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INTRO
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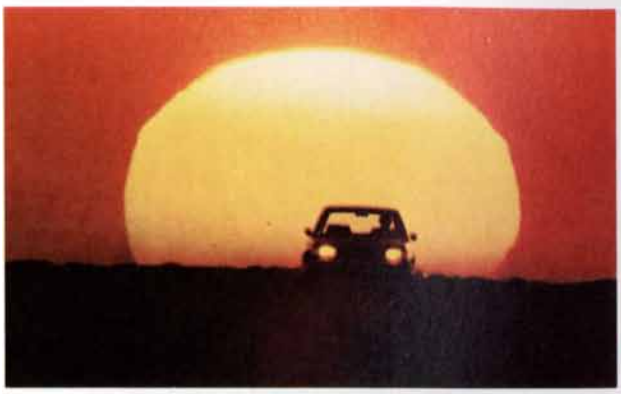

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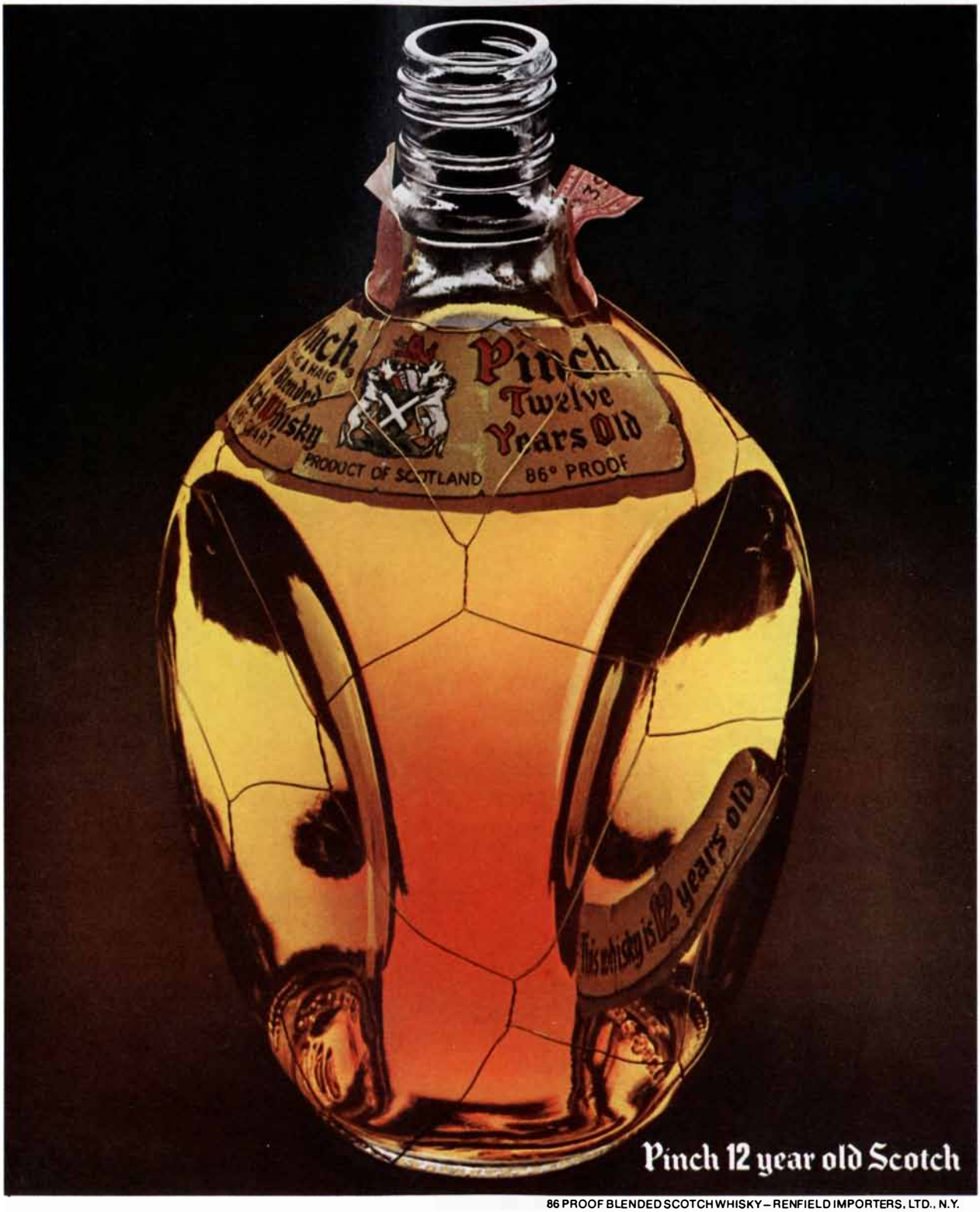

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ARTICLES

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executive health

the report that briefs you on what to watch

Volume XIV, No. 4 • January, 1978 • Pickfair Bldg., Rancho Santa Fe, Calif. 92067 • Area 714:756-2600

Linus Pauling, Ph.D.

VITAMIN C AND HEART DISEASE

Can vitamin C protect you, and how much should you take?

Heart disease and related diseases of the circulatory system are the main cause of death in the United States. Over one million people die of these diseases each year, and probably more than five million people now living are suffering from them in a significant way.

There is no doubt that heart disease is related to the diet. In the 1976 Congressional Hearings on the relation between diet and disease the nation's top health officer, Dr. Theodore Cooper (Assistant Secretary for Health in the Department of Health, Education, and Welfare), stated that

> "While scientists do not yet agree on the specific causal relationships, evidence is mounting and there appears to be general agreement that the kinds and amount of food and beverages we consume and the style of living common in our generally affluent, sedentary society may be the major factors associated with the cause of cancer, cardiovascular disease, and other chronic illnesses."

For about 25 years the major culprits in cardiovascular disease have been thought to be saturated fats, cholesterol, and related fat-like substances (lipids). A tremendous campaign has been waged to promote diets with low cholesterol, low saturated fat, and increased polyunsaturated fat. Despite this campaign, the death rate from cardiovascular disease has remained constant during the last 25 years, and it now seems to be almost certain that the assumption that heart disease is caused by a high intake of saturated fats and cholesterol is wrong.

This development does not mean that diet is not important. A high intake of ordinary sugar greatly increases the incidence of cardiovascular disease (see "Sugar: Sweet and Dangerous" in *Executive Health,* Volume 9, Number 1, 1972). Moreover, much evidence has been gathered recently to show that cardiovascular disease can be controlled to a considerable extent by the proper use of vitamin C.

What is cardiovascular disease?

The general term cardiovascular disease comprises various diseases of the heart and blood vessels. Arterio-

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Technology and the National Energy Plan: Offense or Defense?

When people ponder America's energy future, there is a tendency to blame "technology" for not delivering what was expected of it and to cite "the limitations of technological growth."

The current energy crisis is not a failure of technology, nor does it forecast the end of technological progress.

Since the winter of 1973, we have been told that our supplies of oil and natural gas are rapidly dwindling. And that we are likely to run out of these fuels within the next two decades.

It is not that technology has failed us, nor that we have reached the limits of growth in production and consumption of energy. Our energy problems are due to the fact that the world has suddenly entered a new era of higher-priced energy to which it must adjust. It is an economic problem, not an insoluble technological one.

The National Energy Plan is a necessary step forward. But only a half-step.

Government policymakers appear to have lost sight of the fact that our problems stem from a dwindling supply of oil and natural gas and escalating energy costs. Instead they have developed a National Energy Plan that refers to conservation as its cornerstone and presents a set of complicated measures to limit energy consumption. Few people would disagree that conservation is necessary.

Conservation merely copes with the problem. It doesn't solve it.

The National Energy Plan's emphasis hinders the use of existing technologies to help resolve our problems.

Production of oil and natural gas under the Plan would be suppressed by continual price controls. New taxes on production would raise the price of oil and natural gas to help curtail their use. But much of the resulting revenue would be channeled directly to consumers and would largely be withheld from the energy industries that need it to help finance expensive new exploration and development projects.

Too, present government policies would delay the leasing of federally controlled offshore areas for potential drilling, as well as the opening of new coal mines

Red tape and environmental concerns will severely handicap the construction of nuclear power facilities. Construction lead times for new nuclear plants have now been extended to more than ten years, as compared to less than five years in Japan.

Finally, the National Energy Plan regards coal as the major short-term energy source. But the government's anticipated increased production of coal has been cited by the General Accounting Office as "wholly unrealistic," mainly because new environmental regulations create more economic and production problems than they solve.

The technologies to deliver more energy exist today. But the National Energy Plan does not encourage their application.

The technology for deriving gas and liquid fuels from coal is well advanced in the demonstration stage. The technology for deriving petroleum from oil-bearing shale is now entering the demonstration stage. The Liquid Metal Fast Breeder Reactor is considered by the General Accounting Office to be "the likely vehicle for assuring that nuclear fission will be a reliable energy source through the 21st Century and beyond."

Production of hydrogen from water, coal, or oil shale could produce energy equal to all the natural gas we are now using. And electricity could be produced by "ocean thermal energy conversion."

Any one of these and other alternate sources of energy could provide the "solution" to our problems. That requires a massive commitment and investment. Probably on the magnitude of our commitment to the Manhattan Project and the Apollo program. The investment may seem staggering. But considering the long-range impact on society, the goal of a secure energy future is of equal or greater importance.

Unfortunately, there are signs that government will curtail its support of technology.

The present administration's budget proposals for federal funding on energy research and development focus largely on conservation methods.

Perhaps this attitude reflects political realities. Under the American system of government, elected officials have often been led to focus on the problems of today at the expense of the solutions to the problems of tomorrow.

Solving our energy problems requires statesmanship, not politics. We need leaders of vision who can focus on the horizon of the 21st Century as well as on the rocky path of the next five to ten years.

Ultimately, history will treat more kindly those who would provide solutions to our energy problems than those who would simply have us endure them.

Government policymakers should abandon their defensive posture and take the offensive. There are many things government can do in addition to emphasizing conservation. Such as promote greater tax benefits to motivate industry to invest in energy-related R&D. Federal loan guarantees, such as those already in effect in the housing and shipbuilding industries, are needed for industries which develop energy-related technologies. And government should increase collaboration with private industry to promote development of those technologies that will make our future energy-rich.

As it has in the past, technology *will* provide the solutions. But we need to develop the positive environment for technological progress. Today.

Science and technology can solve many problems. If they don't, what else will?

This message is a condensation of a 12-page Gould White Paper, "Technology and the Energy Plan." For the complete text, write Gould Inc., Dept. S8-2 10 Gould Center, Rolling Meadows, Illinois 60008.

