. Or too bulky. Or immovable. Or too slow, tying up equipment for too long.

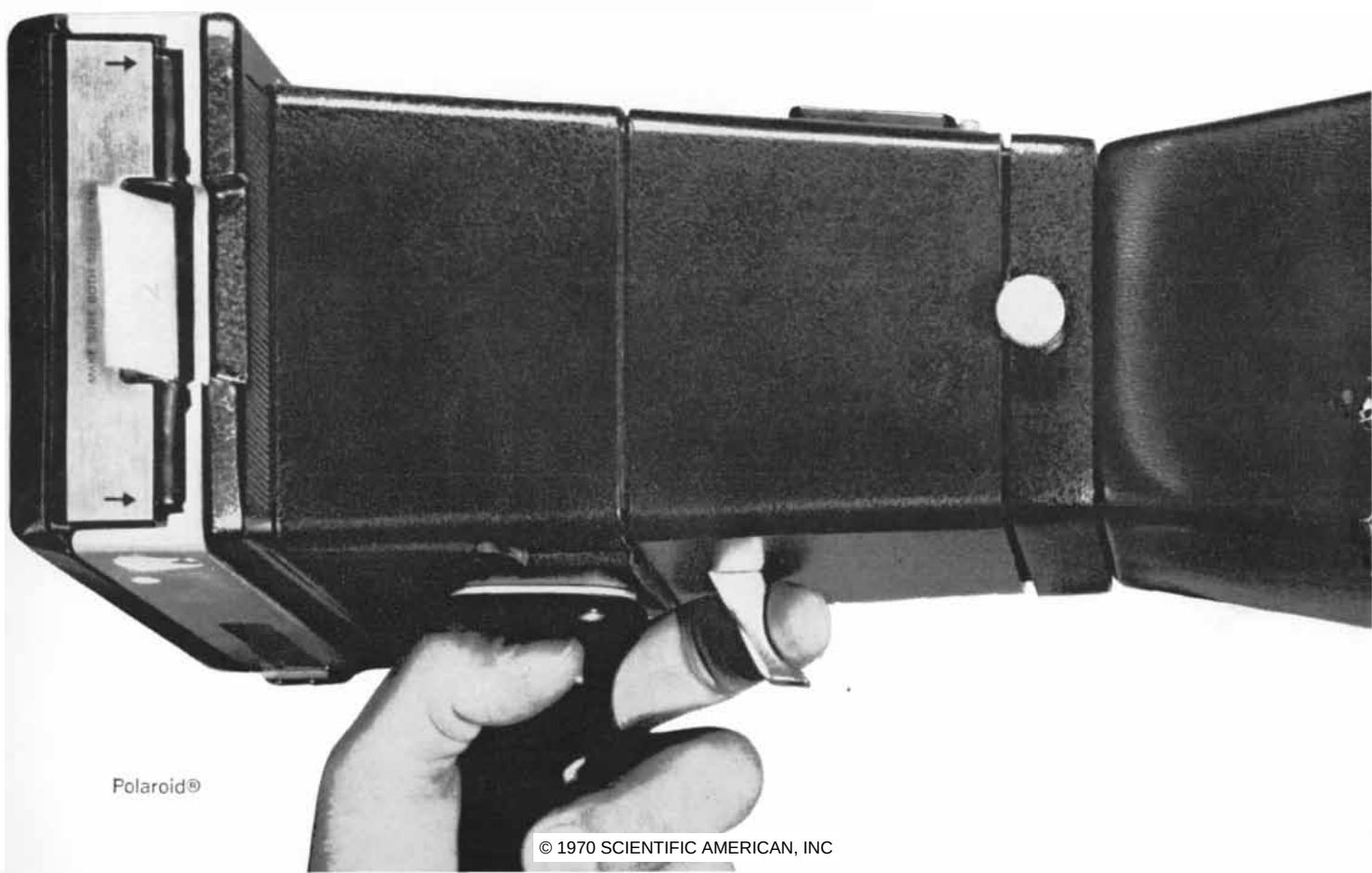
But that's all over. Polaroid's new CU-5 Hard Copy Land Camera has arrived.

You don't have to be a photographer to use it. The hood positions the camera for sharp focus, frames the image, and blocks out ambient light. All you do is hold the camera against the display, pull the trigger, and you have a shot in a split second.

And with Polaroid instant photography, in just seconds more you have the copy in your hand.

It's light in weight and hand held, so using it

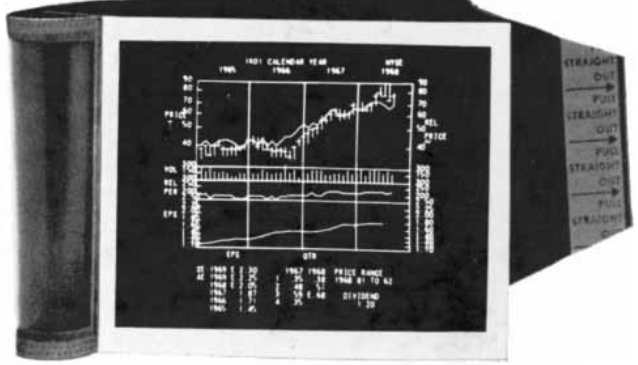
The trouble-shooter: Now Polaroid solves problems for computers.



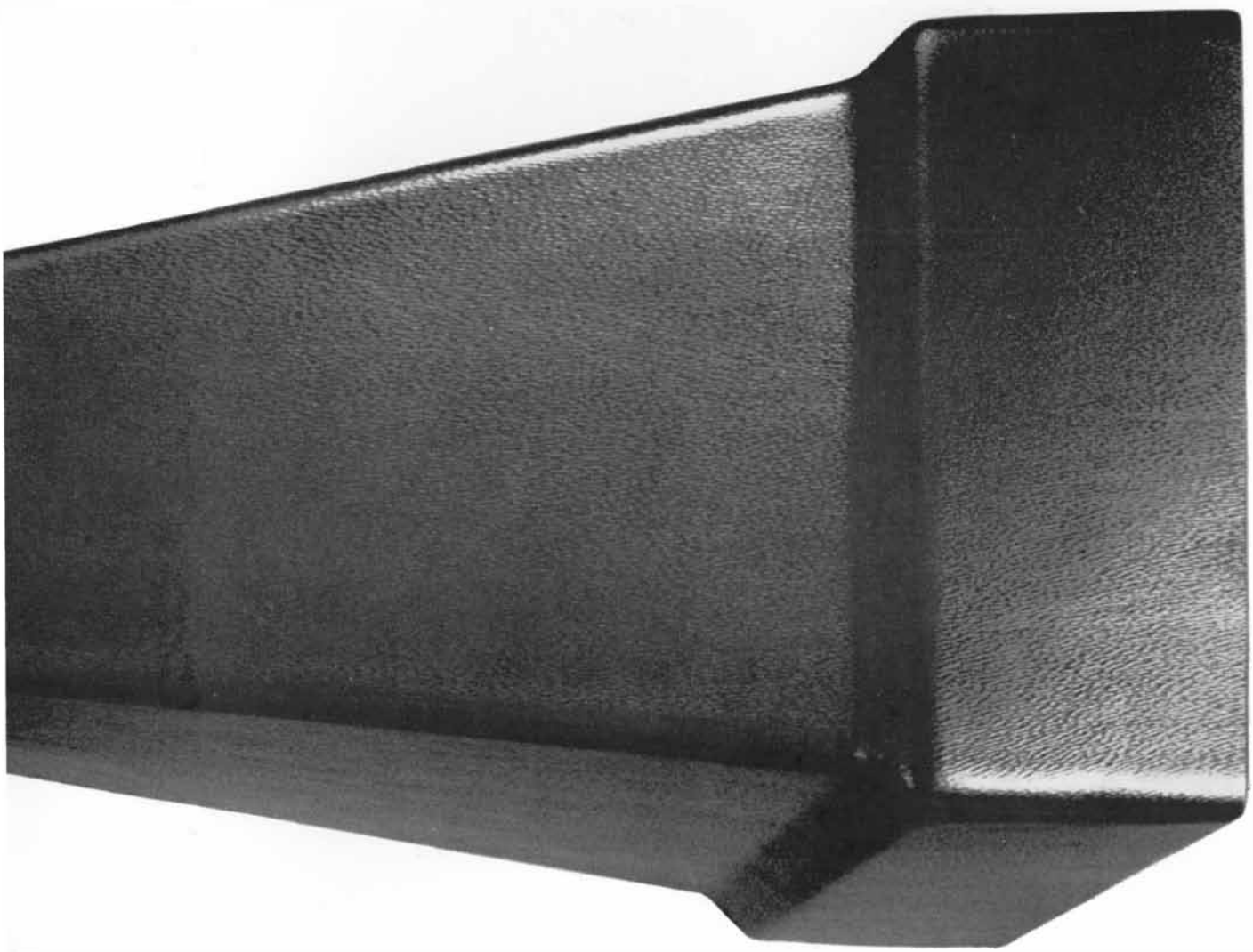
for a number of screens is no problem.

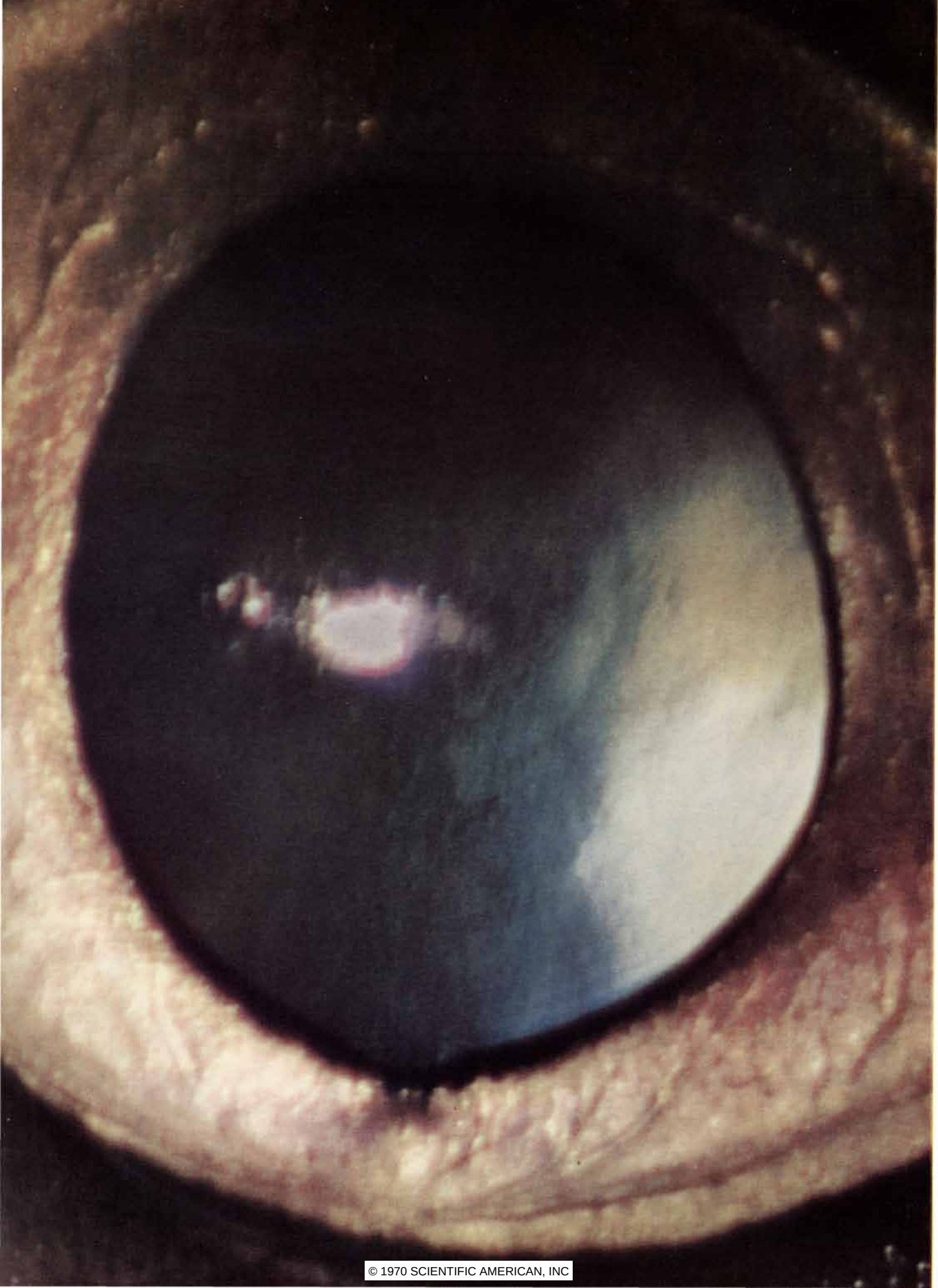
For detailed information, or a demonstration, write to: Polaroid Corporation, Dept. 57-183, Cambridge, Mass. 02139. In Canada, write to: 350 Carlingview Drive, Rexdale, Ont.

What's most remarkable about the CU-5 is the price. It's under $300, a fraction of what other equipment costs. So you won't have to shoot the works to own it.



Polaroid's new CU-5 Hard Copy Camera for CRT terminals. Under $300.





REFLECTORS IN FISHES

Many fishes are able to secrete nitrogenous compounds that form mirror-like layers of reflective crystals. In the scales and the skin the layers are displays or camouflage; elsewhere they aid vision

by Eric Denton

The silvery sides of many kinds of fish are so familiar as to be commonplace, but they are surely among the most beautiful objects in the animal kingdom. What makes the silvery sides silvery? It is the ability of these fishes to secrete certain nitrogenous compounds that form thin crystals. Arrays of the crystals, reflecting light like tiny mirrors, are found in the scales and the skin of the fish. Each array is so small that it takes about a million of them to silver a square centimeter of surface. Such crystals are not, however, restricted to the scales and the skin. In some fishes they form a reflecting layer in the eye, and in luminescent deep-sea fishes they act as reflectors that enable the fish to project the light it produces in special directions, sometimes even into a beam resembling the beam of an automobile headlight.

For a number of years J. A. C. Nicol of the University of Texas and I have been investigating the reflecting layers and their functions. The crystals of the reflecting layer range in shape from oblongs to needles [*see middle illustration on next page*]. For many years they were thought to consist only of the nitrogenous compound guanine ($C_5H_5N_5O$), which is named for the guano deposits from which the substance was first isolated. Recently L. M. Greenstein and his colleagues at the Mearl Corporation in New York have shown that the crystals also contain a closely related compound: hypoxanthine ($C_5H_4N_4O$) [*see illustration on page 67*].

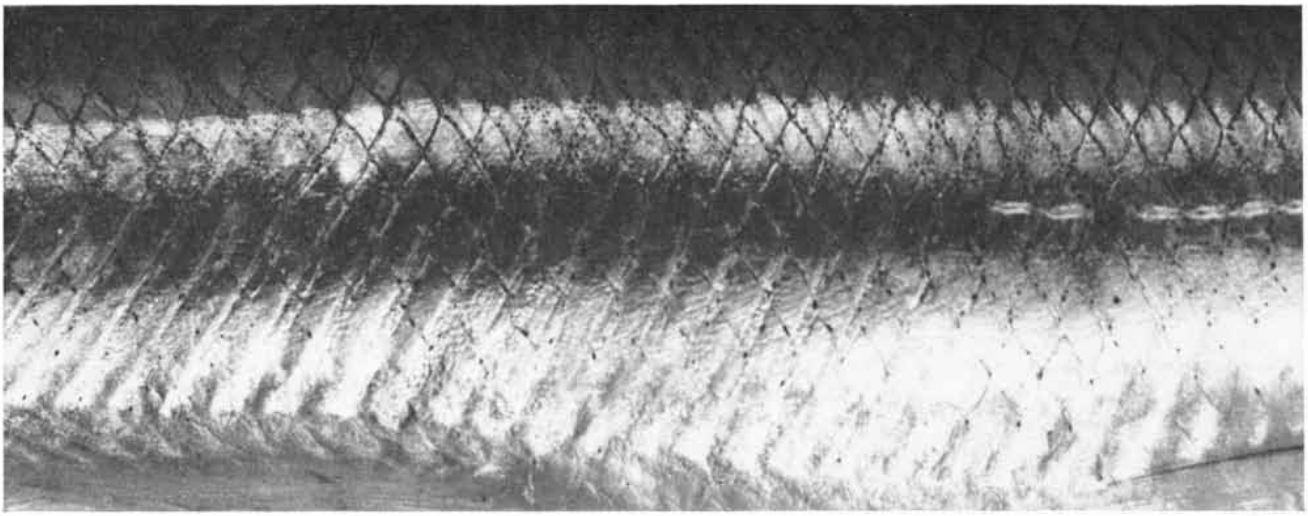
When the individual crystals are immersed in water, they reflect about as well as glass does in air. Within the fish's cells, however, they are highly reflective because they are arranged in special stacks consisting of alternating layers of crystal (with a refractive index of about 1.8) and cytoplasm (with a refractive index of 1.33). Theoretical studies have shown that at any given wavelength of light the highest reflectivity will be found when each crystal and each cytoplasmic space between crystals has an optical thickness (thickness times refractive index) of a quarter of that wavelength. For light in the green part of the spectrum, for example, the ideal thickness of each crystal is seven millionths of a centimeter.

As the number of layers in a single array, or platelet, increases, so does the reflectivity of the platelet, and an ideal quarter-wavelength stack with only five crystals will reflect about 75 percent of the light that strikes it over a range of wavelengths that covers more than a third of the visible spectrum. M. F. Land of the University of California at Berkeley and I have found that platelets with dimensions that approximate the ideal quarter-wavelength characteristics are often secreted by marine animals, and also that platelets are often specialized by having the appropriate thicknesses of crystals and spacing to reflect particular colors. Electron-microscope studies that reveal very thin lamellar structures in reflectors have also been made by S. Kawaguti of Japan and J. M. Bassot of France. These stacks of thin plates behave quite differently from stacks in which the plates are more than a few wavelengths thick. A stack of five such "thick" plates reflects only 20 percent of the light that strikes it, but its reflectivity is fairly uniform over the entire spectrum.

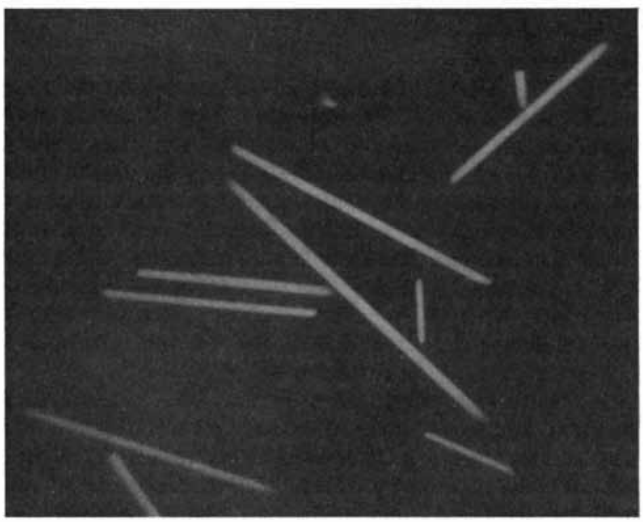
Since many reflective crystal units reflect specific colors, the reader may wonder why a silvery fish is essentially colorless. It is because the platelets are usually arranged in several overlapping layers. A single scale from a herring viewed in white light, for example, displays several bright regions of contrasting color. In the fish, however, the reflecting areas of the scales overlap, and below the scales there are other reflecting layers. On the lower flanks of the herring the skin has a superficial golden layer, and below this layer is yet another layer of thin crystals that is called the argenteum, after the Latin word for silver. Since the colors of individual platelets arise from the interference, and not the absorption, of light, a wave band that is not reflected by the first layer of platelets it encounters can penetrate farther and be reflected by a second, a third or an even deeper layer. The total reflection built up in this manner includes all wavelengths and is therefore silvery [*see bottom illustration on page 69*].

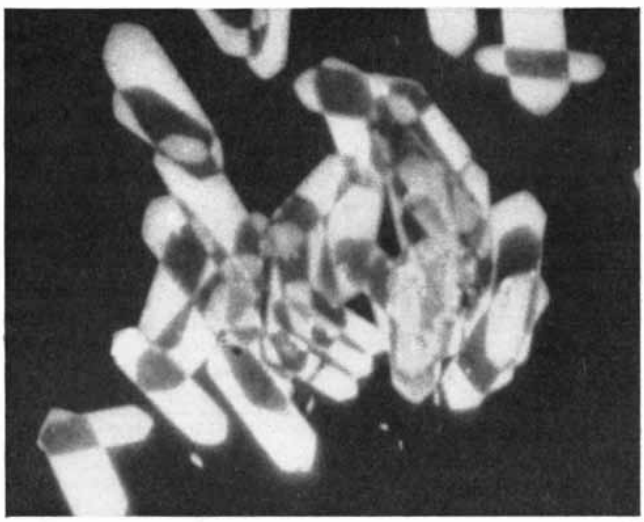
It has long been realized in a general way that the reflective surfaces of such fishes as the herring, the mackerel and the salmon helped to camouflage them; some early underwater photographs taken by Francis Ward demonstrated how difficult it is to see some silvery fishes in their natural medium. Thanks to recent studies of the distribution of light underwater, particularly the investigations conducted by John E. Tyler and Rudolph W. Preisendorfer of the University of California at San Diego and by Nils G. Jerlov and his colleagues in Den-

GLOWING EYE of a small shark, the spiny dogfish, is seen enlarged in the photograph on the opposite page. Some of the light entering the eye is reflected back through the pupil by mirror-like crystals arrayed in a membrane behind the retina that is known as the tapetum lucidum. Any vertebrate whose eyes glow in the dark has a similar reflective membrane.

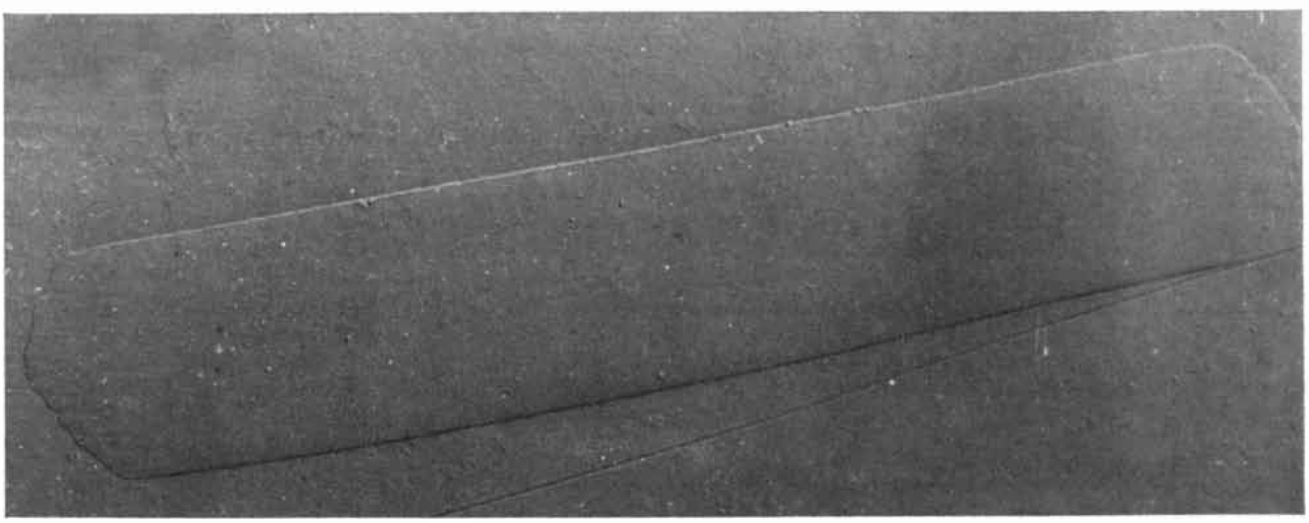


SILVERY SHEEN of the skin and scales of a smelt is produced by the reflections from arrays of crystals like those found in the eyes of the sharks. The crystals embedded in the skin of fishes are long and narrow; those on the inner surface of scales are wider.





CRYSTALS OF TWO SHAPES are shown in these micrographs. They are from the skin of a herring (*left*) and the scales of a lantern fish (*right*). Many of the broader crystals are overlapping. The ends of the crystals are poorly defined because they taper.



SINGLE CRYSTAL taken from the scale of a herring is shown magnified 4,000 times in this electron micrograph. The crystal has been replicated in carbon and shadowed with metal to show how the two ends are tapered. Its thickness at the center is .07 micron.

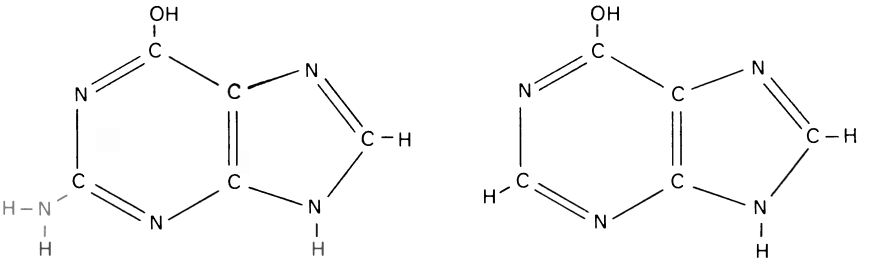
mark, it is now possible to discuss how reflection serves as camouflage in more detail.

Light entering water is affected in three significant ways. First, as it passes from one medium to another it is refracted toward the vertical. Second, the precise angle of refraction is not the same everywhere because the surface of the water is not precisely horizontal but is disturbed by ripples and waves. Third, the light is absorbed and scattered in the water. As a result the greater the depth, the more underwater illumination comes to depend on absorption and scattering. Whether the sky is sunny or cloudy, the illumination underwater is almost constant in the horizontal plane, and regardless of the sun's position it is brightest almost directly overhead. The intensity of the light does, however, decrease rapidly with increasing depth.

The fact that underwater light has a fairly constant angular pattern of intensities simplifies the problem of camouflaging fishes. Consider for a moment how a human designer might undertake to camouflage an imaginary silvery fish with a square cross section. The rule of thumb for invisibility is that any light reflected from the fish to the eye of an observer must have the same intensity as the natural background light.

If the sides of such a fish are perfectly reflecting mirrors, they present no camouflage problem, since they will always reflect light identical in intensity with the light an observer would receive if the fish were not present. If the back—that is, the top—of the square fish is to be camouflaged, however, it must reflect only a fraction of the bright light impinging on it from above, and the reflected fraction must be identical in intensity with the dim light being scattered upward around the fish from below. This camouflage can be achieved by darkening the back of the fish so that it reflects only the appropriate amount of light.

The belly of the square fish presents the most difficult problem. To an observer looking up from below, this surface is always seen against the background of the bright light above. Moreover, all that illuminates the belly is the dim light from below, which is far too weak to keep the fish from being silhouetted against its bright background. Only two courses, or a combination of them, seem to be available to the designer. One is to abandon the square cross section and flatten the fish from the sides, giving it a narrow back and belly.



NITROGENOUS COMPOUNDS that comprise the reflecting crystals in fishes are guanine (*left*) and hypoxanthine (*right*). The molecules are alike except for an amino group (*color*).

The other is to make the belly of the fish luminous, so that it will be as bright as the background above it. As will be seen, some fishes with the combined design have actually evolved. The expedient of producing light is only possible, however, for animals living deeper in the ocean, where the penetrating daylight is relatively dim.

A flattened shape, although it is good for camouflage, is not the shape that enables a fish to swim best. In point of fact most fishes have a shape that represents a compromise between attributes that favor one or another desirable quality, such as inconspicuousness, speed or maneuverability. The fastest fishes are cigar-shaped in profile and not greatly flattened sideways. How much camouflage is possible for them?

The desirable attribute of a dark back is achieved in fishes such as the mackerel and the herring through a special orientation of their reflective platelets. In the horse mackerel, for example, the platelets do not lie so much parallel to the surface of the fish as they lie parallel to one another. As a result an observer looking down from above sees the platelets edge on. Instead of being reflected by a silvery surface the light passes between the platelets and falls on areas of dark pigment in the skin. To an observer looking from the side the flank of the horse mackerel is well camouflaged by its array of parallel platelets. The silvery surface reflects light that has about the same intensity as the background illumination.

All the reflecting platelets in the horse mackerel are embedded in the skin, several layers of differently colored reflecting platelets overlying a silvery argenteum. The salmon and the herring have two sets of reflectors: long, thin crystals that form the layer of argenteum in the skin and other crystals that lie on the inner surface of the scales. The scale platelets are precisely organized and do not lie parallel to the surface of the fish, as a simple experiment demonstrates. When a scale that has been detached from the lower flank of one of these fishes is placed among the scales on the upper flank without changing its orientation with respect to the fish, it will be seen to reflect light best in directions that are quite different from those in which its neighbors do.

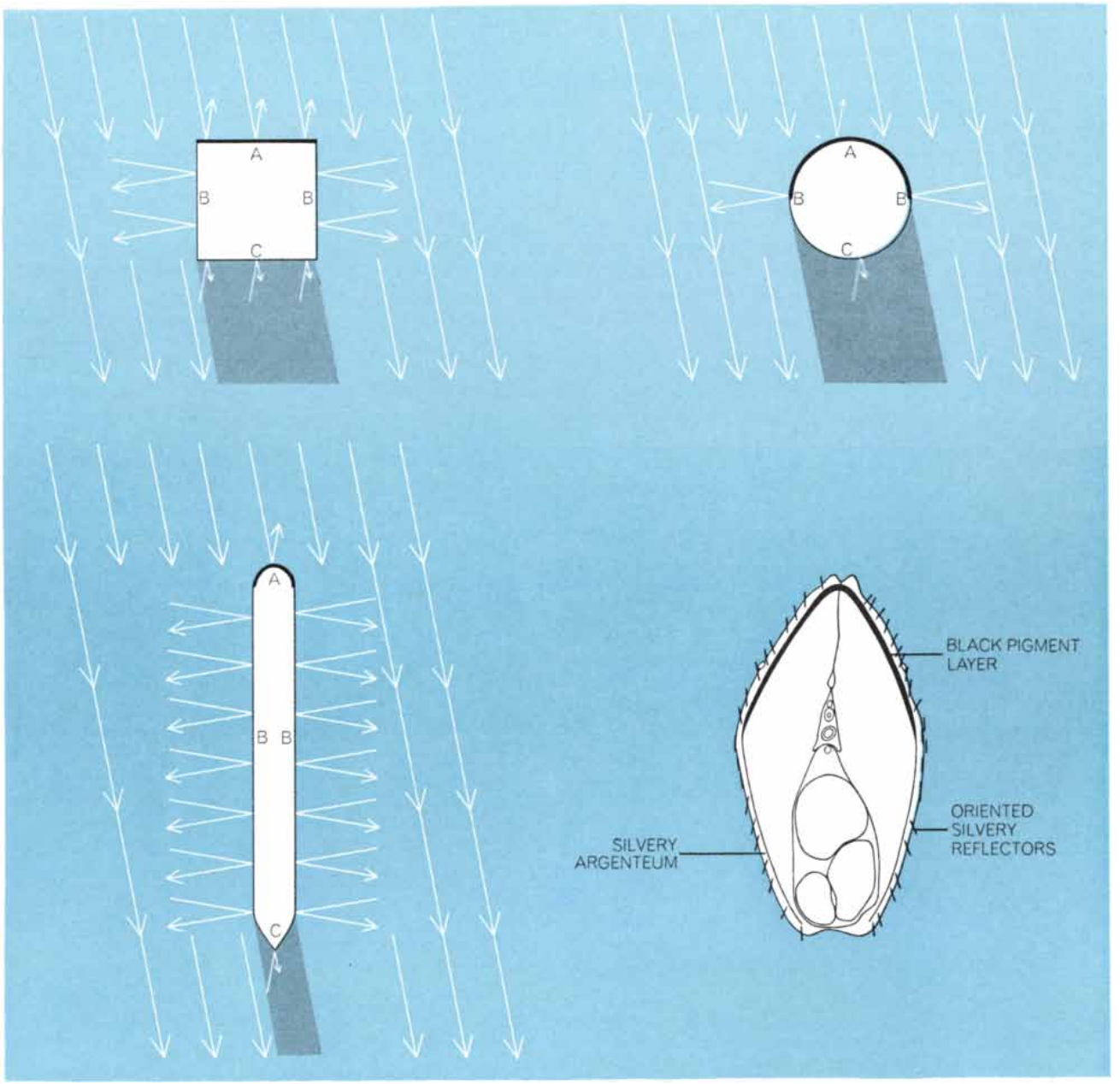
Divers' reports testify to the effectiveness of the camouflage produced by silvering; a school of silvery fish can sometimes come quite close to a diver before he notices them. Only an observer looking up from below finds them easy to see.

A pattern of camouflage that is suited to one environment obviously may not be suitable in another, and fishes that migrate between one environment and another often show marked changes in appearance. A striking example is afforded by the Atlantic salmon. The parr, or immature salmon, lives in freshwater streams. Its back is marked with a disruptive pattern of bars and red spots that enables it to blend in with the stream bottom. As the young salmon approaches the time for its downstream migration to the sea it develops a herring-like camouflage: its back becomes dark and its sides very silvery.

The use of silvery reflecting layers for camouflage is found in marine animals that are themselves virtually transparent. An animal that consisted entirely of almost transparent tissues would of course be very well camouflaged in the diffuse light underwater. Many tissues, however, cannot function properly and still let light pass. The eye, for instance, could not form an image if light entered it from all directions. Red muscles, the liver, the kidney and such specialized organs as the squid's ink sac are other examples of tissues that cannot function and be transparent. Nature's solution is to treat each of these organs as if it were an entire animal: the sides of the organ

are silvered and the top is darkened. The stratagem is evident in the almost transparent larvae of flatfish such as the plaice and the sole. The only readily visible parts of these tiny fishes are their eyes and digestive tract; these organs are darkened on top and silvered elsewhere. The same kind of camouflage is used on the opaque parts of the otherwise translucent squid: its eyes, digestive tract and ink sac.

Surface reflectors do not always serve to provide camouflage. The bright surface markings of such fishes as the neon tetra, an aquarium favorite, are clearly intended for display. Leaving such special cases aside, any silvery fish can be either hard to see or conspicuous, depending on its orientation. Diving friends tell me that on occasion a fish will roll over and swim on its side for a



IMAGINARY AND REAL FISH demonstrate how silvery surface reflectors render many fishes inconspicuous when viewed from above or the side. A square fish (*top left*) is exposed to light of differing intensity: the strongest comes from above (*A*), weaker light comes from the sides (*B*) and the weakest comes from below (*C*). The back of the square fish will be invisible to an observer who looks down from above if most of the light from above is absorbed and the amount that is reflected is only as intense as the weak light from below. Similarly, its sides will be invisible if they act as mirrors and reflect back to an observer light that is equal in intensity to the light from the background. Under most circumstances, however, the belly of the square fish will remain conspicuous to an observer looking up from below because the very dim light that the belly reflects is far less intense than the background light. In effect the fish casts a shadow, and a fish that is circular in cross section (*top right*) casts a much larger shadow than a fish that is equal in area but flattened in shape (*bottom left*). Only a few fishes, however, are so flattened; most fast swimmers are more nearly round. A cross section of a real fish (*bottom right*) shows how nature solves the camouflage problem. The reflecting crystals (*black*) are generally parallel to one another, rather than lying parallel to the surface. This makes the flanks of the fish mirror-like when viewed from most positions to one side. From above only the edges of the reflectors are visible and the dark pigment below them absorbs the descending light. The fish is the horse mackerel; it is well camouflaged except to observers looking up from below.

while; when a silvery fish does this, it becomes very conspicuous indeed. Schools of juvenile fish swimming near the surface can look like rivers of silver. The reason is that the near-surface zone is one where the symmetry of light distribution is least perfect and random motions are most likely to produce eye-catching reflections.

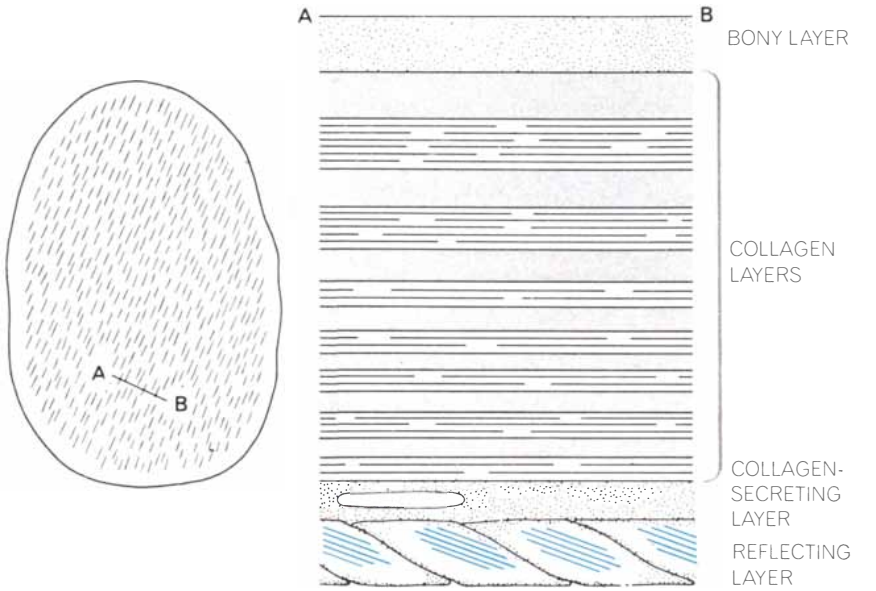
It has been suggested that the loss of camouflage, because of changed orientation, may at times serve a useful purpose. When a school of silvery fish is attacked by a predator, bright flashes are sometimes seen as individual fish in the school twist and turn. It is possible that the flashes distract the predator.

Among the fishes that are not shiny are the cartilaginous fishes: sharks, rays, dogfishes, angelfishes, devilfishes and the torpedo fish. Although such fishes have no crystal platelets in the skin, almost all of them have platelets in the eye. The platelets lie behind the retina, where they form a silvery reflecting layer known as the tapetum lucidum, or "shining carpet." The tapetum is not restricted to fishes; when a cat's or a dog's eyes gleam in an automobile's headlights, the reflection comes from a similar kind of silvery layer behind the retina.