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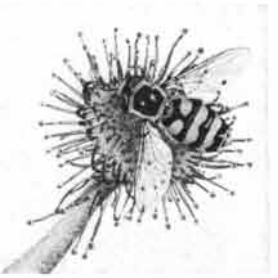

THE COVER

The painting on the cover shows an insect in the process of being trapped by one of the several kinds of plants that augment their supply of nutrients by digesting animal life. The plant, *Drosera rotundifolia,* is one of the sundews. These carnivorous plants capture their prey passively; other plants are active trappers (see "Carnivorous Plants," by Yolande Heslop-Harrison, page 104). The stalks rising from the surface of the plant bear droplets of mucilage that hold the insect. The stimulus of contact makes adjacent stalks lose their turgor selectively and bend toward the insect, tying it down more securely. The same glands that secrete mucilage then exude digestive enzymes and later resorb the digestion products. The trapped insect is the hover fly *Syrphus ribesii.*

THE ILLUSTRATIONS

Cover painting by Enid Kotschnig

Page	Source
38	Wan-go H. C. Weng
46–47	Type Systems Inc.
48–49	Francis A. Countway Library of Medicine
50–53	Type Systems Inc.
55	National Aeronautics and Space Administration
56	Enrico Bonatti, Lamont-Doherty Geological Observatory (*top*); Jose Honnorez, Rosenstiel School of Marine and Atmospheric Science, University of Miami (*bottom*)
57–60	Adolph E. Brotman
61	R. D. Ballard (*top*), Bruce C. Heezen and Hank Chezar (*bottom*)
63	Ben Rose
64–70	George V. Kelvin
71	Ben Rose
73–74	George V. Kelvin
92	Joseph L. Price
93–96	Lorelle M. Raboni
97	Charles E. Ribak (*top*), Lorelle M. Raboni (*bottom*)
98	Lorelle M. Raboni (*top*), Gordon M. Shepherd (*bottom*)
100–102	Lorelle M. Raboni
105	Yolande Heslop-Harrison
106	Ilil Arbel
107	Yolande Heslop-Harrison
108	Yolande Heslop-Harrison (*top*), Ilil Arbel (*bottom*)
111	Ilil Arbel
112	Yolande Heslop-Harrison
131	Ilil Arbel
114	Yolande Heslop-Harrison
117	Carlo M. Croce and Hilary Koprowski (*left*), Bunji Tagawa (*right*)
118	Carlo M. Croce and Hilary Koprowski
119–125	Bunji Tagawa
126–141	Gabor Kiss
145	Mehdi N. Bahadori
146–147	Alan D. Iselin
148	Mehdi N. Bahadori
149–150	Alan D. Iselin
152	Alan D. Iselin (*top*), Mehdi N. Bahadori (*bottom*)
154	Alan D. Iselin
156–160	Michael Goodman

LETTERS

Sirs:

Any resident of Wisconsin who dared assert that the domestic cat rivals its bovine barn companion in economic importance would indeed be foolish. But to maintain that cats "have never had any economic significance" ["Cats and Commerce," by Neil B. Todd; SCIENTIFIC AMERICAN, November, 1977] stretches credulity in the opposite direction. There seems to be agreement, if on circumstantial evidence, that one species or possibly several species of small *Felis* were originally locked in the granaries of ancient cities of Libya and nearby regions. Here they were charged with protecting the stores from hungry rodents over the unproductive winters and through any long sieges. If sparing an entire city from starvation does not constitute economic significance, that notion becomes slippery indeed. Cats were later mousetraps for the Egyptians and the Greeks, although apparently not for the Romans, and their possible role in controlling plague is given at least passing notice by historians.

JACK P. HAILMAN

Professor of Zoology
University of Wisconsin
Madison

Sirs:

The article "Cats and Commerce," by Neil B. Todd, in discussing the blotched-tabby variety of the domestic cat, concludes that there is a British focus, and probably a British origin, for the spread of this mutant, with penetration through France and a rapid spread eastward across the Mediterranean. Dr. Todd also notes that although the reason for the selective advantage of the blotched tabby is unclear, the type is spreading like an epidemic that will involve all cat populations.

There is some evidence from literature that the origin of the tabby may be not Britain but possibly the eastern focus mentioned by Dr. Todd. Thus the spread may have been westward rather than eastward.

John Aubrey, an English country gentleman who lived between 1626 and 1697, was an antiquarian and a member of the Royal Society who compiled and recorded a vast amount of biographical and other data that, published as *Aubrey's Brief Lives,* has proved valuable as source material for historians interested in 17th-century England. According to Aubrey, the tabby cat was a novelty in England in the early 17th century. He noted that W. Laud, a graduate of Cambridge and a lover of cats, was presented with some Cyprus cats, that is, tabby cats, which then (about 1637) sold for five pounds apiece. This apparently started a new fashion, resulting in a change that Aubrey greatly resented. The tabby quickly supplanted the "common English cat," which Aubrey says he well remembers was white with some bluish piedness. "The race or breed of them are now almost lost," Aubrey laments.

GEOFFREY WOOD

Falls Church, Va.

Sirs:

Professor Hailman takes a broader view of the economic importance of the domestic cat than I would usually admit. I am dubious, however, that cats ever saved a city from starvation, except perhaps by providing a reserve food source for the human population. This was the case for the island of Rhodes during the German occupation in World War II, and probably for Leningrad during the German siege. Here the role of cats was not much different from that of wallpaper paste, tree bark and shoe leather. As for controlling the spread of plague, the mortality statistics would not suggest that the cat was notably effective. Anyway, as far as rats are concerned, cats are probably more effective in competition for food than they are in direct predation.

Mr. Wood introduces some intriguing scraps of evidence, but I find them largely impossible to interpret. The "common English cat" that was white with some bluish piedness must now be entirely "lost," because I cannot say I have ever seen one of these beasts. In regard to the supplanting tabby, what kind of tabby was it? I find that most cat owners make no real distinction between blotched and striped.

Recent data on blotched-tabby frequencies in Iran, Pakistan and the U.S.S.R. indicate that the focus is in eastern Iran (Mashhad) and that the area and intensity of involvement are substantially more restricted than they are in western Europe. That suggests a more recent origin in the East, probably the result of an independent mutation, although Mashhad, astride the silk route, may have initially received some blotched tabbies in trade with the West.

NEIL B. TODD

Carnivore Genetics Research Center
Newtonville, Mass.

Sirs:

The article on the four-color-map problem ["The Solution of the Four-Color-Map Problem," by Kenneth Appel and Wolfgang Haken; SCIENTIFIC AMERICAN, October, 1977] called to

mind an enigma posed by Lewis F. Richardson in his *Statistics of Deadly Quarrels*. He comments that nowhere in the world do four sovereign states meet at a point, and he speculated on possible reasons for this interesting state of affairs. It may be worthwhile to remark that since Richardson's book was published (1960) political changes have invalidated his observation and there now exists one place where four states meet at a point. The states in question are Rhodesia, Zambia, Botswana and the Caprivi Strip extension of South-West Africa. (It is immaterial that South-West Africa is not a sovereign state, since it forms de facto part of the Republic of South Africa, which is one.) From a geographical and political, if not a mathematical, viewpoint the situation is clearly anomalous, and it will be interesting to see how the stresses involved will be reduced. It is morally certain that this same point will form the geographical focus of any war between South Africa and its black neighbors.

It may be noted in passing that the map of southern Africa contains the only real-world example of the other configuration excluded from the "normal" maps discussed in the article, that of a state entirely surrounded by another state (Lesotho).

ROGER W. JONES, F.R.G.S.

Llandyssul, Dyfed
Wales

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SCIENTIFIC AMERICAN

FEBRUARY, 1928: "Has the universe a limit? The mathematical physicist employs the word 'universe' in a narrow sense to describe that manifold of space and time with which the theory of relativity deals. Everyone knows now, by hearsay at least, that it is mathematically conceivable the universe may be finite but unbounded. It is not impossible that, if it is finite, human science may be able to measure its dimensions, but all that can now be said is that these dimensions must be so great the distance of the faintest nebulae our great telescopes can reveal must be but a very small part of the way 'around' it. The astronomer is likely to use the word in a still more limited sense to denote the great assemblage of stars that forms the Milky Way. The best calculation of the extent of our galactic universe is the one completed by J. C. Kapteyn. He found that the form of the system is one of a greatly flattened ellipsoid something like a thick, round cake of soap whose diameter is a little more than five times its thickness. The region within which the star density is more than an eighth the density at the center is 16,000 light-years in diameter and 3,000 light-years thick. This 'Kapteyn universe' gives much the best picture of our own universe of stars yet available."

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nia wells yield a steam whose acidity is so low that it can be used in its natural state."

"How far in this age of frankness can a journal such as SCIENTIFIC AMERICAN go in the discussion of sex? We recall that in our time some of the youth obtained their information about sex from their parents. Most of us, however, received it from older youths and from books that in some way implanted in our young minds the falsehood that sex was bad. We therefore make no apology for mentioning here a series of pamphlets we sincerely believe the majority of our readers should know about: the recent publications of the National Committee for Mental Hygiene, prepared by the well-known sociologist Katherine B. Davis. These several pamphlets, which we are advised are available for distribution to serious readers, will inevitably irritate many, for the truth always irritates. They will shock a few of the tender-minded, and they will doubtless confound utterly some of the misbeliefs even of the scientifically minded. What are the 'average' sex practices of the human race? We had thought we knew, yet it appears we did not. We have often mistaken general impressions and traditions for fact. We must liquidate our present beliefs and remold them on a more reasonable basis. In short, if what we have thought to be abnormal in sex life now turns out to have been more the rule, must we not now revise the very criterion of what actually constitutes an average normal sex life?"

SCIENTIFIC AMERICAN

FEBRUARY, 1878: "Mr. Thomas A. Edison recently exhibited his talking machine before the Polytechnic Association of the American Institute in New York. This was the first public showing of the instrument, and although much yet remains to be done to make it fulfill the design of its inventor, its capabilities have already been considerably advanced beyond those it possessed when it was displayed to us in this office shortly after its origination. The mechanical construction, that is, the rotating sliding cylinder, the vibratory membrane and the tin foil strip that receives the indentation and in turn transmits the pulsations to the receiving diaphragm, have not been materially modified, but by the use of reflectors Mr. Edison has succeeded in magnifying the sound so as to render it quite audible throughout a large apartment. The instrument proved its capacity as a linguist by repeating sentences spoken to it in English, Dutch, German, French, Spanish and Hebrew. It imitated with marvelous fidelity the barking of dogs, the crowing of cocks, etc., and then, taking a severe cold, coughed and sneezed and wheezed. It withstood the test triumphantly, and remained in modest silence while praises were lavished upon it and suggestions innumerable made as to its future uses."