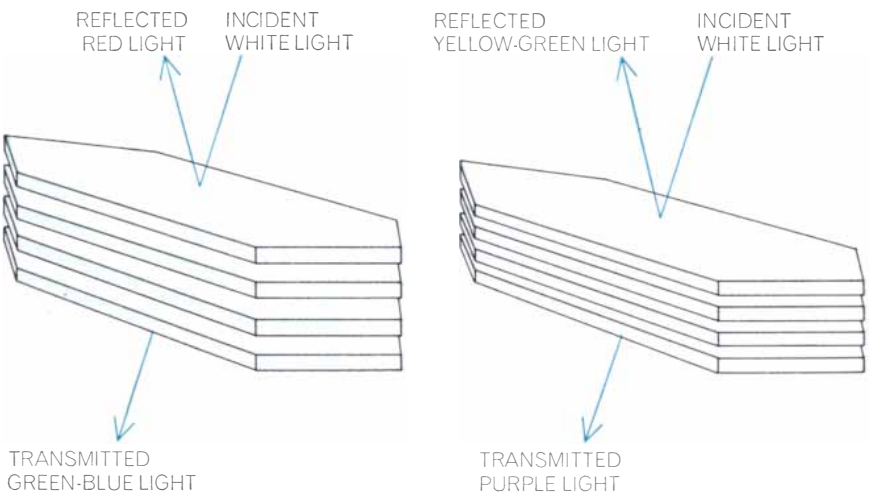
The function of the tapetum is to improve the eye's efficiency. In vertebrates the eye resembles a camera: it has a lens that forms an image of the outside world on a sensitive surface, the retina. Visual pigments in the retina are transformed by the absorption of light, and this is a first step in the process that leads to a message being sent along to the brain. Any light that passes through the retina without being absorbed by a visual pigment is simply wasted. In an eye with a tapetum light that is not absorbed during its inward passage through the retina is reflected back and so has a second chance of being absorbed.

Possession of a tapetum would also have certain potential disadvantages. The reflecting platelets might scatter the light reaching them to other parts of the retina and in so doing make the image of the outside world less sharp. The reflection might also make the animal much more conspicuous, like a cat caught in the headlights. It has been learned, however, that neither of these potential disadvantages actually holds.

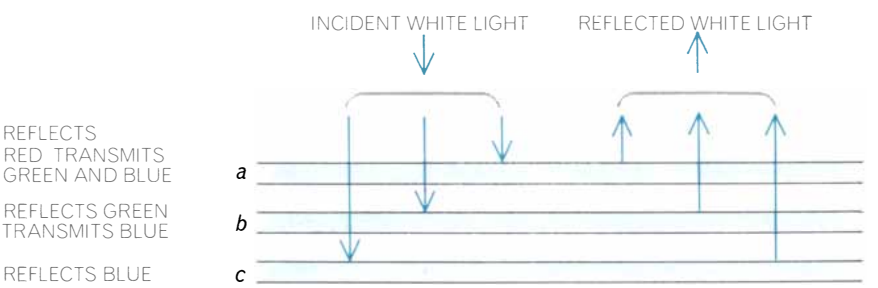
The tapetum of fishes was first examined in detail in the early decades of this century by the German zoologist V. Franz. One of the curious features he discovered was that not all the arrays of reflecting platelets behind the retina were, as might be expected, parallel to



SCALE OF A JUVENILE SPRAT is seen as viewed from the inside and enlarged 60 times (*left*) and in a cross section (*right*). Its actual length is about a millimeter. Dashes that cover almost its entire surface mark the long axes of its numerous arrays of crystal platelets that comprise the reflective surface. The line of cross section is indicated by *A–B;* the bony surface layer of the scale is at the top of the section. Below it are several layers of collagen, a collagen-secreting layer and finally the reflecting layer itself, where individual arrays of platelets, each containing about five crystals, lie at an angle to the plane of the scale.



STACKS OF CRYSTALS reflect different light wavelengths depending on the thickness of the cytoplasmic layers between the crystals. When the cytoplasm is about as thick as the crystal (*left*), the array reflects light of the longer wavelengths in the visible spectrum; when the cytoplasm is only half as thick (*right*), reflectivity shifts to middle wavelengths.

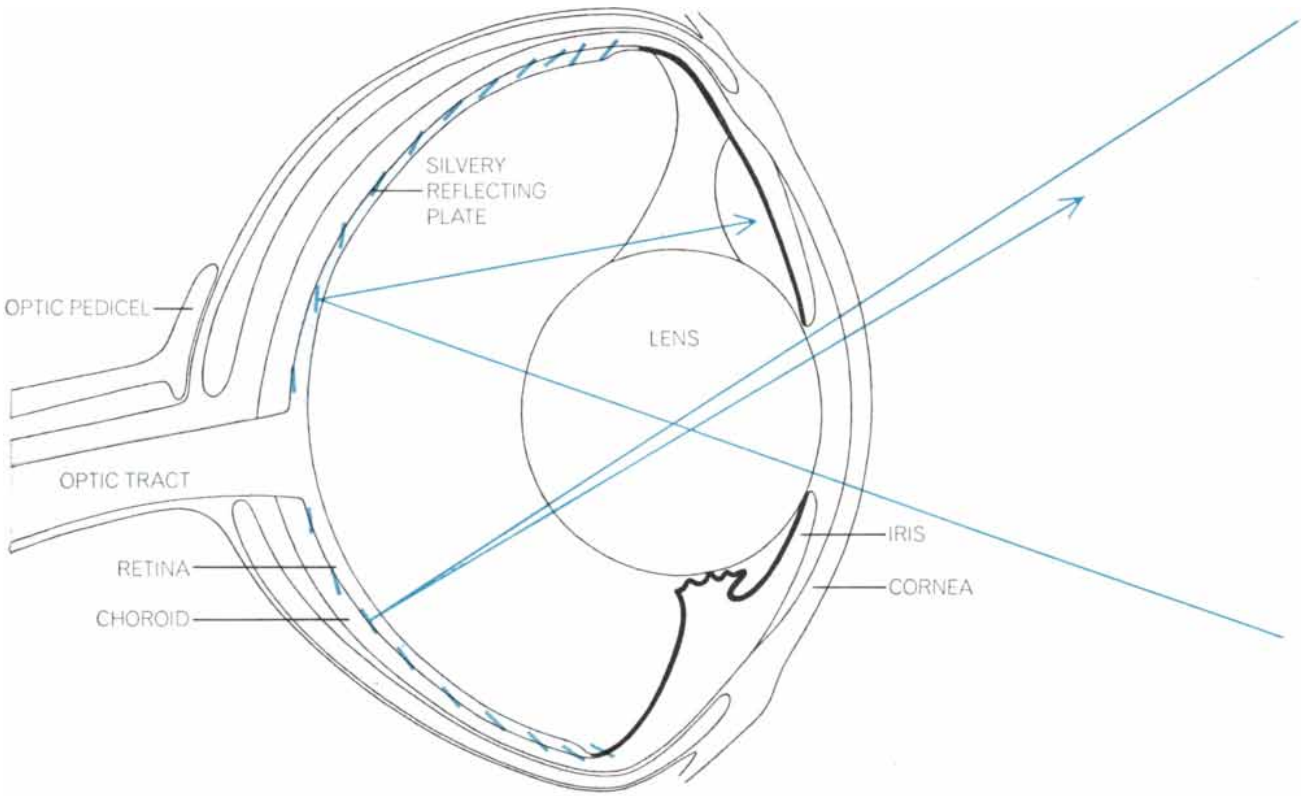


OVERLAP OF REFLECTORS produces the bright sheen characteristic of silvery fishes. If the first layer (*left*) reflects red light (*a*), the second green (*b*) and the third blue (*c*), the reflected increments (*right*) will reach an observer's eye as light of full spectral range.

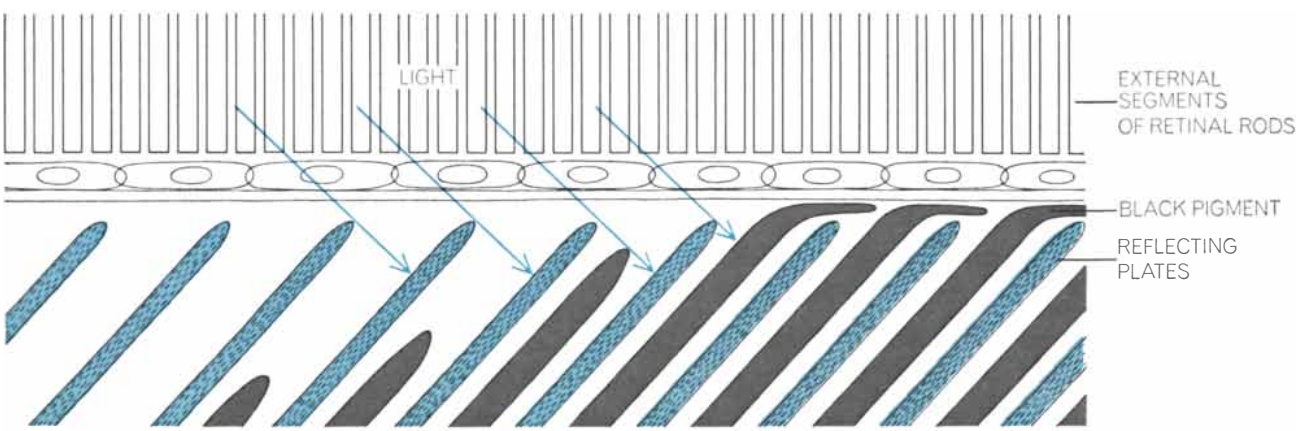
the surface of the retina. In many parts of the tapetum they were inclined at a considerable angle to the surface. Franz also discovered that when some fishes with a tapetum were exposed to bright light, a black pigment soon appeared in the reflecting layer and covered up the platelets.

The reason many of the platelets lie at an angle to the retinal surface is now clear. In the eye of the spiny dogfish, for example, once the way the iris restricts the entering light is taken into account it becomes evident that all the platelets in the tapetum are approximately perpendicular to the rays that strike them. Any light that does not interact with the visual pigments before or after reflection either escapes from the eye through the pupil or is absorbed by the black inner surface of the iris. The arrangement of the platelets prevents their scattering light to other parts of the retina and thereby diminishing the sharpness of the visual image [*see upper illustration below*].

It has been thought that the function of the appearance of black pigment in the tapetum in response to bright light is to reduce the rate at which the visual pigment is bleached. Since, for some of these animals, the brightest light to which they are exposed in life is prob-



REFLECTORS IN TAPETUM of shark's eye (*color*) are oriented so that when light rebounds from them, it is absorbed either by the retinal rods or by the black inner surface of the iris, or leaves the eye through the pupil. Diagram omits refractive role of lens.



PIGMENT IN TAPETUM advances between the reflector arrays when the eye is exposed to bright light and soon halts further reflectance; progress of the advance is shown from left to right in this drawing. The mechanism makes the animal less conspicuous.

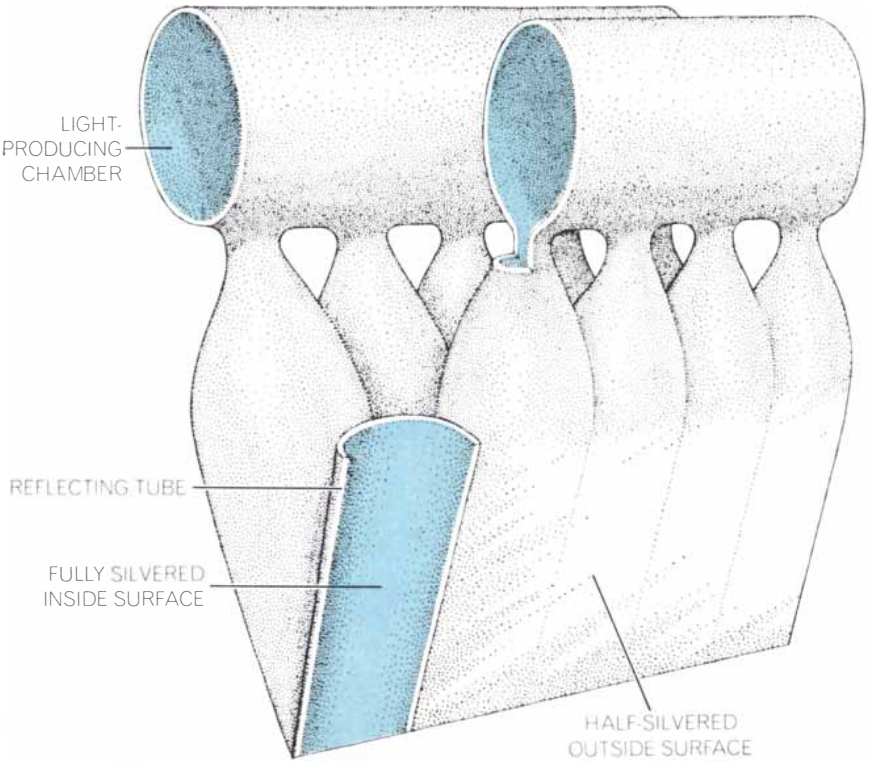
ably 100,000 times brighter than the light at which they can just see, and the maximum pigmentation of the tapetum can only reduce the absorption of light by about 40 percent, this can scarcely be true. It is much more likely that the function of the pigment is to reduce the risk that eyeshine from the tapetum would betray an otherwise inconspicuous fish to predators or prey.

We also found that an eye with a tapetum usually contains about half the visual pigment per unit area found in the eye of an animal that lives in the same environment without the benefit of a tapetum and, in accord with this, that the parts of the receptor cells that contain the visual pigment are only about half as long. The greater efficiency of an eye with a tapetum enables it to absorb about the same amount of light as an eye without a tapetum in spite of its having a smaller amount of visual pigment.

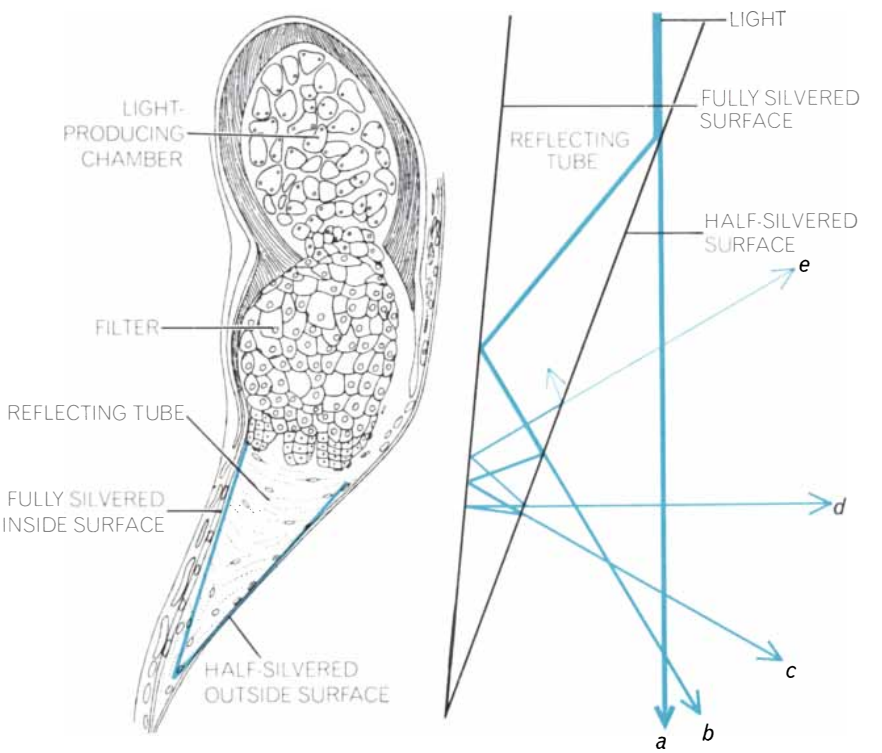
Many deep-sea fishes have light-producing organs, and in some of them the light is aimed in a particular direction. Such aiming is achieved by reflecting mirrors and by lenses. E. R. Gunther reported observing an unusual fish of this kind on a voyage of the research vessel *William Scoresby* in the 1930's. The fish was silvery and eel-shaped and from nine to 12 inches long. Gunther wrote: "From a pair of luminous organs in the orbital region the fish . . . emitted a beam, of varying intensity, of strong blue light which shone directly forwards for a distance of about two feet."

A more sophisticated device is found in some fishes that live in the middle depths of the ocean. During the voyage of the Royal Research Ship *Discovery* in 1969 J. B. Gilpin-Brown of the Marine Biological Association in Plymouth, P. G. Wright of Makerere University College and I studied such fish of the genus *Pachystomias*. We found that large light-producing organs that are situated close to the eyes and face outward in the same direction are covered with a tissue that could only transmit orange and red light. In one of the fishes these organs were seen to emit flashes of orange-red light.

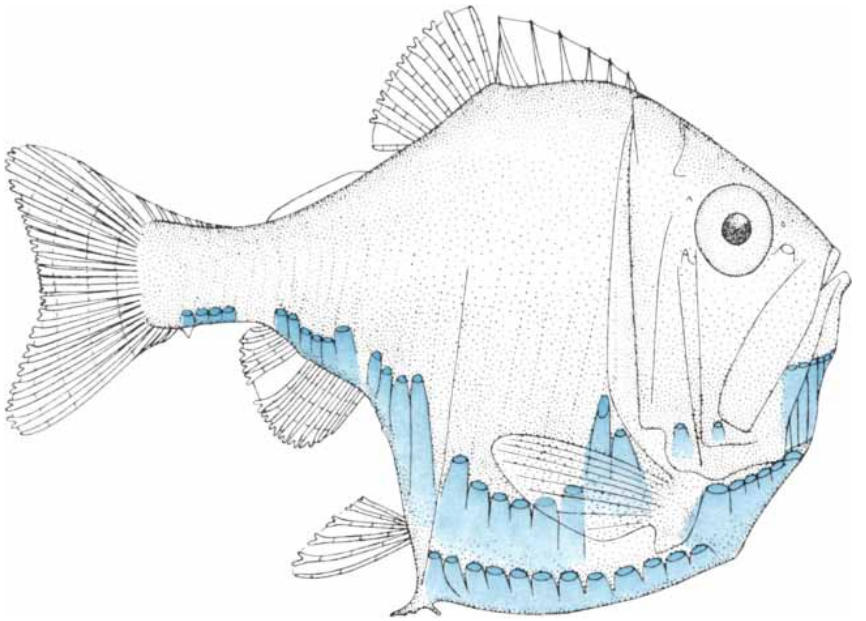
Almost all the deep-sea fishes have eyes that are sensitive to light in the blue-green region of the visible spectrum because it is light of these wavelengths that penetrates most deeply into the ocean. One consequence of this adaptation is that deep-sea fishes are generally very insensitive to red light. *Pachystomias*, however, has retinal pigments that are particularly sensitive to red light. In



BIOLUMINESCENT ORGAN of one species of the deepwater hatchetfishes has a pair of cylindrical tubes with reflective linings (*top*) that feed light into two arrays of wedge-shaped reflecting tubes that emit the light downward along both flanks of the fish. In the drawing parts of the structures have been cut away to reveal the reflective inner linings (*color*).



SINGLE UNIT from a light-emitting organ of a related hatchetfish species is seen in cross section (*left*). The reflecting surfaces of its wedge-shaped lower structure are outlined in color. The light path through such a structure is shown schematically (*right*); the outer wall is only half-silvered, so that some of the light entering from above escapes (*a*), and the balance is progressively reflected and emitted at diminishing intensities (*b*—*e*). This is exactly the angular distribution of light needed to match underwater light conditions.



HATCHETFISH of the species *Argyopelecus aculeatus* is one of those the author and his colleagues studied aboard the research ship *Discovery*. The fish is about seven centimeters long; an array of down-pointing lights runs from chin to tail, mainly on the ventral surface.

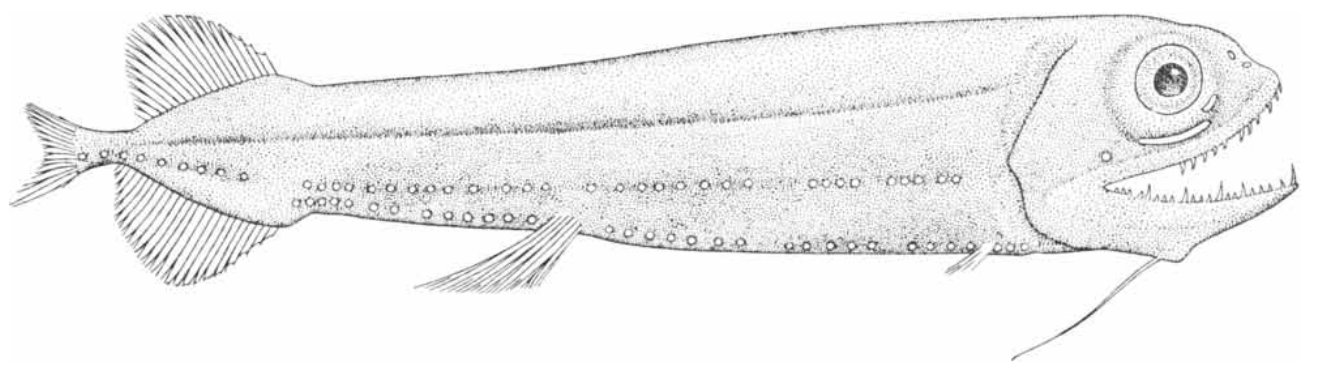
other words, fishes of this genus are like a sniper armed at night with an infrared "snooperscope." They can see their prey without being seen themselves.

Pachystomias also has photophores, or light-producing organs, aimed downward and located along the belly. These photophores have filters that confine the emission of light to the blue part of the spectrum. Downward- and sideways-directed blue lights are characteristic of many fishes, such as the hatchetfishes, which live in the middle depths of the sea. The purpose of the downward-directed illumination has been suggested by William Dixon Clarke of the General Motors Defense Research Laboratories: it eliminates the "shadow" the fish casts with respect to an observer looking up from below. Fishes with such photophores, unlike all the others, are able to camouflage their belly. The blue-transmitting filters on their photophores ensure that the wave band of the emitted light matches the wave band characteristic of the attentuated daylight in the depths where they live.

On the *Discovery* Gilpin-Brown, B. L. Roberts and I examined in detail the photophores of certain hatchetfishes, *Argyopelecus aculeatus* in particular. We found that the organs had ingenious features that enabled the fishes to match their background regardless of the angle of view. Sets of photophores in *A. aculeatus,* for example, are located fore and aft along the fish's belly [*see illustration above*]. The light is produced in chambers that share their light among groups of reflecting tubes. Sometimes reflecting tubes on both sides of the fish receive light from a common chamber. The interior of such a chamber is highly reflective, and the light can leave it only through small holes in its floor that lead into the reflecting tubes.

The reflecting tubes are typically wedge-shaped and are lined with reflecting material of two kinds. The lining of the inner surface of a tube consists of a dense array of long, thin crystals with their long axes running from top to bottom. The crystals on the outer surface of the tubes are quite different; they are broad and few in number, so that the part of the organ in contact with the surrounding water is only "half-silvered" and can emit light.

When light from above strikes the half-silvered outer surface of the tube, some of the light passes into the water and some is reflected. The reflected light is then returned to the front surface by the highly silvered inner surface of the tube but this time at a different angle. Because of the wedge shape of the photophore each double reflection bends the remaining light increasingly upward in the direction of the surface. As a result the brightest emitted light is directed downward and the emission becomes progressively dimmer as the angle of view is changed from the bottom to the side. This is precisely the pattern of illumination that is needed to match the natural distribution of daylight in the deep ocean. We have shown that some fishes do in fact emit light whose angular distribution is close to that required to match the natural distribution of daylight in the sea at the depths where these animals live. In effect the silvered interior surfaces that reflect and diffuse the luminescence of the deep-sea fishes are performing the same function as the external reflectors of other fishes: both kinds of silvering help to make the animals hard to see.



DEEP-SEA PREDATOR of the genus *Pachystomias* produces bright flashes of light in the red part of the spectrum from organs near its eyes. Deep-sea fishes are largely insensitive to red light, but this predator is not. Thus it can see prey and yet remain unseen.

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Some things are changing for the better.

Radar for the family car

For years, Sunday supplement writers have been predicting the use of radar in the family car to detect approaching vehicles and automatically avoid collisions. Although technically feasible, the idea has been completely impractical because the equipment required to measure closing velocities is much too large, takes too much power, costs over $1000, and is notoriously unreliable.

That was yesterday. Auto safety engineers can now seriously contemplate doing this part of the job with the new HP 35200A Doppler Radar Module. It weighs six ounces, operates on a few watts of 12-volt power, can be produced for less than $100 in volume and is intrinsically more reliable than almost any other part of the modern automobile. Yet it measures speed within 0.01%, easily surpassing the accuracy required for automotive use as well as for continuous traffic flow control, intrusion alarms, and rapid rail transit control.

No scientific breakthrough underlies this improvement but rather the painstaking development of a new manufacturing art that extends the advances of integrated circuits (IC's) — lower cost, greater reliability — to microwave frequencies. The products of this new technology, "thin-film hybrid IC's", get their name from the fact that all passive circuit elements and the transmission paths between them are deposited as thin films on a jewel substrate, while the active elements (transistor and diode chips) are bonded in place later. The emphasis is on achieving the circuit performance and transmission line characteristics that are essential at microwave frequencies, while preserving the dramatic cost and reliability advantages of IC's.

At HP, thin film technology has been a reality for more than two years. We produce thousands of circuits a month, some for use in our own microwave instruments, some for shipment as components. We'll be glad to answer your inquiry on our thin-film capability or send you a description of the 35200A Doppler Radar Module.

The wavelength: a better way to measure distance

The surveyor's way of measuring distance has not really changed since before the days of the Pharaohs. He still uses an accurate ruler — engineer's chain or a surveyor's tape, usually 100 feet long — and painstakingly measures his course with it. Although extremely slow, the method has survived the ages because it was the only accurate way of doing the job.

But things are finally changing for the better. A new HP instrument, the 3800A Distance Meter, makes it possible for the surveyor to be free of his ancient chain and yet measure distance accurately in one-tenth the time, with a crew of two rather than three men.

The 3800A makes its measurements by comparing the unknown distance to the precisely measured wavelength of a modulated beam of infrared light. Here's how it works. The modulated beam is chopped 30 times a second and alternately split into two paths — an external path which is aimed at a retroreflector placed at the other end of the course, and an internal reference path. When the two beams are recombined at the receiver optics, the phase of the reflected beam lags behind that of the reference beam a discrete amount, depending on the distance to the reflector. The 3800A measures the phase shift and converts it to distance.

Because the infrared beam is modulated at four different frequencies, it has an effective wavelength of 10, 100, 1000 and 10,000 feet, thus allowing the surveyor to make any measurement within the range of the instrument without ambiguity. He first nulls the instrument at the highest frequency to establish the fraction of 10 feet; then at successively lower frequencies, to establish the fraction of 100, 1000 and 10,000 feet respectively. The final measurement, corrected for air temperature and pressure, is completed in less than two minutes and read directly on the instrument's digital register to a resolution of 0.002 foot and an accuracy of 0.01 foot plus 10 ppm.

Measurement is continuous since the

3800A's internal reference system automatically calibrates it 30 times each second. Momentary interruptions due to traffic in the line of sight therefore do not affect the measurement. By the same token, the 3800A can be used to detect the sway of buildings and the movements of glaciers.

The new instrument weighs 17 pounds and its separate power unit, 13 pounds. Cost is less than $5000. A technical paper that describes the instrument, its principle of operation and some performance tests over a USC&G course will be sent to you on request.

A much better way to test logic circuits

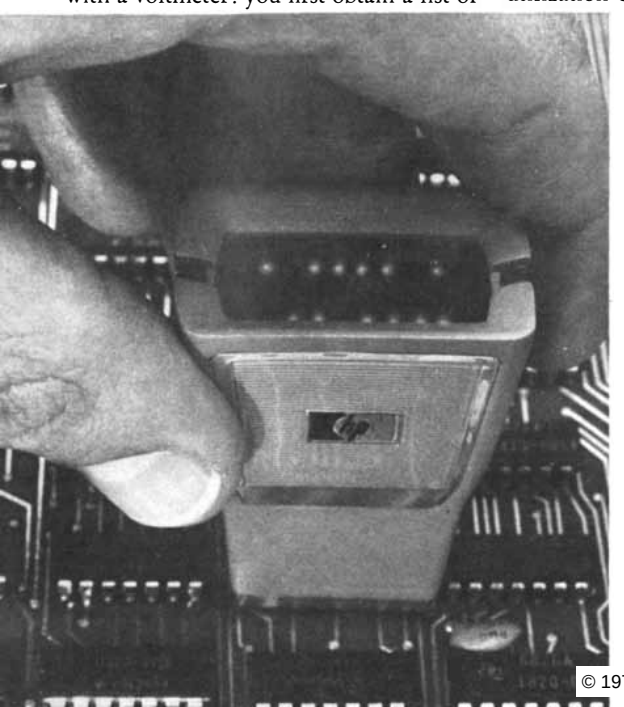
When you first see the new HP 10528A Logic Clip, you might think that it looks more like a modernistic clothespin than a proper addition to the Hewlett-Packard family of precision test instruments. Yet never has HP produced a more effective, practical and easy-to-use instrument. If the superlatives surprise you, read on.

The traditional way to test dual in-line Integrated Circuit (IC) logic is with a voltmeter: you first obtain a list of design voltages for each of the IC's 14 or 16 pins, place the voltmeter probe at each pin, look up to the voltmeter, jot down the reading pin by pin, and compare the two lists. Imagine the headache you can develop checking out a circuit board with 50 or 60 IC's, each with 16 pins. And the frustration, because you don't really have to know the voltage of each pin, only whether it's at a high or low logic state.

One of HP's enterprising instrument designers, convinced that there had to be a better way to do the job, proved it by inventing the Logic Clip. Deceptively simple in appearance, the Logic Clip is really 16 binary voltmeters that simultaneously measure the logic state of all the pins of a dual in-line IC (TTL or DTL). Clip it on the IC as you would a clothespin, and it instantly displays a pattern of bright red squares that tell you which pins are at a high logic state. You can't clip it on wrong because its 16 internal circuits automatically find the IC's power and ground pins and thus orient the pattern correctly, even when the 10528A is upside down or off center. You don't have to supply power because the Logic Clip borrows all it needs to operate and illuminate its 16 light-emitting diodes from the test IC, without overloading it. It has no adjustments, fits into the palm of your hand and costs $125. We'll send you a description of all its superlatives on request.

A practical way to automate a GC lab—one step at a time

Although gas chromatographs (GC's) are built for around-the-clock operation, most of them are used only a few hours each day. Since most GC labs operate on an eight-hour day, it simply has not made good economic sense to add a second and third shift simply to realize a fuller utilization of the GC's.

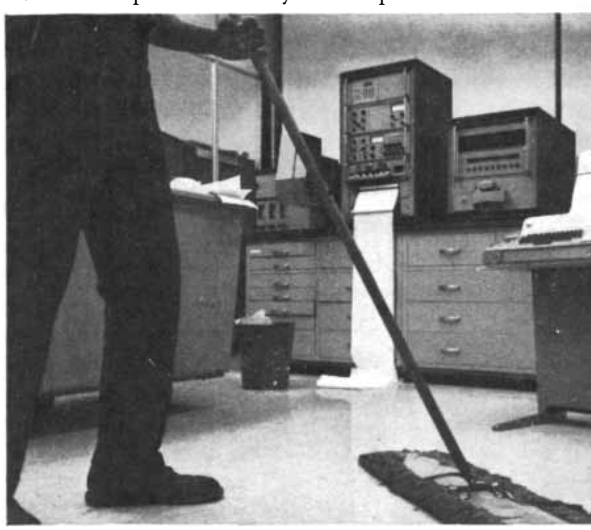


But that's no longer the only solution. Some new instruments have recently appeared on the scene that allow you to triple the output of your GC lab without increasing your staff or number of GC's. And you can do it a step at a time as your budget allows.

First there's the 7670A Automatic Sampler. Since it injects as many as 36 samples consecutively into a GC, completely unattended, it allows a single chromatographer to keep a GC productive around the clock, making well over 200 runs a week — triple his best output with manual injections. Cost is $2850.

Then there's the 3370A Integrator. It automatically quantitates the GC analysis, cutting about 10 minutes of computation per sample. Apply this to a 7670A-equipped GC and you eliminate 30 hours a week from the chromatographers' load, enough to pay for the 3370A, which costs $4950, in about four months.

The third and most decisive step to full automation is the 3360A GC Data Processing System, whose HP 2114B Computer is fully programmed for GC. It processes data simultaneously from eight GC's and automatically prepares a complete typewritten report of each analysis, cutting an additional 20 minutes of computation per sample. To understand its impact on a GC lab that has eight 3370A-equipped GC's, one must realize that the 3360A costs less than $20,000 installed, and that it is theoretically capable of processing 6000 samples a month. Even if you use the 3360A for as few as 1000 samples monthly, it will cut more than 300 hours of computation from your manpower budget, enough to pay its entire cost in little more than six months.



Write for the Fall 1970 issue of Analytical Advances, a 32-page study of the technology and economics of HP's step-by-step automation for the GC lab.

A new handbook about DC Power Supplies, containing information for the user, has been published by Hewlett-Packard. The 138-page book covers definitions, principles of operation, AC and load connections, remote programming, output voltage and current ratings, and performance measurements. If you would like to receive this handbook or any of the other material mentioned in this ad, just write: Hewlett-Packard, 1509 Page Mill Road, Palo Alto, California 94304; Europe: 1217 Meyrin-Geneva, Switzerland.

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CIRCUIT BREAKERS

The problem is how to interrupt a high-voltage current quickly but not too quickly. The answer lies in cultivating and then quickly dousing the arc that forms when the circuit is broken

by Werner Rieder

Whoever first interrupted an electric circuit unwittingly exploited the properties of a plasma, the state of matter in which electrons are removed from atoms or molecules, creating an electrically conducting gas. Although the word plasma is associated nowadays with such exotic schemes as magnetohydrodynamic generators and controlled thermonuclear reactions, the engineers who must deal routinely with plasmas and their useful properties are the designers of circuit breakers for the electric power industry. After more than 70 years of engineering effort the best way to tame a plasma arc in a circuit breaker remains a subject of technical debate. As the voltages used in power transmission have risen from 230,000 volts, considered high 20 years ago, to 550,000 volts and most recently to 735,000 volts, the problem of designing reliable circuit breakers has steadily intensified and the debate continues. The power blackout that swept across the northeastern U.S. in November, 1966, began with the tripping of a circuit breaker in Quebec during a momentary overload. As the overload was shunted to neighboring parts of the power grid, circuits were broken in a rising cascade. Although the disaster was due not to a faulty circuit breaker but to a basic defect in the design of the grid, it demonstrates how dependent an industrialized society has become on the reliability of these little-known devices.

The switch that interrupts a circuit carrying several hundred thousand volts must perform the same basic functions as the toggle switch on the wall in a 120-volt household circuit. What makes the design difficult as voltages increase is that the functions of a switch are contradictory. When the switch is closed, it must carry the current without significant loss; when it is open, it must insulate without significant leakage. Moreover, it must be able to change from one state to the other almost instantaneously without creating overvoltages as it opens and without becoming welded shut when it closes. Whereas other electrical devices such as generators, motors and transformers can be optimized for a single duty, switches and circuit breakers must be optimized for duties that are the antithesis of each other.

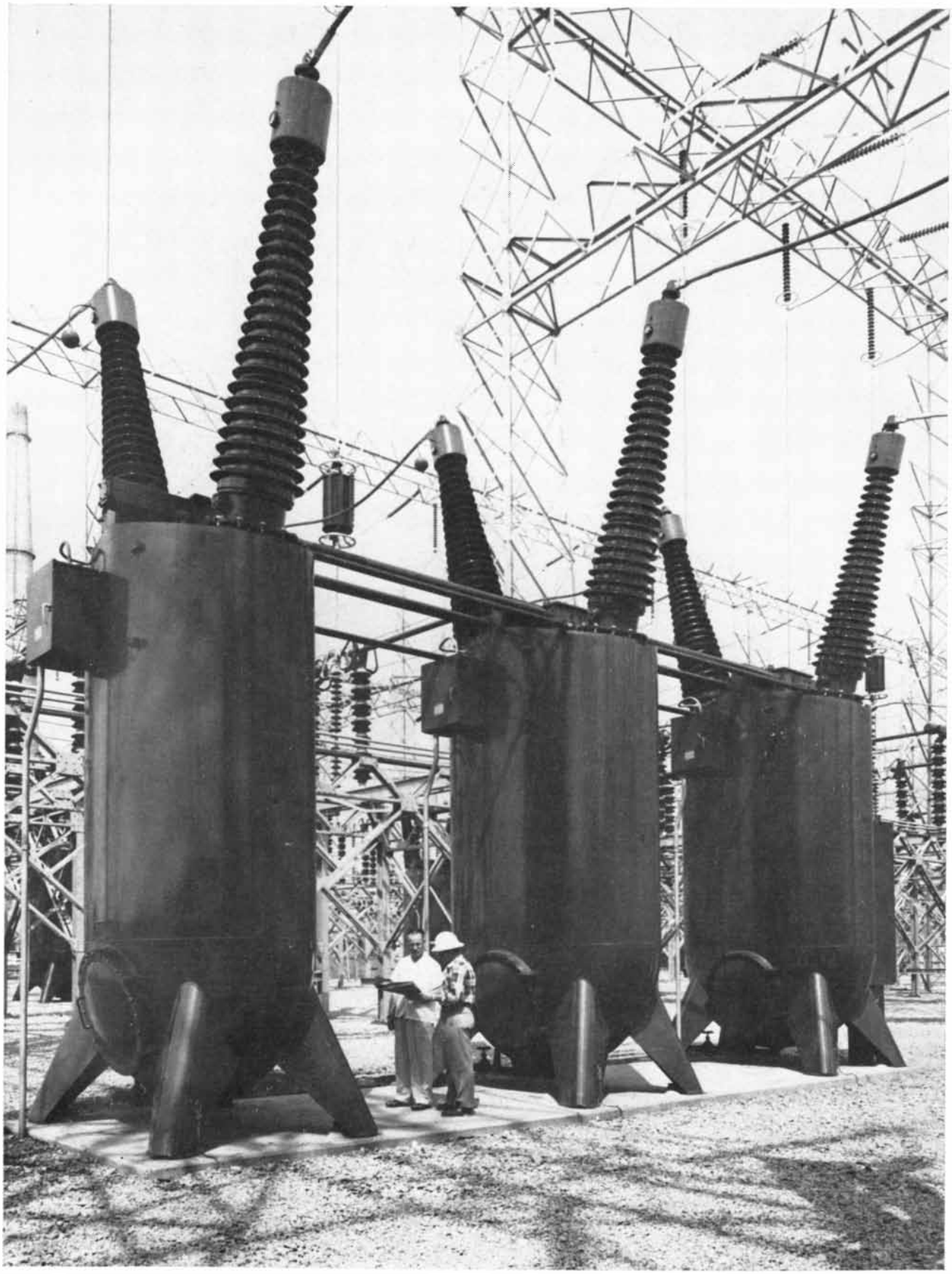
The simplest circuit breaker is the ordinary knife switch, which can still be found in most electrical-supply stores [*see top illustration on page 78*]. Bigger versions of the knife switch, widely used in early power stations, have several obvious disadvantages. The sizable arc that forms between the contacts when they are opened may burn the hand of the operator. If the switch is not opened quickly or is not opened completely, the arc may continue for so long that it melts down the contacts. Finally, the stationary contact in a simple knife switch is usually designed to act as a spring to grip the movable blade; with repeated use and repeated heating the temper of the spring deteriorates.

These drawbacks were overcome fairly early by designing a knife switch in which the handle is connected to the blade by a spring that opens the circuit more rapidly and more consistently than is possible by hand [*see bottom illustration on page 78*]. In addition the jaws that hold the knife blade in the closed position are squeezed together by external springs that are not in the circuit path and are therefore less likely to deteriorate through heating.

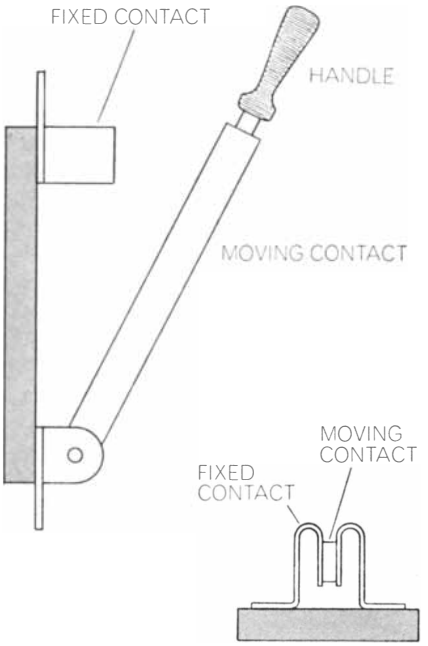
The use of a spring to open the knife blade soon led to an automatic device in which the energy for opening the contacts is stored by the closing operation. Then only a small force and a short time is needed to open the switch by means of a simple latch that, when it is tripped, releases the stored energy that opens the contacts. The switch now becomes a true circuit breaker, which can interrupt the current under predetermined conditions, for example when a short circuit occurs or when excess current endangers an electric motor [*see top illustration on page 79*]. A final design feature must be introduced for the safety of the operator. The handle for resetting the switch must be disconnected from the strong spring that opens the contacts; otherwise if the device were to retrip immediately after being reset, the handle might strike the operator with considerable force [*see bottom illustration on page 79*].

The plasma arc that momentarily bridges the gap when a pair of contacts is opened might seem like an unwanted phenomenon that hastens the deterioration of the contact surfaces. In actuality the arc is fundamental to the success of a circuit breaker. If the arc did not appear and if the circuit were somehow chopped instantaneously, large overvoltages would be created that would destroy the very equipment the circuit breaker was installed to protect. The overvoltages would arise because current flowing in a wire always induces a surrounding magnetic field. The energy stored in the field is retransformed into electrical energy when the current decreases and the field collapses. The faster the current decreases, the faster the magnetic field collapses and the higher the induced voltage is.

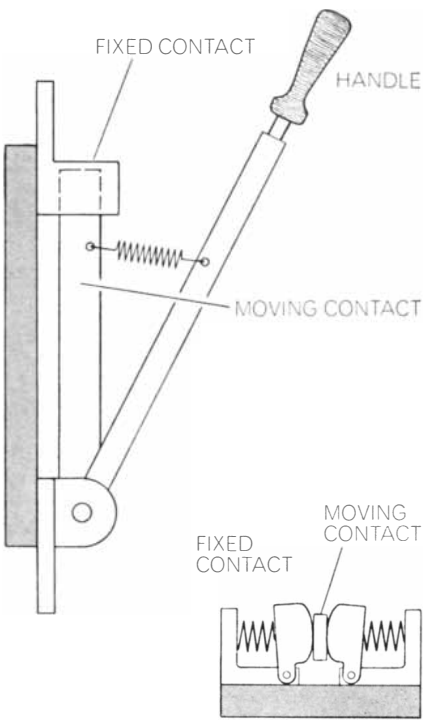
The arc, because it consists of the electrically conducting plasma, allows the current to flow briefly between the open contacts and thus prevents the magnetic field from collapsing too quickly. How is the arc so fortuitously creat-



OIL CIRCUIT BREAKERS built by the Westinghouse Electric Corporation protect a system carrying 345,000 volts. There is one breaker for each phase of the three-phase circuit. The tanks hold several thousand gallons of oil. European practice favors designs with minimum amounts of oil, as shown at the bottom of page 81. Diagrams of oil circuit breakers appear at the top of page 83.



PRIMITIVE KNIFE SWITCH, operated manually, is suitable only for interrupting circuits of low voltage and low current. When the circuit is broken, a small arc forms between the two contacts. If the voltage and current are substantial, the arc may harm the operator. The fixed contact (*cross section at right*), which acts as a spring to grip the moving contact, is subject to fatigue.



SNAP-ACTION SWITCH employs a spring between the moving contact and the handle to ensure a rapid and uniform action, thereby regulating the arc. Another improvement is that the fixed contact provides pressure on the moving contact by means of springs (*right*) that are not in the circuit path.

ed? As the contacts begin to move apart the surface area that remains in contact begins to decrease. Consequently the resistance to the current flow rises and the temperature of the diminishing contact area rises also. When the melting point of the contacts is reached, only a thin bridge of molten metal remains to carry the current. At this instant the temperature rises so steeply that the metal evaporates, creating ideal conditions for initiation of a plasma arc.

The plasma column that forms between the contacts is created by ionization of the surrounding gas, which is normally air, an excellent insulator at room temperature. An air gap of one centimeter can withstand about 30,000 volts at normal pressure and temperature, or more than an equivalent thickness of glass. When air is converted into a plasma at 5,000 degrees Kelvin (degrees Celsius above absolute zero), its conductivity increases by more than 13 orders of magnitude, or by a factor of more than 10 trillion, approaching the conductivity of carbon [*see top illustration on page 80*]. This tremendous range from excellent insulator to efficient conductor cannot be reproduced by matter in any other form; hence the plasma arc is the most effective switching medium known.

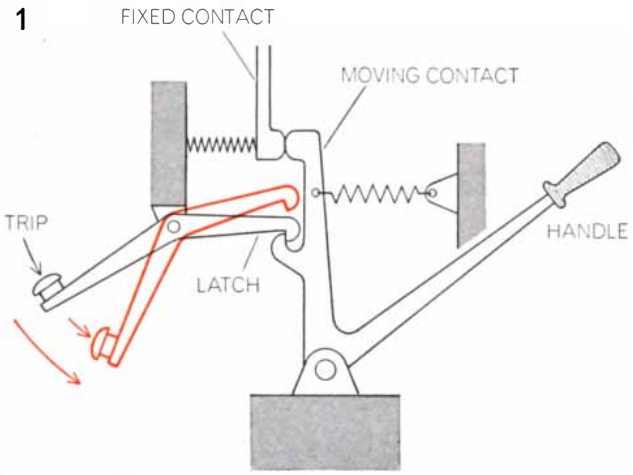
Once an arc has been initiated by the separation of contacts in a circuit breaker, the high temperature needed to sustain the arc is provided by the current passing through the arc itself. At this point we must remember that virtually all power-transmission systems employ alternating current, which means that the current drops to zero either 120 times per second (in standard U.S. systems) or 100 times per second (in European systems). When the current falls to zero, it can no longer sustain the arc and the circuit is broken. No overvoltage is created because at zero current no magnetic energy is stored in the circuit.

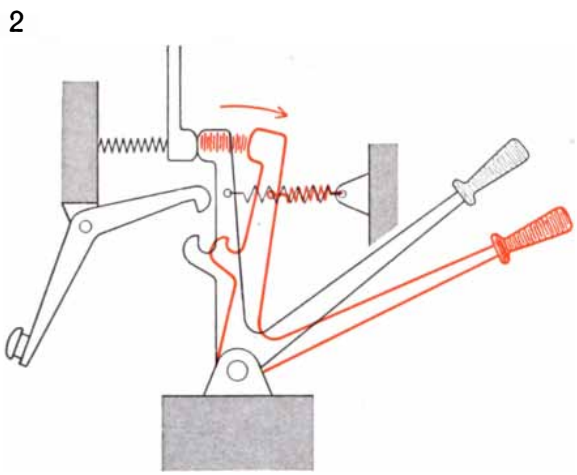
Unfortunately the heat stored in the arc column does not disappear instantaneously at zero current, and if too much remains, the arc may be reignited when the current swings upward from zero. As long as voltages are low the switching arc is kept from reigniting by a sheath of positive ions that appears at the negatively charged contact within a microsecond after the recovery voltage rises [*see bottom illustration on page 80*]. The sheath is able to withstand a few hundred volts depending on the contact material and its surface conditions. Double-break or multibreak devices can exploit this effect even at higher voltages.

In circuit breakers designed to operate at thousands of volts, means must usually be provided for cooling the arc columns to prevent reignition. Cooling the arc is not as easy as one might think. If one tries to hasten the heat loss either by using a more effective cooling gas (such as hydrogen) or by forced convection, the arc temperature does not decrease but increases markedly. This seemingly perverse behavior can be understood if one keeps in mind that the outer zones of the arc do respond to the forced cooling and lose their conductivity. The net effect, however, is to reduce the conducting cross section of the arc column, so that if it is to carry the same current, the current density must increase and with it the temperature. Nevertheless, forced cooling is effectively used in high-voltage circuit breakers because the rate at which an arc column loses heat is inversely proportional to its cross section; thus the thinner the column is, the faster it loses heat.

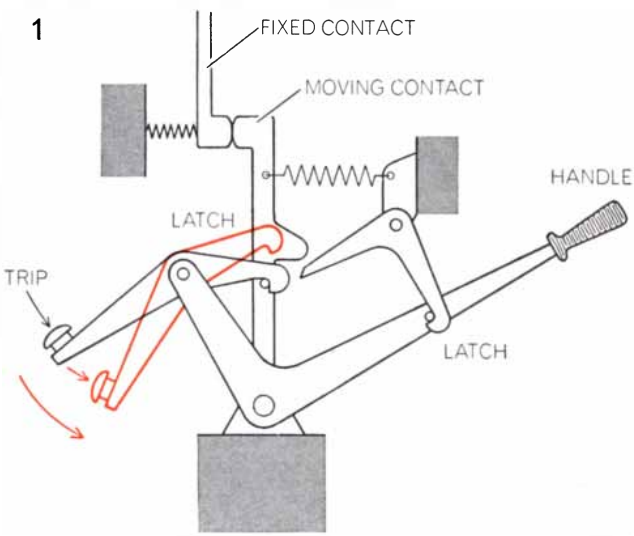
One might think that an obvious solution to the circuit-breaking problem in alternating-current systems would be simply to interrupt the circuit when the current and voltage are exactly zero. On examination, however, this solution presents such formidable problems of timing and contact velocities that it has never been satisfactorily solved. One can calculate that if air is the insulating medium, and if the voltage is 100,000 volts, the contacts must be separated by a hundred-thousandth of a centimeter in the first billionth of a second after the current is exactly zero and has started to rise. Although this may seem like a very small gap, the time needed to achieve it is so short that the contacts must be accelerated with a velocity equivalent to 10 billion times the force of gravity.

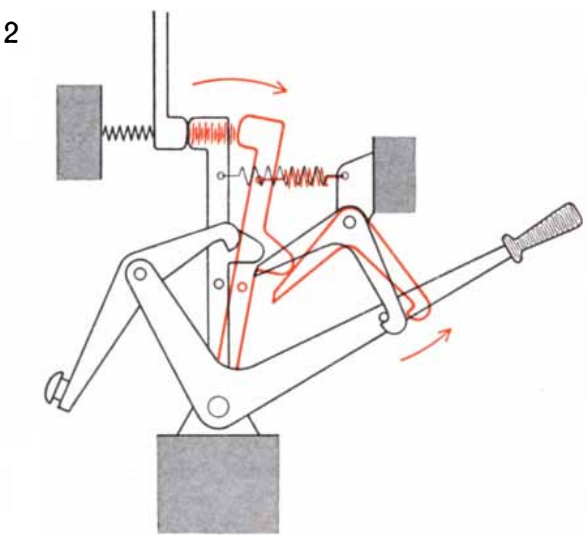
Since there is no substitute for a plasma arc as a circuit-breaking medium, the engineer's task is to examine the range of conditions under which arcs can be produced and extinguished. The variety of arc mediums and pressures may well seem confusing and illogical to those who are not actually engaged in this kind of work. For example, whereas some circuit breakers employ a vacuum of a billionth of an atmosphere, others operate at a pressure of more than 60 atmospheres. Some circuit breakers use oil—an obviously inflammable substance—to extinguish the hot arc. When the oil decomposes, it releases hydrogen, which is an excellent cooling medium because of the low mass and high velocity of its molecules. Other circuit breakers employ an exceptionally heavy gas, sulfur hexafluoride, as the medium for quenching

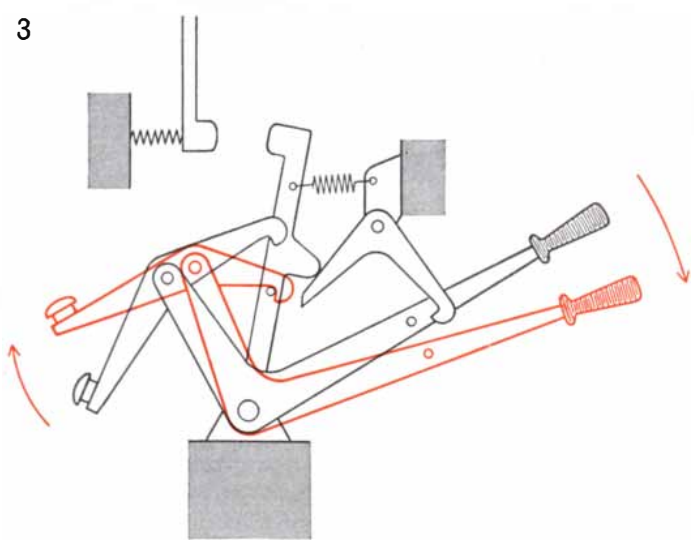




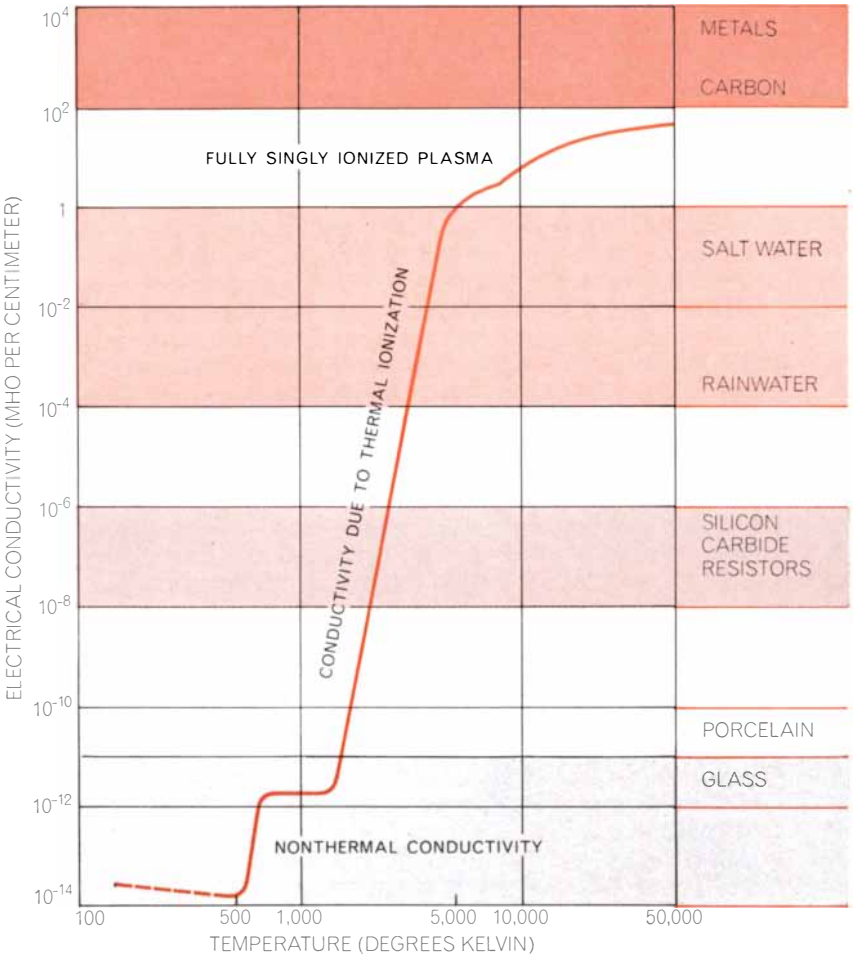
AUTOMATIC SWITCH interrupts the circuit when pressure is applied to a trip button. The pressure releases a latch that holds the moving contact tightly against the fixed contact (*1*). When the latch is released, a spring activates the moving contact, breaking the circuit (*2*). Because the handle used for remaking, or closing, the circuit is integral with the moving contact, the operator could be injured if the circuit were to be immediately broken before he could release the handle and move his hand from its vicinity.



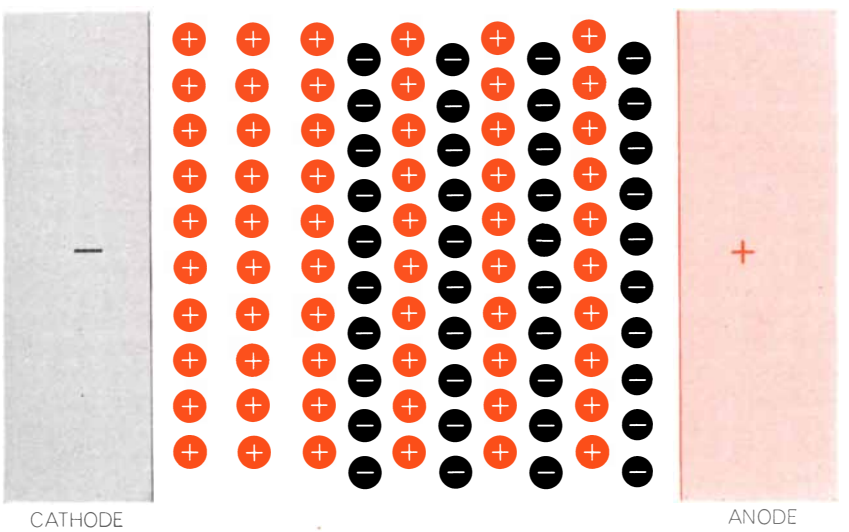




AUTOMATIC SAFETY SWITCH is designed so that the handle for closing the circuit is independent of the moving contact, thereby eliminating the hazard inherent in the switch shown at the top of the page. Pressure on the trip releases the latch holding the moving contact (*1*). The moving contact, actuated by a spring, strikes a second latch that releases the handle (*2 and 3*). Even if the circuit were to be broken immediately after it had been remade, the handle could not fly back and injure the operator.



ELECTRICAL CONDUCTIVITY OF AIR increases a trillionfold when its temperature is raised from 1,500 degrees Kelvin (degrees Celsius above absolute zero) to 5,000 degrees K. Below 700 degrees K. air is a better insulator than glass; above 5,000 degrees it approaches the conductivity of carbon. Air becomes conducting when thermal collisions remove electrons from the outer shells of nitrogen and oxygen molecules, and later from the outer shells of their constituent atoms. Conductivity rises with the plasma's degree of ionization.



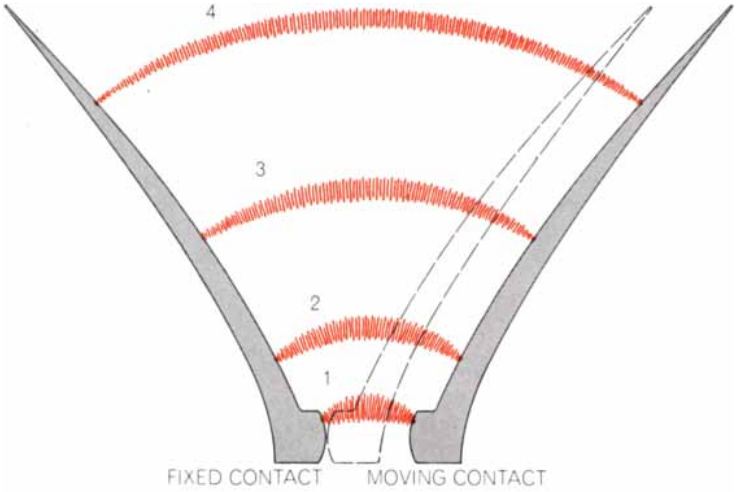
"SPACE CHARGE," consisting of positively charged atoms (chiefly N^{+}), appears near the cathode of an air circuit breaker after the circuit is broken and helps to keep the arc from reigniting when the current rises from zero. The heavy positive ions remain near the cathode while the electrons, moving about 1,000 times faster, are attracted to the anode. The space charge is effective in preventing arc reignition only below a few hundred volts.

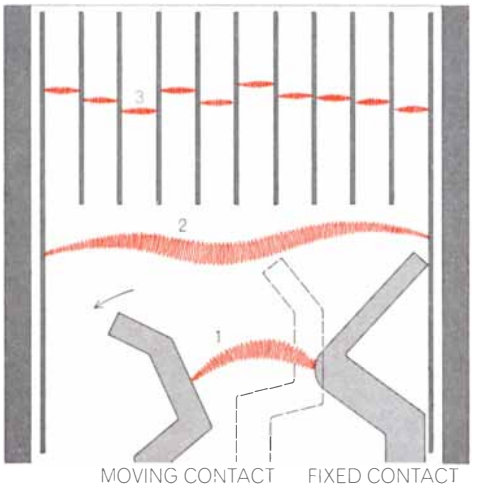
the arc. The most successful devices for interrupting the highest currents of all simply use air. Each device has its advantages and disadvantages, and no one is wise enough to predict which will be dominant in the future. Here I shall briefly discuss each of the major types of circuit breaker.

Circuit breakers that employ air at the interrupting medium are of two general types: magnetic breakers and air-blast breakers. In magnetic breakers the contacts are made in the shape of two horns that are placed in a magnetic field [*see top illustration on opposite page*]. The arc initially strikes across the shortest distance between the horns, but it is then driven steadily outward by the perpendicular magnetic field until it extends from one tip to the other when the horns are fully separated. Finally the arc is pushed away from the horns, and thereafter it can be lengthened in open air or in an arc chamber, where it can either be magnetically pressed against a refractory surface or split up into many short segments by metal plates. In the latter case each of the short arcs is prevented from reigniting by the sheath of positive ions that forms on each cathode. Such magnetic circuit breakers are effective in circuits carrying up to 16,000 volts or so, but at higher voltages they cannot compete with designs in which the arc column is deliberately cooled at zero current fast enough to prevent reignition.

In air-blast breakers the arc is extinguished by a blast of air moving through a nozzle at supersonic velocity [*see illustration on page 82*]. By the time the current has dropped to zero the arc has been stretched into such a thin column that it rapidly loses heat by direct conduction to the surrounding mass of cool air. The capacity of nitrogen (the chief component of air) to conduct heat reaches a maximum at around 7,000 degrees K., the temperature at which atomic nitrogen, created by dissociation in the arc, reverts to molecular form. A single pair of air-blast contacts can interrupt a circuit of some 100,000 volts, which means that several pairs of contacts in series are required for circuits of several hundred thousand volts.

In oil circuit breakers the arc originates in oil. The heat of the arc immediately evaporates the surrounding oil and dissociates it into carbon and a substantial volume of gaseous hydrogen at high pressure. The expanding hydrogen cools and extinguishes the arc. Oil circuit breakers employ various stratagems for concentrating the expanding hydro-

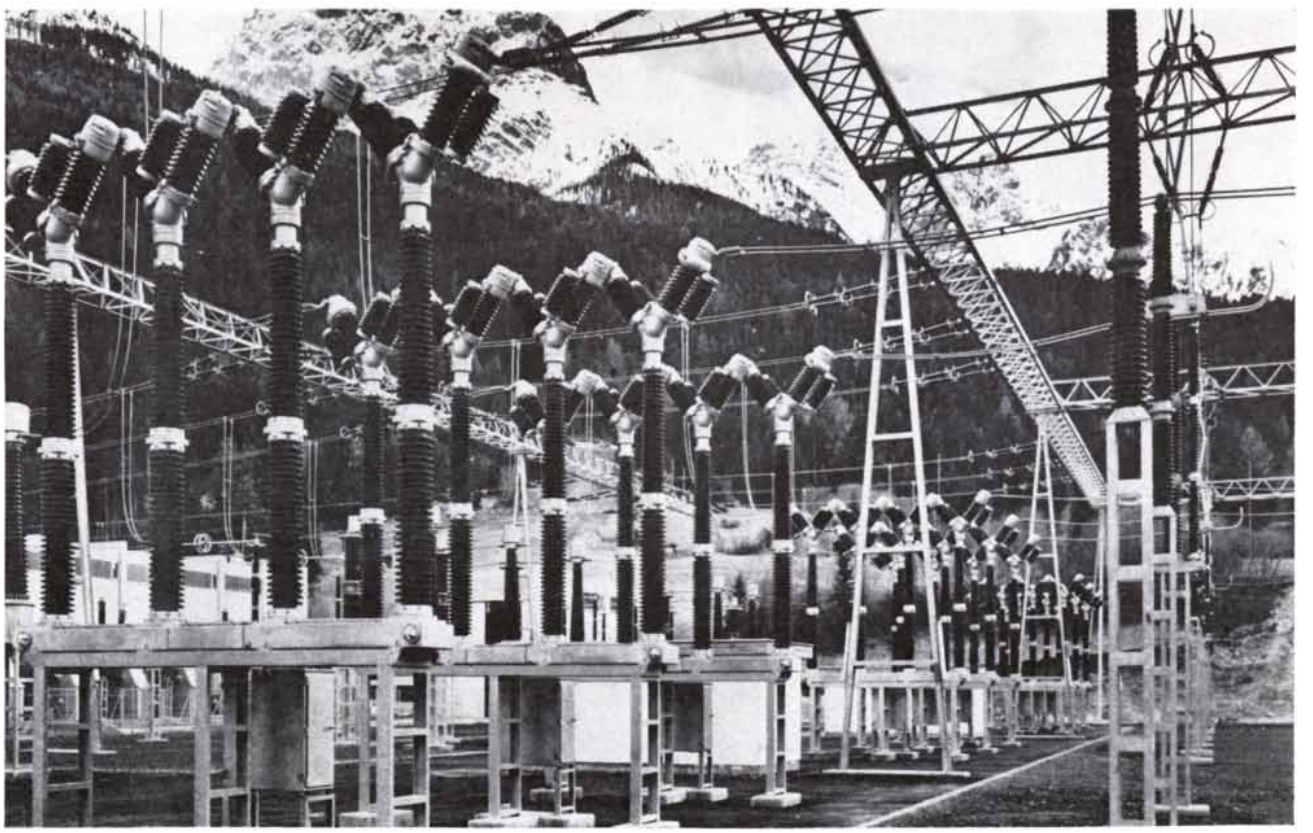




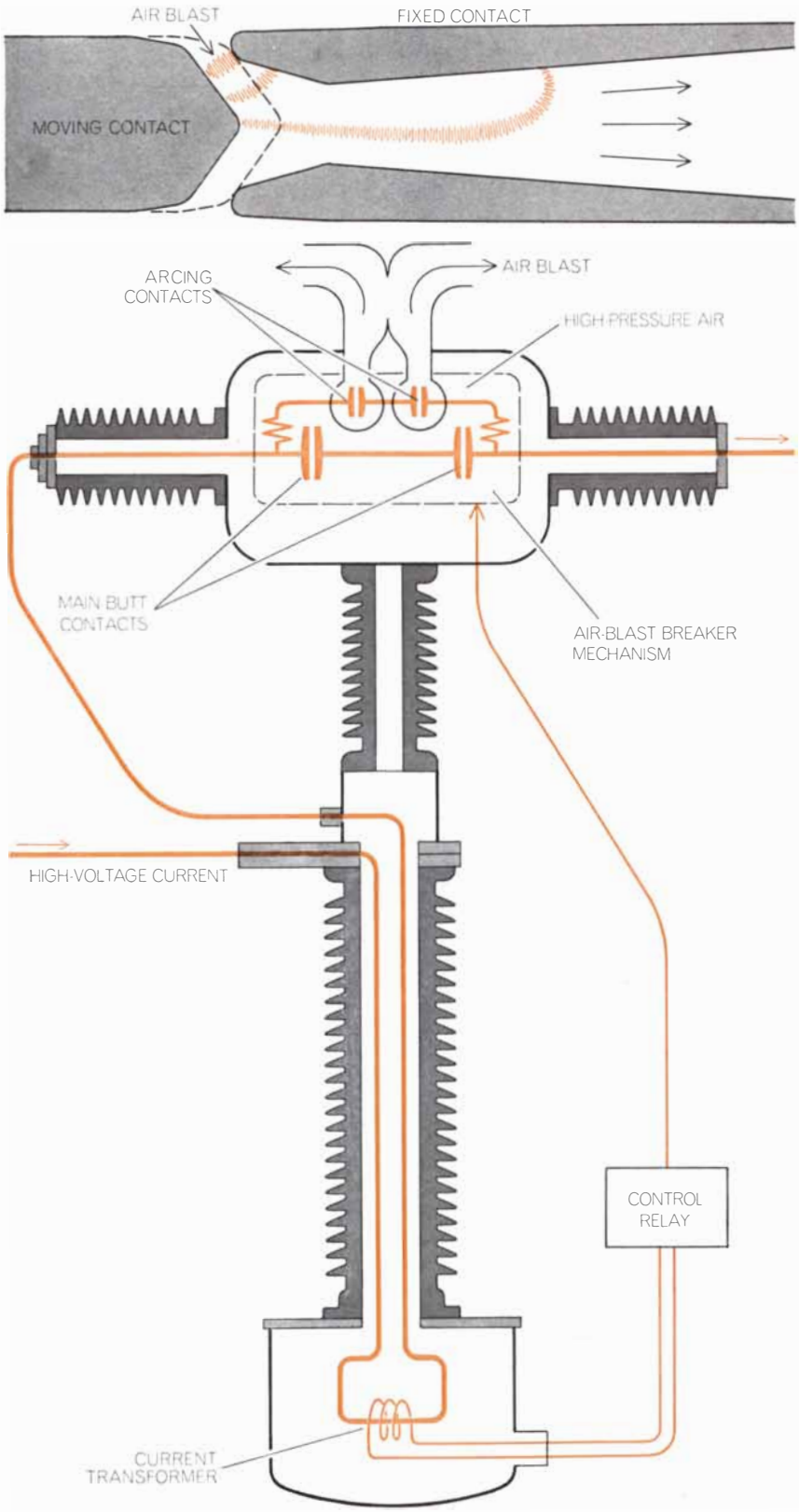
MAGNETIC-BLAST CIRCUIT BREAKERS employ contacts in the shape of horns. A low-voltage breaker is shown at the left. When the circuit is broken, an arc first forms at the base of the horns (*1*). A magnetic field perpendicular to the plane of the diagram then drives the arc outward (*2, 3 and 4*). The air at the base of the horns thus has a chance to cool before the current rises from zero. The magnetic breaker at the right also has horn-shaped contacts but is designed so that the arc (*1 and 2*) is ultimately subdivided between closely spaced metal sheets (*3*). At zero current a space charge forms on the sheets and prevents arc reignition.

gen gas against the arc to achieve the maximum extinguishing effect [*see top illustration on page 83*]. The reassociation of atomic hydrogen into molecular hydrogen is not of crucial importance in cooling the arc, unlike the reassociation of atomic nitrogen into molecular nitrogen in air-blast breakers. The chief virtue of hydrogen is its high heat conductivity, which is due to the high velocity of its very light molecules. The chief drawback, of course, is the hazard of fire if a defective oil circuit breaker should fail under pressure and cause an explosion.

The noncombustible heavy gas sulfur hexafluoride was successfully introduced as an arc-extinguishing medium some 25 years ago [*see bottom illustration on page 83*]. One important property of sulfur hexafluoride is a strong affinity for electrons. The sulfur hexafluoride molecule, SF_6, readily acquires any free electron, forming a heavy negative ion,



MINIMUM-OIL CIRCUIT BREAKERS built by Brown, Boveri & Company Limited protect a circuit of 420,000 volts. European engineers developed oil breakers containing minimum amounts of oil following a major disaster in Prague after World War I.



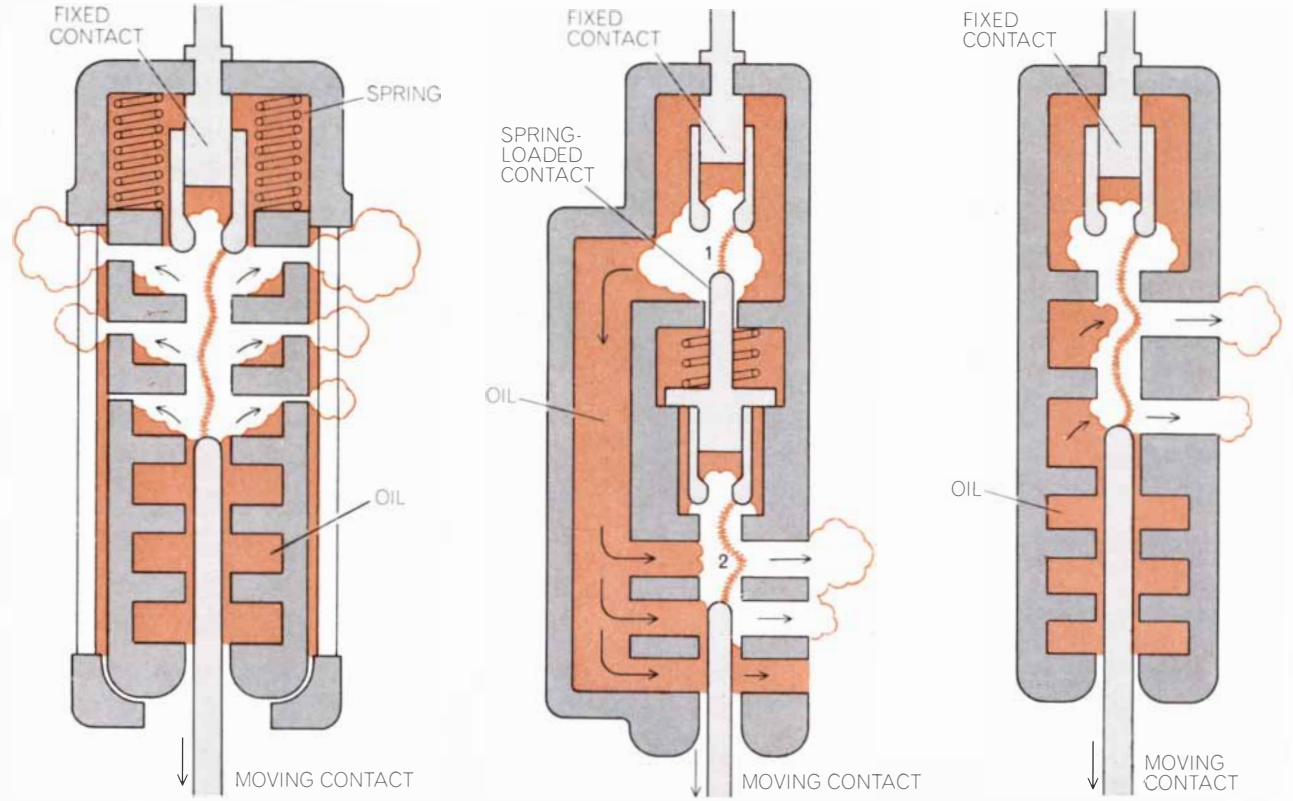
AIR-BLAST BREAKERS are preferred for the highest voltages and currents. The bottom illustration is a schematic view of one of the units designed by the General Electric Company for service at 500,000 volts, shown on the cover of this issue of SCIENTIFIC AMERICAN. The heavy line in color indicates the path of the primary current. The transformer at the base provides a sensing current of low voltage that trips the air-blast mechanism. The main butt contacts separate first but no arc forms because the current is immediately shunted to the arcing contacts arranged in series with heavy resistors. When these separate an instant later, an arc forms between each pair of contacts. Simultaneously the arcs are hit by a blast of high-velocity air. The blast attenuates the arc, as shown in the illustration at the top.

SF_6^-. This tends to remove free electrons and thus prevents them from forming an electron avalanche that would promote reignition of the arc after it had lost its conductivity. This effect, however, does not operate at elevated temperatures before the arc is extinguished and therefore cannot fully explain the great success of sulfur hexafluoride as an arc-quenching medium.

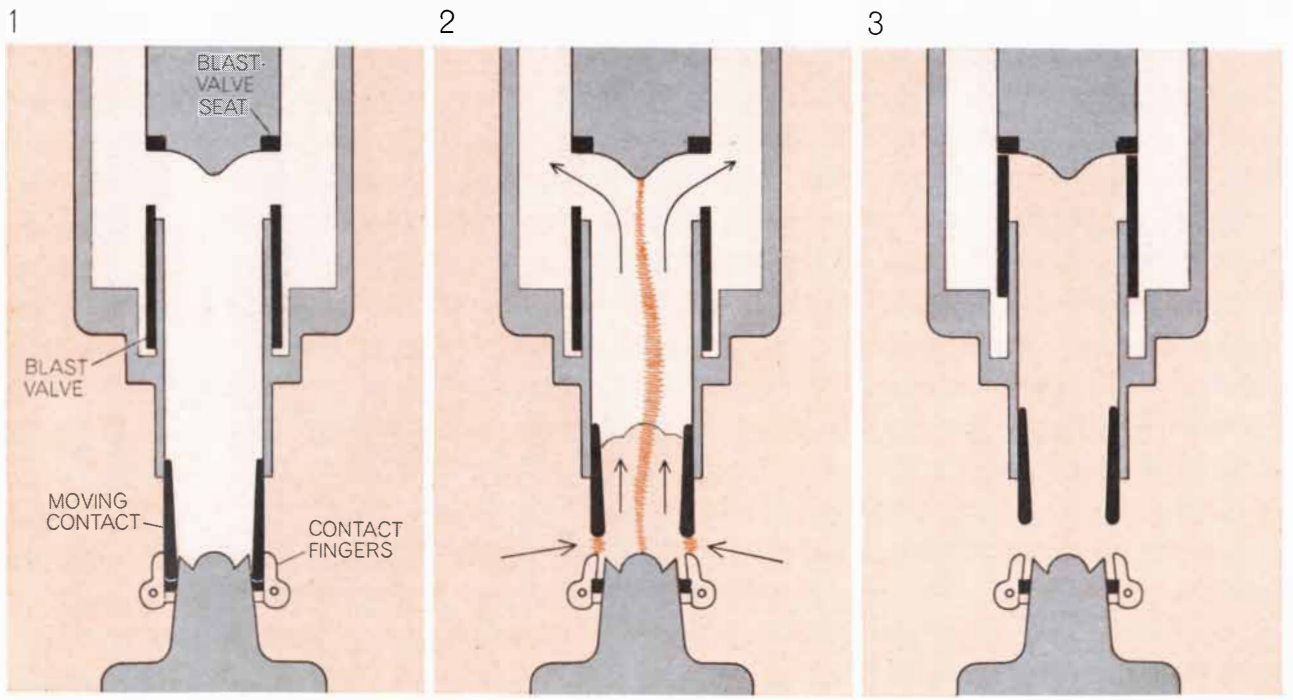
Other factors in its efficacy are the particular energies required for ionizing the molecule and ultimately for dissociating it into its atomic constituents. At temperatures above 2,000 degrees K. it supports an arc that has a fairly low voltage and that does not generate a great deal of heat. When the current approaches zero, the fluorine atoms start recombining with sulfur at the low temperature of 2,000 degrees K. (compared with 7,000 degrees for the recombination of nitrogen atoms) and thus produce a sharp peak in the heat-conduction curve at the precise instant that the simultaneous disappearance of free electrons and sulfur causes the gas to lose its electrical conductivity.