"On the 22d of December, 1877, oxygen was for the first time liquefied by M. Raoul Pictet. Little more than a century has elapsed since the first discovery of this gas (by Priestley, in 1774), and vast has been the progress of science since that time. Gases at one time were looked upon as uncondensable vapors, but within the century first one and then another has given way to the persevering efforts of experimentalists, till at last the number of incompressible gases, with the liquefying of nitric oxide about a month ago by M. Louis Cailletet, was reduced to three—oxygen, nitrogen and hydrogen. Now that oxygen has succumbed only two remain unliquefied."

"The interest Mr. Graham Bell's telephone has aroused among scientific men is extraordinary. We hear in all quarters of experiments being made in connection with it, with a view to throwing light upon its mode of action. Mr. Bell and others are striving to measure the strength of the electric currents induced by the vibration of the iron diaphragm. These currents are of extreme feebleness, and are incompetent to affect the most delicate galvanometer or electrometer, since they rapidly succeed each other in opposite directions. Other physicists are investigating the mode of vibration of the iron membrane, and the part played by the steel magnetic core."

"The convocation of the University of London has by a large majority agreed to accept what is called the Supplemental Charter, the effect of which would be to admit women to degrees in all the faculties, on the same conditions as men. This was done in the very teeth of the Medical Faculty, which in May last declared in the most unmistakable manner its strong protest and decision against the admission of women to medical degrees. Sir William Gull, it appears, considers it the least desirable of all things that women should be encouraged to practice medicine. Professor Lester claimed that in such a case the Medical Faculty itself should decide the question. Sir James Paget declared that it would be a scandal and a disgrace to examine women for medical degrees as men are now examined for them. Sir William Jenner was strongly opposed to the innovation, and condemned the advocates of the women's party. Sir William said that he had but one daughter, and he would prefer to see her upon the benches of the dissecting room than pursuing the course of study necessary to entitle her to take a medical degree."

Consumer Reports thinks you should know:

How good is the bologna in that sandwich?

Of the 35 brands and varieties of bologna tested by *Consumer Reports* for quality, *nine* were rated Poor or Very Poor for taste. The samples, bought in food stores, were either rancid or showed beginning signs of rancidity.

The start of rancidity can often be detected by a perfume-like scent. So the sweet smell of your bologna may be trying to tell you something.

How does the bologna sandwich compare with the others?

Hamburger	Bologna	Tuna Salad	Peanut Butter
(¼ lb. raw beef, cooked, 1 tbsp. catsup) on bun	(3½ ounces bologna, 1 tbsp. mustard) on white bread	(3½ ounces tuna, 1 tbsp. mayonnaise) on white bread	(1 ounce peanut butter) on white bread

The bologna sandwich earned our lowest vote of confidence.

Consumer Reports explored this in detail in its article "How Good is the Bologna in that Sandwich?"

Here's how bologna stacked up against the other three sandwich foods... (1) Highest in cost-per-ounce of protein (2) Highest in fats and calories. The bologna sandwich, in fact, was over *four* times as expensive as the cheapest sandwich—peanut butter—at the prices prevailing when we made our test. What's more, bologna contains a potentially harmful additive called sodium nitrite.

Consumer Reports gives you the facts behind the "baloney".

Today's supermarket is no place to be on your own.

Without help, it's hard to know about subtle product differences that can cheat your family of nutrients and maybe even cost you more in the bargain.

That's why *Consumer Reports* rates food and household products by testing standards just as rigorous as those we use for automobiles and expensive appliances. Equally rigorous standards are applied to our research into services, such as banking, insurance and much more.

Consumer Reports is the nonprofit, reader-supported magazine of Consumers Union—the nation's leading independent organization for testing and rating consumer products and services.

We don't accept advertising from anyone.

We buy what we test at the same stores you do. And we never accept "free samples" from manufacturers.

Five facts our readers learned that you could have used:

1. Pepperidge Farm Whole Wheat Bread was rated lower nutritionally than Wonder Enriched White Bread.

2. Pizza Hut's 10" Supreme pie gave us the most nutritional buy out of eight fast-food meals we tested... Arthur Treacher's Fish & Chips the least.

3. Bounty may be a "quicker picker upper" than lower-priced paper towels. But you may be able to handle most of your cleanup jobs with the cheapest towel you can find.

4. That much-squeezed-on-TV bathroom tissue that touts its softness whittled 150 sheets off each roll. (Once again, it's the customer who gets squeezed.)

5. Two banks can advertise the same interest rate for your savings account. But one pays only $44.93 for the same period for which the other pays $75.30. It's how they *calculate* your interest that counts. (And some of the biggest banks in the country are the stingiest when it comes to paying you interest.)

A lot of companies may not like what we have to say.

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THE AUTHORS

ELLEN L. BASSUK and SAMUEL GERSON ("Deinstitutionalization and Mental Health Services") are respectively a psychiatrist and a psychologist who have collaborated on a study of the statewide psychiatric emergency service in Massachusetts. Bassuk is assistant psychiatrist at Beth Israel Hospital in Boston and instructor in psychiatry at the Harvard Medical School. She attended Brandeis University and the Tufts University School of Medicine, where she obtained her M.D. in 1968. After an internship at Mount Auburn Hospital in Cambridge, Mass., she did her first two years of psychiatric training at the Boston University School of Medicine, going to the Harvard Medical School in 1971 as a third-year resident. Bassuk is currently director of the Psychiatric Emergency Service at Beth Israel Hospital and chairman of the Psychiatric Emergency Directors Committee of the Massachusetts Psychiatric Society. Gerson is instructor in psychology at the Harvard Medical School, staff psychologist at the Cambridge Hospital and assistant in psychology at Beth Israel Hospital. He attended City College of the City University of New York, where he received his master's degree in education in 1973, and he is now completing his thesis research for a Ph.D. in clinical psychology from the University of Texas at Austin.

ENRICO BONATTI ("The Origin of Metal Deposits in the Oceanic Lithosphere") is senior research associate at the Lamont-Doherty Geological Observatory of Columbia University and adjunct professor of marine geology at the University of Miami. Born in Rome, he attended the University of Pisa, where he obtained his doctorate in geological sciences. In 1960 he went to Yale University on a Fulbright fellowship and became involved in reconstructing the climate of southern Europe during the last ice age by analyzing sediments from small Italian lakes. The following year his interests turned to the geology of the ocean floor, and he moved to the Scripps Institution of Oceanography. There he remained until 1965, when he joined the faculty of the Rosenstiel School of Marine and Atmospheric Science of the University of Miami; he moved to Columbia in 1975. Bonatti has led a number of oceanographic expeditions in four oceans, and he has done fieldwork in the Afar Rift of East Africa, in the Philippines and in the Alps.

JAMES L. NEVINS and DANIEL E. WHITNEY ("Computer-controlled Assembly") are research engineers at the Charles Stark Draper Laboratory in Cambridge, Mass. Nevins is the principal investigator on a project to develop a programmable industrial assembly system; he also directs the laboratory's research on instrumentation and control systems for nuclear reactors. He attended Northeastern University, where he received his bachelor's degree in electrical engineering in 1952. That year he joined the Draper laboratory (then the Instrumentation Laboratory of the Massachusetts Institute of Technology) as a test engineer, and in 1956 he obtained his master's degree from M.I.T in the department of aeronautics. At the Draper laboratory Nevins has, among other things, helped to develop the guidance, navigation and control systems for the Apollo spacecraft and the lunar landing module. Whitney is a mechanical engineer at the Draper laboratory He did his undergraduate work at M.I.T in the humanities and mechanical engineering and after two years in the Navy returned to receive his Ph.D. in mechanical engineering in 1968. He then joined the M.I.T. faculty, working for six years in the department of mechanical engineering before going to the Draper laboratory in 1974.

GORDON M. SHEPHERD ("Microcircuits in the Nervous System") is associate professor of physiology at the Yale University School of Medicine. He studied zoology as an undergraduate at Iowa State University and obtained his M.D. from the Harvard Medical School in 1959. He then went to the University of Oxford to work on the electrophysiology of the olfactory system, receiving his D.Phil. in physiology in 1962. That year he became a research associate in the Mathematical Research Branch of the National Institute of Arthritis, Metabolism, and Digestive Diseases. Shepherd then worked for two years in the department of physiology at the Karolinska Institute in Stockholm before joining the Yale faculty in 1967

YOLANDE HESLOP-HARRISON ("Carnivorous Plants") is currently Leverhulme Research Fellow at the Welsh Plant Breeding Station of University College of Wales. She attended the University of Durham, where she obtained her doctoral degree in botany. She then lectured at the University of London and did research at the Royal Botanic Gardens in Kew. In addition to carnivorous plants her interests include the study of the lives of eminent Victorian scientists through their letters and other archival material and the archaeology of early technology in the English Midlands.

CARLO M. CROCE and HILARY KOPROWSKI ("The Genetics of Human Cancer") work at the Wistar Institute of Anatomy and Biology in Philadelphia. Croce, who is professor of genetics, attended the University of Rome where he received his M.D in 1969 The following year he joined the staff of the Wistar Institute, and his research has focused on the factors that control gene expression and on the genetics of malignancy Koprowski is director and institute professor at the Wistar Institute and professor of research medicine at the University of Pennsylvania. He obtained his M.D at the University of Warsaw in 1939 and came to the U.S in 1944 He joined the institute in 1957 after working for 12 years at the Lederle Laboratories of the American Cyanamid Company His current scientific interests include the expression of immune functions by hybrid cells and the mechanisms of viral latency in chronic and persistent infections.

DANIEL Z. FREEDMAN and PETER VAN NIEUWENHUIZEN ("Supergravity and the Unification of the Laws of Physics") are members of the physics faculty at the State University of New York at Stony Brook Freedman attended Wesleyan University and the University of Wisconsin, where he obtained his Ph.D in 1964 He spent the next four years on postdoctoral fellowships at the Imperial College of Science and Technology the University of California at Berkeley and the Institute for Advanced Study in Princeton, N.J In 1968 he joined the Stony Brook faculty he is currently on leave for a year as visiting professor at the California Institute of Technology Van Nieuwenhuizen was educated at the University of Utrecht, where he received his doctoral degrees in mathematics and theoretical physics under Martin J G Veltman. From 1969 to 1971 he was a fellow at the European Organization for Nuclear Research (CERN), and then he moved to the University of Paris at Orsay for two years on a Joliot-Curie fellowship In 1973 he went to Brandeis University and two years later he joined the Stony Brook faculty He is now on leave as a visiting scientist at CERN

MEHDI N BAHADORI ("Passive Cooling Systems in Iranian Architecture") is professor of mechanical engineering and director of the Solar Energy Center at Pahlavi University in Iran. He writes: "I should like to thank the Pahlavi University Research Council for supporting my research and the cultural offices of the cities of Yazd, Kerman and Bam for facilitating my visits to buildings of interest in those cities I am also grateful to S H Izadpanah for making similar arrangements for the city of Semnan, and to Professors Sabzevari and Shahinpoor for the interesting discussions I have had with them "

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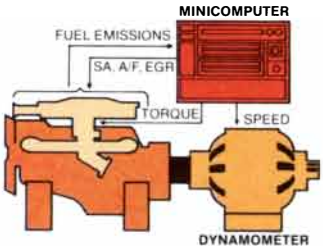
We wish that were the case... that raising a car's miles per gallon lowers its exhaust pollutant parts per million. But mpg and ppm don't seesaw. They tend to move up or down together, unfortunately.

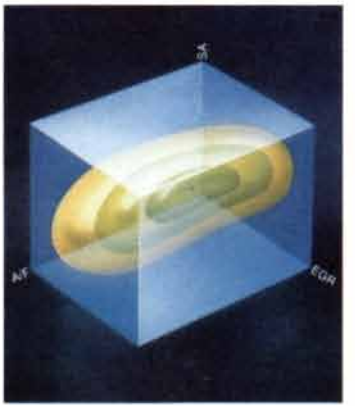
Given that tendency and a fixed pollutant limit, how do you achieve good fuel economy in an automobile engine?



Electronics engineers here at the General Motors Research Laboratories are helping close in on the answer. They're doing it through an understanding of the dynamic interaction between spark advance (SA), air-fuel ratio (A/F), and exhaust gas recirculation (EGR) and how this affects fuel economy and emissions. Their goals have been to determine the optimum control strategies for the three variables and devise systems to implement these strategies.

By extending and applying microprocessor (minicomputer) technology and optimal control theory — the same kind of sophisticated theory used to control the descent of lunar modules — Lab engineers have:

- Produced the first on-line dynamometer system in which a computer, programmed with a mathematical optimization algorithm, automatically converges on the maximum economy point (represented at right) in a running engine within specified emission limits. It does this at speed-load points typical of federal driving schedules.



- Modified this system so that the computer makes the engine think it's in a vehicle, then drives the "vehicle" through federal schedules.
- Developed a unique computerized test facility in a station wagon to evaluate experimental control concepts in a real-world environment.

Not exactly a giant leap for mankind. Just three of the many determined steps we're taking on earth to push mpg up while holding ppm down.

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MATHEMATICAL GAMES

On checker jumping, the amazon game, weird dice, card tricks and other playful pastimes

by Martin Gardner

The equipment used in familiar games—dice, chessmen, checkers, cards and so on—has always been a rich source of problems in recreational mathematics. Here are some recent examples of such problems, chosen for their variety and elegance. Most of the questions are answered here but I am withholding one solution until next month and another until I hear from readers.

I shall begin with dice. Is it possible to number the faces of a pair of cubes in a way completely different from that of standard dice so that the cubes can be used in any dice game and all the odds will be exactly the same as they are when standard dice are used?

As far as I know, Col. George Sicherman of Buffalo was the first to pose and solve this question. The answer is yes, and the weird pair of dice in the illustration on this page show the only way it can be done if we assume that each face must bear a positive integer. It does not matter how the six numbers are arranged on each die. Sicherman has placed the numbers so that opposite sides of the left die total five and opposite sides of the right die total nine.

At the left in the top illustration on page 22 is the familiar matrix that displays all the ways each sum from 2 through 12 can be made with a pair of standard dice. There are 36 combinations. To determine the probability of throwing a given sum, n, count the number of n's on the chart and divide by 36. For example, there are three 4's, and so the probability of throwing a 4 is 3/36, or 1/12. The corresponding chart for Sicherman dice is at the right in the illustration. It proves that the odds for each sum are exactly the same as with ordinary dice. A casino could use Sicherman dice on the crap table without altering any of its betting rules or changing the vigorish (house percentage), although it might be hard to convince customers that the probabilities were unaltered.

To demonstrate that there is no other way to construct such a chart with positive integers takes a bit of doing that I shall not go into here. Sicherman also found that it is impossible to redesign a set of three or more dice that have the same odds as ordinary dice without utilizing his two dice. For example, Sicherman's pair plus one conventional die have the same odds as three ordinary dice, two pairs of Sicherman dice behave like four ordinary dice and so on.

The standard way numbers are arranged on Western dice (opposite sides total 7, and 1, 2 and 3 go counterclockwise around a corner) is involved in many puzzles and magic tricks and even in bits of numerology. The four edges of each face of a die represent the four seasons. The 12 edges of the cube stand for the 12 months. There are three pairs of digits on a die that add up to 7, the number of days in a week. If $7 \times 7 \times 7$ is added to $7 + 7 + 7$, the sum is $343 + 21$, or 364. Adding 1 for the die gives 365, the number of days in a year.

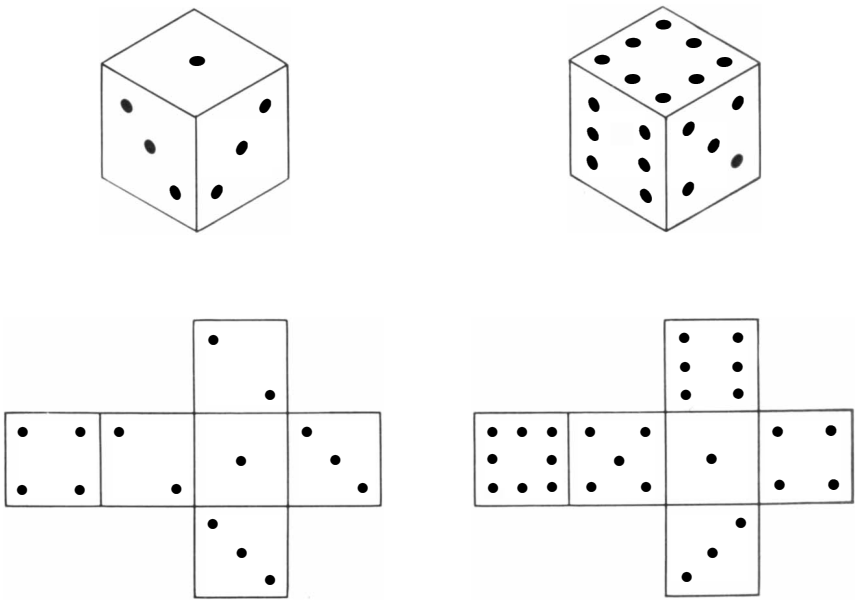
A die can be held so that one, two or three faces are visible. Is it possible to turn the die in different ways so that what is seen adds up to every number from 1 through 15? Curiously, only the unlucky 13 is impossible. Multiplying 13 by 4 (for the four corners of a face) gives 52, the number of weeks in a year.

Karl Fulves, a New Jersey magician, writer and computer scientist, recently invented an unusual extrasensory-perception trick based on the way the digits are arranged on a die. The magician hands someone a die, turns his back and gives the following instructions. The subject is asked to place the die on a table with any face uppermost. If the top number is even, he must give the die a quarter turn to the east (to his right). If the top number is odd, he must give the die a quarter turn to the north (away from him). This procedure is repeated sequentially, always obeying the rule: Turn east if the top face is even, turn north if it is odd. Every time the subject moves the die he calls out, "Turn." He does not, of course, reveal the number he started with or any subsequent top number.

After a few turns the magician tells the subject to stop as soon as 1 appears on top. The subject is then asked to give the die one additional turn (in compliance with the rule) and next to concentrate on the number this brings uppermost. It seems as though the number could be any one of four possibilities. Nevertheless, with his back still turned, the magician names the number.

A little experimentation discloses the secret. After at the most five turns the die enters the following loop: 1–4–5–6–3–2, 1–4–5–6–3–2,.... Therefore the number following 1 is always 4. Actually the die loops within three turns except when it is initially placed with 6 up and 5 facing the subject.

The following combinatorial problem was sent to me several years ago by Christer Lindstedt, a correspondent in Sweden. Imagine a three-by-three-by-



Sicherman dice

Ever wonder about * and

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A New Kind of Network.

New telecommunications technology designed by Bell Labs and manufactured by Western Electric is bringing you this versatile network. Its main elements are an array of electronic switching systems (ESS) interconnected by high-capacity transmission links, and a new "signaling" system to carry call-handling information.

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At the heart of each ESS is something called stored-program control. With it, the system's calls are controlled by coded instructions, stored in a memory and executed by a central processor. New features can be added by updating the stored instructions rather than rewiring or making complex equipment changes.

The new signaling system that will connect these switching systems operates like a high-speed private intercom. It carries all the information needed to handle each call and frees time on the voice circuits that previously carried such information.

Over 1000 local and long-distance ESS's are already in service, and twenty regional centers for the new signaling network are in place.

These innovations are possible largely because of advances in solid-state electronics. Because of their decreasing cost, low power consumption and speed of operation, today's integrated circuits are enabling engineers to design more capability into communications systems at lower cost.

Building on Bell System accomplishments such as Direct Distance Dialing, digital communications and high-capacity transmission systems, modern electronics permits the new network to handle a wide variety of communications needs.

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All these technical achievements, and their integration into the telecommunications network, result from the close collaboration of Bell Labs, Western Electric and Bell System telephone companies.

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	1	2	3	4	5	6
1	2	3	4	5	6	7
2	3	4	5	6	7	8
3	4	5	6	7	8	9
4	5	6	7	8	9	10
5	6	7	8	9	10	11
6	7	8	9	10	11	12

	1	2	3	4	5	6
1	2	3	3	4	4	5
2	4	5	5	6	6	7
3	5	6	6	7	7	8
4	6	7	7	8	8	9
5	7	8	8	9	9	10
6	9	10	10	11	11	12

Chart of odds for standard dice **(left)** *and Sicherman dice* **(right)**

three cube formed with 27 standard dice. There are 54 pairs of facing numbers in such a configuration. Multiply each pair of numbers and then add the 54 products. What is the minimum sum that can be achieved by a suitable arrangement of the dice? What is the maximum sum? I do not know the answer to either question, and I do not see any good way to find the answers without a computer. Interested readers should send me their best results. I cannot acknowledge the letters, but I shall report later on the best answers. At the moment I am not even sure of the maximum and minimum sums for a cube of eight dice. The best results I have obtained are 306 and 40.