In spite of these nearly ideal properties, sulfur hexafluoride has certain serious disadvantages. Although the compound itself is inert, its decomposition products, sulfur and fluorine, are both corrosive, particularly the latter. This greatly limits the materials that can be used as conductors, insulators and lubricants in sulfur hexafluoride circuit breakers. Moreover, all traces of moisture must be excluded, which means it is virtually impossible to open these devices for inspection or maintenance. Because the gas is so heavy and viscous it is more difficult to ensure the gas flow needed to cool the arc than it is with air. At the same time the gas liquefies so readily (at about 10 degrees C. at the typical operating pressure of 250 pounds per square inch) that it must be kept heated if the circuit breaker is to be used outdoors. For all these reasons it seems doubtful that sulfur hexafluoride devices will ever supersede air-blast and oil circuit breakers.

The vacuum circuit breaker employs the simplest principle of all: it requires only two contacts that can be separated in a vacuum chamber. As in other circuit interrupters, an arc jumps between the contacts when the circuit is opened because the rising current density vaporizes some of the contact metal. The particles so vaporized, however, fly almost unimpeded to the walls of the chamber. Thus when the current rises from zero, there are virtually no particles present of any kind to be ionized



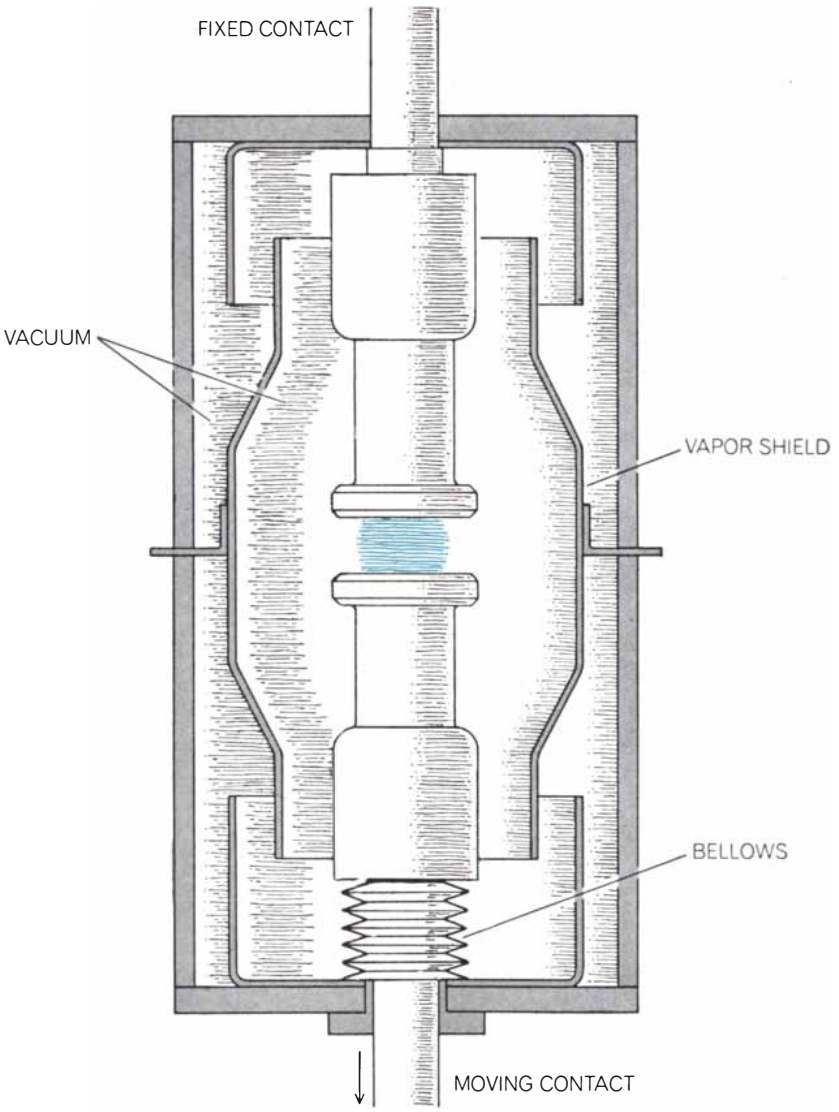
THREE OIL CIRCUIT BREAKERS employ slightly different means to cool the arc rapidly. In each case the cooling medium is gas, chiefly hydrogen, generated by the decomposition of the oil in the vicinity of the arc. The first design (*left*) incorporates safety ports that open if the pressure is excessive. In the second design (*middle*) the circuit is broken by two moving contacts that operate in sequence. The arc formed by the upper pair of contacts generates a blast of gas that helps to extinguish the lower arc. In the third design (*right*) withdrawal of the moving contact opens exhaust ports through which the high-pressure gas can escape.



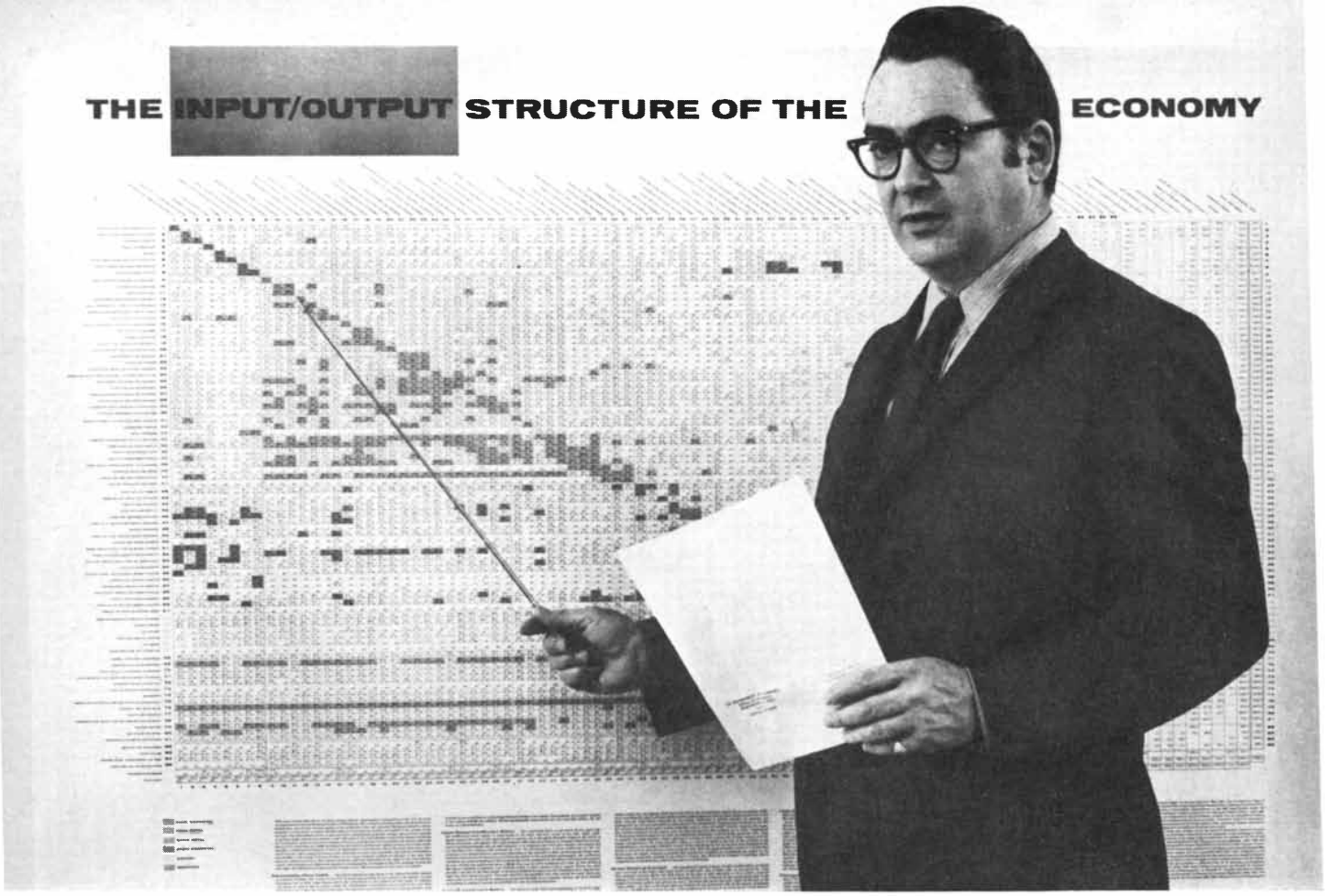
SULFUR HEXAFLUORIDE CIRCUIT BREAKER employs a heavy gas with unusual electrical properties to snuff out the arc created when the contacts are opened. It is quieter than air-blast breakers. The unit shown here follows a design developed by Westinghouse. When the circuit is closed (*1*), sulfur hexafluoride at a pressure of more than 200 pounds per square inch surrounds an inner chamber containing gas at five pounds per square inch. When the breaker is activated (*2*), an arc initially forms between the contact fingers and the moving contact but is immediately driven inward by the high-velocity flow of gas. When the arc is extinguished (*3*), high-pressure sulfur hexafluoride gas is present both inside and outside contacts and acts as an excellent insulator.

and to provide a pathway between the open contacts. Although the concept of a vacuum circuit breaker is very old, the practical difficulties of achieving high vacuums in tight housings that will not leak appreciably for at least 20 years have deterred the development of satisfactory units until quite recently.

None of the types of circuit breaker I have described is subject to any inherent limitation in voltage or current. Nor can anyone say categorically that one principle is better than another. The main problem in designing a circuit breaker is not in choosing the best medium for taming an arc but how to make full use of the advantages of a given medium and how to compensate for its disadvantages in the most reliable and economic way. For the foreseeable future it seems likely that air-blast circuit breakers will continue to be favored for interrupting extremely high currents. Sulfur hexafluoride units have advantages for high-voltage indoor stations. Oil circuit breakers will remain the cheapest for many purposes. Vacuum circuit breakers should become competitive for medium-voltage applications, replacing the larger magnetic breakers, if manufacturing costs can be lowered somewhat. Even more than in the past electric utilities must be concerned in the very largest and most critical installations with reliability.



VACUUM CIRCUIT BREAKER employs the simplest principle of all, but it is limited to voltages below 20,000 volts. It is also much more expensive than other designs. The original arc is supported by metal atoms and ions released by the vaporization of the contacts at the instant they move apart. These metallic particles fly directly to the walls of the vacuum chamber, virtually unimpeded, and thus are not available to support a reignition of the arc.



WHAT DOES IT TAKE TO PRODUCE A $1000-BILLION GNP?

The Editors of SCIENTIFIC AMERICAN have prepared a wall chart, based upon the latest Federal input/output table, displaying the interindustry flows of raw materials, intermediate products and business services required to carry the U.S. economy to the benchmark Gross National Product of $1000 billion.

Input/output tables provide management, government administrators, economists and market analysts with a powerful new tool for forecasting and measuring the indirect as well as the direct interindustry relationships that structure our industrial economy.

This handsome and informative wall chart (70" x 46", in eight colors) offers a unique entry into the rapidly developing discipline of interindustry (or input/output) analysis. Based upon input/output tables issued by the Office of Business Economics of the U.S. Department of Commerce, the chart can be used as a teaching tool and for study of practical and theoretical questions about the U.S. economy.

The chart presents an interindustry matrix of 99 rows and 99 columns; each of the nearly 10,000 cells in the matrix shows (1) the direct input/output coefficient, (2) the "inverse" coefficient and (3) the interindustry dollar flow for a $1000-billion Gross National Product. The input/output coefficients as published by OBE have been recomputed by the Harvard Economic Research Project to reflect gross domestic output. The 370 sectors of the detailed tabulations have been selectively aggregated to 99 sectors to provide maximum feasible detail for the wall chart. Where the ratio of input to output exceeds 1/100, the cell is tinted in the color-code of the industrial bloc from which the input comes. This device, combined with triangulation of the matrix, brings the structure of interindustry transactions into graphic visibility.

Offprints of five SCIENTIFIC AMERICAN articles on the technique of input/output analysis accompany the chart. The articles are:

Input/Output Economics
by Wassily W. Leontief

The Economic Effects of Disarmament
by Wassily W. Leontief and Marvin Hoffenberg

The Structure of Development
by Wassily W. Leontief

The Structure of the U.S. Economy
by Wassily W. Leontief

The Economics of Technological Change
by Anne P. Carter

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Induced Mutations in Plants

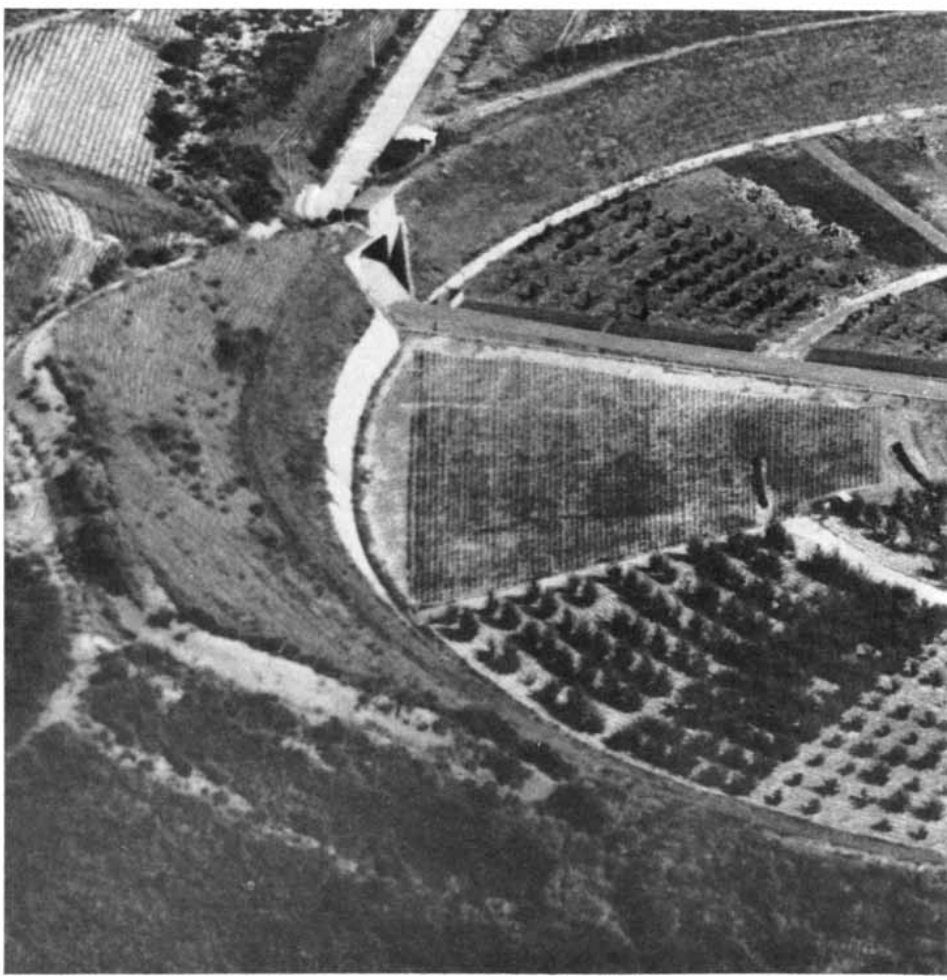
The intentional exposure of seeds to mutagens has produced many new characteristics for the intensified breeding of plants. This procedure has played an important part in the "green revolution"

by Björn Sigurbjörnsson

Mutations occur spontaneously in all living things. By changing the chemistry of the organism's genetic material or altering the structure of a chromosome a mutation changes the structure or function of the organism and its offspring. Most often the mutation is harmful, and the change is erased by natural selection. Once in a while a mutation is beneficial, increasing the organism's chance to survive and reproduce or, in the case of plants and animals that are directly useful to man, increasing its value.

On this foundation a number of breeders of plants have ventured to induce mutations artificially and then to take advantage of the beneficial ones. The principal mechanism for inducing mutations is the irradiation of seeds, although mutations are also induced by irradiating entire plants and by treating seeds with mutagenic chemicals. This idea appears straightforward and promising, and so it seemed soon after the artificial induction of mutations was discovered in 1927. For lack of understanding of the biological processes involved in mutation, however, the first efforts at inducing mutations to improve plants were not successful, and the procedure fell into disfavor. Only in recent years has the state of knowledge improved to the point where it is possible to obtain generally good results. Lately more than 100 varieties of induced-mutant crop plants—including wheat, rice, barley, oats, soybeans and a number of other legumes, fruit trees and ornamental plants—have been released to growers and are being raised by farmers on millions of acres throughout the world. It has gone largely unnoticed that some of these varieties have played a part in the "green revolution" that has resulted in substantial improvements in crop yields. Further applications of induced mutations promise to play a significant role in sustaining and consolidating the revolution.

Recognizing the interest of atomic-energy authorities in the peaceful application of isotopes and radiation and the interest of agriculturists in harnessing these tools for improving the production and protection of food, the Food and Agriculture Organization of the United Nations and the International Atomic Energy Agency established in 1964 in Vienna a joint division to coordinate such applications. This division, of



RADIATION BREEDING is carried out in this gamma field at the Institute of Radiation Breeding in Japan. The field is 200 meters in diameter. It is surrounded by a high wall,

which I am deputy director, is concerned with radiation and isotope applications in soil, plant and animal science and in entomology, pesticides and food preservation. We hope that as a result of our efforts the promise of induced mutation for the improvement of agricultural plants will be realized still more widely and quickly than it has been up to now.

In essence mutations are sudden changes in the hereditary material of an organism. Regarded broadly they include all such changes that cannot be accounted for by the normal recombination of the units of heredity. Mutations are the very source of genetic variability, and so they are ultimately responsible for the evolution of all present forms of life.

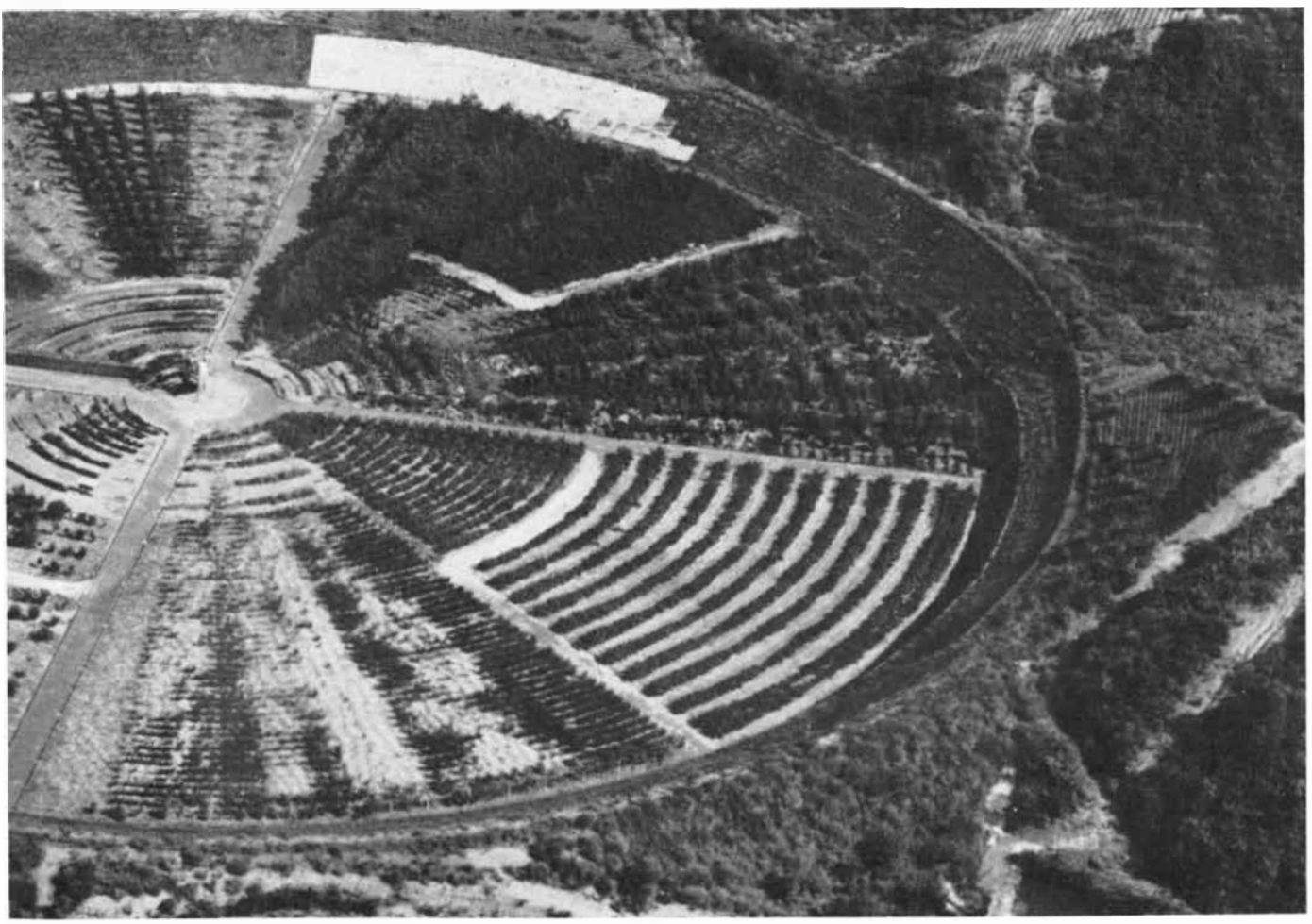
A mutation can affect the chemistry of the hereditary material—the DNA and RNA—in various ways. For example, it can alter the sequence of the base pairs that constitute the triplet code alphabet of the hereditary language. It can also entail the loss of a base pair, resulting in a "misreading" of an entire "line" of the hereditary text [*see illustration on page 89*]. The protein synthesized according to the instructions of the mutated DNA would differ from the protein resulting from the original DNA.

Mutations can also result from a loss or a rearrangement of part of a chromosome and from the loss of entire chromosomes. Parts of chromosomes may exchange places—the phenomenon termed translocation. A piece of broken chromosome may rotate 180 degrees before rejoining the chromosome; this is called inversion. Perhaps a broken piece is lost altogether, with a consequent loss of the genetic information that it carried. Mutations also include the duplication of chromosome parts and the occurrence of additional chromosomes. Any of these mutational changes can affect the structure or function of the organism, although not all the changes are visible.

Natural, or spontaneous, mutations have a number of causes. The cosmic rays that constantly bombard the earth can penetrate matter readily; if one of them strikes a chromosome, it can produce a mutational change. Normal physical phenomena such as heat can cause mutations. So can pure oxygen under pressure. It has been shown that genetic material can mutate simply through the process of aging. A number of substances, including caffeine, have been shown to be potentially mutagenic.

The rate of spontaneous mutations, however, is rather low. For instance, among 10,000 barley seedlings one can expect to find two that are not normally green, having undergone spontaneous mutations affecting their chlorophyll. The spontaneous mutation rate does vary: some genes mutate more often than others.

In 1927 the American geneticist H. J. Muller published a paper describing his discovery that mutation frequency is increased following irradiation of the



with access gained only through a heavy steel and concrete door that serves as a radiation shield. A tower in the center of the field holds a 2,000-curie source of the radioactive isotope cobalt 60, which radiates gamma rays for inducing mutations in the plants.

MUTANT RICE was developed by S. Tanaka at the Institute of Radiation Breeding in Japan. Starting with the variety Norin 8 (*left*), he developed by radiation a mutant (*right*) that reaches maturity about two months earlier and has seeds with more protein.

fruit fly *Drosophila melanogaster* with X rays. (In 1946 Muller was awarded the Nobel prize in physiology and medicine for this work.) At almost the same time that Muller made his discovery the phenomenon was demonstrated in corn and barley by another American worker, L. J. Stadler.

For a long time after Muller's discovery it was widely believed that induced mutation had the potential to revolutionize plant breeding. The reason for these expectations can be seen in the fact that plant breeding is perhaps best defined as controlled or guided evolution. Natural evolution is based on three main factors: spontaneous mutation, which is ultimately responsible for all variability in living things; hybridization, which reshuffles mutations into virtually unlimited genetic patterns, and natural selection, which favors the perpetuation of individuals with genetic patterns that make them better able to survive and reproduce.

Traditionally the plant breeder has been able to control two of these factors: hybridization (by deliberately choosing the parents when crossbreeding plants) and natural selection (by applying deliberate selection pressures and his trained eye to pick out superior plants). Confronted now with the possibility of being able to affect the third factor by artificially increasing the rate of mutation, many plant breeders undertook to try inducing mutations. The number of interested breeders increased after World War II, when isotopic sources of gamma rays and reactor sources of neutrons became generally available. Even farmers became enthusiastic; there was a story of the farmer who had heard of the wonderful neutrons and wanted to buy a bagful to sow with his seeds.

These early efforts suffered from a lack of knowledge both of how best to induce mutations and of how to apply them. Little was known about the radiation sensitivity of seed, the effect of the seed's physiological condition at the time of treatment, the effect of radiation on the plant or how succeeding generations would develop. Even when successful mutations were achieved, their application was hampered by insufficient understanding of the need to establish specific breeding objectives, choose appropriate parents and properly handle the succeeding generations.

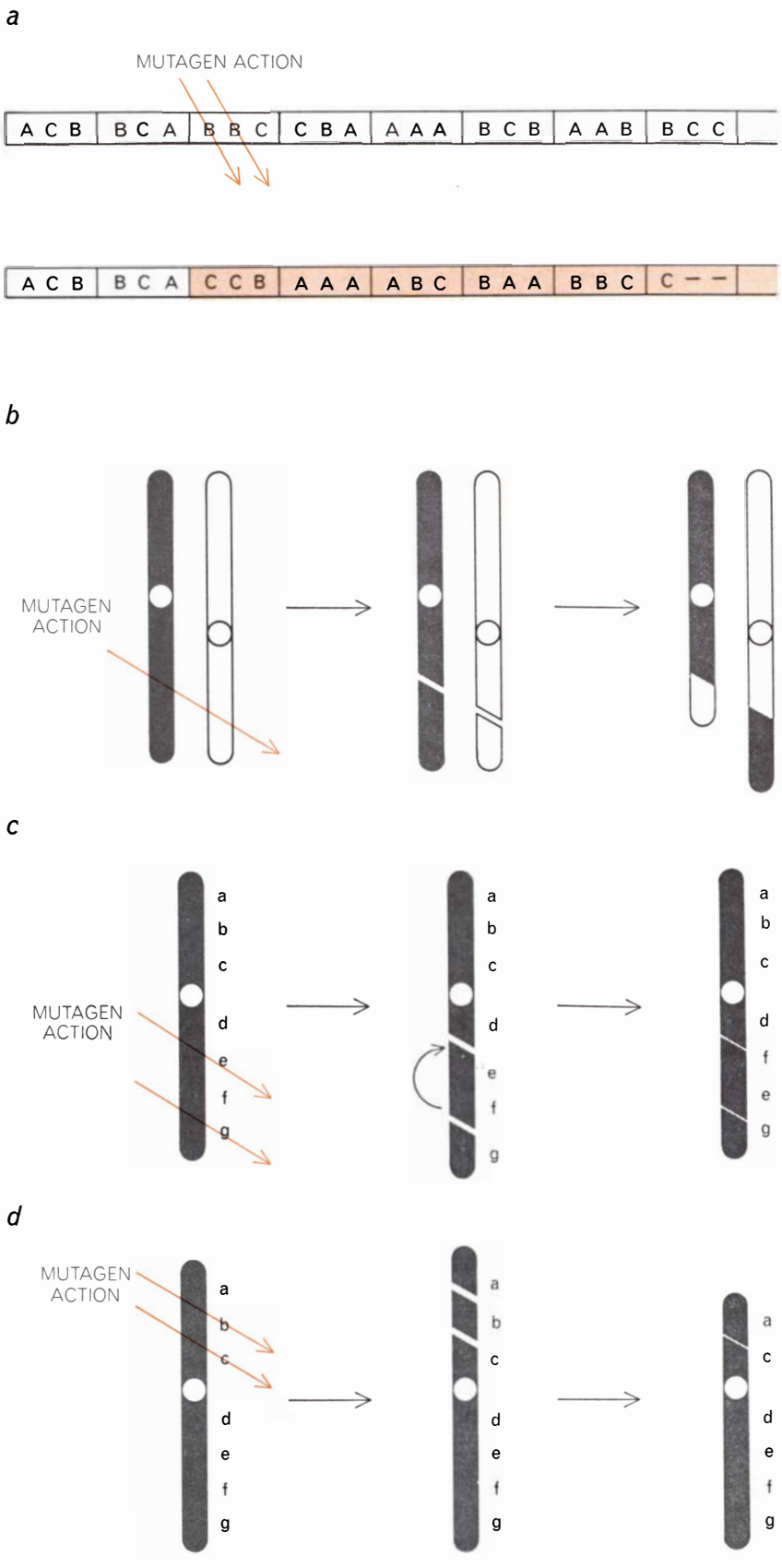
As a result the expected miracles failed to materialize. Breeders found to their dismay that their nurseries contained stunted and deformed plants of no apparent agronomic value. These

failures might have brought an end to mutation breeding had it not been for a few investigators who realized that the fault lay not with the principle of induced mutations but with inadequate knowledge of the nature of mutations, how they were induced and how they affected plants. Special mention must be made of Åke C. Gustafsson of the University of Lund, whose foresight and contributions over the years were particularly effective in helping the pendulum to swing back.

When X rays pass through tissue, they ionize atoms in it by detaching electrons from them. The result may be a regrouping of the molecules along the track of ions left by the X rays. Such regrouping can lead to gene mutations or to chromosomal breaks and rearrangements. The X rays can also bring about chemical changes in the environment of the chromosomes. Most important is the production of hydrogen peroxide and free radicals, which are highly reactive and can lead to mutational changes in the genetic material.

Gamma rays have effects almost identical with those of X rays. Neutrons, however, are more densely ionizing than X rays and gamma rays and are therefore more effective in inducing mutations at the same dosages. This difference can be significant, because high dosages of radiation not only affect the genetic material but also damage the organism physiologically. In plants high dosages of radiation result in less frequent germination, stunted growth and reduced vigor. With X rays and gamma rays attention must be paid to various physiological conditions of the seed in order to achieve the maximum rate of induced mutation with minimum physiological damage. In contrast, the effect of irradiation with neutrons is less dependent on the physiological condition of the seed.

The increase in the rate of mutation following irradiation is considerable: after treating barley seeds with 10,000 roentgen units of X rays one can expect to find, one generation later, about 200 chlorophyll mutants among 10,000 plants instead of the two that could be expected to result from spontaneous mutations. The frequency of mutations induced by X rays is almost directly proportional to the dosage of radiation, so that at high dosages the rate of mutation can be thousands of times higher than the spontaneous rate. At still higher dosages the mutation frequency levels off. Eventually the organism is killed by the radiation, the lethal dosage level de-



GENETIC CHANGES that can be induced by radiation or chemicals include (*a*) alteration of the triplet code of DNA so that a new sequence (*color*) is created. Mutations also arise from changes in chromosomes, such as translocation (*b*), inversion (*c*) and deletion (*d*).

pending on the radiation sensitivity of the organism. The artificially induced mutations are in principle of the same kind as the spontaneous ones. Thus the artificial induction of mutations can be regarded as an amplification of the natural phenomenon.

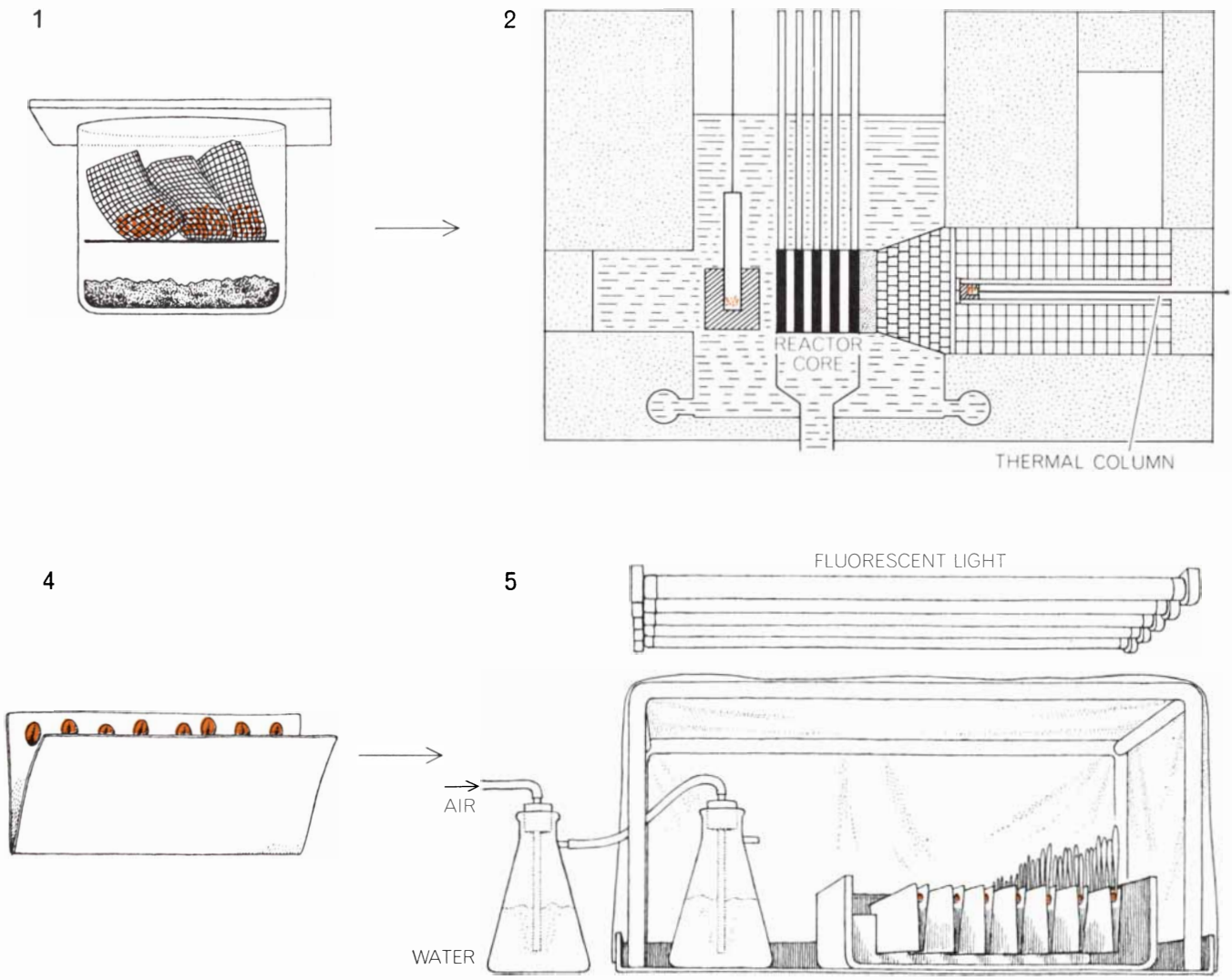
It should be noted that a mutagen does not produce a specific mutation. What is achieved is an increase of the general mutation frequency and thereby an increased likelihood of an agronomically valuable mutation. There are some indications of specificity among the different mutagens, but so far at least it is not possible to use mutagens to produce certain specific mutations and not other ones.

Until fairly recently X rays and gamma rays were the principal agents employed to induce mutations. They were not always effective because the importance of controlling the physiological condition of the seed (primarily its content of oxygen and moisture) at the time of treatment was not adequately appreciated. On the other hand, treatment with neutrons has entailed the difficulty of measuring dosages reliably in nuclear reactors, particularly when fast, or highly energetic, neutrons were employed.

The difficulties with the effective use of these two types of radiation have recently been overcome through intensive studies by teams of biologists, chemists and physicists, resulting in vastly improved efficiency in inducing mutations. Ionizing radiations are now readily available to most plant breeders: X rays from X-ray tubes and other devices; gamma rays from radioactive isotopes (chiefly cobalt 60 and cesium 137), and neutrons from nuclear reactors or special neutron generators. It must be said, however, that considerable room remains for improvement in employing the technique.

In addition to the ionizing radiations as a means of inducing mutations there are a number of chemical mutagens. Their effect is so similar to that of radiation that they have been called radiomimetic substances. The most effective chemicals are several derivatives of sulfonic acid, notably ethyl methane sulfonate (EMS).

Although chemical mutagens and ionizing radiation have similar effects, they apparently do not work in quite the same way. A serious limitation of chemical mutagens as compared with ionizing radiation is their ineffectiveness when they are applied to the vegetative parts of a plant. As a result they are still used only as supplementary mutagens for treating seeds. On the other hand, there seem to be subtle qualitative differences between

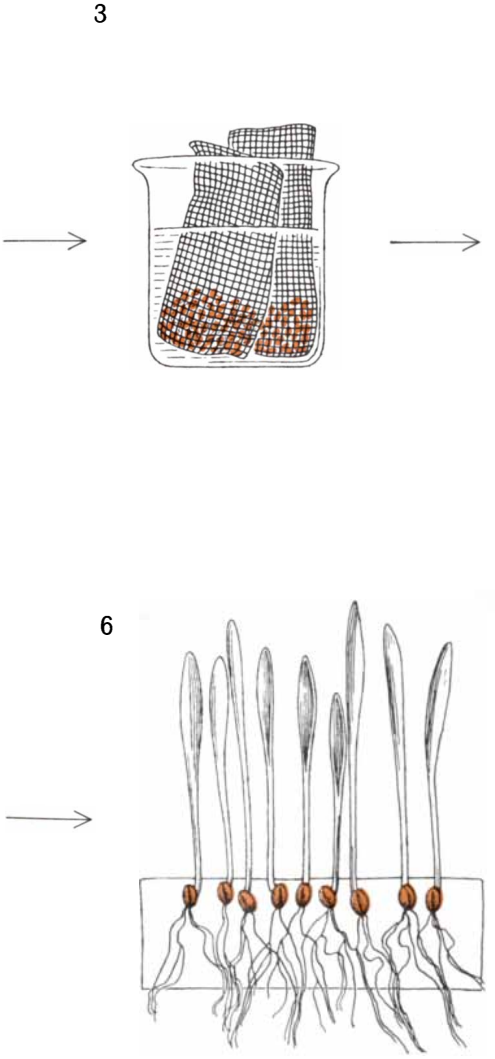


IRRADIATION OF SEEDS IS A COMMON way of inducing mutations. Seeds (*color*) are pretreated for two weeks in a desiccator (*1*) and then put near a source of radiation, in this case (*2*) a nuclear reactor producing neutrons. After irradiation the seeds are soaked in distilled water (*3*) for about an hour at a temperature near 20 degrees Celsius. Next (*4*) the seeds are put between blotters, 10 seeds to a blotter sandwich. Sandwiches, grouped in a tray containing a shallow layer of distilled water, are put in an illumi-

these two types of mutagen with regard to the kinds of mutation induced.