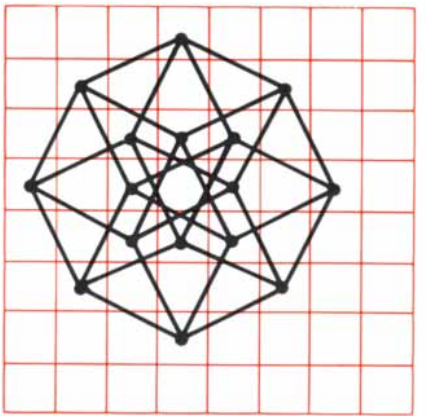
Here is a little-known chess task problem with a special case that provides a pretty puzzle, although the general case is unsolved. Can five queens of one color and three of another color be placed on a five-by-five chessboard so that no queen of one color attacks a queen of the other color? You can sketch the board on paper and use pawns or coins for queens. Surprisingly, there is only one solution (not counting rotations and reflections). I shall not spoil the reader's pleasure by giving the solution this month, but I shall include it in next month's column.

On the same order-5 board (a board with five cells on a side) it is impossible to place five queens so that more than three cells are unattacked or to place three queens so that more than five cells are unattacked. This fact suggests the more general problem. Given a board of order n, and k queens of one color, what is the maximum number of unattacked cells that can be produced by a suitable arrangement? Of course, queens of a different color can be placed on the unattacked cells, so that this problem is the same as asking for the maximum number of, say, white queens that can be placed along with k black queens on an order-n board so that no queen of one color attacks a queen of the other color.

The general problem is meaningless for boards of orders 1 and 2, and it is easy to see that on the order-3 board a queen can be put on a corner or side cell to leave a maximum of two cells unattacked. The problem starts to get interesting when n equals 4. It is not known whether there are unique patterns for k queens on boards of order higher than 5, and finding a formula for the general problem seems difficult, if not impossible.

There are dozens of classic chess task problems involving knights. Some of them are given in Chapter 14 of the latest collection of my columns, *Mathematical Magic Show*. Scott Kim has proposed the following knight task, which I have not seen before. Can 16 knights be placed on the standard chessboard so that each knight attacks just four others? The illustration below displays the beautifully symmetric solution. The black lines, which show all the attacks, form a planar projection of the skeleton of the hypercube.

In April, 1977, Jan Mycielski, a mathematician at the University of Colorado, wrote to ask if the following problem, suggested by his colleague Richard J. Laver, is new. Can a finite set of equal-sized squares be drawn on the plane in such a way that every corner of every square is also a corner of at least one other square? The squares may over-



Hypercube solution to Kim's knight problem

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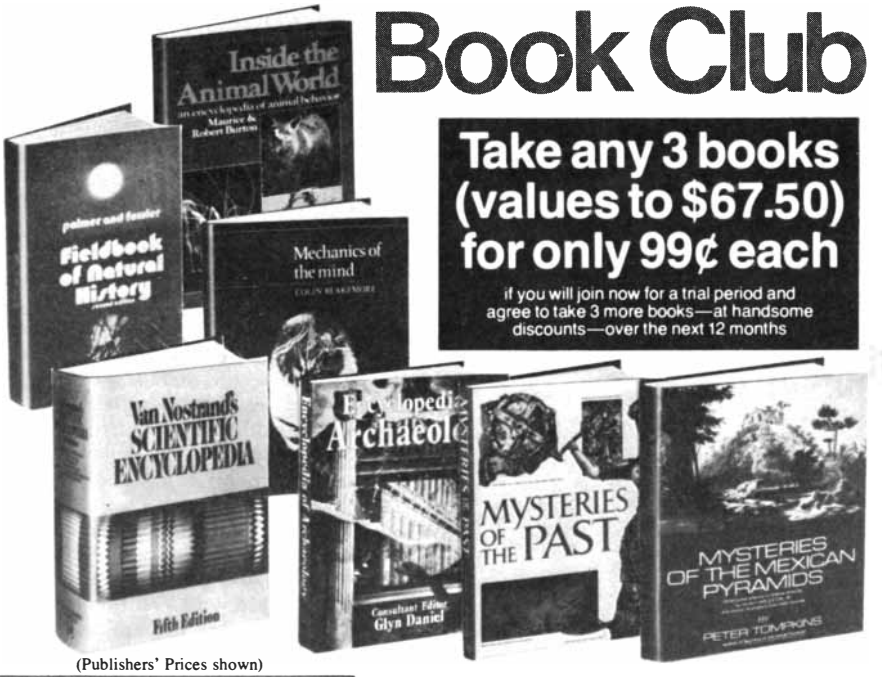

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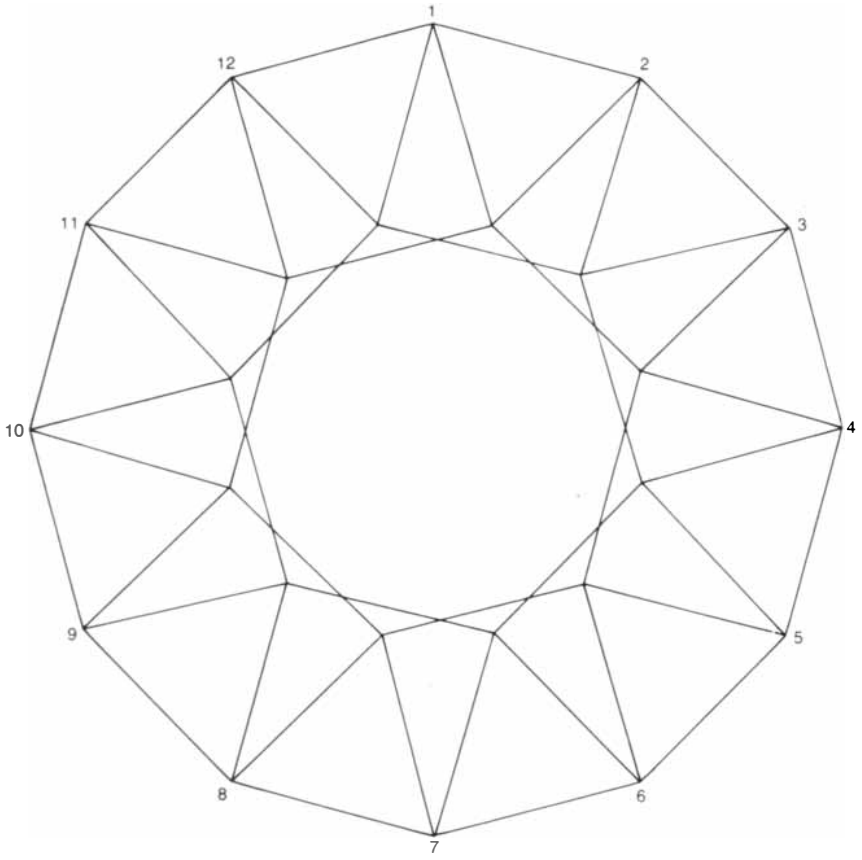
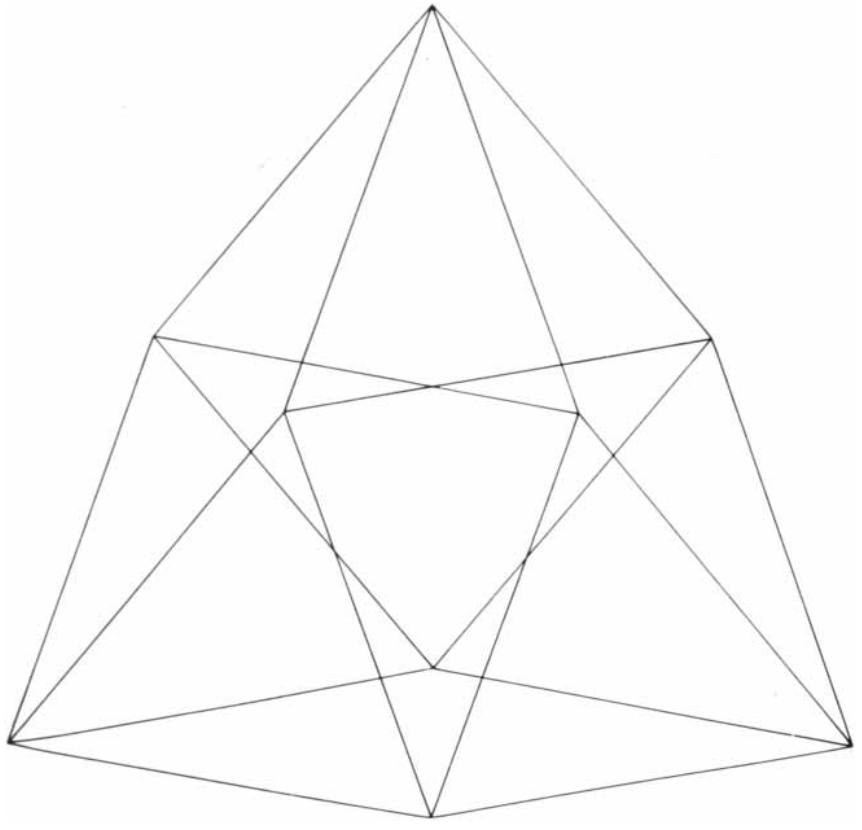


A 12-square solution to Richard J. Laver's problem



Projection of a four-dimensional simplex that solves a triangle problem

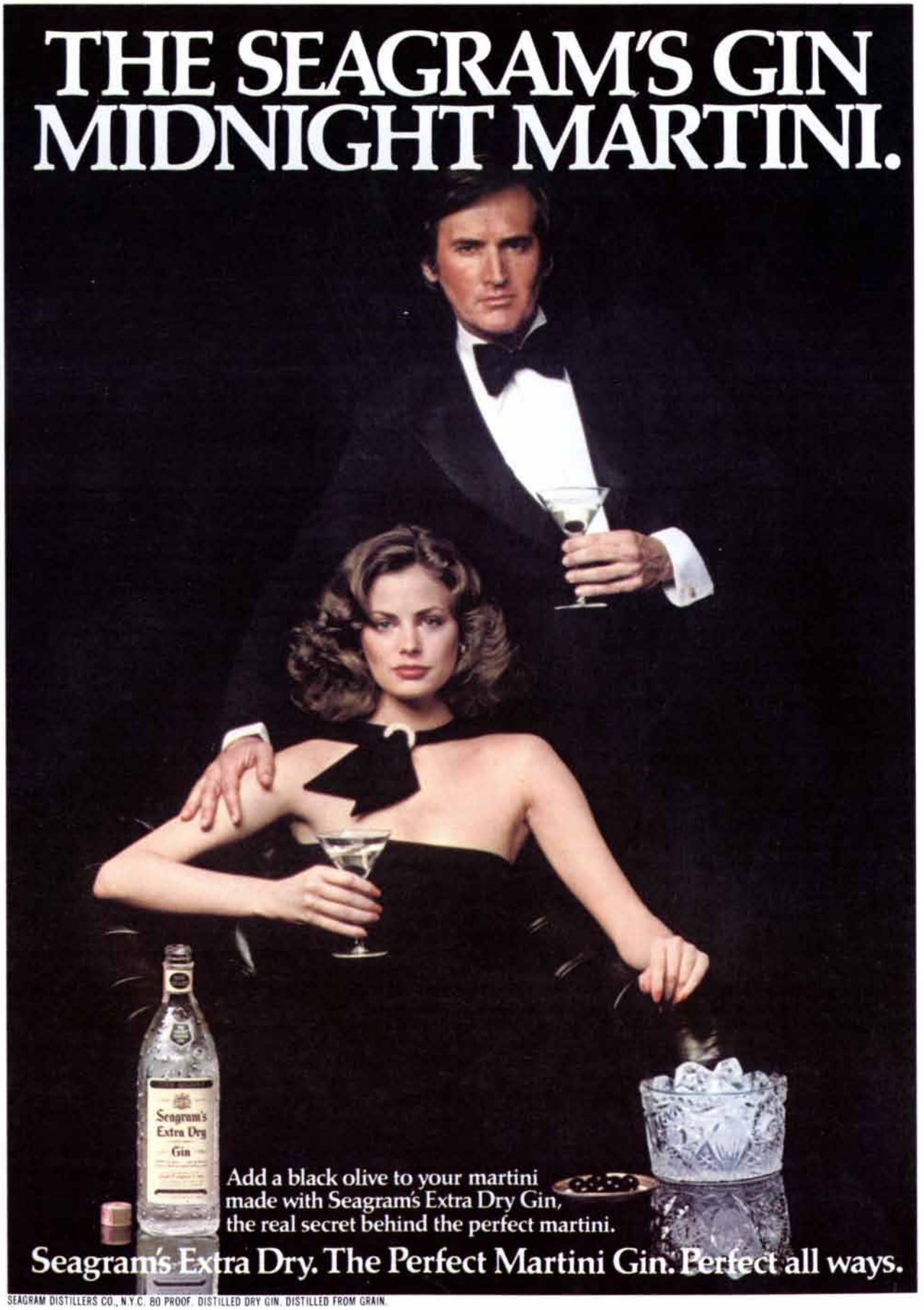
lap. Mycielski had found a set of 576 squares that solves the problem, and he wondered if that number could be reduced. Shortly thereafter he reported that another colleague had found a solution with 40 squares, and then that two other colleagues had independently brought the number down to 12 [*see top illustration at left*]. Finally, Andrzej Ehrenfeucht, a professor of computer science at the university, found a solution with eight squares.

Last October I mentioned the problem to Kim without telling him of any of the above results. He staggered me by saying instantly, "It can be done with eight." He had, of course, remembered his 16-knight problem that solves Laver's problem with eight squares. There is surely no solution less than eight, but I have no proof of that In three dimensions the problem can be solved with three squares. On the plane six identical equilateral triangles can be arranged so that every corner belongs to two triangles but no edge belongs to two triangles [*see bottom illustration at left*]. Not surprisingly, the solution is a planar projection of the four-dimensional simplex, an analogue of the regular tetrahedron.

David L. Silverman, author of *Your Move* (a splendid collection of puzzles based on games), invented a novel board game, not included in his book, involving a nonstandard chess piece that is usually called the amazon. An amazon combines the power of a queen and a knight. The game is played on a standard chessboard with two amazons and a supply of counters. Queens can be employed as amazons, but it is important to remember that each such piece also has the power of a knight.

White opens the game by placing his amazon on any cell. Black then places his amazon on any unattacked cell From that point on the players take turns, each player transferring his amazon to any vacant cell not under attack by the other amazon. An amazon is not moved like a queen or a knight. It is simply picked up and placed on any cell that is not threatened. After each move a counter, say a penny, is placed on the vacated cell. A cell with a counter is out of play (henceforth no amazon can occupy it), but the counter does not block any attack. As the game proceeds the cells slowly fill with pennies until eventually a player is unable to find a safe spot for his amazon The last player to move wins.

If Silverman's amazon game is played on an order-5 board, the first player wins immediately by occupying the center square. Since all cells are attacked, the second player cannot even put his amazon on the board On the standard chessboard the second player can always win by Silverman's clever pairing strategy He mentally divides the board into four



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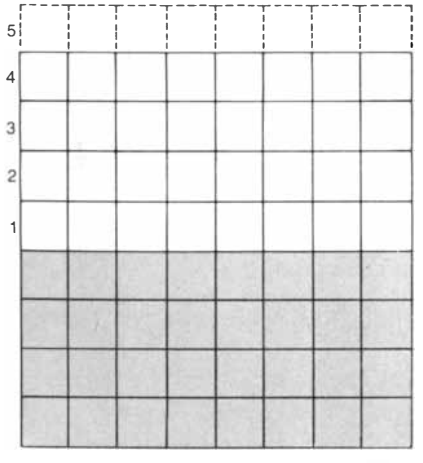
eight-by-two rectangles and numbers the cells of each rectangle as is shown in the upper illustration below. (Each number from 1 to 8 appears twice in each rectangle.) After each play by White, Black simply occupies the cell that is in the same rectangle as, and that has the same number as, the cell occupied by White. The game is an excellent example of the extraordinary power of a trivial pairing strategy to win a game that appears to be quite difficult to analyze. The pairing strategy obviously applies to any board of an even order higher than 4, and it is easy to devise slightly more complicated pairing patterns for first-player wins on all boards of odd order higher than 5.

Ross Honsberger's *Mathematical Gems II*, as exciting a collection as his earlier volume, discloses for the first time a remarkable result in checker jumping that was discovered by the University of Cambridge mathematician John Horton Conway. Imagine a standard checkerboard divided in half as is shown in the lower illustration below. The bottom half is shaded and the rows of the unshaded half are numbered (from bottom to top) 1 through 4. Now imagine a fifth row just beyond the top edge. If a checker jumps off this edge, it is considered to have jumped to row 5.

1	2	3	4	5	6	7	8
5	6	7	8	1	2	3	4
1	2	3	4	5	6	7	8
5	6	7	8	1	2	3	4
1	2	3	4	5	6	7	8
5	6	7	8	1	2	3	4
1	2	3	4	5	6	7	8
5	6	7	8	1	2	3	4

A pairing strategy for the amazon game



John Horton Conway's checker problem

All jumps must be orthogonal, that is, horizontal and vertical but not diagonal. As in checkers, pieces that have been jumped over are removed. The problem is to determine the minimum number of checkers that can be placed on the shaded half of the board in such a way that a sequence of jumps will place a checker on row n.

It is obvious that two is the minimum number of checkers required for getting a piece to row 1. They are placed as is shown at the top left in the illustration on page 30, and one jump does it. Four is the minimum number of checkers needed to get to row 2. They can be placed as is shown at the top right in the illustration. The bottom checker jumps to row 1, and then the checker farthest to the left makes two jumps to end on row 2. To get to row 3 eight checkers must be placed in the starting position shown at the bottom left in the illustration. So far the minimum numbers are in a doubling sequence, but to get to row 4 the sequence is broken. At least 20 checkers are required. They can be arranged as is shown at the bottom right in the illustration. The arrows show how the jumps begin, and it should not be difficult to find a way to continue that will get a checker to row 4.

How many checkers are needed to get to row 5, that is, to jump one checker off the board? Astonishingly, no arrangement of checkers on the shaded cells will get a checker to row 5. The situation is even more hopeless. No matter how far the shaded section is extended downward and to the left and right no pattern of checkers, however large, will boost a piece to row 5. Interested readers will find Conway's ingenious impossibility proof given in detail in Chapter 3 of Honsberger's book.

Turning to playing cards, there are so many new puzzles and magic tricks based on mathematical principles that it is agonizing to have space for only one. A few years ago Martin D. Kruskal, a physicist at Princeton University, made a strange discovery that is now known among card magicians as Kruskal's principle.

The principle is best explained by describing the card trick to which Kruskal first applied it. The subject shuffles a deck of cards and then thinks of any number from 1 to 10. He deals the cards slowly from the top, placing each card face up in a pile. As he deals he counts to himself, noting the value of the card dealt at the chosen number.

Assume that he thought of 7 and the seventh card is a 5. Without hesitating in his deal he mentally calls the next card 1 and as he deals he counts silently from 1 to 5. Suppose the fifth card is a 10. As before, the next card is mentally called 1, and as he deals he counts silently from 1 to 10. This procedure is repeated until all 52 cards have been dealt. The cards

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at the end of each count, which determine how high the next count goes, are called "key cards." The last key card of the counting chain must be remembered by the magician's subject. It is the "chosen card" that has been selected by this randomized counting procedure.

It is unlikely, of course, that the final count will end on the last card. It is more likely that it will not be possible to complete the final count. The subject is cautioned to deal the cards slowly, in a regular rhythm, so that no hesitations in dealing will give away the key cards. If the final count cannot be completed, he still must remember the last key card, but in order not to reveal it he must continue dealing to the end.

To make the counting easier, the magician explains, all face cards are given a value of 5. Thus if a count ends on, say, a queen, the next count is not to 12 but to 5. To make the procedure clear the illustration on page 32 shows a typical chain with the values of all the key cards indicated. The subject began by thinking of 4. The chosen card, which he remembers, is the jack of hearts. It has a value of 5, but because there are only three cards after it the last count cannot be completed. It is obvious that this procedure, performed with a shuffled deck, can select any of the last 10 cards.

After the counting is finished and the subject has his chosen card in mind the magician takes the deck, picks a card from the last 10 and places it face down on the table. The subject names his card. The magician's card is turned over, and it is *probably* the chosen card.