To what extent these differences between the mutagens are real or are caused by adjustable physiological factors of the treated material is not very clear. In practical plant-breeding programs it is common to rely on more than one mutagen to ensure the induction of a maximum spectrum of mutations. Many plant breeders make a practice of having different batches of seed treated with gamma rays, neutrons and one chemical mutagen, such as EMS. They then choose from the material resulting from these three treatments. Combined treatment, using different mutagens for the same seeds, has not proved to be advantageous.

Induced mutations can be used in plant breeding in many ways. The most direct way is to multiply the seed of the induced mutant and make it available to the grower as soon as enough seed has been produced. One of the advantages of this method is the short time usually required for developing an improved variety.



nated chamber maintained at high humidity (*5*). Plant growth is periodically measured and charted (*6*). Mutations are normally found in second generation after irradiation.

A case in point is provided by the experience of M. S. Swaminathan, now director of the Indian Agricultural Research Institute, when in 1963 he brought the first varieties of Mexican wheat to India and tested them. He was immediately struck by their remarkable yield under Indian conditions and made arrangements for their speedy introduction into Indian agriculture. At the same time he knew as soon as he opened the first bag of seeds that the Mexican varieties could not easily be sold to Indian consumers: the grains were red, whereas an Indian likes his whole wheat, unleavened chapati bread to have an amber color. A red chapati probably appeals to the Indian appetite about as much as an uncolored margarine does to mine.

Swaminathan therefore decided to initiate a "crash" breeding program to change the color of the Mexican grain while maintaining the high yield and other good agronomic characteristics of the wheat. He used all the usual methods of plant breeding, including the treatment of the Mexican seeds with gamma rays. In his huge population from the offspring of the irradiated seeds a few plants containing the desired amber seeds were discovered. From then on the breeding effort consisted solely of testing and multiplying the chosen lines. In three and a half years the induced-mutant variety Sharbati Sonora was released to growers. It was readily accepted.

Swaminathan had earlier used this method to add awns (the spiny projections of the wheat head) to an awnless variety of wheat. Farmers disliked the awnless variety, believing that the awned head is less attractive to birds.

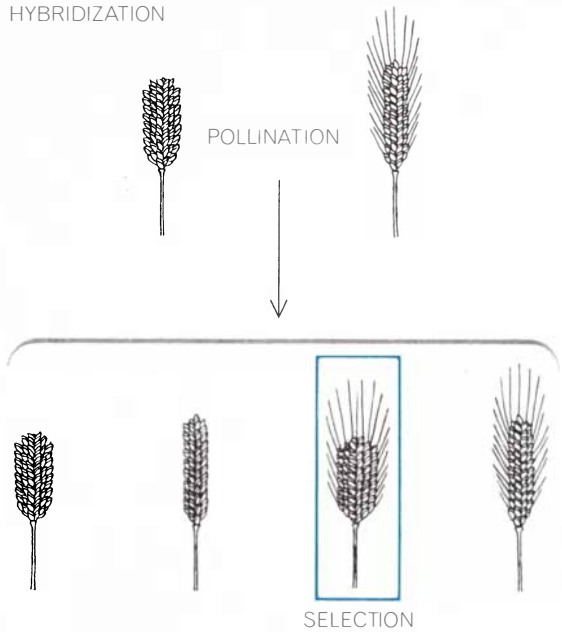
Workers at Swaminathan's institute, using the same approach, recently succeeded in reducing the time required for a variety of castor bean to reach maturity from about 270 days to 120 days. In this way they freed enough time and space for an additional crop to be grown within the original period. The yield of the new variety, Aruna, is also higher than that of the original variety because of its synchronous flowering and its resistance to drought.

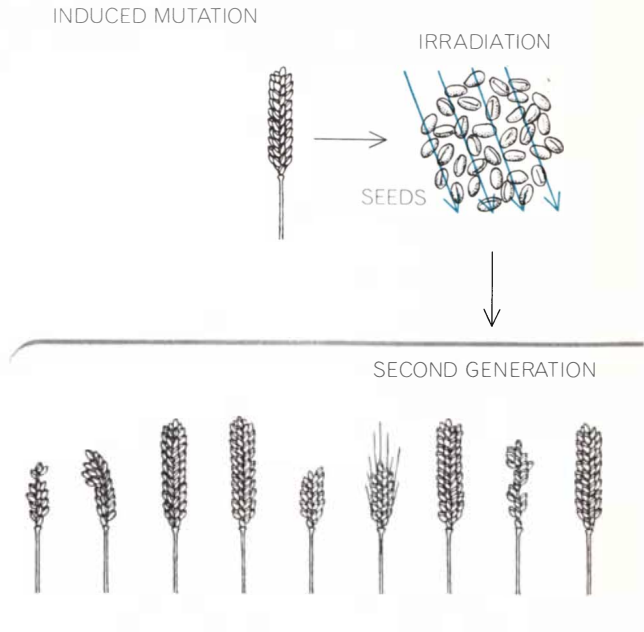
Another advantage of the direct utilization of induced mutants as commercial varieties is the specificity of the improvement usually achieved. An ideal application of this principle can result in the restoration of a generally successful and adapted variety that is on the decline for want of a specific agronomic trait, such as strength of stem or resistance to a disease. The alternative would be to find the missing trait in another variety, cross-pollinate that variety with the commercial one and then go through a long selection procedure, selecting for all the good attributes of the original variety plus the one trait sought from the other variety.

This result is not always easy to achieve, since the desired trait may be governed by a gene located on the same chromosome as other genes that give rise to undesirable characteristics. Such linked genes are often difficult to separate by conventional means. Even here a mutagenic treatment is useful because it can result in breaking up such linkages, that is, freeing the desired gene from its undesirable associates. Mutagenic treatment of the commercial variety may, of course, result in a mutation giving rise to the desired trait directly without resort to a cross-pollination program. It is quite common for a plant containing such an induced mutation to remain unchanged in most other significant agronomic traits, although there are exceptions.

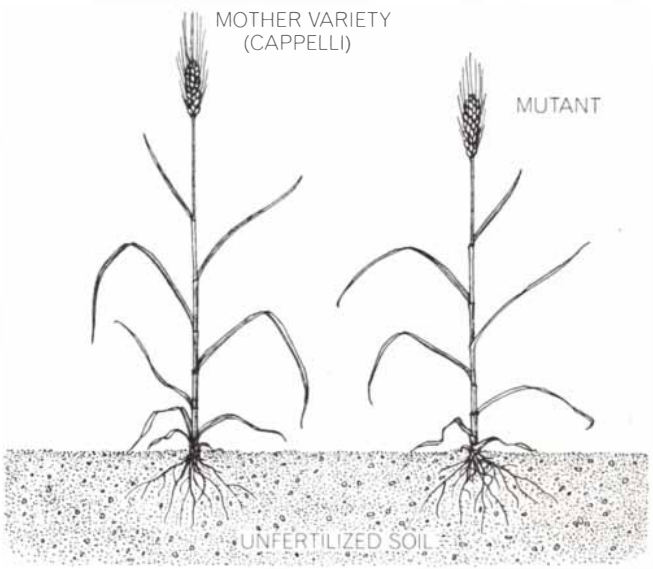
This special attribute of induced mutants is extremely important and provides the plant breeder with a unique complementary approach. A number of commercial varieties have been developed on this principle. New varieties of Italian durum wheat provide a good example. The Italian pasta does not really live up to its reputation unless one uses special kinds of durum wheat. The Italian standard is the old variety called Cappelli. Some of Italy's neighbors know this, and they grow what they call Senator Cappelli to sell to the Italians. Of course pasta (spaghetti, macaroni and other noodles) is no longer eaten only by Italians, and good durum wheat is needed in many parts of the world.

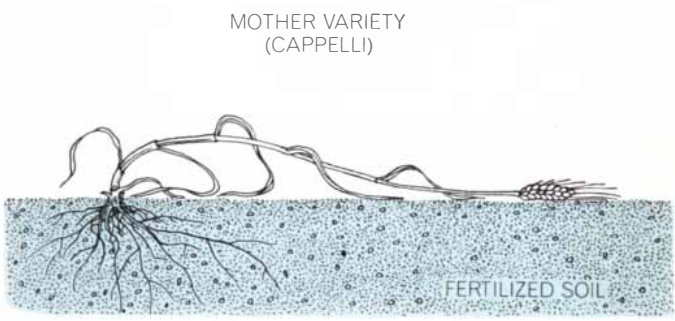
Cappelli was considered a high-yielding variety. When yields of bread wheat were increased by the application of large quantities of fertilizer and by the introduction of new varieties of wheat that responded to the fertilizer, however, the old Italian pasta varieties lagged behind. The problem is that when more fertilizer is applied, the old wheat varieties, in contrast to the new dwarf types, respond by growing in height. The stems become weak and, particularly during rain and wind, are not able to



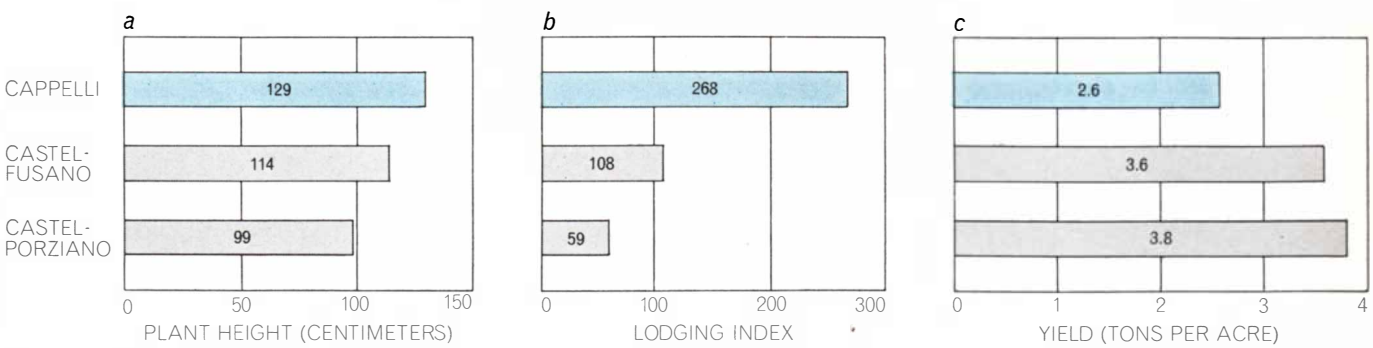


METHODS OF BREEDING include cross-pollination of two varieties of a plant (*left*) and induced mutation (*right*), in this case by irradiating seeds. Cross produces plants combining characteristics of both parents, whereas progeny of plants arising from irradiated

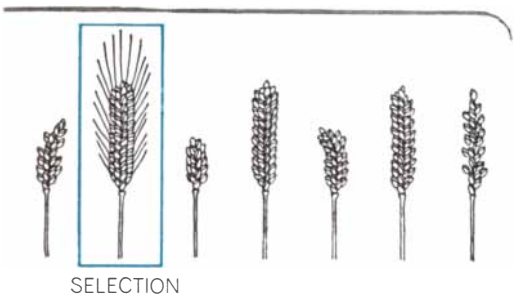




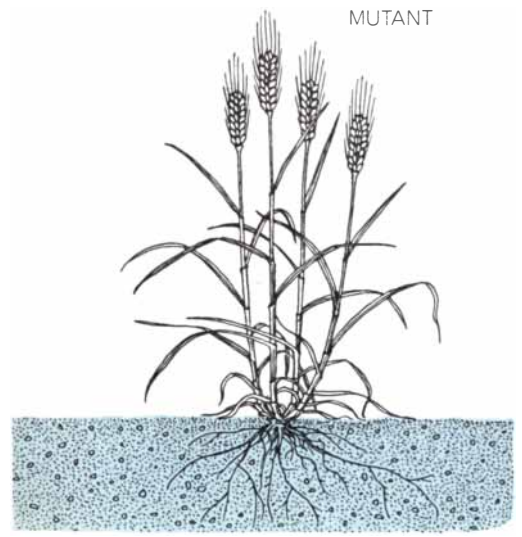
DURUM WHEAT was improved in Italy by induced mutation. The standard Cappelli variety was satisfactory when grown in unfertilized soil, but in fertilized soil (*color*) it tended to lodge, or bend, during wind and rain. As a result of induced mutation new



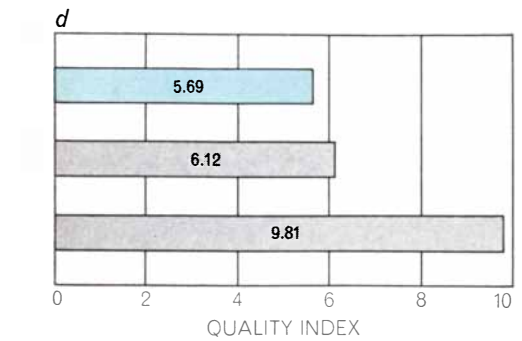
CHARACTERISTICS of Cappelli durum wheat and two mutant varieties, Castelfusano and Castelporziano, are compared. Cappelli, the mother variety, is represented by colored bars, the mutants by gray bars. In the lodging index a lower figure shows less lodg-



seeds will show a number of mutant characteristics not found in the mother plant.



varieties were developed that were shorter and had stronger stalks and so did not lodge.



ing; in the quality index a lower number shows fewer undesirable spots on the grains.

carry the weight of the grain heads. The result is that the plants lodge, that is, their stems bend or break, resulting in a reduction in yield rather than an increase [*see illustration on next page*]. Improvement was achieved by crossing the old wheat with other high-yield and lodging-resistant varieties, but the quality of the pasta suffered.

G. T. Scarascia-Mugnozza, who was then working at the Italian nuclear research center at Casaccia, solved the problem by treating seeds of Cappelli with neutrons and selecting for shorter and stronger stems and high yield while retaining the other good qualities of Cappelli. The two new mutant varieties, named Castelfusano and Castelporziano, are considerably shorter than Cappelli, and their stem is much stronger, making them essentially immune to lodging. Their yield is higher, and their grain quality remains nearly the same as that of Cappelli for one of the mutants; the other mutant has a quality that is lower but is still acceptable [*see bottom illustration on opposite page*].

The spring barley variety called Bonneville is widely grown and well liked in Utah. Farmers complained, however, that it was difficult to thresh: the awns tended to remain after threshing. This variety was irradiated, and among the offspring were several plants with brittle awns that were easily broken off during threshing. One of these mutants was released last year under the name Bonneville 70, indicating that it is really an improvement over Bonneville and not simply a new variety.

Although the mutant is almost indistinguishable from Bonneville, it does have another changed characteristic in that it seems more susceptible to loose smut under field conditions. Why other characteristics can be affected in a given mutant variety is usually explained by one of two reasons. One is pleiotropism: the mutant gene that was selected governs characteristics of the plant other than the characteristic sought. The other reason is that the mutant variety may represent more than one mutation.

An example of direct mutation breeding in the peppermint plant illustrates the success of mutation breeding where all other methods had failed. It could be called the story of how the peppermint flavor was saved. The problem was serious. The peppermint flavor is used in chewing gum, toothpaste and candy—products worth more than $1 billion per year. It comes from peppermint oil, which is obtained by steam distillation of the hay of the peppermint plant. Since 1890 all the commercial peppermint oil in the U.S. has been distilled exclusively from the hay of a single strain (the Mitcham variety) of the peppermint plant *Mentha piperita* L.

Some years ago this strain was seriously threatened by attacks of a disease called verticillium wilt. *M. piperita* lacked resistance to the disease, but a related species—*M. crispa* L., a wild, fertile spearmint plant—does have resistance. It is possible, but most difficult, to hybridize these species; Mitcham peppermint is sterile. Extensive crossing programs, also involving other species of *Mentha*, were carried out in the 1940's and 1950's. Many of the hybrids showed wilt resistance, but their flavor was no longer truly peppermint and therefore they were unacceptable to industrial consumers of peppermint oil.

In 1955 Merritt J. Murray of the A. M. Todd Company decided as a last resort to turn to radiation breeding, which at the time seemed like quite a gamble. He took bags of dormant stolons (bud-producing branches) of the Mitcham strain to the Brookhaven National Laboratory and had some irradiated with X rays and others with neutrons. After three years of tests to determine the correct treatment he spent 10 years growing immense populations of the offspring of the irradiated stolons. By 1960 there were some six million plants in his test area.

Attacks by the disease so reduced this stand that only 1 percent of the plants survived into the sixth year. Out of this population Murray was able to isolate 15 strains that had varying degrees of resistance to the wilt. Tests for oil quality and other agronomic traits of these mutants showed that several of the resistant strains retained the delicately balanced flavor of the original Mitcham strain.

This story also illustrates the importance of growing large populations that are subject to rigorous selection. On the basis of his experience Murray has suggested that mutation breeders should concern themselves more with specific breeding objectives and a proper screening procedure than with the type of damage done to the plant by irradiation. In his experiments harmful mutations affecting chlorophyll and growth were eliminated by six years of natural selection.

There are many other applications of induced mutations in plant breeding. One is the use of desirable mutants as breeding material for crosses with other varieties. For this purpose the induced mutants are usually handled in the same way as any other breeding material containing a desired characteristic. The

breeding objective is to transfer, through controlled hybridization and appropriate selection, the desired characteristic or characteristics from the mutant variety to another variety or vice versa. It seems likely that before long the use of induced mutations in crossbreeding will constitute their greatest potential contribution to plant breeding.

Two other lines of work that are made possible by induced mutations are what might be called chromosome engineering and adapting to various crops the hybrid-vigor breeding technique that revolutionized the production of corn. The pioneer work in chromosome engineering was done by E. R. Sears of the University of Missouri. By means of irradiation he transferred a gene for resistance to leaf rust from the wild grass species *Aegilops umbellulata* to common wheat. He first employed a complicated crossing procedure to transfer the entire *Aegilops* chromosome containing the desired gene to a wheat plant, which thus had 43 chromosomes instead of its normal complement of 42.

In addition to the desired gene for resistance to leaf rust, however, the extra chromosome carried other harmful or less desirable genes from the *Aegilops* parent. A treatment with X rays broke up the *Aegilops* chromosome and a wheat chromosome in that plant. When the broken parts had rejoined, one of the reconstructed chromosomes consisted almost entirely of the wheat chromosome, with the addition of a small piece of the *Aegilops* chromosome containing the desired gene.

The main problem in applying the hybrid-vigor breeding technique to crops other than corn is ensuring specific hybridization between two or more selected lines on a large scale. This means either emasculating one of the lines, which is a most tedious process, particularly with crops that are normally self-pollinating, or achieving male sterility in one of the lines. Irradiation and induced mutations have been used for this purpose, and there are promising indications that male-sterile lines so obtained may form the basis for production of such plants as hybrid barley.

The attitude among plant breeders toward the possibilities offered by radiation-induced mutations ranges from overenthusiasm to skepticism. Our joint division of the Food and Agriculture Organization and the International Atomic Energy Agency has attempted to steer a middle course between these views. On the basis of our own experiments and advice from prominent breeders we have prepared a *Manual on Mutation Breeding,* which was published last year. Our laboratory and the Austrian Atomic Energy Research Center have collaborated in developing a facility for use in nuclear reactors, where seeds can be irradiated with neutrons. The facility screens out gamma rays and slow neutrons so that the dosage of fast neutrons can be determined with precision.

We have organized coordinated research programs in a number of countries. As a result of a typical program under way in Southeast Asia several improved mutant lines of rice are undergoing advanced agronomic testing. Korean and Japanese agronomists working in collaboration have isolated mutants resistant to the devastating disease called blast. An Indian group has improved the cooking quality of rice by conferring the fine-grain characteristics of the "indica" type of rice plant, which is nonsticky and rich in the starch amylose, to the "japonica" type, while retaining all the other traits, including resistance to bacterial blight, of the japonica strain. This is a particularly significant achievement in view of the difficulty of bringing the combination about by crossing the two types, which had been tried with limited success for 20 years.

In cooperation with other interested agencies our division has organized international field trials of promising mutants of rice and wheat. Rice mutants that had been developed before the coordinated program started were tested immediately, in collaboration with the International Rice Research Institute. The indica mutants did not yield quite as

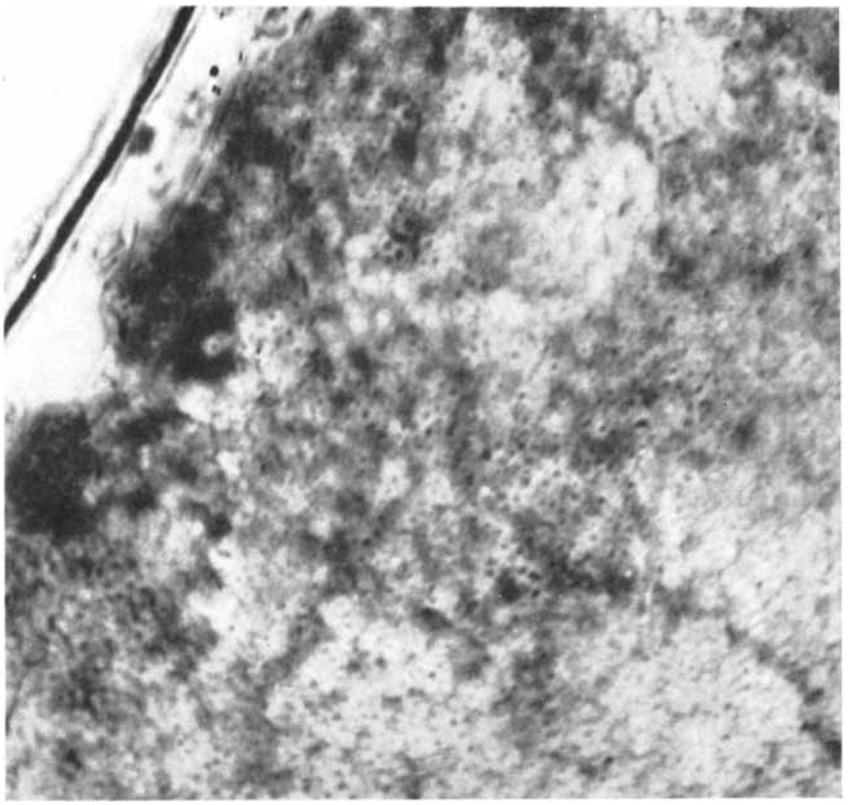
LODGED WHEAT appears as the lighter areas in this photograph made at a test plot in Italy. The wheat has been bent over by wind and will have a poor yield as a result. Mutant varieties that are resistant to such lodging appear as dark areas in the photograph.

well as the new high-yield varieties from the Philippines, although the eating quality and local adaptability of some of them better suited the countries where they were developed. The japonica mutant Reimei was the highest-yielding line tested in its region of adaptation. We are now planning international trials to test the mutant lines that have been developed under our program.

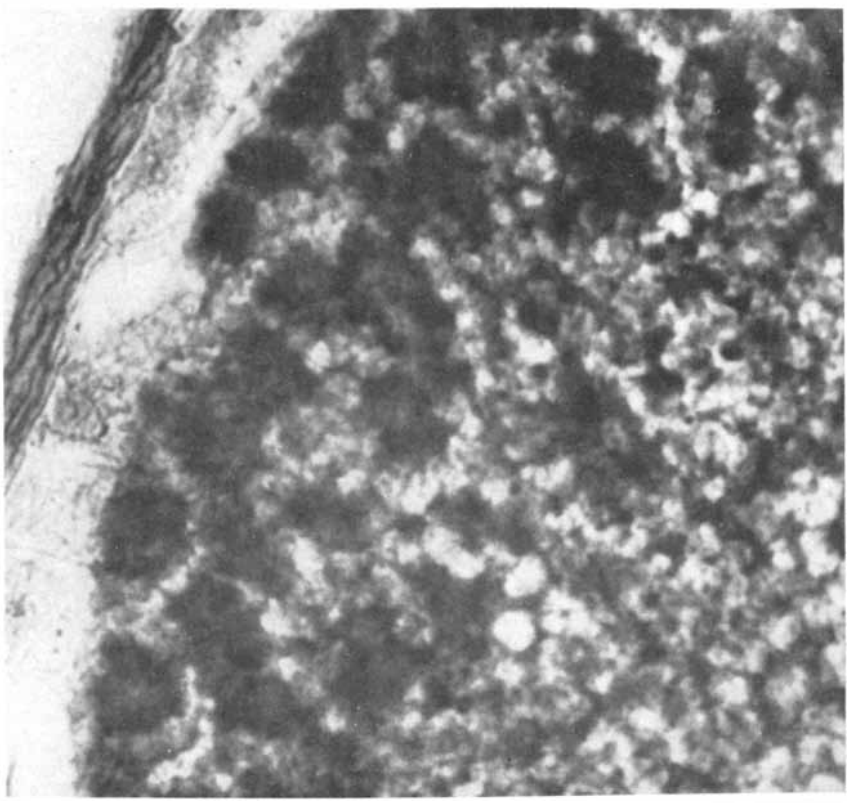
The wheat trials involved the durum mutants developed in Italy by Scarascia-Mugnozza. These trials have been carried out every year since 1966 in a number of countries around the Mediterranean and in the Middle East. The mutants have shown superiority in yield and lodging resistance in nearly all the countries over those years when compared with the best local durum varieties and with other control varieties.

Our division is now considering coordination of research on the use of induced mutations to improve specific deficient characteristics of crop plants. Particular attention is being given to problems of disease resistance and protein content. I have already described several successes in improving resistance to disease by means of induced mutations. There are also promising results with proteins. S. Tanaka of the Institute of Radiation Breeding in Japan, working with the rice variety Norin 8, has developed mutants that contain considerably more protein than the standard variety. Increases in protein in barley have been reported by Ewald A. Favret of Argentina, in the lysine content of barley by Hans Doll of Denmark and in corn protein by J. Dumanovic of Yugoslavia. Results with rice reported by Swaminathan and his associates in India indicate that it may be possible through induced mutations to redistribute protein in the rice kernel. Normally the protein is confined to the outer layers. Redistribution would be a most significant achievement in view of the general preference for polished rice, which loses a good deal of its protein when the outer layers are removed. Many naturally high-protein varieties of the legume family also have been improved by mutations.

Our division is coordinating a number of projects involving the induction of mutations for improved protein. We also plan to coordinate studies on the application of radiation and isotopes to analytical techniques for rapid mass screening of plant seeds for improved protein. If successful, these ventures could contribute significantly to the problem of providing adequate supplies of nutritious food for the world's growing population.



STANDARD RICE has most of its protein in the outer layers of the grain. In this cross section of a grain the protein appears dark as a result of staining. Since most rice is milled or polished, which removes part of the outer layers, much of the protein is lost.



MUTANT RICE containing more protein (*dark areas*) that is distributed throughout the grain was developed at the Indian Agricultural Research Institute. The induced mutant contains 13 percent protein, as compared with about 8 percent in the original strain of rice.

The Origins of Hypodermic Medication

The injection of drugs is now taken for granted, but originally it was a bold innovation. The man who introduced the procedure some 120 years ago sought only to relieve the pain of neuralgia

by Norman Howard-Jones

The hypodermic syringe shares with the stethoscope the distinction of being almost a symbol of the practicing physician. There must be few people with access to medical care who have not received a hypodermic injection to protect them from disease or to give rapid relief from pain. Millions of diabetics have been taught to give themselves daily hypodermic injections of insulin.

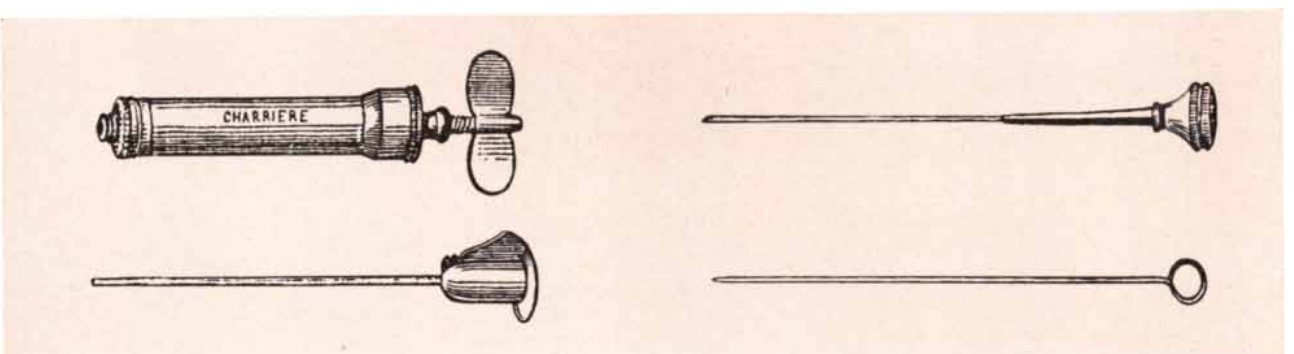
The main advantages of this method of administering drugs, which takes its name from the Greek words meaning under the skin, are that the active principles are quickly absorbed into the bloodstream from the subcutaneous tissue and that they are not altered or destroyed by the digestive juices. These advantages were not, however, what the Scottish physician Alexander Wood had in mind when he introduced the procedure in 1853. He intended it as a means of anesthetizing peripheral nerves and thereby relieving pain in patients with neuralgia. Another peculiarity in the history of this method of administering drugs was that for many years it was not recognized that the hypodermic injection of morphine, which was regarded as a harmless substitute for taking the drug orally in the form of opium, was the equal of or the superior to opium-eating in producing drug addiction. A third curiosity in this strange story is that nearly all the standard histories of medicine attribute the introduction of hypodermic medication to the wrong man, the French physician Charles Gabriel Pravaz.

A noteworthy feature of the opening two decades of the 19th century was the isolation for the first time of the active principles of a number of drugs, most of them alkaloids. They included morphine, atropine, strychnine and many less familiar compounds. The availability of compounds that were highly active in minute doses was a stimulus to the search for new methods of administering them.

In 1809 the French physiologist François Magendie, who experimented with animals in various ways in an effort to elucidate physiological processes, administered a Javanese arrow poison to dogs by coating the point of a wooden barb with it and thrusting it into the rump. The effects were lethal. The active principle of this poison was subsequently found to be strychnine. (Magendie's venture may well have been the first step in experimental pharmacology. Later another arrow poison, curare, used by primitive South American tribes, was to become a valuable aid in modern anesthesiology.)

The notion of administering drugs through the skin gained ground slowly. In 1825 the French physician A. J. Lesieur published an account of what he termed the "endermic method." It consisted of the application of a vesicant to blister the epidermis; then the drug—usually one of the recently isolated alkaloids—was applied to the denuded skin as a powder, a solution or an ointment. Six years later Sir Robert Christison, a Scottish physician, suggested that whales might be killed by fastening a phial of prussic acid to a harpoon "in such a way that the phial should break when a strain was put upon the harpoon after entering the body of the animal."

In 1836 the French physician G. V.

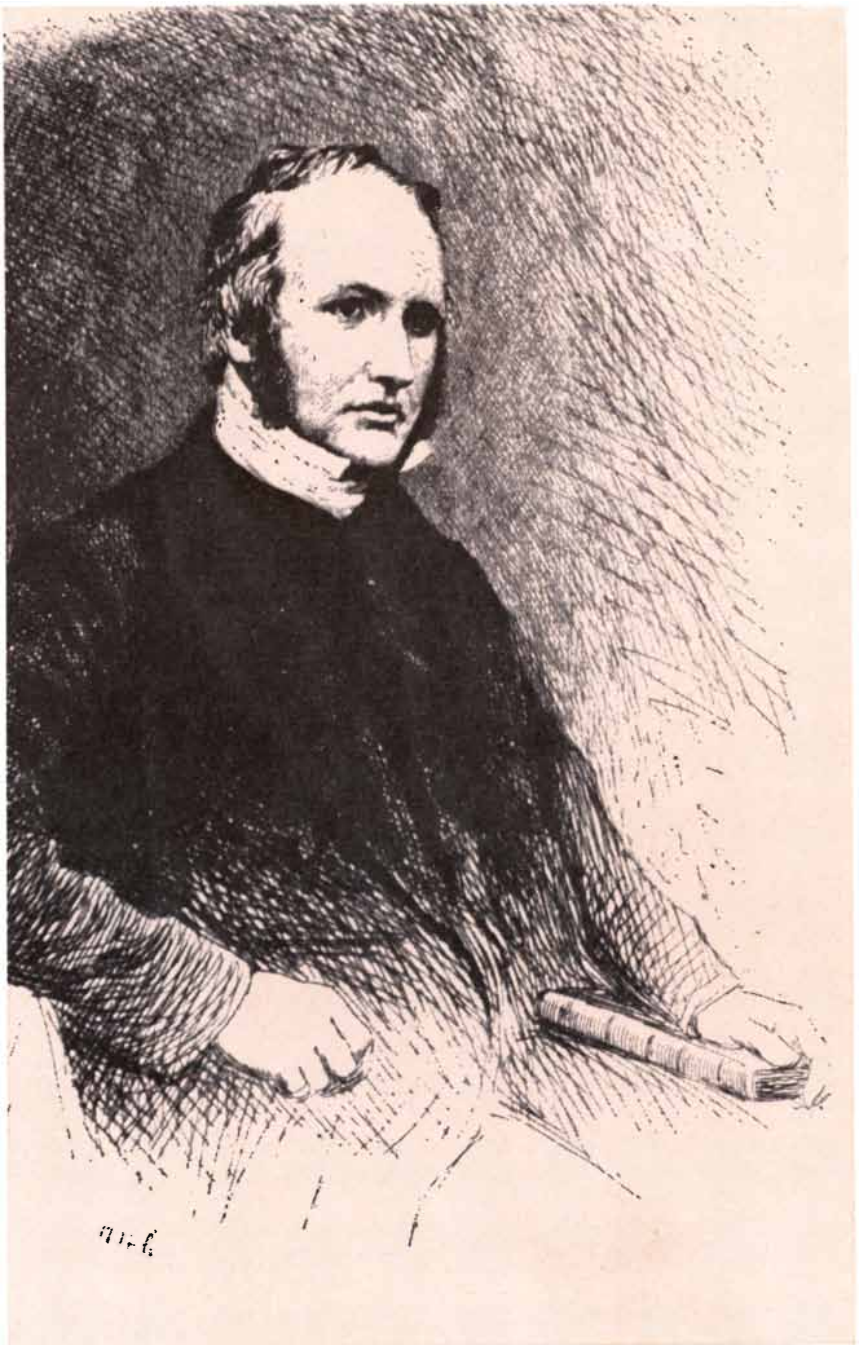


HYPODERMIC SYRINGE of the kind used in the late 1850's to administer a variety of drugs is illustrated in an article that a French physician, Louis Jules Béhier, published in 1859. Its cylinder is metal; to deliver the dosage the threaded piston is screwed down. Béhier called his syringe a "Pravaz apparatus," honoring the French physician and animal experimenter Charles Gabriel Pravaz.

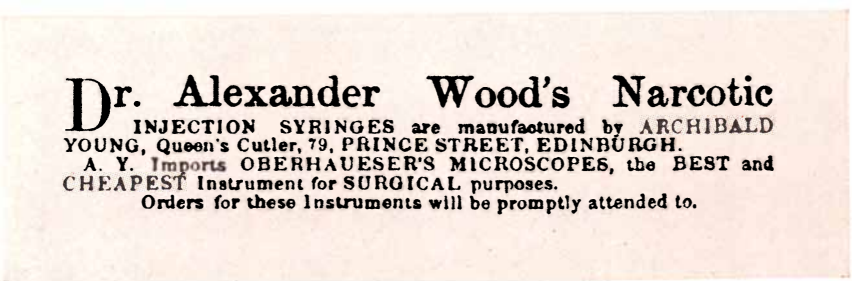
Lafargue took a further step toward hypodermic medicine as it is now known. In papers read first in Paris to the Academy of Sciences and then to the Academy of Medicine he described how, after using the Lesieur method, he conceived the idea of introducing morphine under the skin by means of a vaccination lancet. The point of the lancet was dipped in morphine and then forced almost horizontally under the skin. After a few seconds it was withdrawn. Although Lafargue regarded his inoculation primarily as a form of local medication, he did pose the question of whether or not the morphine so administered might have a general action on the organism. He did not, however, pursue the idea.

In 1859, after Wood's method had become known, the French physician Louis Jules Béhier published an account of his own experience with hypodermic medication. He had used a syringe that differed from the one employed by Wood, and he called it the "Pravaz apparatus." Pravaz had used this type of syringe to inject chemical coagulants into the blood vessels of animals (he was trying to find a treatment for aneurysm in humans) but never for hypodermic medication either in his patients or in animals. Nevertheless, Béhier's use of Pravaz' name led to the belief that it was he who had invented the hypodermic syringe and introduced hypodermic medication into practice. (In 1927 *La Presse Médicale*, the leading French medical weekly, reported a campaign to save the memory of Pravaz from oblivion by erecting a monument in his native village to "the father of the hypodermic method.")