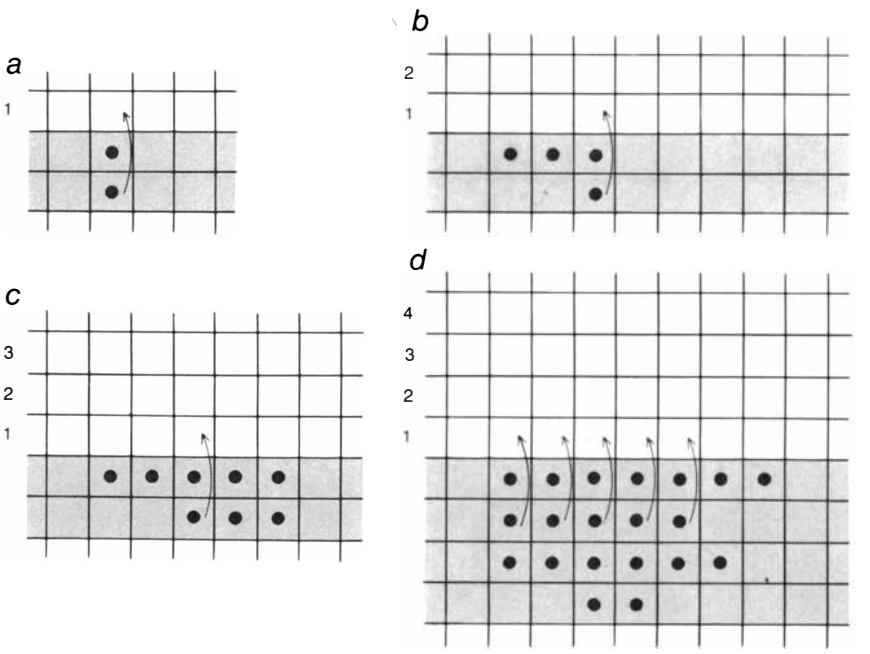
I have italicized "probably" to emphasize the strange way Kruskal's trick differs from almost all other tricks in which a magician finds a selected card. In this trick the magician cannot know the card with certainty. The probability that he will know the card is about 5/6.

Now for the curious secret. As the subject deals, the magician notes any fairly low card among the first few that are dealt. He treats this card as the first key of a chain that he counts silently to himself while the subject is counting his own chain. Kruskal's counterintuitive discovery is that about five times out of six the last key card of the magician's chain will be the same as the last card of the subject's chain! To put it another way, the probability is about 5/6 that any two arbitrarily started chains will intersect at a key card. Once this happens the chains will be identical from that point on.

Giving face cards a value of 5 increases the number of keys in an average chain and thereby increases the probability of intersection. By starting his count on a low card among the first few (instead of picking an arbitrary number from 1 to 10), the magician adds slightly to the probable number of keys in his chain. This raises the odds of success a trifle more. If the trick is done with two decks shuffled together, a failure is extremely unlikely.

One of the best variations on Kruskal's trick comes from Cy Endfield of London. The trick is first performed as I have described it and is presented as a feat of telepathy. When the magician removes the (probably) chosen card, he notes the card immediately under it. If that card is low enough to allow another count, he continues the silent counting and remembers the last key card. The removed card is not returned to the deck.

The magician then hands the 51-card



How to get a checker to rows 1, 2, 3 and 4

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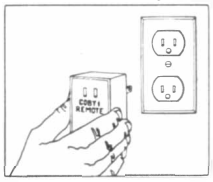

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When you come home, Coby 1 can have the house warm (or cool, in summer), the porch light on, the sofa lamp on, and the hi-fi on to welcome you.

CONSIDER THE ENERGY SHORTAGE.

Coby 1 can do wonders for your electrical bill. It never forgets to turn things off. It can turn car heaters, air conditioners, or electric heaters on just far enough ahead to make things comfortable—no need to have them on constantly. You can change the times from your easy chair. No mechanical timers; no wasted power.

WE'RE INTRODUCING THE COBY 1 SYSTEM AT A SPECIAL LOW PRICE.

We're interested in how you users put Coby 1 to work. **So until February 28, 1978, we'll accept advance orders for a Coby 1 Control at $399.00, the price to include a free Coby 1 Remote.** Suggested retail prices through stores will be $450.00 for the Control, $45.00 for the Remote. Other remotes will be extra.

Simply fill out the coupon and send it with your check, money order, or credit card data. You can also call in your order or get more information by calling (505) 526-3358. We'll ship your Coby 1 along with full instructions and suggestions on its use, after our first production run in January. We'll also include our 1 year parts-and-labor limited warranty.

WHO ENERGY TECHNOLOGY IS:

The company was started by the three of us, Brook Reece, Phil Reed, and Keith Burn. We developed the system ourselves. We're excited about Coby 1 because everyone we've talked to has expressed real interest in the product and sees a need for it.

We've been working on Coby 1 for months. Development and testing of production models is now complete. They'll be ready to ship in January.

Dealer inquiries invited. Energy Technology, Incorporated, 1601 South Main St., P.O. Box Q, Las Cruces, NM 88001. Phone: (505) 526-3358

Patents Pending for Coby 1 and Coby 1 Remotes.

Mail to:

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Put me down for one of the first Coby 1's.

Ship me one Coby 1 Control and one 15-amp plug-in Coby 1 Remote at the *Special Introductory Price* of $399.00, shipping included. $399.00

In addition, I want to order the following:

___ more 15-amp plug-in Coby 1 Remotes @ $45.00 _____

Total _____

New Mexico residents please add Gross Receipt tax _____

☐ Check ☐ BA/V ☐ MC ☐ Money Order Total _____

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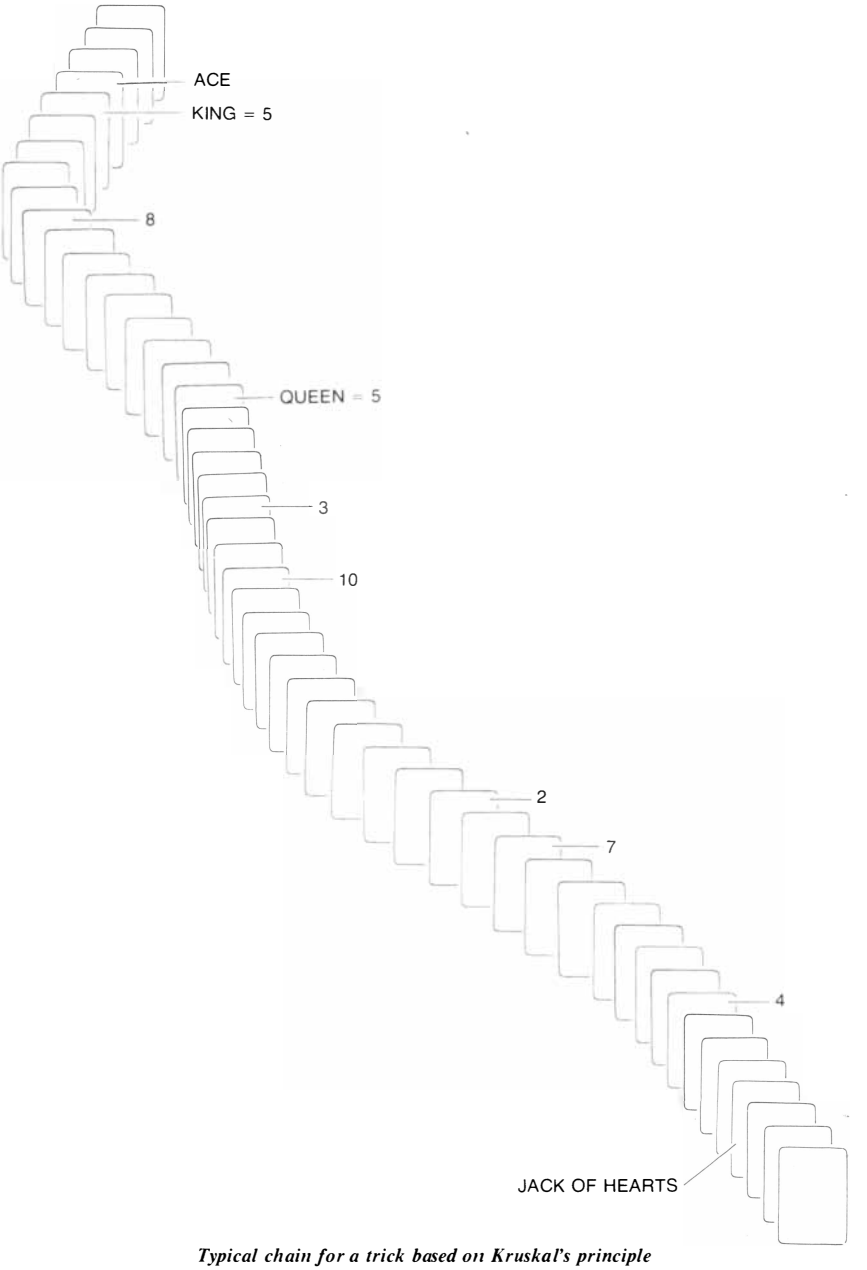
SA2-78

Signature _____

pack to the subject (without shuffling it) and asks him to repeat the trick, using a different starting number. "This time," the magician says, "I shall try to name your card by precognition." He writes a prediction on a sheet of paper that is folded and put aside. What he writes, of course, is the card he is remembering. Since the structure of the deck has not been altered, it is likely (with the same odds of about five to one) to be the second chosen card.

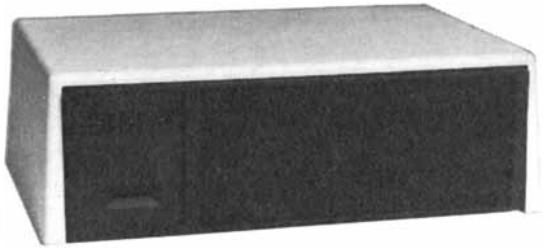
It should also be possible to program a computer to play the role of the psychic. Fifty-two punched cards would bear the names of the playing cards. The subject shuffles, selects a card by the Kruskal count and feeds the deck to the computer. The computer is programmed to guess the card and simultaneously to remember the card most likely to be chosen when the trick is repeated. If the first guess is correct, the chosen card is removed from the computer's deck and the trick is done again with a new starting number. This time the computer prints out the name of the card without examining the deck.

Even a computer will not always be right, but the fact that the trick sometimes fails makes it all the more impressive. When Uri Geller failed on the Johnny Carson show a few years ago (Carson, a former magician, guarded the test materials carefully before going on camera), Merv Griffin declared that the failure proved to him that Geller's powers were genuine. Magician's tricks, Griffin explained, always work. We all know how the "force" comes and goes. Why should a psychic robot control it any better than a humanoid?



Typical chain for a trick based on Kruskal's principle

Burglar Alarm Breakthrough



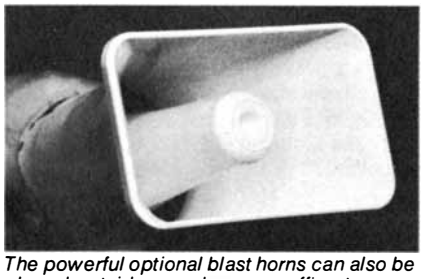
A new computerized burglar alarm requires no installation and protects your home or business like a thousand dollar professional system.