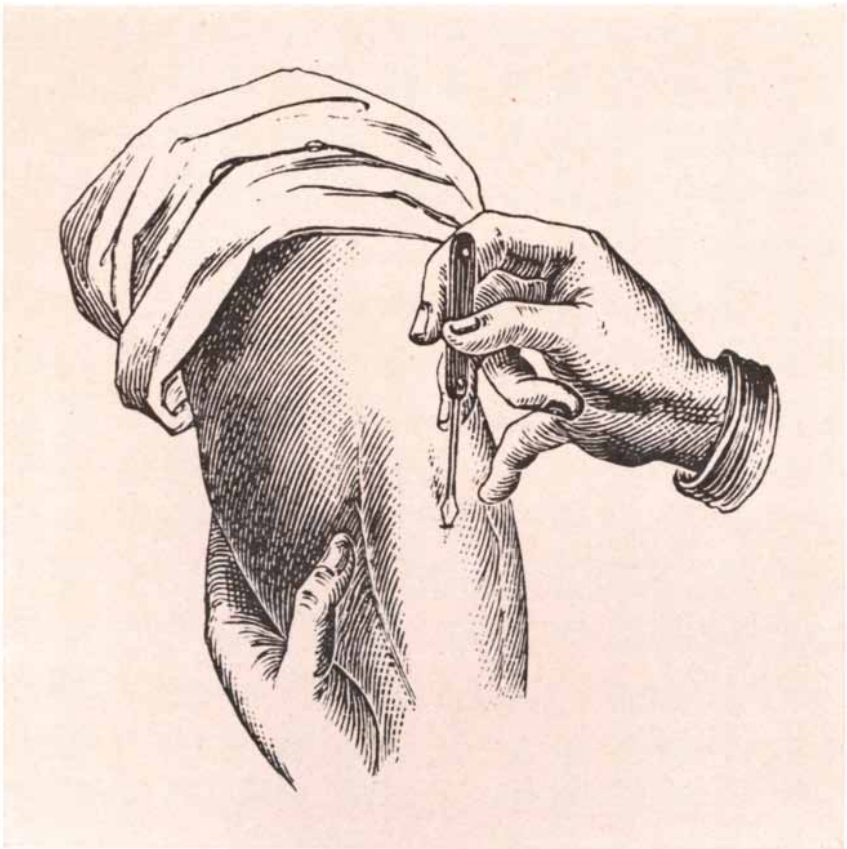
As interest in the hypodermic injection of medicaments grew in France, Lafargue came on the scene again to raise a dissenting voice. He felt, he wrote in 1861, that he should break the silence about "Wood's method." Syringes were costly and delicate; they deteriorated rapidly, and handling them required a deft touch. Only a few physicians had them, and few patients had had or would be likely to have the opportunity of benefiting from Wood's method. Lafargue proposed an alternative method, which he called "hypodermic inoculation by plugging." It consisted of inserting medicated pellets under the skin by procedures that now seem rather bizarre. The skin was pierced—a darning needle would do the job, according to Lafargue—and the pellet was inserted with the fingers or with tweezers. The puncture was then covered with a piece of stamp paper or whatever other adhesive might



SCOTTISH PHYSICIAN, Alexander Wood, introduced the technique of hypodermic medication in 1853, administering morphine subcutaneously to relieve the symptoms of neuralgia.



EDINBURGH CUTLER, Archibald Young, offered "narcotic injection syringes" designed by Dr. Wood to the medical profession in this 1858 advertisement in *British Medical Journal*.



PRESYRINGE METHOD of administering morphine subcutaneously was developed by the French physician G. V. Lafargue in 1836. A vaccination lancet was dipped in morphine and thrust under the skin. Lafargue later used a "dry" syringe to implant medicated pellets.

be ready to hand. Lafargue also devised a kind of implantation gun, which he called a dry syringe. (The implantation of solid pellets reappeared as an original discovery in 1937, when two British workers described a technique for implanting in animals tablets containing hormones. The method was briefly employed in Britain and the U.S. in the treatment of human patients.)

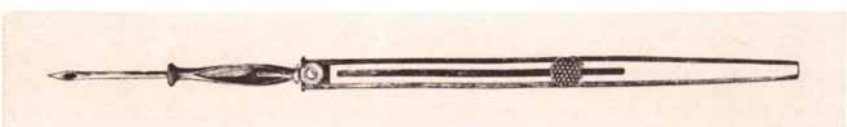
As late as 1873 physicians were exercising their ingenuity to find new techniques for the subcutaneous administration of drugs. In that year the British physician J. M. Crombie, giving as his justification "the dearness and delicacy of the syringe," advocated the use of morphine-impregnated silk threads slowly drawn through two perforations in the skin by means of a suitable needle. Neither this method nor the others survived the competition of hypodermic injection.

It cannot be said that the search for new methods of administering drugs had a sound scientific basis. The new alkaloids had been discovered; they undoubtedly had a powerful effect on the human organism, and doctors were determined to use them. Wood wrote in 1858 of having tried strychnine in neuralgia. He said he had cured a case, "but I never tried it again, for it seemed likely to kill two people: my patient, an old lady, who nearly died of the poison; and myself, then a young doctor, who nearly died of fright." Béhier preferred to treat neuralgia with massive doses of atropine. He dispassionately described the side effects, which included malaise, dizziness and hallucinations.

Most of the therapeutic results claimed by the early users of hypodermic medication are so inconsistent with the present knowledge of the pharmacological action of the drugs administered that scant reliance can be placed on any of the observations made. This skepticism is fully justified by the astonishing claims made in the latter years of the 19th century for the injection of pure water as a therapeutic procedure. A French physician, L. Lafitte, read a paper on the subject in 1875. After seeing, as he recounts, the "miraculous and immediate manner" in which several hypodermic injections of water, administered by his then chief in 1872, had "cured or relieved" the symptoms of a boy with acute articular rheumatism, Lafitte employed the treatment systematically. "Always," he says, "success sanctioned my trials." He thought that water exerted a physical action on nerve endings and suggested that it should replace morphine.

This communication was followed by letters from several physicians who had also been practicing this remarkable form of hydrotherapy. One of them, E. Lelut, explains how he had unwittingly injected water into a patient with sciatica who had previously been receiving morphine injections. The next day the patient thanked Lelut effusively, saying: "Doctor, how grateful I am to you! You relieved my pain today without upsetting my stomach." Lelut thought he had injected a solution of morphine, but on investigating the unusually satisfying therapeutic result he found that the hired girl had upset the bottle containing the morphine solution and, to cover her traces, had substituted plain water. He adds that since this happy experience he has employed nothing but water for injections. In the years that followed many papers were published on the therapeutic value of water administered by hypodermic injection.

Ten years before Wood published the first account of hypodermic injection an Irish physician, F. Rynd, gave an account of a method that came very near to it. On May 5, 1844, a woman aged 59 was admitted to the Meath Hospital and County Dublin Infirmary. From Rynd's description she would appear to have been suffering from pain involving the trigeminal nerve of the face. Rynd states, rather cryptically, that on June 3 "a solution of fifteen grains of acetate of morphia, dissolved in one drachm of creosote [!], was introduced to the supra-orbital nerve, and along the course of the temporal, malar and buccal nerves, by means of an instrument made for the



IMPLANTATION NEEDLE was devised by a German physician, V. von Bruns, in the 1860's as an alternative to Lafargue's "dry" syringe for placing medicated pellets under the skin.

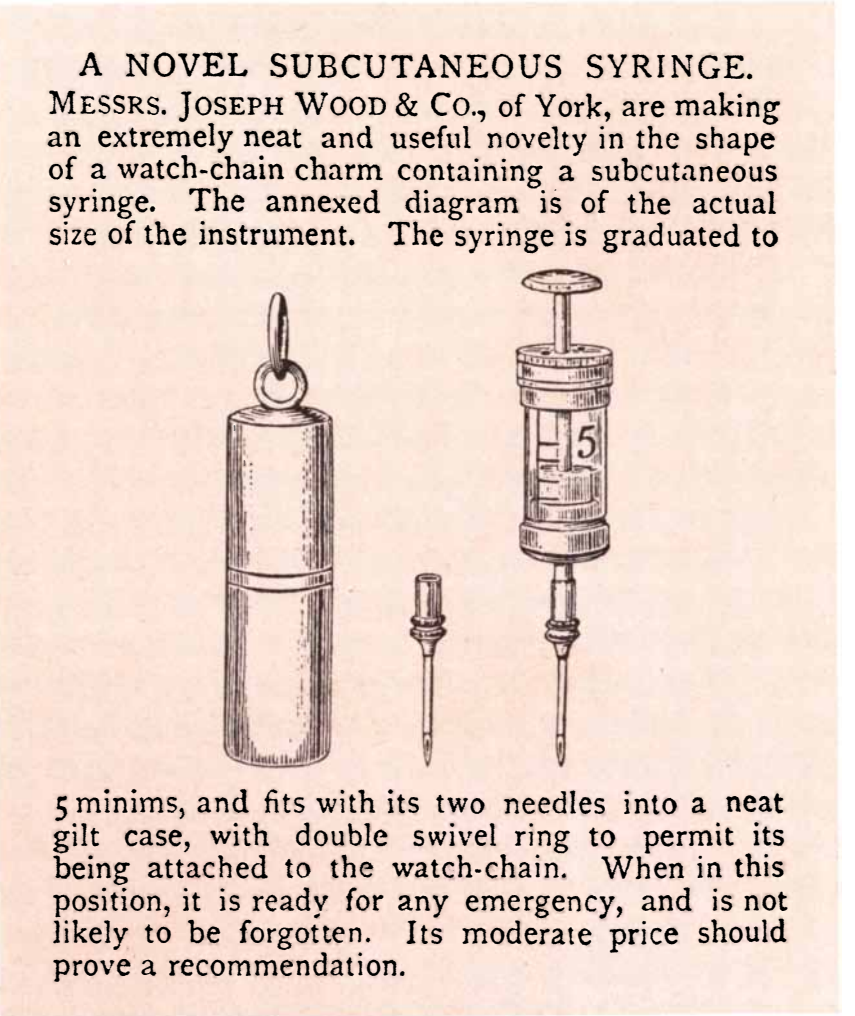
purpose." As is so often the case with new medical treatments, the result was regarded as a success.

It was not until 1861 that Rynd published a description of the instrument he had used. It was essentially a kind of hollow needle through which the morphine solution was introduced by gravity. It was typical of the rather brash claims to priority of the time that Rynd stated: "The subcutaneous injection of fluids, for the relief of neuralgia, was first practised in this country [then meaning the British Isles] by me, in the Meath Hospital, in the month of May, 1844." (He seemed to have forgotten that in his original publication in 1845 he had given June as the month.)

Rynd's gravity-flow method was not hypodermic injection as it is now known. The true innovator was Wood, whose first description of the method, published in 1855, was titled "New Method of Treating Neuralgia by the direct application of Opiates to the Painful Points." The title expresses the essence of Wood's idea: injecting morphine hypodermically to induce a local analgesia at tender points in a nerve.

Wood was apparently unaware of Rynd's 1845 publication. Since it had appeared in the *Dublin Medical Press,* which was far from being a leading British medical periodical, Wood's lack of knowledge of it is not surprising. Wood was influenced by observations made in France by François-Louis-Isidore Valleix that sensitive points could be detected along nerves in cases of neuralgia. Valleix used the technique of blistering the skin over such points with vesicants and then applying a solution of morphine to the broken surface. Wood had the idea that he could apply the morphine more directly to the affected nerve by using "one of the elegant little syringes constructed ... by Mr Ferguson of Giltspur Street, London." These syringes were intended for the injection of chemical coagulants into birthmarks; the idea was that the coagulants would close the blood vessels and result in a less unsightly birthmark. Wood said it had occurred to him that the syringe "might supply the means of bringing some narcotic to bear more directly than I had been able to accomplish on the affected nerve in neuralgia."

Fired with this notion, Wood decided to try his new method on an elderly spinster whose "cervico-brachial neuralgia" prevented her from sleeping. He ascertained the most tender spot and injected subcutaneously about two-fifths of a grain of a salt of morphine. This was a heroic dose that cured the patient's insomnia, if nothing else, for at least one night. Indeed, Wood, visiting her the next morning, was "a little annoyed to find that she had never wakened; the breathing was also somewhat deep, and she was roused with difficulty."



GILT WATCH-CHAIN CHARM, containing a tiny syringe and two needles, was touted in an 1876 catalogue of surgical instruments as a "useful novelty ... ready for any emergency."

It is rather extraordinary that notwithstanding this incident Wood continued to be convinced that hypodermic injection had a purely local effect on the nerves. It is also odd to read today that for his historic first injection he used sherry as a solvent for the morphine. "I thought that it would not irritate and smart so much as alcohol," he said, "and ... it would not rust the instrument as a water solution of opium would do."

By 1858 Wood had improved on the Ferguson syringe by graduating the barrel and by using a finer needle, which caused less damage to the tissue. In the *British Medical Journal* of October 23, 1858, an advertisement appeared for "Dr. Alexander Wood's Narcotic Injection Syringes." His second paper, published in 1858 and giving particulars of the improved syringe, attracted considerably more attention than the first one had and resulted in an extension of the use of the hypodermic method beyond the Scottish border.

In 1858 Wood was still dominated by the idea of a local action of morphine on the peripheral nerves. He maintained that the injection should be made not at the site of the pain but at a point found to be tender on pressure. He told of a woman with neuralgic pains whom he had "punctured upwards of one hundred times, always in different places; but no sooner had the pain been driven from one spot, than it took up its seat in another." He continued: "At last I had expelled it from every part of the body, except a corner of the head, and there I was puzzled how to deal with it. The fact was, I could detect no painful point

in the scalp." For Wood "no painful point" meant no injection, and the woman departed for several months with her husband to take a cure at the German baths. On her return Wood examined her twice, and on the second occasion he found "the point where the needle should be inserted." According to Wood, this final "puncture" completed the cure of the woman's neuralgia.

Among those who were stimulated by Wood's second publication to try the subcutaneous injection of medicaments was Charles Hunter, a young London surgeon who in 1858 wrote to the medical press to describe his own experiences with "the local treatment, by narcotic injection into the part." He said that two patients he had treated obtained considerable relief from the local injection of morphine, and he concluded that the narcotic "appears to exert more benefit on the local affection when it has to be absorbed from the part affected itself, probably from being brought more directly into contact with the nerves involved in the disease."

Only two weeks later, however, he wrote again to the medical press with a different conclusion. "I have given up the localisation of the remedy as proposed by Dr Wood," he said, "viz. the injecting of the narcotic into the most painful spot affected by neuralgia...." What had happened was that both of the patients had developed abscesses at the site of the injection, and Hunter therefore continued the treatment by injecting morphine in sites remote from the seat of pain. The patients obtained just as much relief as when he injected the drug into the painful area. Hunter accordingly formulated two new conclusions: "1. That by the injection of the narcotic into the cellular tissue of a part distant from that affected with the neuralgia, the relief that follows appears quite as great as when the injection is into the cellular tissue of the neuralgic part. 2. That therefore the idea that relief results from the localisation of the remedy in the painful part is erroneous—equal relief being afforded in either case (injected into the painful part or elsewhere)."

Having made an important discovery, Hunter succumbed to two temptations: he tried to build a therapeutic system around it, and he conceived an exaggerated idea of his own originality. In order to distinguish his "plan" from Wood's he introduced the term "hypodermic." In 1865 the *London Medical Times & Gazette* endorsed Hunter's claims, saying: "It is now six years [in fact it was seven] since Mr Hunter proposed the injection of medicines into the cellular tissue with their general therapeutic effect in view. In the case of medicines thus injected for general effects, he called the method 'hypodermic,' to distinguish it from the endermic, and from the local injection of Wood.... The hypodermic differs from the 'method of Wood.' The latter plan has for its object the local treatment of a local affection."

Until then Wood had not contested Hunter's claim, but this statement goaded him into a reply that was to lead to an acrimonious and undignified public exchange of correspondence. Writing to the same journal, Wood said that Hunter "is reported to have said 'the hypodermic differs from the method of Wood.' To this I reply that it does so merely in name. I called my method 'subcutaneous,' borrowing from the Latin; Mr Hunter, in appropriating it, called it hypodermic, a Greek compound having precisely the same meaning." Wood insisted that injection into the painful area was often more effective than injection at a remote site. In any case, he said, credit was due the man who "showed the plan of using the cellular tissues as a medium for the introduction of remedies into the system," namely himself.

Hunter riposted: "Does Dr Wood de-

DATE	EXPERIMENTER	SUBSTANCE USED	METHOD OR INSTRUMENT	OBJECTIVE
1809	MAGENDIE	STRYCHNINE	WOODEN BARB	TEST EFFECTS OF NEW ALKALOIDS
BEFORE 1825	LESIEUR	VARIOUS ALKALOIDS	APPLIED TO PREVIOUSLY BLISTERED SKIN AREA	LOCAL TREATMENT OF NEURALGIA
1836	LAFARGUE	MORPHINE	VACCINATION LANCET	LOCAL ANALGESIA
1844	RYND	MORPHINE	DRIP NEEDLE	LOCAL TREATMENT OF NEURALGIA
1853	PRAVAZ	COAGULANTS	CHARRIÒN SYRINGE FOR ENTERING BLOOD VESSEL	ANEURYSM OCCLUSION
1853	WOOD	MORPHINE	FERGUSON SYRINGE	LOCAL TREATMENT OF NEURALGIA
1858	HUNTER	MORPHINE	FERGUSON SYRINGE AS IMPROVED BY WOOD	GENERAL TREATMENT OF NEURALGIA
BEFORE 1859	BÉHIER	ATROPINE AND OTHER ALKALOIDS	"PRAVAZ APPARATUS" (CHARRIÒN SYRINGE)	LOCAL TREATMENT OF NEURALGIA
1861	LAFARGUE	VARIOUS SUBSTANCES IN PELLET FORM	"DRY" SYRINGE	LOCAL TREATMENT OF NEURALGIA
1869	VON BRUNS	VARIOUS SUBSTANCES IN PELLET FORM	IMPLANTATION NEEDLE	LOCAL TREATMENT OF NEURALGIA
1873	CROMBIE	MORPHINE	NEEDLE AND IMPREGNATED THREAD	LOCAL TREATMENT OF NEURALGIA
BEFORE 1875	LAFITTE	WATER	SYRINGE, UNSPECIFIED	LOCAL TREATMENT OF NEURALGIA

PRECURSORS AND FOLLOWERS of Alexander Wood in the practice of injecting or otherwise introducing substances under the skin include the French physiologist François Magendie, whose subjects were exclusively animals, and Charles Gabriel Pravaz, who is mistakenly called "the father of the hypodermic method." Pravaz used syringes experimentally but not for hypodermic medication.

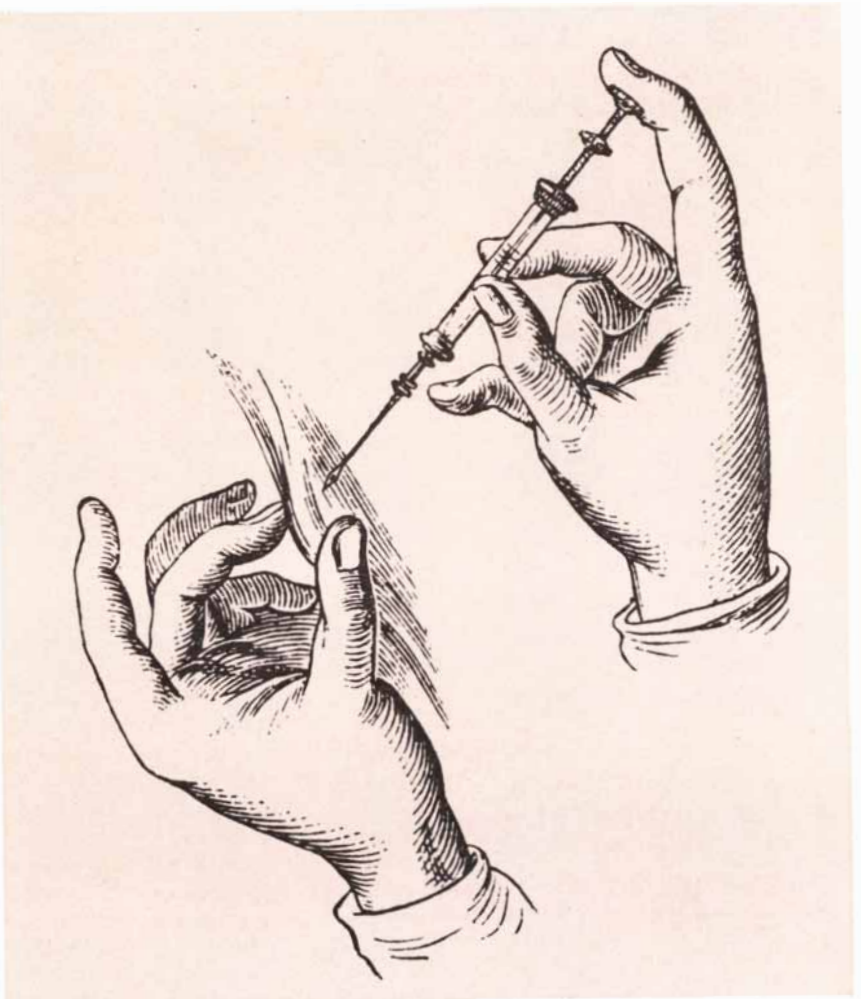
sire to claim a double priority, as to his own theory and practice, and as to one which he admits is a modification, and which is both theoretically and practically different to his plan?" Wood countered by pointing out that he had described general effects in his 1855 publication, adding: "So I did not rest my claim on my *theory* being the correct one." That statement amounted to a tacit admission by Wood that the theoretical basis of his introduction of the subcutaneous injection of medicaments was erroneous. Hunter was not content with such an admission. Wood, he said, "now hankers after more credit.... It was I who first publicly advanced the view... that the localisation of Wood was unnecessary."

At this point the editor closed the correspondence. Many other physicians had joined it, but the editor published only two of their letters. Both took Hunter's part.

In retrospect, and with the benefit of hindsight, Hunter's conclusion that the effect of hypodermic injections of morphine and other alkaloids was general rather than local seems obvious. At the time, however, it was a revolutionary idea. Indeed, it was so revolutionary that the Medical and Chirurgical Society of London appointed a special committee to settle the question. After two years the committee published its findings, which were wholly in favor of Hunter's conclusion.

Had Hunter confined himself to maintaining that the results obtained by Wood's technique were due to a general rather than a local action, he would have been fully vindicated. That he should have put himself forward as the inventor of a new technique, however, seems hardly to have been warranted. It is noteworthy that neither of the protagonists seems to have realized that the injections were not curing a disease but simply alleviating a symptom. Nor did either of them have any concept of the danger of repeated injections of morphine for trivial ailments.

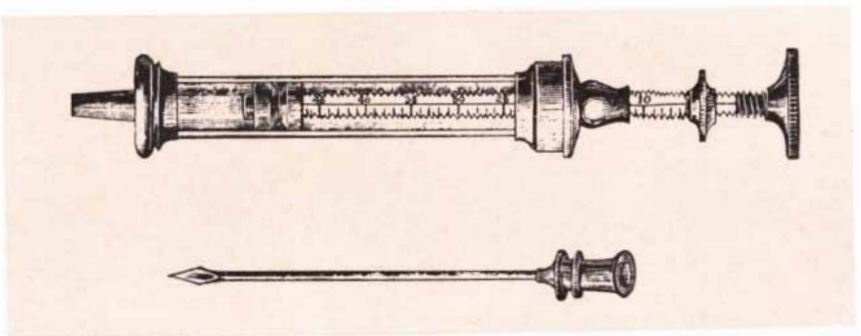
The idea of a local action of hypodermically injected medicine passed into oblivion long ago, but the absence of such an action has never been conclusively proved. More than 20 years ago, when I could find no statement in any standard textbook of pharmacology concerning whether or not morphine had a local action on peripheral nerves, I wrote to the then professor of pharmacology at one of the two ancient English universities. He replied that he would set up



INJECTION TECHNIQUE was illustrated in von Bruns's text on hypodermic medication, published in Tübingen in 1869. Syringe is the Luer model, which remains the most popular.

experiments to arrive at an answer. I heard nothing further from him. Some doubt therefore remains in my mind whether Wood and later proponents of localization may have been not altogether wrong.

Perhaps the most remarkable blind spot exhibited by the early workers in the field of hypodermic medicine was their failure to foresee the danger that repeated injections of morphine would produce addiction. In 1865 the *London Medical Times & Gazette* reported on a Professor Nussbaum of Munich who, suffering from neuralgia, "had injected morphia under his own skin more than 2000 times—sometimes to the extent of five grains of morphia in twenty-four hours." The journal apparently did not



LUER SYRINGE of an earlier design, not yet incorporating a glass piston in its cylinder, also appears in the von Bruns book. A German instrument maker, Luer lived in Paris.

consider the large number of injections and the size of the daily dose worthy of comment.

In the same year the special committee of the Medical and Chirurgical Society reported that "to confirmed opium-eaters this method has been found of much service, smaller doses than those previously taken by mouth being requisite." Hunter recommended morphine injections "as a nerve tonic in cases of great nervous exhaustion, or of irritability or great mental depression." Lafitte, illustrating the popularity of morphine injections, complacently remarked in 1875 that patients commonly cried: "Doctor, doctor, give me an injection quickly; I am suffering like someone possessed; it's my neuralgia, etc."

The first considered warning of the danger of morphinism came in 1870 from Thomas Clifford Allbutt (later Sir Thomas), who subsequently became the Regius Professor of Medicine at the University of Cambridge. "Among the numerous essays and records concerning the hypodermic use of morphia which have been published of late, both at home and abroad," he wrote, "I cannot call to mind one in which its possible dangers have been considered.... While my fears were indefinite, I felt the time had not come for me to speak. Now my experience has been greater, I have a large number of cases before me, and yet the uncomfortable fear of mischief is growing rather than diminishing." Is it not true, he asked, that doctors are often consulted by patients "who have been injecting themselves daily or more than daily during long periods of time, for neuralgias which seem, nevertheless, as far from cure as they were at the outset?" He then refers to nine patients suffering from "various forms of neuralgia" who all find relief in the "incessant use of the syringe" and who all declare that without the syringe "life would be insupportable."

A hundred years later this picture is all too familiar, with the difference that the early victims of the hypodermic syringe were not sensation-seeking adolescents but mostly respectable Victorian ladies introduced to the habit by their physicians, who were often themselves addicts. Perhaps understandably, it took a long time for Allbutt's warning to be generally heeded.

In later years history was to repeat itself. Morphine injections were first regarded as a harmless substitute for opium-eating. Then heroin and later pethidine were to become "harmless substitutes" for morphine, only to be recognized in time as no less addictive. Barbiturates and amphetamines were to be equally harmless in their turn. The medical profession cannot disclaim all responsibility for the modern scourge of drug addiction.

Another remarkable feature of the early years of hypodermic medication was the absence of any reference to infection resulting from the injection of nonsterile fluids with unsterilized syringes. It was not of course until 1867—12 years after Wood's first publication—that Joseph Lister published his first paper on surgical antisepsis, and the idea that microbial contamination could be responsible for the suppuration of wounds was not accepted for some years.

The early innovators of hypodermic medication were fortunate, as are the many diabetics today who do not get abscesses although their aseptic precautions may be far from perfect. Hunter, whose first two recipients of subcutaneous injections developed infections, was less fortunate in this respect. On the other hand, it was these misfortunes that led him to evolve the "hypodermic plan" as opposed to the "localisation of Wood." Nonetheless, even Hunter maintained in 1865 that if the site of the injection was continually varied and the "puncture" was made "with care and celerity," there was "no fear of abscess or diffuse inflammation."

In the same year Albertus Eulenberg of Germany dismissed as completely groundless the fear of local inflammatory reactions. He supported his contention by reference to a patient whose breast he had injected more than 1,200 times. Fifteen years later Eulenberg admitted that abscesses sometimes occurred, but he maintained that they were "almost exclusively" due to the use of irritant drugs or solvents.

At the same time, however, H. H. Kane in the U.S. left the problem in no doubt. As a result of a questionnaire that he published in "every prominent medical journal of Great Britain, France, Germany and America" he said of morphinists: "In some of these persons the condition of the body is terrible. Abscesses are to be seen at every stage."

By 1885 the dangers of addiction and infection were generally recognized. The passage of time since Wood had introduced the technique represented a generation. It took that long for the complications attending hypodermic medication to be widely acknowledged by the medical profession.

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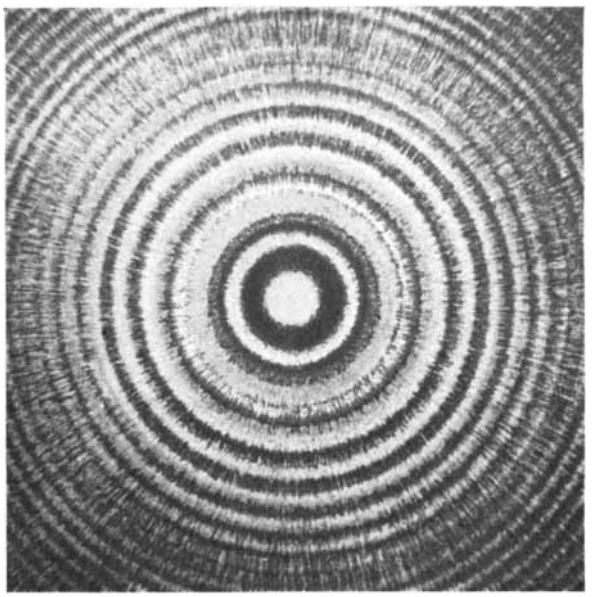

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MATHEMATICAL GAMES

Lessons from Dr. Matrix in chess and numerology

by Martin Gardner

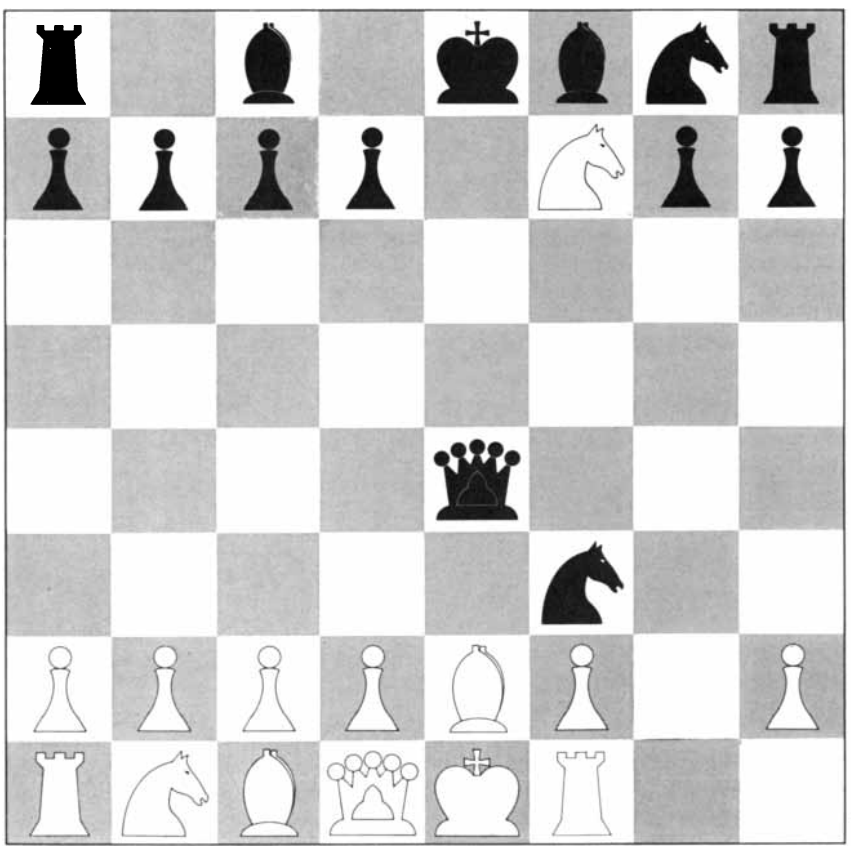
In spite of the soft winds of Hawaii, its bright azure skies and the friendly smiles of the islanders, I always have the feeling that strange mysteries lurk behind every window in this homeland of Charlie Chan. I was therefore not surprised, when I recently attended a mathematical congress at the University of Hawaii, to encounter Dr. Matrix as I was leaving the coffee shop in my Honolulu hotel. The eminent numerologist was finishing his breakfast and his hawklike nose was buried in a Japanese newspaper. I did a double take and spun around to greet him.

"Yes, it's been more than two years since we last met," he said, standing up to shake hands. He was dressed nattily in a white linen suit and his gray hair was cut in fashionably long sideburns. Two viridescent eyes regarded me with quizzical amusement.

"Are you here for the mathematics gathering?" I asked.

"No. Iva and I are on our way to Tokyo, but we stopped off in Honolulu for three weeks of relaxation in the surf."

Iva is Dr. Matrix' beautiful Eurasian daughter by his deceased Japanese wife. She was spending the morning on Waikiki Beach, just outside our hotel, but Dr. Matrix said he expected her back before lunch and he invited me to their rooms in the meanwhile. I accepted at once, even though it meant missing the morning's symposium on new developments in topology.



Dr. Matrix' smothered mate

The first thing I noticed when we entered Dr. Matrix' spacious suite was a large chess table in the center of the room. A set of intricately carved black and white ivory pieces was set up for play.

"I didn't know you liked chess," I said.

"Yes. Unfortunately I play an excellent game. Wasn't it Montaigne who wrote that chess was too serious to be entertaining and too frivolous to be taken seriously?"

"I'm not sure, but I recall Philip Marlowe, in one of Raymond Chandler's detective novels—*The Long Goodbye*, I think—saying that chess is 'as elaborate a waste of human intelligence as you could find anywhere outside an advertising agency.' "

"Quite true," said Dr. Matrix. "Why don't we waste a little intelligence while we talk?"

We seated ourselves. Dr. Matrix picked up a white and a black pawn, rattled them in his cupped hands, then held out two fists. I tapped his right hand, but when he opened it, the hand was empty. Before I could say anything he closed his right hand and opened his left. It too was empty. He quickly closed his left hand, then opened both fists. A pawn rested on each palm!

"Just some sleight of hand I learned from Tenkai, the Japanese magician," Dr. Matrix explained, chuckling. "I worked for a while as his assistant when I was young. But you *did* pick the white pawn, so it's your move."

We carefully rotated the table to bring the white pieces around to my side. "I'm not a good player," I said, shoving my king's pawn forward two squares.

Dr. Matrix made the same move with his king's pawn. I jumped my knight to king's bishop three, then Dr. Matrix protected his attacked pawn in the usual way by moving his queen's knight to her bishop three. I placed my king's bishop on bishop four—the old Giuòco Piàno opening.

"What's new in numerology?" I asked.

"The inevitable correlations," he replied. "Have you noticed how many coincidences have been turning up lately—of course they're not really coincidental—between the names of famous people and their activities?"

I shook my head as I took a pencil and small notepad from my shirt pocket.

"Well, take Lionel Tiger, for instance. He's the anthropologist who's becoming so well known for his writings on animal behavior and its relation to human behavior. His round face even *looks* a bit

lionish or tigerish. Tiger's been working closely with his colleague at Rutgers, the anthropologist Robin Fox. They first met, you know, at the London zoo. Then there's Miss Iris C. ["I see"] Love, an archaeologist at Long Island University. In 1969 she unearthed the Temple of Aphrodite at Cnidus in Turkey. Last November she identified what may be the original head of the famous nude statue by Praxiteles—the temple's main attraction. I've always regretted that in my previous incarnation as Pythagoras I lived too early to see it."

"As I recall," I said, "Miss Love found the head in the dark, dusty depths of the British Museum."

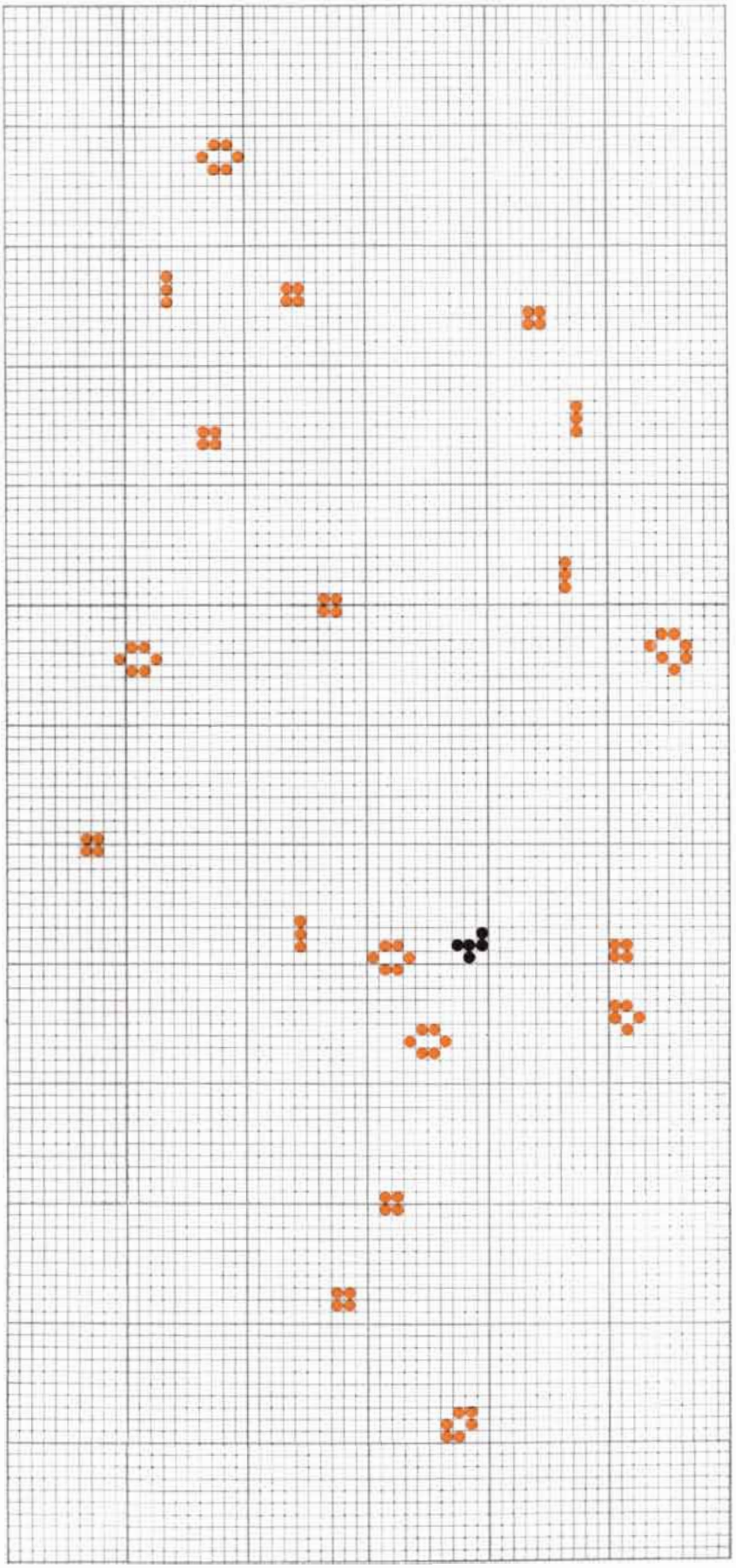
"Yes, and did you notice that the museum had given it the catalogue number 1,314? Of course 1314 is a cyclic permutation of the first four digits of pi, the most elegant of all ratios. The circle has always been *the* symbol of female beauty. Last August a book called *Oh! Sex Education* caused quite a stir. It was written, naturally, by Mary Breasted. A person's name often influences his work. There's J. J. C. Smart, the leading philosopher of Australia, and the Chinese physicist Kuan-Han Sun of Westinghouse, who's doing such exciting research on the influence of the solar wind on the moon. I could go on and on. A shoe company in St. Louis is owned by a man named Shoemaker, Dr. Shuffle is a podiatrist in Washington, D.C., a remarkable number of people named Glasser are engaged in the glass and glazing business in New York and—"

"I was told recently by Leon Svirsky, the science writer," I interrupted, "that Philip Morrison, the physicist who edits our book review section, is a friend of Morris Philipson, the director of the University of Chicago Press."

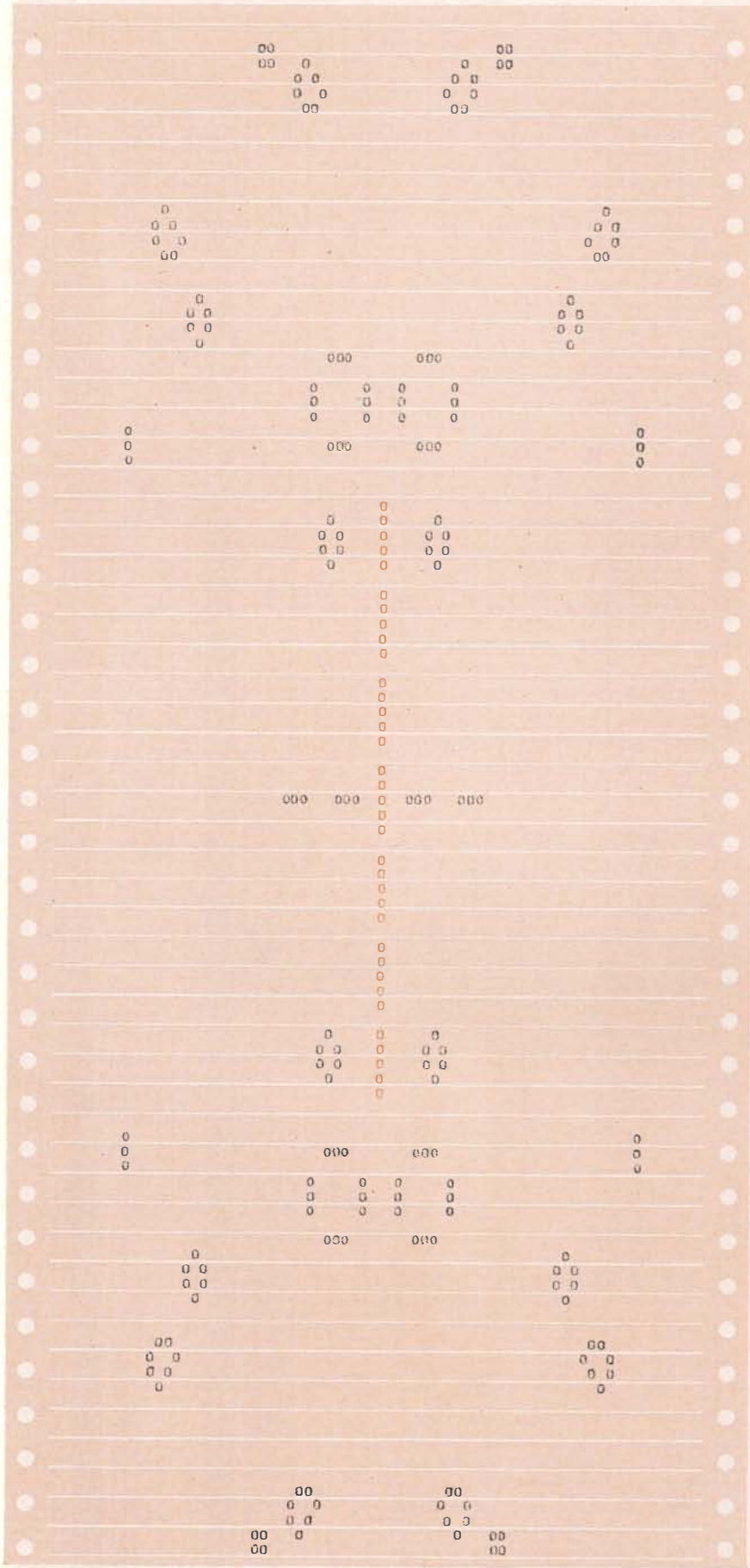
"But of course," Dr. Matrix said. "Only a dull-witted iconoclast would suppose such patterns are accidental. You find them everywhere, particularly in connection with creative people. Consider the traditional spelling rule, '*i* before *e* except after *c*, or when sounding as *a*, as in *neighbor* and *weigh*.' The rule is broken twice by 'ancient science.' Then along came Albert Einstein, who broke so many basic laws of ancient science. His last name also violates the rule twice."

Dr. Matrix waited until I had written all this down before he continued.

"In July, 1969, Dorothy Hodgkin, a British chemist, was the first to work out the exact three-dimensional structure of the insulin molecule. Observe the repetition here of the sacred digit seven. There are seven letters in *insulin, Doro-*



R *pentomino's original* (black) *and final* (color) *state. (Six gliders are out of sight.)*



Initial pattern (color) *and final state* (black) *of the 5-5-5-5-5-5-5 row*

thy, Hodgkin and *Britain.* July is the seventh month and 1969 has a digital root of seven. Insulin was first discovered by the Canadian scientists F. G. Banting and J. J. R. Macleod, both of whom have seven-letter last names."

I have space for only a portion of the rest of Dr. Matrix' analysis. He pointed out that insulin is a *hormone,* a *protein* that increases the rate at which *glucose* enters muscle tissue. The three words each have seven letters. "And the insulin molecule," Dr. Matrix said, "has precisely 777 atoms. But we're neglecting our game."

Dr. Matrix' third move caught me off balance. He placed his knight on his queen five square, leaving his king's pawn unprotected. Was it a deliberate gambit or a careless oversight? I could see no serious threat from his knight, and so I took his pawn with my knight. My bishop and knight were now both attacking his vulnerable king's bishop pawn.

Dr. Matrix ignored the attack. When he moved his queen out to knight four, I lost no time grabbing his bishop's pawn with my knight. The knight now threatened both his queen and his rook, so that I was certain of winning the rook. And Dr. Matrix had boasted of his chess prowess! I felt a twinge of embarrassment for him.

He seemed unconcerned. "Some letter patterns are difficult to interpret," he said. "Take Martin Luther King's initials, MLK. They are three consecutive letters of the alphabet in reverse order. That's unusual for a person's name, but in this case I'm not sure what it signifies. On the other hand, the terminal letters of his assassin's three names, James Earl Ray, have an obvious meaning, particularly if you include the last two letters of his last name. Pierre Elliot Trudeau's initials spell PET. It explains why so many teen-age girls try to kiss him. First and last letters of familiar sets of words also conceal many strange correlations. NEWS, which comes from all directions, is spelled with the initials of North, East, West and South. The initials of the nine planets, in order from the sun, contain SUN. The last letters of the names of the numbers one through 10 end with TEN. My friend Theodore Katsanis of Berea, Ohio, has a son named Jason who was born in September. September is the middle month of five consecutive months with initials that spell JASON."

Dr. Matrix paused to take my knight's pawn with his queen. I had anticipated that. To save my rook I was obliged to move it to the bishop's square.

"Mary McCarthy is a brilliant woman," Dr. Matrix went on. "In her book

Cast a Cold Eye there is a story called 'C.Y.E.' It tells about the inscrutable nickname, Cye, given her by a group of classmates at a convent school. They never told her what it meant and Mary tries to guess. The initials of Catch Your Elbow? Clean Your Ears? Clever Young Egg? It's curious Mary didn't see that her 'cold eye' is the clue. Take out *olde* and her youthful nickname is left."

Dr. Matrix took my king's pawn with his queen and said, "Check."

I gave a start. It was a ploy I had failed to see. The only way I could escape checkmate and not lose my queen was, of course, to interpose my bishop. I moved it back to the square in front of my king. The threatened mate was blocked, but now I would surely lose my knight. On the other hand, the black king would be exposed, and with an open file for my rook perhaps I could mount a quick counterattack.

"Can we move on to numbers?" I asked. "As you know, I like to give my readers little problems. Any curious number puzzles that are new?"

"In this age of digital computers," Dr. Matrix replied, "they turn up every month by the hundreds. Robert E. Smith, a mathematician with the Control Data Corporation, told me how a student at one of his company's institutes improved on an ancient result given by Plato. In his *Laws,* Book 5, Plato recommends that a city be divided into plots of land so that the number of plots has as many proper divisors as possible. He suggests 5,040 because it has 59 divisors, a rather large number. [This includes 1 but not 5,040.] Your readers who have access to computers, even some who don't, might like to know that the largest number of proper divisors a number less than 10,000 can have is 63, which tops Plato's number by four divisors. There are just two such 63-divisor numbers. One is 9,240."

"Delightful," I said. "I'll ask our readers to try to find the other one before I reveal it the following month."

"What's your room number?"

I took out my hotel key to check. It was a number with three digits.

"Remarkable," said Dr. Matrix, his green eyes squinting through a window and over the waving palm trees. "I trust you recognized it as a square number. Now, if you write it down, then put a certain other three-digit square number directly under it, you produce an unusual matrix. Each of the three two-digit numbers that make the three columns, when read from the top down, is also a square number."

After Dr. Matrix showed me the only

solution (which I withhold until next month) he pushed a concealed button on the side of the chess table. The room was instantly filled with music.

"It's the score of Sir Arthur Bliss's 1937 ballet *Checkmate*," Dr. Matrix said as he lifted his knight and slammed it down on his king's bishop six square.

I stared at the board, my jaw sagging. It was indeed checkmate. My bishop, pinned by the black queen, could not take the checking knight, and there was no empty square next to my king. It was one of those rare events in chess, one that only knights can execute: a smothered mate [*see illustration on page 104*].

"Sorry about that, Gardner," said Dr. Matrix, "but I wanted to end the game with my seventh move. It's an old chess hustler's trap. I'm surprised you fell for it."

The hall door opened and Iva entered on bare feet, enveloped by a pale purple beach robe and a cloud of well-remembered perfume. "Aloha!" she called out, her black eyes flashing a smile. "How on earth did you know my father and I were here?"

"I didn't. My being in Hawaii now, believe me, is purely occidental. I hope you're free this evening to pilot an ignorant mainlander around the city."

"One more stupid pun," Iva said, wagging a scarlet-nailed forefinger in my face, "and the deal's off."

I was about to add that I had great difficulty getting myself properly oriented in Honolulu, but I kept my mouth shut.

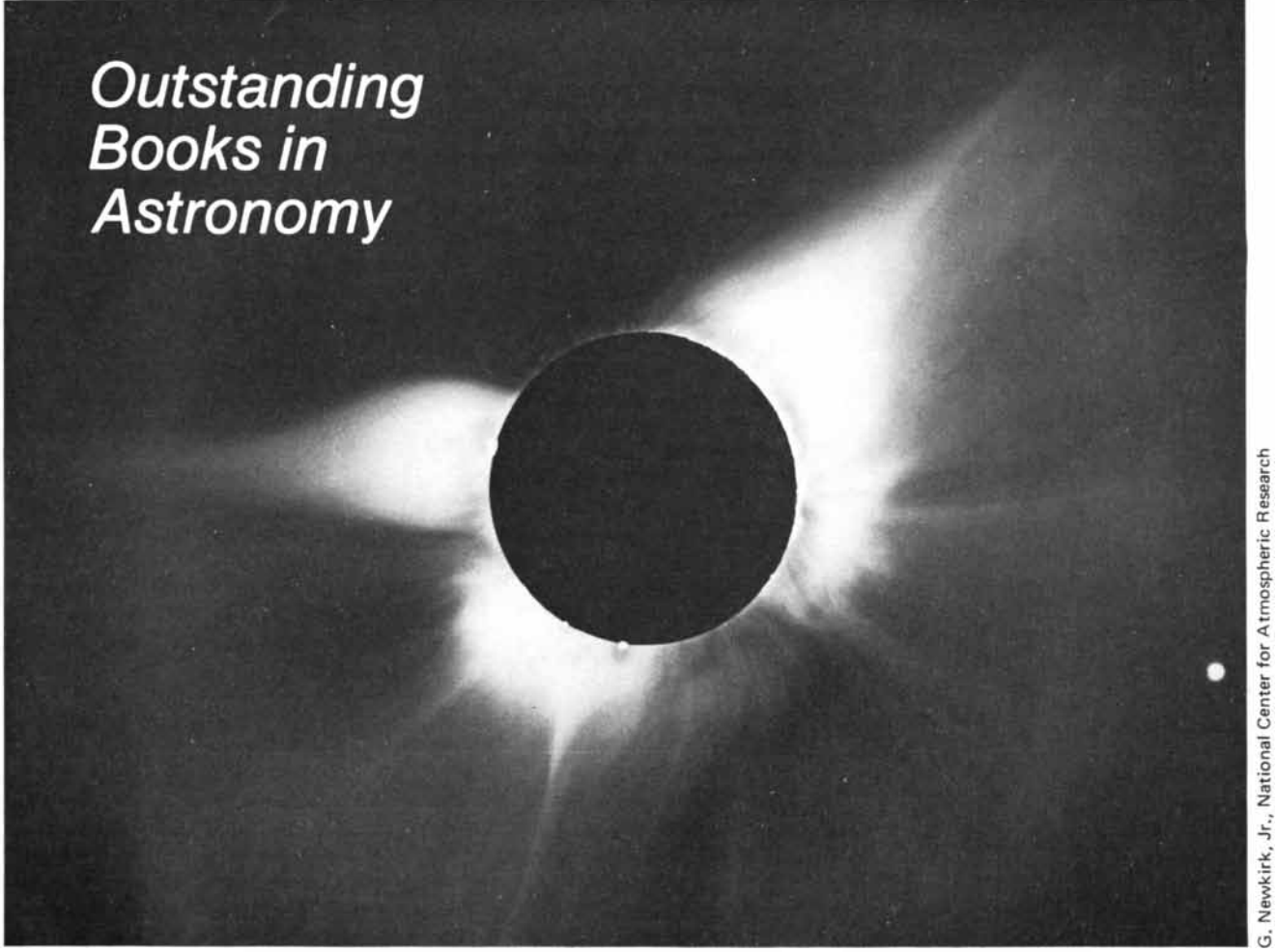
Last month's problem has the following answer. The probability that two randomly selected cards, from a set of two red and two black cards, are the same color is 1/3. If you list the 24 equally probable permutations of the four cards, then pick any two positions (for example second and fourth cards), you will find eight cases in which the two cards match in color. One way to see that this probability of 8/24 or 1/3 is correct is to consider one of the two chosen cards. Assume that it is red. Of the remaining three cards only one is red, and so the probability that the second chosen card will be red is 1/3. Of course, the same argument applies if the first card is black. Most people guess that the odds are even, when actually they are two to one in favor of the cards' having different colors.

Next month this department will be devoted to "cellular automata theory," a new field that includes John Horton Conway's game "life," the topic for last October. I shall report then on what readers have discovered about Conway's game and sketch the historical background for games of this type. Meanwhile I am pleased to report that two unresolved questions in October's column have been settled: the final destinies of the *R* pentomino and the 5–5–5–5–5–5–5 row (seven sets of five counters on the same orthogonal row, with single vacant cells separating the sets).

The *R* pentomino reaches a "steady state" after move 1,103. Six gliders have been produced and are traveling outward. The debris left at the center [*see illustration on page 105*] consists of four blinkers, one ship, one boat, one loaf, four beehives and eight blocks. This was first established at Case Western Reserve University with a computer program written by Gary Filipski and Brad Morgan; the results were sent to me by Ranan B. Banerji, professor of engineering. At the time of writing later confirmations have been received from Jonathan Kring, North Olmsted, Ohio; Robert Slaughter, University of Nebraska Computing Center; D. M. Saul, University of Illinois; George A. Miller, Rockville, Md. (who supplied the graph reproduced here), Robert Bison, IBM Corporation, Kingston, N.Y.; Robert Maas, Mountain View, Calif.; Leonard A. Adleman, San Francisco; Eric Werne, Carnegie-Mellon University; Maynard C. Cheney, University of Chicago, and a group at Honeywell's Computer Control Division in Framingham, Mass., that includes Keith McClelland, Tom Holmes, Mike Sporer, Bill Woods and Don Woods.

The fate of the 5–5–5–5–5–5–5 was independently found at about the same time by the Honeywell group cited above, by D. M. Saul and by Robert T. Wainwright, Yorktown Heights, N.Y. The pattern stabilizes after move 323 with four traffic lights, eight blinkers, eight loaves, eight beehives and four blocks—a total of 192 bits. The printout of this spectacular end result [*see illustration on page 106*] was supplied by Wainwright. Because symmetry cannot be lost in the life histories of any initial pattern, the vertical and horizontal axes of symmetry of the original figure are preserved in the final configuration. The maximum population (492 bits) occurs in generation 283.

Although I did not say so before, it should be apparent that rows of the *n-n-n*... type become interesting only when *n* is at least 5, which allows the sets to interact. Rows of 1–1–1... and 2–2–2... immediately vanish. The 3–3–3... row is simply a row of blinkers and the 4–4–4... becomes a row of stable beehives on the second move.



G. Newkirk, Jr., National Center for Atmospheric Research

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THE AMATEUR SCIENTIST

On the differential operational amplifier, a device that simulates almost anything

Conducted by C. L. Stong

A few evenings at the workbench have convinced me that the differential operational amplifier is one of the most entertaining experimental gadgets to turn up in a long time. With a few inexpensive accessories it can simulate the performance of things as diverse as levers, cams, clocks, litmus paper, light meters, a variable weight for an analytical balance and a host of others. The following description of the amplifier and a few of the experiments that I have enjoyed is submitted by Stanley Froud, an electronics consultant of 817 West End Avenue, New York, N.Y. 10025:

"Differential operational amplifiers are made in two ways. One type is assembled with discrete parts: transistors, resistors, capacitors and related components. They are self-contained. The second type is made by chemically treating a small wafer of silicon. This type requires the addition by the user of several accessory parts. The following discussion is based on amplifiers of the self-contained type.

"Typically they resemble a small block of plastic about an inch square and half as thick. Seven short stubs of wire protrude from one side of the device; they are the terminals. The internal parts include complementary transistor circuits, each consisting of several stages of amplification that terminate in a single output, plus a number of auxiliary circuit elements that automatically compensate for changes in temperature and voltage supply and for aging effects. Familiarity with the details of these highly sophisticated circuits is not essential for putting the amplifier to work. With a basic understanding of how the device operates the beginner can immediately use it as a fundamental building block in instruments and apparatus of many kinds.

"In performance the differential operational amplifier can be roughly likened to a galvanometer with a pointer that makes frictionless contact with a resistance wire [*see illustration below*]. The center of the movable coil of the galvanometer is connected to ground or to the chassis on which the instrument is mounted by a flexible lead. The center of the resistance wire is similarly grounded. A potential of 20 volts is maintained across the resistance wire by a pair of batteries connected in series. The connecting wire is also grounded.

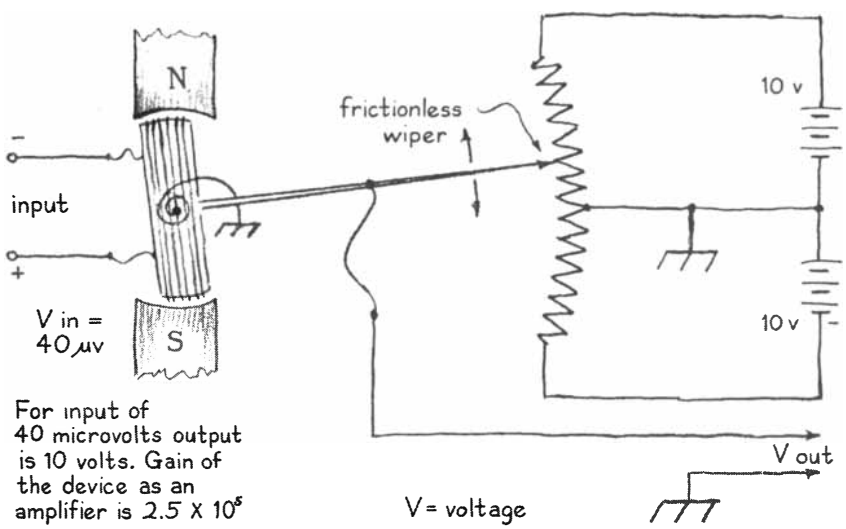
"The sensitivity of the hypothetical galvanometer is such that a potential of 40 microvolts, applied between either end of the coil and the ground, causes the pointer to move from its normally centered position to one end or the other of the resistance wire, depending on the magnitude and polarity of the applied voltage. A flexible wire connected to the pointer, which is insulated from the coil, serves as the output terminal.

"The assembly is an amplifier. Application of 40 microvolts between either end of the coil and the ground causes a potential of 10 volts from the battery to appear between the output terminal and the ground. The voltage gain is therefore 250,000.

"A galvanometer has an adjustment screw for centering the pointer on zero at the mid-scale position. When the pointer is centered, no output voltage appears. The differential operational amplifier works the same way, but its response is much faster and more precise than that of an electromechanical device.

"The amplifier is depicted in wiring diagrams by a triangle [*see upper illustration on page 112*]. Two short lines that extend from the base of the triangle represent the input terminals, one positive and one negative. The output terminal is represented by a similar line at the apex. Two lines that extend from opposite sides of the triangle near the base represent positive and negative terminals for connection to a pair of external power supplies, each providing a potential of 15 volts. The power supplies are connected in series by a grounded wire.

"The seventh terminal of the amplifier, known as the trim, is represented by a line adjacent to the positive power terminal. It is analogous to the zero screw of the galvanometer. A variable resistor connected between the trim terminal and the positive power terminal can be adjusted to the point where no output



Hypothetical galvanometer amplifier analogous to the differential unit

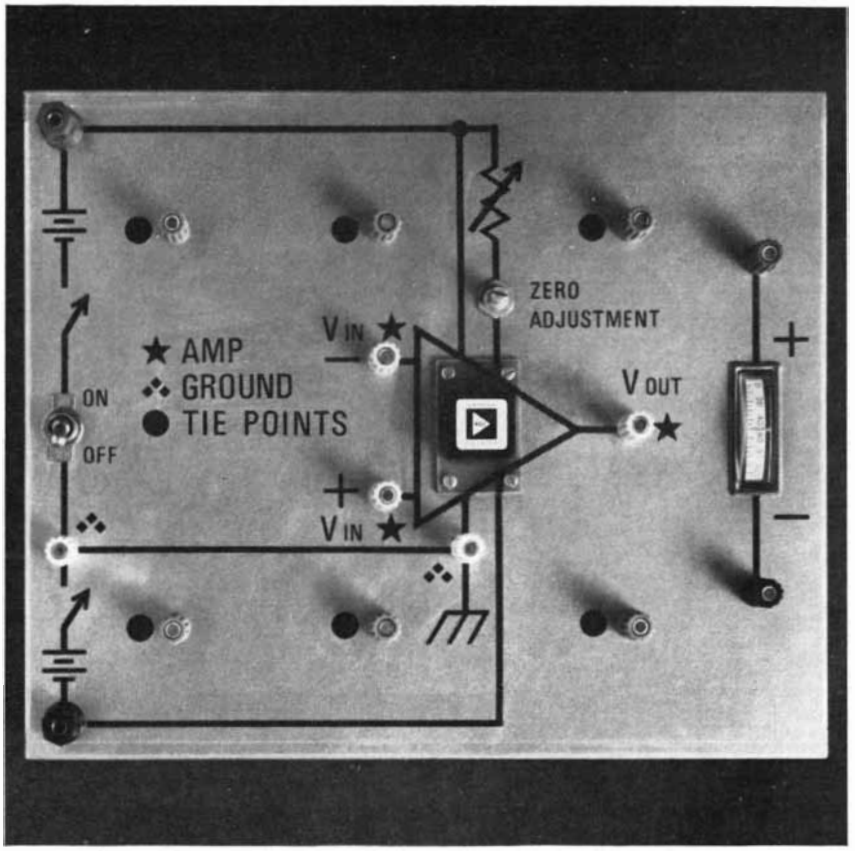
voltage appears until a signal is applied to the input.

"Wiring diagrams are frequently simplified by the omission of the power-supply connections, the trim adjustment and most of the ground connections. It is understood that these connections are invariably required. Currents from the signal source and the load always return through the ground. Nearly all operational amplifiers fit interchangeably into a standard socket. Printed labels on the bottom of the socket identify the terminals.

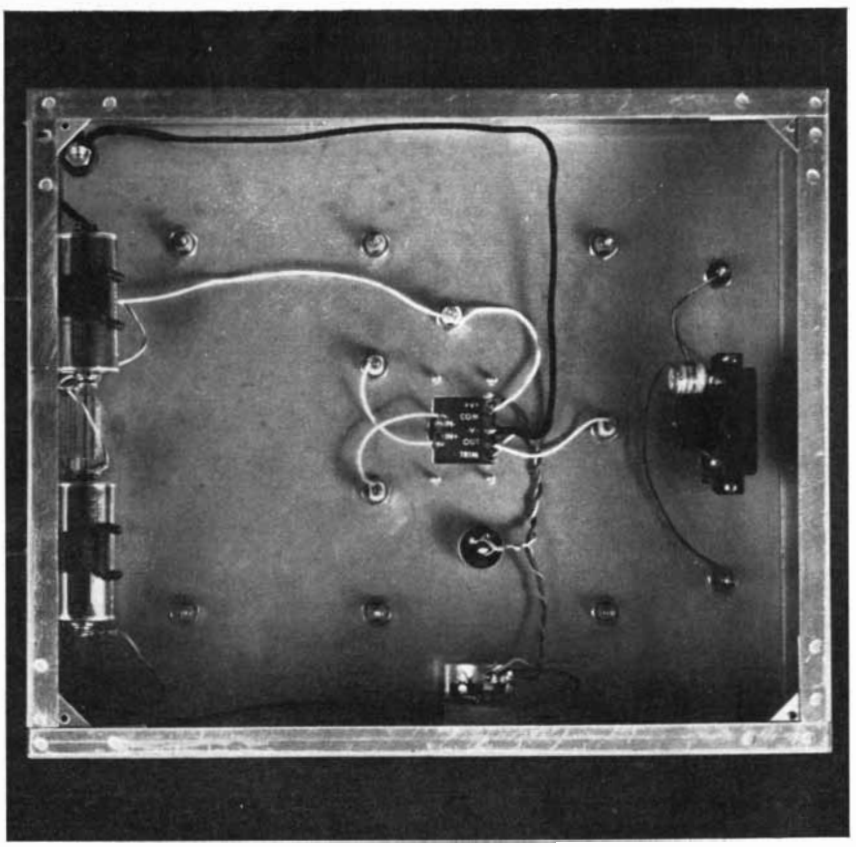
"The performance of all operational amplifiers is influenced to some extent by changes in temperature. The amplifiers can be designed for maximum stability with respect to current or to voltage, but not both. Therefore two broad families of operational amplifiers have evolved. One type is for amplifying voltage and the other is for amplifying current. For example, the Type 40J amplifier manufactured by Analog Devices, Inc., is stabilized with respect to current; the Type 118A, with respect to voltage. All the experiments to be described can be done with either of these two amplifiers or with equivalent ones made by other manufacturers, but I suggest that the experimenter get both types for observing the relative performance of each. The 40J costs $12 and the 118A $11. The sockets are $3.50. The devices are available on a cash basis from the Techno-Scientific Supply Co., Inc., P.O. Box 191, Baldwin, N.Y. 11510. The price of operational amplifiers increases with their stability. It also increases as the amount of current they draw from the signal source goes down. This current, known as the bias current, can range from 10^{-8} to 10^{-15} ampere, depending on the design of the amplifier.

"The 40J amplifier requires an external, variable trim resistor of 1,000 ohms and the 118A a similar resistor of 50,000 ohms. To make the trim adjustment ground both input terminals of the amplifier, apply power and set the variable resistor to the point where the voltage output falls to zero, as indicated by a voltmeter. I was unable to find a source of 15-volt batteries, but the Mallory Type TR-289 batteries that develop 12 volts are adequate. A special power supply manufactured by Analog Devices and specifically designed for operational amplifiers is available from Techno-Scientific.

"Typically the devices can amplify the voltage of a direct-current signal by a factor of 200,000 or more. That much gain is rarely needed. Instead part of the



Top view of Stanley Froud's "breadboard" for the operational amplifier (center square)



Bottom view of the breadboard

output voltage is returned in opposition to the signal. This opposing voltage, a negative feedback, cancels some or all of the gain and in so doing stabilizes the performance of the overall circuit, much as the governor of a steam engine stabilizes the speed of the flywheel in spite of changes in the load. In effect, negative feedback converts the operational amplifier into a precision device.

"In general the amplifiers are used in one or another of four basic wiring schemes: noninverting, inverting, differential and current-to-voltage conversion circuits. The choice for a specific application depends largely on the internal resistance of the signal source, the amount of current or voltage that can be taken from the source and the amount of gain that will be required to operate the load. With this information at hand the design of a desired apparatus needs only a bit of arithmetic, in contrast to the tedious and complex equations that must be solved to design an equivalent circuit with transistors.

"Assume that the experimenter wants to measure the voltage across the mercury-dropping electrode of a polarograph, the low potential stored by a small capacitor or the bioelectric potential generated by the heartbeat of a microscopic animal such as the water flea *Daphnia*. The voltage of such a source falls if current is drawn from it, thus spoiling the measurement. The measuring instrument must present high resistance to the source—so high that almost no current is drawn. An ideal instrument for such a measurement is an operational amplifier wired in the noninverting configuration. The input resistance ranges from a million ohms to a million megohms, depending on the characteristics of the amplifier. The polarity of the output signal is the same as the polarity of the input signal, hence the name noninverting.

"The inverting configuration develops an output signal of reversed polarity with respect to the input signal. It is characterized by a unique property: the input terminal of the amplifier, as distinct from the input terminal of the circuit, remains at substantially ground potential even when more than one signal is applied to the negative, or inverting, input terminal through separate resistors. For this reason the amplifier responds to each signal as though the others did not exist. If all the input resistors are identical, the output voltage is equal to the sum of the input voltages multiplied by the gain of the amplifier. The multiplying factor, or gain, is exactly equal to the ratio of the feedback resistor (R_2) divided by the input resistor or resistors (R_1). Incidentally, the feedback resistor should have a value of not less than about 10,000 ohms in any of the four circuit configurations.

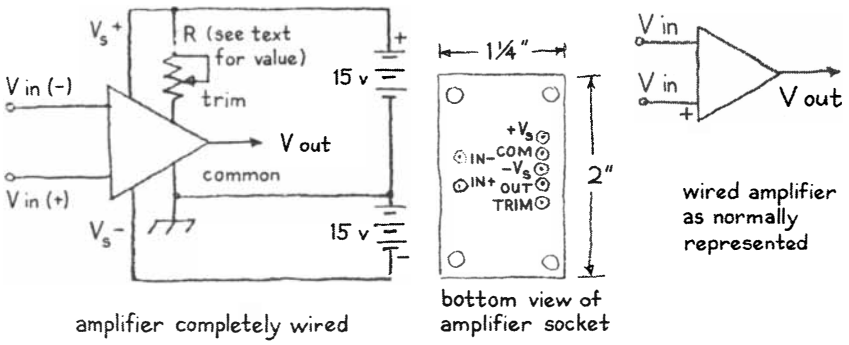
"The differential configuration compares voltages from two sources. In effect, it subtracts one quantity from another. Its applications include automatic control devices and pen recorders.

"The current-to-voltage configuration is a powerful circuit for amplifying the output of sources that develop small current signals rather than small voltages. An example is a photovoltaic cell. Formulas for computing the voltage gain, the voltage output and the input resistance appear in the accompanying illustration [*top of opposite page*].

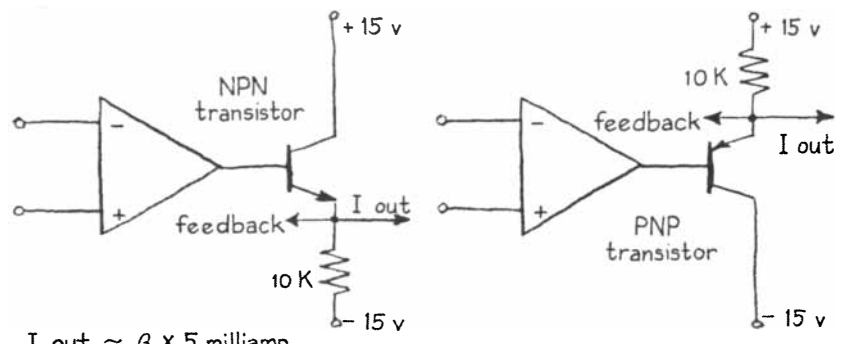
"The 40J and 118A amplifiers develop a maximum output of 10 volts and five milliamperes, as do most operational amplifiers. Additional current can be made available by connecting a transistor to the output of the amplifier. Almost any transistor rated for a potential of at least 30 volts between the collector and emitter electrodes can be employed. Of course, the transistor must also be rated for the desired current. The transistor should be included in the feedback loop by transferring the feedback connection from the output of the amplifier to the output of the transistor [*see lower illustration at left*].

"For general experimentation I acquired an assortment of fixed resistors ranging in value from 500 ohms to 10 megohms. A few are accurate to 1 percent. I also obtained several capacitors ranging from .1 to .0005 microfarad, a reasonably good voltmeter, half a dozen potentiometers ranging from 1,000 to 50,000 ohms, and an oscilloscope, which is handy for observing the wave form of alternating-current signals but is not needed in experiments that involve direct current.

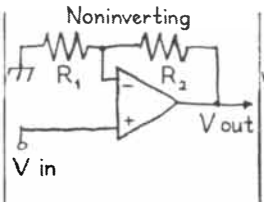
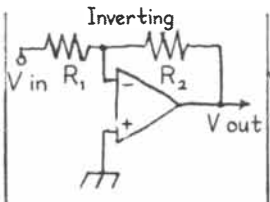
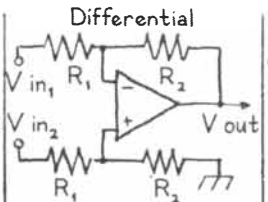
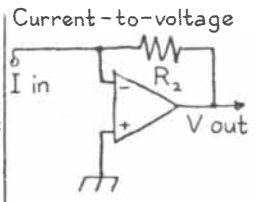
"I mounted the socket for the amplifier in the center of an aluminum chassis about a foot square. A power supply consisting of dry cells was mounted inside the chassis and permanently connected, through switches, to the power terminals of the socket. A variable trim resistor was also mounted and wired to the socket. Binding posts of the type that accept both banana plugs and spade terminals of test leads were connected to the pow-



Electrical arrangement of the differential operational amplifier



The arrangement with a transistor added to the amplifier

	Noninverting	Inverting	Differential	Current-to-voltage
				
voltage gain	$(R_1 + R_2)/R_1$	$-R_2/R_1$	R_2/R_1	R_2
voltage output	$V_{in} \times \frac{R_1 + R_2}{R_1}$	$-V_{in} \times \frac{R_2}{R_1}$	$(V_{in_2} - V_{in_1}) \times \frac{R_2}{R_1}$	$I_{in} \times R_2$
circuit input resistance	R (from specifications)	R_1	R_1	very low ($R_2 \div$ amplifier gain)
typical input resistance of circuit	$10^6\ \Omega - 10^{12}\ \Omega$	$10\ \Omega - 10^8\ \Omega$	$10\ \Omega - 10^7\ \Omega$	$.1\ \Omega - 10^2\ \Omega$

Four basic circuits for the amplifier

er supply, the inputs, the output and the ground terminal of the socket.

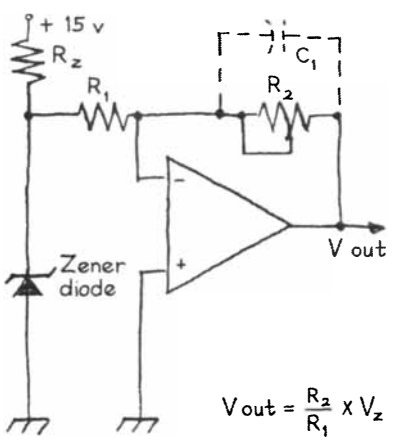
"The chassis also incorporates a voltmeter with a zero-centered scale for measuring potentials up to 15 volts. In addition I mounted four sets of binding posts, each consisting of three binding posts wired together, to serve as convenient tie points [*see top illustration on page 111*]. This improvised 'breadboard' (plus an assortment of test leads equipped with banana plugs, spade terminals and alligator clips) enables me to wire up almost any circuit configuration and have it working within 10 minutes. A rather more elaborate breadboard is available from Analog Devices.

"The following experiments illustrate a few basic types of project that offer particularly suitable applications for an operational amplifier. For example, an amplifier can convert an inexpensive voltmeter into an instrument for measuring from millivolts to kilovolts and from microamperes to amperes. If the experimenter has a Zener diode, a device that develops an accurately known reference voltage, the amplifier can also be used for calibrating the original scale of the voltmeter.

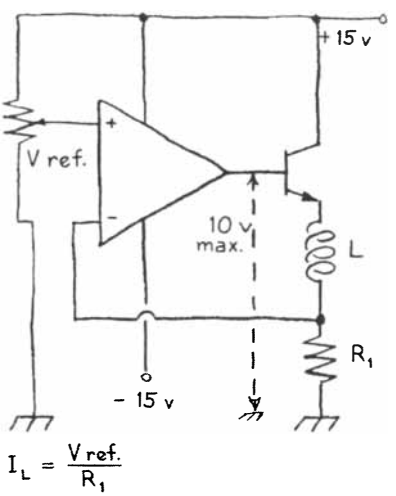
"To make the calibration connect the amplifier in the inverting configuration with a pair of fixed resistors of known value. The accuracy of the calibration can be no better than the accuracy to which the values of the resistors are known. The known reference voltage of the Zener diode is applied to the input [*see illustration at left below*]. Connect the voltmeter that is to be calibrated to the output of the amplifier. Before applying the Zener voltage turn on the power supply and adjust the trim for zero output. Apply the Zener voltage. Record the voltage indicated by the meter adjacent to the known output voltage, as computed. Substitute another resistor of different but known value for R_2 and again record the known and the indicated voltages. Continue until a number of calibration points have been determined throughout the range of the meter. The points can be plotted as a graph that displays the error of the meter completely across its scale.

"The same circuit can be harnessed for eliminating the awkward fraction that always appears in the rated output voltage of Zener diodes. For instance, the actual output potential of a six-volt Zener diode usually turns out to be 6.741 volts or 5.017 volts or something equally inconvenient. Substitute a variable resistor for R_2, connect the calibrated meter to the output of the amplifier and then, by turning the knob of the variable resistor, crank out any desired whole number that is within the range of the meter. The slight error introduced by the amplifier will lie far to the right of the decimal point.

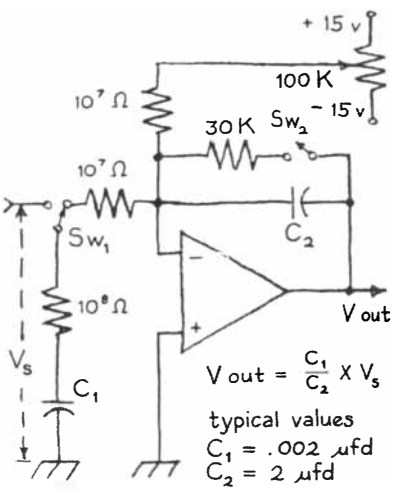
"Many experiments require a source of current for developing a constant mechanical force, a constant electrochemical reaction, a constant source of light



Circuit for amplifying Zener voltage



Constant-current circuit



Measuring high potential

and so on. A convenient source of constant current can be made with the noninverting configuration. For example, a vernier for an analytical balance can be easily improvised for splitting the final milligram into fractions.

"The vernier consists of a small solenoid that applies a variable force to one end of the beam. An operational amplifier provides current to the solenoid and so controls the force. The armature of the solenoid can be a bit of iron wire snipped from the end of a paper clip. The coil of the solenoid can be a 1,000-microhenry choke of the kind that has an air core.

"Cement the iron wire to one end of the beam with a dab of epoxy. Restore the beam to balance by adding a counterweight to the opposite end. Rigidly attach the coil to the frame of the balance at a point where the armature extends partway into the air core. Current in the coil is adjusted by a potentiometer that applies a voltage to the input of the amplifier [*see middle illustration at bottom of preceding page*]. I used a 10-turn potentiometer and calibrated its scale in intervals of 10 micrograms. The magnitude of the force can be increased by adding a transistor to the output of the amplifier.

"The 40J amplifier can be employed as an electrostatic voltmeter for measuring potentials up to 10,000 volts to an accuracy of about 2 percent. The circuit includes a voltage divider consisting of two capacitors. The smaller capacitor, preferably one of the type that is insulated with glass plates in oil, is first charged by voltage from the source through a single-pole, double-throw switch [*see illustration at right at bottom of preceding page*]. Charge so acquired is transferred to the larger capacitor by operating the switch. The larger capacitor should be insulated with polystyrene.

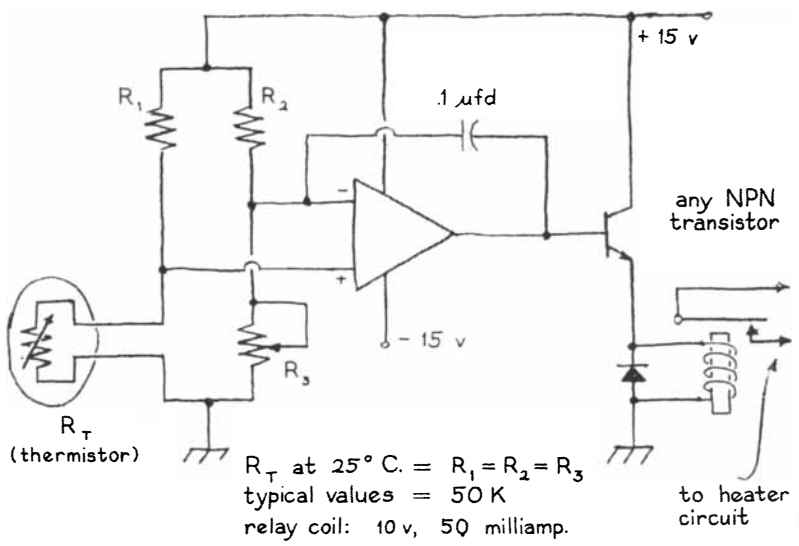
"The output voltage is measured by a conventional, low-voltage meter. The unknown voltage is equal to the output voltage multiplied by the ratio of the capacitors. The 100,000-ohm potentiometer serves as a zero adjustment. The larger capacitor is discharged by momentarily closing the single-pole switch (Sw_2) in preparation for the next measurement. Incidentally, capacitors can accumulate a hazardous charge even when they are connected to such normally harmless apparatus as a small electrostatic generator. When you are working with capacitors, proceed cautiously!

"Equally interesting are applications that involve automatic control. An example is an apparatus for maintaining a substance (such as a fluid) at a desired temperature. Input voltage for the amplifier is obtained from a Wheatstone bridge, one arm of which includes a thermistor as the temperature-sensing device. Current in the output is boosted by a transistor for operating a relay that turns a heating element on and off. The desired temperature is set by a variable resistor that is the balancing arm of the bridge. A diode suppresses the pulse of high voltage that appears across the coil of the relay at the instant the amplifier shuts off the current [*see illustration at left below*]. Thermistors are available in a range of resistances from dealers in radio supplies. The resistors in the bridge should equal the resistance of the thermistor at a temperature of 25 degrees Celsius. The apparatus will respond to changes in temperature of less than one degree C.

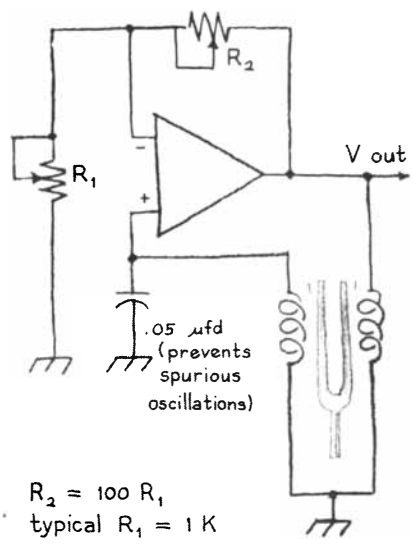
"Although the operational amplifier is primarily a direct-current device, designers find numerous uses for it in alternating-current circuits, particularly at frequencies below 10,000 hertz (cycles per second). The gain of the amplifier is maximum for direct current and falls uniformly to unity at about one megahertz. In a typical application the amplifier generates an alternating current for driving a tuning fork of the kind used as the time reference in watch regulators. The tuning forks are available inexpensively on the surplus market.

"The tuning-fork assembly includes a pair of electromagnets. One drives the fork. The other generates signal voltage for the amplifier. The fork vibrates at a constant frequency of 400 hertz. It develops some output even when it appears to be at rest. The tines are never still but oscillate continuously at low amplitude in response to external vibrations. Although at this amplitude the electrical output amounts to less than a microvolt, it can be detected by an operational amplifier in the noninverting configuration [*see illustration at right below*].

"When the amplifier is turned on, nothing seems to happen for about a minute. A discernible voltage then appears at the output of the amplifier. During the next three minutes the amplitude of the output voltage gradually increases to approximately 10 volts. By connecting an oscilloscope to the output you can watch the initially faint signal fight its way up through the noise to emerge as a perfect sine wave. The stability of



Circuit for maintaining constant temperature



Tuning-fork circuit

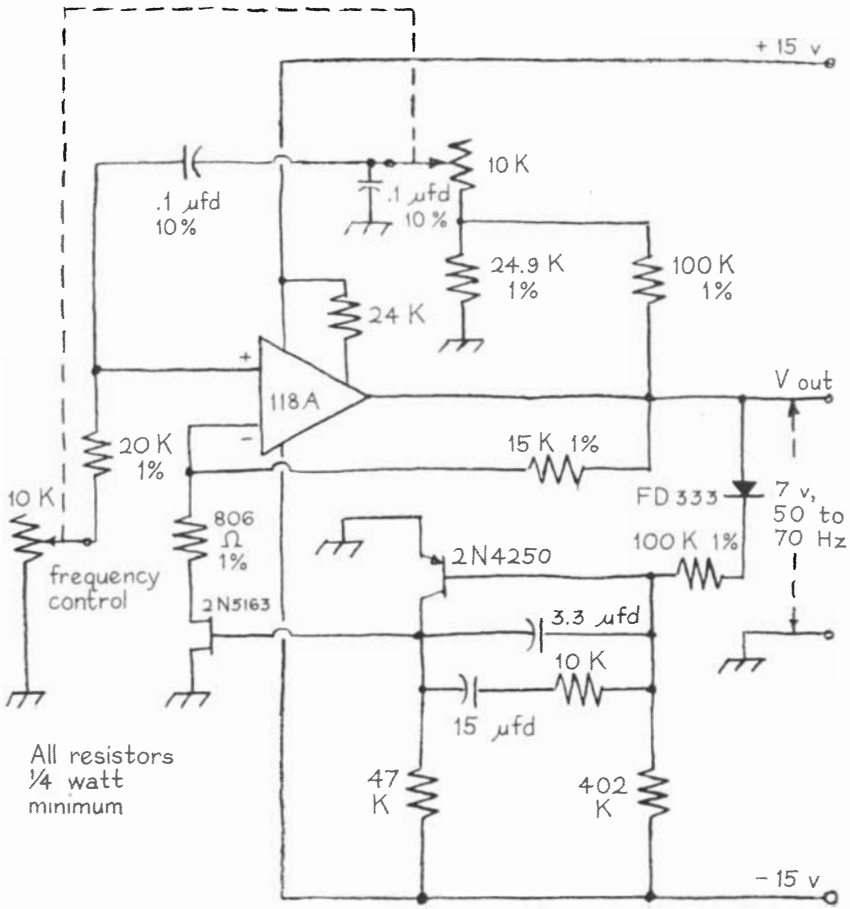
the signal approximates one second per month.

"The 118A amplifier becomes an impressively stable oscillator in its own right when it is combined with a few capacitors and resistors, a diode and a couple of transistors. The accompanying circuit configuration [*top illustration at right*] was designed specifically to generate an alternating voltage with a frequency that can be varied continuously from 50 to 80 hertz. If the oscillator is combined with a power amplifier, the output can be harnessed for driving a telescope of any size in synchrony with the apparent motion of the fixed stars. The driving rate can be altered at the twist of a knob for locking the telescope onto the moon, the planets and comets. The short-term frequency stability of the oscillator is significantly better than that of 60-hertz power lines.

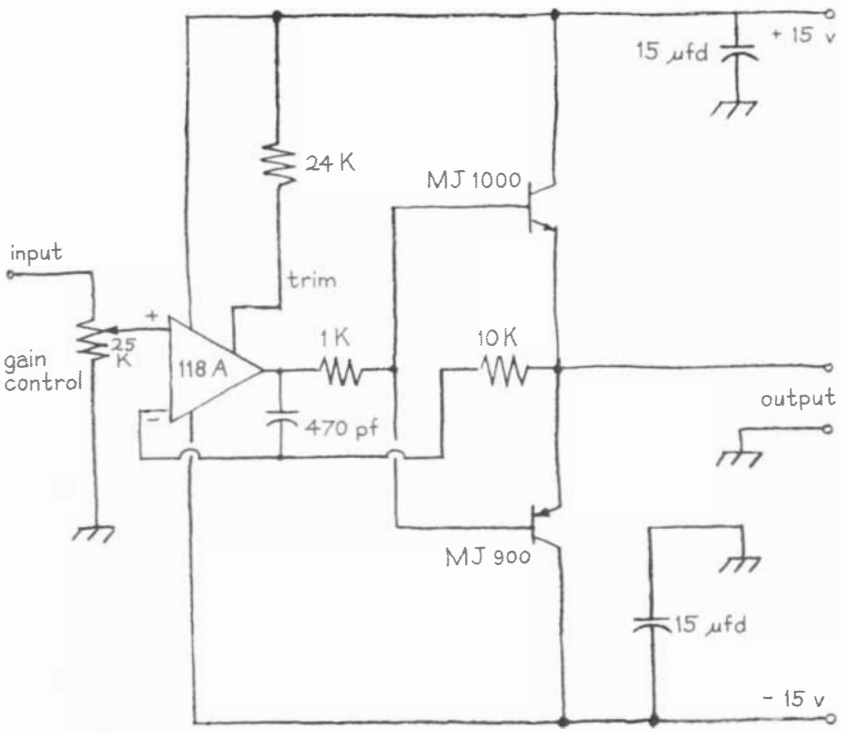
"The oscillator delivers an output of seven volts in the form of a sine wave of less than 1 percent distortion. The oscillator is automatically stabilized by a variable resistance consisting of a field-effect transistor (2N5163) in series with a fixed resistor of 806 ohms. The resistance of the field-effect transistor is controlled by the amplitude of the output voltage. Part of the output is rectified by the diode and compared with the power-supply voltage by means of the 2N4250 transistor, which functions as an integrating amplifier. The difference voltage controls the resistance of the field-effect transistor.

"A power amplifier that is designed to operate as a companion to the oscillator but can be employed for other purposes delivers up to nine volts at a maximum current of two amperes [*see bottom illustration at right*]. The output potential of the amplifier can be increased to 120 volts by a transformer for operating a synchronous motor, such as the Hansen Synchron Type 900. The motor, when it has been geared down to the rate of one revolution per sidereal day, can exert a maximum torque of 150 foot-pounds on the polar shaft of a telescope.

"Operational amplifiers are designed to perform mathematical operations such as adding, subtracting, generating logarithmic functions and solving problems in the differential and integral calculus. This implies that they can perform almost any operation that can be described by an elementary mathematical equation and suggests something of their versatility as well as the breadth of the experimental opportunities opened by their development."



A low-frequency oscillator



A power amplifier

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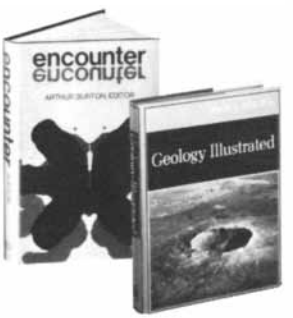

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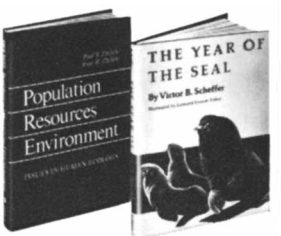

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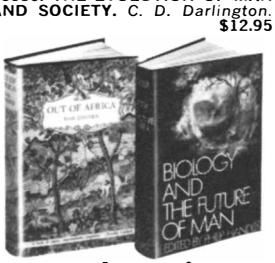

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BOOKS

The early support of science in America, and old and new attempts at metrication

by Philip Morrison

DOLLARS FOR RESEARCH: SCIENCE AND ITS PATRONS IN NINETEENTH-CENTURY AMERICA, by Howard S. Miller. University of Washington Press ($9.50). The first American Ph.D.'s were awarded in the decade 1861–1871. They were, all 20 of them, from Yale. Fourteen of the degrees were in the sciences, and one young postdoc was Josiah Willard Gibbs. The battle for professional specialized research in America was making its first gains. By 1902 the Carnegie Institution of Washington, the first "university in which there are no students," was formed, richly endowed by that philanthropic magnate, largely under the persuasive influence of Charles Walcott, once director of the United States Geological Survey. The battle was fully won. Its overwinning may now have come with the wide recognition of the utility of research-based high technology, if the present crisis in Ph.D. employment and prospects is rightly read.

The fight began about 1838, in the view of Professor Miller, the historian who has written this readable and incisive prehistory of the quest for grants. It was then that the packet with James Smithson's 11 boxes of gold, about half a million good hard dollars, sailed into New York harbor. The legislation that spent that legacy was fought over for eight years. "Is it the diffusion of science, or the encouragement of research that American science requires?... Do we need talkers or workers?" So spoke Alexander Dallas Bache, a leader of the Order of Scientific Lazzaroni, an informal group of scientists (including Bache, Joseph Henry, Louis Agassiz and Oliver Wolcott Gibbs) who named themselves "after the poorest class of Neapolitan beggars" and met for planning at "one good great happy annual winter feast." So it was in those days, when President Tyler welcomed the scientists attending a Washington conclave as the Marine band played.

The Smithsonian Institution represented a legislative compromise, but the bequest had called for "the increase & diffusion of knowledge among men." Bache's candidate, the great Princeton physicist Joseph Henry, became the Institution's first head. By his administrative skill he kept the funds flowing into research and publications, starving the library and slowing down the grandiose building plans. Horace Greeley saw what Henry was doing, but even his opposition came to nothing. Congress sided with the research scientists at the first test in 1855, when Representative James A. Pearce of Maryland struck out against "the *hiving* of knowledge." One beaten regent of the Institution was bitter: "Vindicate art, taste, learning... against sciologists, chemists, & catchers of extinct skunks." For the first time in America big money went into research.

The second front of American science was an unexpected one: the stars. Almost uninterruptedly for 120 years a telescope in scientifically provincial America has been either the biggest in the world or the runner-up. The first permanent American observatory, set up in 1838 after an 1833 meteor display and a set of comets had rekindled interest in astronomy, was at Williams College. In colonial times astronomy had been a welcome support to natural theology, but the days of the pious amateurs were passing. The Government got a Naval Observatory, smuggled into the budget under the guise of a Depot of Charts and Instruments. Then in 1845 Cincinnati financed a 12-inch Fraunhofer telescope. It was bigger and better than the one at the Dorpat observatory in Russia, which had been purchased 20 years earlier for $5,000 by the "autocrat of all the Russias." He was now outdone by "an obscure individual in this wilderness city in a republican country ... by voluntary gift."

So spoke the promoter-enthusiast, Ormsby MacKnight Mitchel, a West Point graduate teaching at Cincinnati College. The great comet of 1843 left in its train another observatory, Harvard College's. Cincinnati had a "republican observatory," founded so that ordinary folk might look at the stars, but Harvard's more aristocratic support was in the research vein: there was plenty of Boston money to pay for professional astronomers. Then came Lick, Yerkes and the Bruce telescopes, all the gifts of wealthy donors. George Ellery Hale's Mount Wilson was largely the result of foundation largesse. By 1902 there were more than 140 observatories dotting the land. Most of them claimed a research interest, but as a committee of the time wrote, "the first need [is] for more astronomical workers to use the appliances ... already provided." In 1903 half of all research endowment was spent on astronomy.

The book also tells the Agassiz story: his extraordinary social success and his rivalry with Asa Gray (who was a Darwinian from the start, which Louis Agassiz never became). The St. Louis Botanical Garden and the Harvard museums and laboratories are monuments to these complex and personal histories. Paleontology, searching time as the telescopes did space, prospered under the philanthropy of Gilded Age magnates, and were also well served by the drive of Government scientists such as John Wesley Powell. In 1886, with the issue impassioned by cutthroat rivalry among the fossil-seeking scientists and their friends, the Herbert bill to control the Geological Survey was introduced; it would have "lopped off paleontology entirely, except for the collection ... of fossils." It sought to cut the famous monographs of the Survey to a brief annual report. Behind the bill was Louis Agassiz' son Alexander, who was affronted by the arrogant behavior of Othniel Charles Marsh of Yale. His hand was strengthened by Congressional worry about the impracticality of costly old bones. Once again the researchers won by counterattack. Scientific research was henceforth accepted as a legitimate function of the Federal Government. No De-

partment of Science arose; that proposal was first rejected in 1886, as it has been ever since.

The book is quiet about any economic connection between basic research and the public. Chemistry and electromagnetism go almost unmentioned. Yet the cut-and-try Baconians such as Goodyear, Bell and Edison, as well as the more deductive Steinmetz, were also early signs of the 20th century. The research laboratories of the Bell Telephone Company, General Electric and Universal Oil Products were prototypes of a hundred industrial organizations that arose to conduct more basic work, usually with a good measure of Government support. Professor Miller does not take us quite so far. He shows us an 18th century given over to the philosophical and religious gentleman investigator, and his 19th century is gripped by the successful struggle to preserve pure research at professional levels, within the powerfully pragmatic climate of Yankee invention and industry.

The 20th century has seen basic research become accepted and merge into the largest issues of national and economic life. Its own product has grown to the level of communication satellites and fission-fusion bombs, results that are totally beyond the reach of Edisonian trial and error. Only a few weeks ago an informed public official suggested that the study of quasars might yield a new source of energy! Well, maybe; a new source of appropriations might have been more to the point. It may be that the recent ill-health of science, both among the young and in the domain of endowments, jobs and prospects, suggests we again need a different mix: a better balance between the increase of knowledge and its diffusion among men.

SCIENCE IN FRANCE IN THE REVOLUTIONARY ERA, DESCRIBED BY THOMAS BUGGE, edited by Maurice P. Crosland. The M.I.T. Press ($10). THE METRIC SYSTEM: A CRITICAL STUDY OF ITS PRINCIPLES AND PRACTICE, by Maurice Danloux-Dumesnils, translated by Anne Garrett and J. S. Rowlinson. Oxford University Press ($2.50). METRIC CHANGE IN INDIA, edited by Lal C. Verman and Jainath Kaul. Indian Standards Institution, New Delhi ($15). PREPARE NOW FOR A METRIC FUTURE, by Frank Donovan. Weybright and Talley ($5.95). In the summer of 1798, known locally as Year VI of the Republic, in the month of Thermidor, a perceptive, independent Danish astronomer arrived in Paris. Thomas Bugge was privileged: few foreigners came to that revolutionary capital, at once the Peking, New York and London of its day, the source of political and cultural change. His book, which was a quick best seller in several languages, is excerpted and extensively annotated by Professor Crosland, with special attention to the cultural and scientific institutions of France under the Directory. There is plenty of fascinating material, for instance the first school of military balloonists, working with hydrogen-filled taffeta aircraft, the splendid menagerie and the public lectures of R. J. Hauy on minerals and J. A. C. Charles on physics and chemistry. What a stir there was in Paris! Sundays were gone; the day of rest came only every 10th day. (There were, however, plenty of holidays.) Bonaparte and the army were off to Egypt, and in the gardens of the Louvre stood "the large and strong four-wheeled carriages" that had just conveyed to that gallery the rich collections newly liberated from the princes of Italy.

Bugge was no mere tourist. He was an official delegate to the founding International Commission on the Metric System, perhaps the first such congress of scientists ever held. The representatives of the main neutral and satellite nations of Europe were there; they met for some months, but the work of measurement could not meet the schedules of the diplomats. Bugge tells a good deal about the birth of metrology under the demands of the metric system; for example, the density maximum of water at four degrees centigrade was found by L. Lefevre-Gineau "by the most delicate experiments" with the big brass cylindrical vessel whose volume and weight measurements were to give the kilogram as the true weight of one decimeter of pure water. Bugge was admiring but unconvinced. ("States that already have a system of weights and measures have no sufficient reason for adopting the new metric system.") He went home early.

The powers of 10 did not sweep everything before them. The metric time units proposed to set 10 hours to the day, 100 minutes to the hour and 100 seconds to the minute. ("I have seen only two clocks in Paris with dials divided according to the new time.") The clock industry beat this scheme back, for which, as an astronomer depending on old records, Bugge was grateful.

Professor Danloux-Dumesnils, in a personal, reasoned and instructive little volume—good reading for every teacher and student—reviews the present state of units in a tasteful book; indeed, a book refreshingly tart. He seeks a more rational approach to the metric system, in the spirit of Borda, Coulomb, Laplace and the rest. The International System of Units, with its strange concessions to the illuminating engineers, is not without bad faults. Surely the lumen and the candela are illogical as physical standards, and the watt, suitably qualified by visual efficiencies, solid angles and areas, will someday do it all, even for the lampmakers. ("It is outrageous to place the candela on the same footing as the metre, the kilogramme, the second.") Danloux-Dumesnils's logic is matched by the interest of his book, with its clear summaries of history and means of measurement, and admirable logarithmic scales presenting the entire range of phenomena for a dozen important physical quantities.

Danloux-Dumesnils would like to metricate plane and solid angle (already done in part by the founding fathers but never adopted outside France), and he exclaims against "the Chaldaean units," but he will accept the day and the second as admirably international and long-lived. An appendix raises the urgent matter of teaching and using the power-of-10 notation in some compact and publicly welcome form; Danloux-Dumesnils's economical solution—Avogadro's number becomes (23) 602—will appeal to many readers. This is an urgent notational problem that has existed since Simon Stevin gave us the decimal point.

The history of metrication is rich in implications. It was Talleyrand, acting for the French constitutional monarchy in 1790, who first invited the world to adopt unified units. He insisted that "Franco-British collaboration" was the condition of success. The British Foreign Secretary called the plan "almost impracticable," a "diplomatic expression for the word NO." The U.S. Senate was also negative, simultaneously turning down another decimal plan of Jefferson's on the ground that the metric system was under consideration in Britain and France. Danloux-Dumesnils dryly remarks that the current opposition of these countries can be understood: "When one has refused to collaborate in a scheme, one cannot forgive its subsequent success."

Only the U.S., Canada, Australia and New Zealand remain nonmetric (Britain is en route) among the nations that have appreciable industry. How India converted is the tale of the book edited by Verman and Kaul. It was the political climate of independence from Britain, with the strong support of Jawaharlal

Nehru, that set India the double task of going over to decimal coinage and the metric system. The legislation was passed in 1956. After two bank holidays in 1957 and plenty of work on the railroad fare system, in the post office and particularly in the mints, the naya paisa, a hundredth of a rupee, with its multiples, two, five, 10, 25 and 50, has replaced the 16 annas divided into four paise of the British Raj.

A change in currency touches everyone, but this change is simple and the incentives are high. Metric weights and measures are of course far more complex: they extend from maps and milestones to wire sizes, paper dimensions, screw threads, standard lamps, timber, brick and much more. The cheerful and effective civil servants whose essays compose this book tell the detailed story of how the changes were made. Ten years was legally allowed for the task. After seven years the newspapers stopped giving their weather reports in both metric and British units. The paper manufacturers have stopped complaining and instead adjust their machines. The schoolbooks, particularly the more specialized ones, still lag. While both schemes were taught the pupils felt an added burden. The manufacturers of weights first tended to stall; they did not want to make the investment. Then they were pressed and were offered some aid, and so they went ahead. Then they could not sell the weights, just as they had feared. Finally the legal deadline came. Suddenly all the tradesfolk rushed for new gear. They found the long neglected manufacturers ready to sell what the storekeepers had to have but now at inflated prices!

In retail and wholesale trade the conversion is essentially complete. Land records lag; engineering schools are nearly converted; in engineering, industry, machine tools and the like "a good deal remains to be done." Above all, write the editors, "the common man had proved to be extremely receptive to the new idea and the fact of the change... the illiterate... more [so] than the more sophisticated and educated classes."

Prepare Now for a Metric Future is a swift, clear, journalistic treatment of the entire problem, its history, controversies (including some chauvinist period doggerel about "A perfect inch, a perfect pint,/The Anglo's honest pound") and the prospects here in the U.S. The Miller-Pell bill of 1968 has set up a serious Federal study of the task. Donovan, a worldly and well-informed writer, reckons that a gradual conversion will

soon begin, pushed by Government procurement policy, not by legislative compulsion. Britain too has avoided compulsion. The difference, and it is not slight, is that Britain depends much more heavily on export to the metric world. The push there came from industry.

When the Allies invaded Sicily in 1943, someone asked Enrico Fermi if the advance would be an important step toward final victory. "Maybe it will about make up," he said, "for the fact that the U.S. and Britain do not use the metric system."

THE VOCABULARY OF SCIENCE, by Lancelot Hogben, with the assistance of Maureen Cartwright. Stein and Day Publishers ($6.95). As combative, lively and blunt as ever, Professor Hogben here seeks to bring the classics to the tens of thousands, that is, to give the student of natural science a minimum reasonable knowledge of those Latin and Greek forms that make up the international language of the scientist, particularly, of course, in medicine and biology. The late-Renaissance decline of Latin as the lingua franca of Europe was followed by an explosion in the need for new terms. The acronyms of our day—a target of Hogben's scorn—are neither reasonable nor in any degree international; such contrivances were not used in those times. The speech of the period felt the long legacy of Latin, and there was already a clear pattern in English and French, and evidently in Italian as well, for adding newcomers of Latin origin. Lavoisier invented a scheme for the chemist's logical use of the words and affixes of Latin, and men who spoke English used a language that still shows the hybrid vigor brought in by the Normans. Thus English and French led the way as vernacular making full use of the classical sources. Indeed, scholars such as Carl Friedrich Gauss still wrote in Latin at a time when Latin papers from Thomas Young or Faraday or Ampère would have been astonishing. The entry of Greek roots was easy because the old Latin tongue already knew them. It was Linnaeus, anxious for a rich source of new words for his thousands of new classifications, who explicitly set out rules for the assimilation of Greek roots in the botanical volume of his *Systema Naturae*, published in 1737.

The latter two-thirds of Hogben's book, after a few "hints" about the grammar of the old tongues, offers an interesting glossary of Latin and Greek words and roots, classified by subject matter and then indexed alphabetically. There are about 2,400 terms listed, roughly half of them Greek and half Latin. *Strobeo* means "I spin" in Greek. "Belomancy" must mean divination by the use of missiles; it is a word not much encountered (possibly because it usually occurs in classified documents?). The lists are not complete; for example, *mantis*, the Greek for seer or prophet (invoked in belomancy) does not occur. The book is nonetheless good reading and a reference tool of utility and pleasure, although it is auxiliary to a good dictionary.

CHILDREN AND SCIENCE, by Lazer Goldberg. Charles Scribner's Sons ($6.95). It is a joy to find a book about teaching that is as helpful as this one. Part of a series of "guides for parents and teachers," it is accessible and attractive, from its typeface to its philosophy, although one misses pictures. It is a personal book, yet it is not in any way a private one; Dr. Goldberg, a member of the education faculty at Hofstra University, quotes scientists and poets, R. P. Feynman and Countee Cullen, William Harvey and the Book of Job—all to the point. The book unfolds in a series of disarmingly informal essays, free of jargon and written with taste and care. Instead of reading about behavioral objectives for the affective domain one sees headings about play, games, error and failure, and questions and problems. They sum up to three important ends: (1) a substantial rationale for a flexible, decent and effective way of bringing science to elementary school children, (2) detailed tips out of Goldberg's long experience on how to respect and to respond to the needs and efforts of diverse children, and (3) sketchy but suggestive descriptions of experiences and materials in many fields of science well suited to the classroom. There is, mainly by allusion, an introduction to current issues of the nature of teaching, of testing and of the classroom.

Under "Error and Failure" one reads: "If young children are shown shadows, but not the objects creating them, and are asked to figure out what the objects may be, their first inclination is to guess. They soon discover that shadows are tricky.... A thin line may turn out to be a phonograph record.... Some children begin to hesitate.... They say that they are unsure and ask that the object be turned. At this point a new rule is added to the game. The children may request that the object be moved... with the statement 'I don't know.'... Their smiles suggest, 'I don't know yet, but... there are things I can do... I'm pretty smart.' ... The aim of this experience is to help children learn that in the absence of adequate information it is not possible to know.... It was in the course of this game that a little boy announced, 'I made a thing out of clay. No matter how you turn it in the light, it always makes the same shadow.' " (Chosen for its brevity, this example is more heavily teacher-weighted than is typical of Dr. Goldberg's book.)

Anyone who wants to enter that hard but rewarding trade of science teaching, not in rivalry as much as in shared tasks, not for external certainty but for hopeful progress out of internal doubt, will find this humane guide just about the best start to be had.

THE WANDERERS IN THE YEAR OF THE YOUNGER METAL BOAR: 1971, by David E. Alter, Jr. The Wanderers, P.O. Box 1101, Silver Spring, Md. ($2.50). Twenty-odd spiral-bound wide sheets, each twice the size of a letterhead, make up this handsome almanac-calendar, a bargain for anyone who enjoys viewing the sky with the unaided eye. The heart of the matter is a double spread for each month. One large page bears a strong scratchboard drawing of a figure appropriate to the zodiacal constellation, set in a clear star map of the region, flanked by text paragraphs of mythology and lore, and by a list of the names and magnitudes of the unaided-eye stars. The other page carries a calendar of the days, with entries for the usual positional events worth noting in the sky and also for our earthly holidays. The latter page presents a strip map of the ecliptic region, with the tracks of the sun, the moon and the planets mapped among the stars for that segment of their great round. Supporting sheets describe the planets physically, supply a star map of the entire sky and recite other lore in a rich and reasoned mix of the decorative and the useful, the mythical and the factual. The author-artist-publisher knows what he is doing, and his work is reliable. (One might dispute some of the spelling.) The wanderers are of course the planets, and the year name is derived from the correlations of five elements and 12 zodiacal animals of the traditional 60-year cycle of the Chinese culture sphere, given in what is said to be the Shaka version. The extensive use of black ground and white line is striking and apt. It is not easy to read out the evening and morning stars from the crowded tracks; they can be deduced from the calendar entries, al-

though probably not by real beginners. The coming year promises no particularly fine eclipses or multiple conjunctions. About November 15 three of the wanderers will enrich the sunset. A.D. 1972 is the year of the elder water rat.

THE PENCIL OF NATURE, by William Henry Fox Talbot. With a new introduction by Beaumont Newhall. Plenum Publishing Corporation ($35). This handsome large book is a facsimile of the first photographically illustrated books, published serially from 1844 to 1846. Tipped into the ornamented Victorian text are 24 sepia halftone reproductions of Fox Talbot's original photographs, which were made on paper coated with silver chloride. Fox Talbot was preceded in photography (but not in publishing the process) by Niecéphore Niépce and Louis Jacques Mandé Daguerre, the partners who turned Niépce's 1826 chance invention into an 1839 commercial venture. Daguerreotypes, however, were unique positive pictures made on silver metal plates; they could not lead to any form of multiplication of the image. Both the French process and Fox Talbot's required exposures of at least several seconds in full sunlight.

The photographs show mainly buildings, sculpture, still-life scenes and facsimiles of printed pages or drawings, with one group of three patient men, "artistically arranged, and trained by a little practice to maintain an absolute immobility for a few seconds of time." It is no more time-consuming to depict groups than it is single figures, Fox Talbot reminds us. He tells the history of the art very well and fairly, and he foretells photography using light beyond the violet end of the visible spectrum. Perhaps the most beautiful picture is a contact positive of a parsley-like leaf—made "without the use of the Camera Obscura."

Fox Talbot was a landed gentleman, an amateur scholar and a scientist successful with cuneiform, philology, optics, internal-combustion engines—and photography. He commissioned a Dutch member of his household staff to set up a "Talbotype Establishment" in Reading. For *The Pencil of Nature*, which appeared in six paper-covered installments, each with the same red-and-black knot design on the cover, the Talbotype Establishment produced about 5,000 prints, in the "first mass production photofinishing laboratory in the world."

This book is a convincing, sumptuous and unusual period piece, a photographer's Gutenberg Bible.

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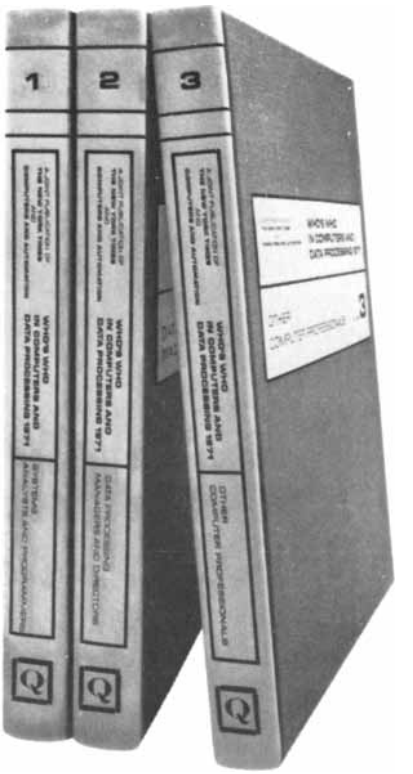

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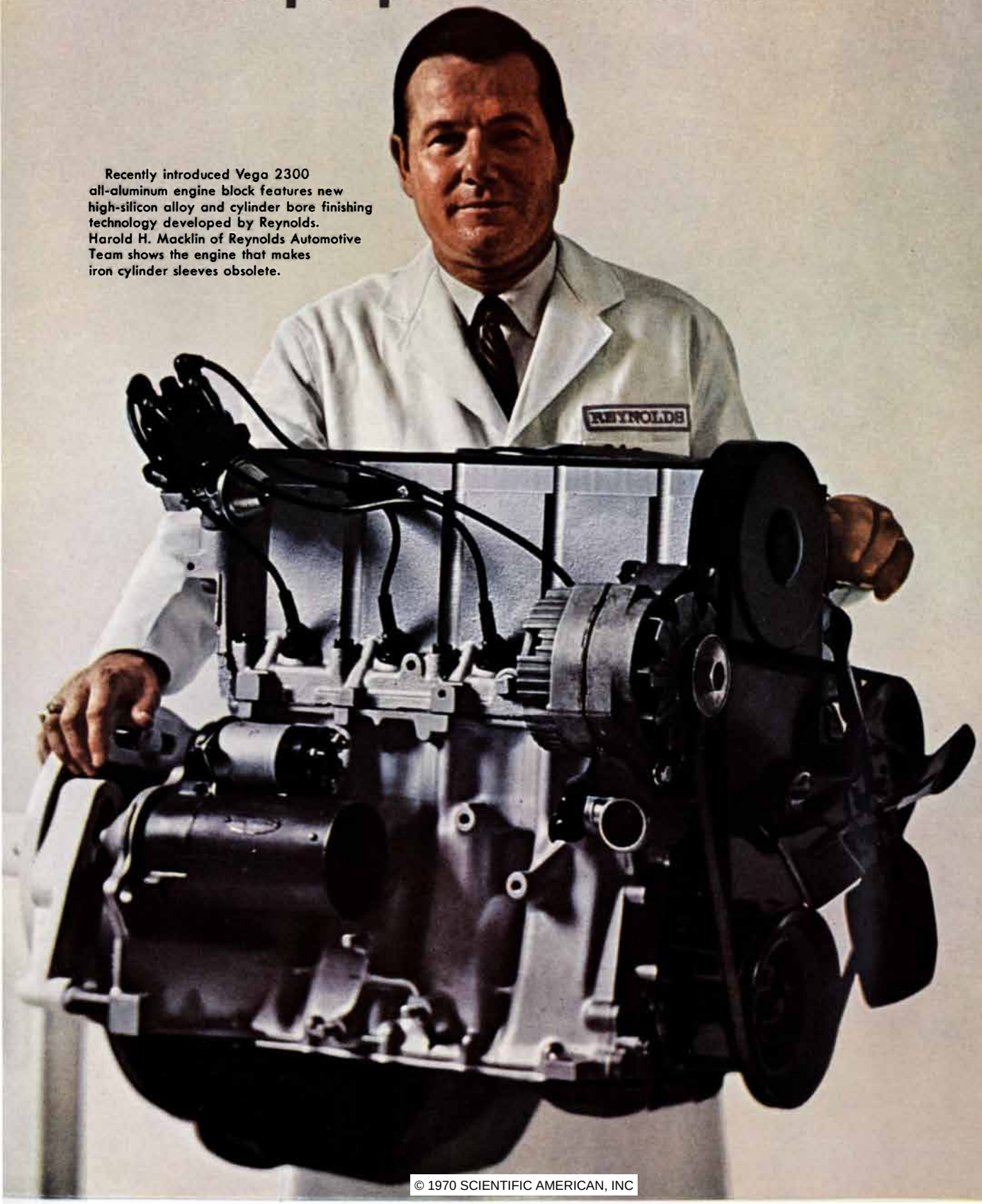

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