The Midex security computer looks like a handsome stereo system component and measures only 4"x 10½"x 7."

It's a security system computer. You can now protect everything–windows, doors, walls, ceilings and floors with a near fail-safe system so advanced that it doesn't require installation.

The Midex 55 is a new motion-sensing computer. Switch it on and you place a harmless invisible energy beam through more than 5,000 cubic feet in your home. Whenever this beam detects motion, it sends a signal to the computer which interprets the cause of the motion and triggers an extremely loud alarm.

The system's alarm is so loud that it can cause pain–loud enough to drive an intruder out of your home before anything is stolen or destroyed and loud enough to alert neighbors to call the police.



The powerful optional blast horns can also be placed outside your home or office to warn your neighbors.

Unlike the complex and expensive commercial alarms that require sensors wired into every door or window, the Midex requires no sensors nor any other additional equipment other than your stereo speakers or an optional pair of blast horns. Its beam actually penetrates walls to set up an electronic barrier against intrusion.

NO MORE FALSE ALARMS

The Midex is not triggered by noise, sound, temperature or humidity–just motion–and since a computer interprets the nature of the motion, the chances of a false alarm are very remote.

An experienced burglar can disarm an expensive security system or break into a home or office through a wall. Using a Midex system there is no way a burglar can penetrate the protection beam without triggering the loud alarm. Even if the burglar cuts off your power, the four-hour rechargeable battery pack will keep your unit triggered, ready to sense motion and sound an alarm.

DEFENSE AGAINST PEEPING TOMS

By pointing your unit towards the outdoors from your bedroom and installing an outside speaker, light, or alarm, your unit can sense a peeping Tom and frighten him off. Pets are no problem for the Midex. Simply put them in one section of the house and concentrate the beam in another.

When the Midex senses an intruder, it remains silent for 20 seconds. It then sounds the alarm until the burglar leaves. One minute after the burglar leaves, the alarm shuts off and resets, once again ready to do its job. This shut-off feature, not found on many expensive systems, means that your alarm won't go wailing all night long while you're away. When your neighbors hear it, they'll know positively that there's trouble.

PROFESSIONAL SYSTEM

Midex is portable so it can be placed anywhere in your home. You simply connect it to your stereo speakers or attach the two optional blast horns.

Operating the Midex is as easy as its installation. To arm the unit, you remove a specially coded key. You now have 30 seconds to leave your premises. When you return, you enter and insert your key to disarm the unit. You have 20 seconds to do that. Each key is registered with Midex, and that number is kept in their vault should you ever need a duplicate. Three keys are supplied with each unit.

As an extra security measure, you can leave your unit on at night and place an optional panic button by your bed. But with all its optional features, the Midex system is complete, designed to protect you, your home and property just as it arrives in its wellprotected carton.

The Midex 55 system is the latest electronic breakthrough by Solfan Systems, Inc.–a company that specializes in sophisticated professional security systems for banks and high security areas. JS&A first became acquainted with Midex after we were burglarized. At the time we owned an excellent security system, but the burglars went through a wall that could not have been protected by sensors. We then installed over $5,000 worth of the Midex commercial equipment in our warehouse. When Solfan Systems announced their intentions to market their units to consumers, we immediately offered our services.

COMPARED AGAINST OTHERS

In a recent issue of a leading consumer publication, there was a complete article written on the tests given security devices which were purchased in New York. The Midex 55 is not available in New York stores, but had it been compared, it would have been rated tops in space protection and protection against false alarms–two of the top criteria used to evaluate these systems. Don't be confused. There is no system under $1,000 that provides you with the same protection.

YOU JUDGE THE QUALITY

Will the Midex system ever fail? No product is perfect, but judge for yourself. All components used in the Midex system are of aerospace quality and of such high reliability that they pass the military standard 883 for thermal shock and burn-in. In short, they go through the same rugged tests and controls used on components in manned spaceships.

Each component is first tested at extreme tolerances and then retested after assembly. The entire system is then put under full electrical loads at 150 degrees Fahrenheit for an entire week. If there is a defect, these tests will cause it to surface.

PEOPLE LIKE THE SYSTEM

Wally Schirra, a scientist and former astronaut, says this about the Midex 55. "I know of no system that is as easy to use and provides such solid protection to the homeowner as the Midex. I would strongly recommend it to anyone. I am more than pleased with my unit."

Many more people can attest to the quality of this system, but the true test is how it performs in your home or office. That is why we provide a one month trial period. We give you the opportunity to see how fail-safe and easy to operate the Midex system is and how thoroughly it protects you and your loved ones.

Use the Midex for protection while you sleep and to protect your home while you're away or on vacation. Then after 30 days, if you're not convinced that the Midex is nearly fail-safe, easy to use, and can provide you with a security system that you can trust, return your unit and we'll be happy to send you a prompt and courteous refund. There is absolutely no obligation. JS&A has been serving the consumer for over a decade–further assurance that your investment is well protected.

To order your system, simply send your check in the amount of **$199.95** (Illinois residents add 5% sales tax) to the address shown below. Credit card buyers may call our toll-free number below. There are no postage and handling charges. By return mail you will receive your system complete with all connections, easy to understand instructions and a one year limited warranty. If you do not have stereo speakers, you may order the optional blast horns at **$39.95** each, and we recommend the purchase of two.

With the Midex 55, JS&A brings you: 1) A system built with such high quality that it complies with the same strict government standards used in the space program, 2) A system so advanced that it uses a computer to determine unauthorized entry, and 3) A way to buy the system, in complete confidence, without even being penalized for postage and handling charges if it's not exactly what you want. We couldn't provide you with a better opportunity to own a security system than right now.

Space-age technology has produced the ultimate personal security computer. Order your Midex 55 at no obligation, today.

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BOOKS

The variable sun, the cuisine of China, primates of the night and other matters

by Philip Morrison

THE SOLAR OUTPUT AND ITS VARIATION, edited by Oran R. White. Colorado Associated University Press ($8.95). Unsleeping Cassius had his theory: the fault was not in our stars. This remarkably diverse and readable collection of papers by an international set of experts assembled in the spring of 1976 tends to take the other side, at least in the short run, where we have some direct evidence. The present 11-year sunspot cycle is beyond doubt (although lately even that cycle has been shown anew to be itself inconstant). This volume includes a summary of the historical evidence from which the absence for centuries of sunspots, auroras and even of the eclipse-revealed corona is convincingly inferred. To these data is joined a careful study of tree rings and the associated radioactivity in carbon 14, a comparison made possible by the bristlecone pines that have so long endured the inhospitable climate of the Sierra Nevada summits. The conclusion from the 7,000-year carbon record, full of noisy signal, suggests irregular solar activity all right, but activity that averages out in the long run. The Little Ice Age coincided with the last two irregular sunspot declines; could the Great Ice Age 10 millenniums ago have come from the same cause extended?

We certainly do not know. A fine paper from a paleoclimatologist who deals in the geological record takes quite the opposite view, closer to the Cassius remark. Three well-established glacial intervals are revealed in a billion-year record in the rocks. For two of the glaciated epochs the continents were so arranged that land covered the South Pole; there are good continental-drift data to show it. Climate modeling suggests that the ocean-land arrangement sets the stage for widespread glaciation, thus exonerating the sun. The oxygen-isotope ratio in the shells of microplankton recovered from deep-sea sediments is a measure of the water held as ice on continental highlands. The waxing and waning of the ice volume suggests three recurrence periods, which match ("persuasively," the editors say) the periods of the small perturbations in the earth's orbital path around the sun. (A reader will not be persuaded by this volume alone, because the authors in question have put their earlier statistical studies elsewhere.) Those 100,000-year jiggles are the fault, so to speak, of Venus, Jupiter and Saturn. They work differently from solar flicker. The total sunlight falling annually on the earth is not much affected by orbit wobbles; rather, its distribution between hemispheres changes. Subtle feedback loops (for example, the ice cap reflects more heat as it grows, and then grows still faster) are then invoked.

But what of sunlight itself? Is the gross input wattage, what is called the solar constant, really unvarying? The global surface temperature has varied by about one degree Kelvin during the past 10 millenniums or so. A "state-of-the-art, order-of-magnitude" estimate suggests that such a change could arise from a variation of the solar constant by between .2 percent and 2 percent that lasted for some years; so far the climate modelers can offer no better accuracy Since the turn of the century simple ground-based monitors of the input of sunshine in the dominant spectral region, the visible and very near infrared, have been at work around the world. Only in the past decade, however, has a serious international effort concerned itself with absolute measures that are reliable for more than the relative readings of a single type of instrument at a single location. A dozen measurements from mountaintops and balloons, from rockets and satellites were available to provide sure answers for energy flow in the range of accuracy below 1 percent.

The ground stations had a terrible handicap in that absorption by the atmosphere amounts to some 20 percent, so that a small change in clarity over the years would vitiate any result. Russian high-altitude balloon experiments in the mid-1960's seemed to show the solar constant changing with sunspot number. The latest work (reported here although it was completed only after the end of the conference), done from the *Nimbus 6* weather satellite in orbit, does not confirm the balloon result. Over the years from 1969 to 1976, perhaps half of the latest solar cycle, it looks as though the sun offered us a power input that was unchanging to within 75 percent. In the 1980's shuttle-recoverable instruments that can be recalibrated and still better instruments in high orbit may answer the questions.

More than half of the volume reviews the spectrum of many wave bands of small and often strongly variable solar output: radio, far infrared, ultraviolet, X rays soft and hard. Particles too come from the sun, both the strong, low-speed proton flux of the solar wind and the chancy flares ranging up to cosmic-ray energies. All those diverse flows account for many phenomena here on the earth, but if they are to affect climate, they can do so only by way of some amplifying step, some link with photochemistry, some ionosphere trigger that is still unguessed. There is simply not much energy in all these wide-flung colors: more than 99 percent of the solar radiation lies in the visible and the relatively near infrared.

The sun is a star among stars, and two interesting, if technical, papers examine the theory of the sun as a star in the context of stellar activity in general. The factor of more than a billion by which the flux of the sun overweighs that of the distant stars has given us too dazzling a look, it may be, at solar complexities. The sun has its starry sibling: Alpha Centauri. With the same spectral type and a little greater mass, that star seems much like the sun but further evolved, perhaps twice as old. We know nothing much of its spots, its cycles, its corona or its versions of other enigmatic layers that engage our attention whenever we regard our own sun, the only star close enough to see warts and all.

This rich, comprehensive and yet tentative book (very neatly made) leaves a reader full of doubt and hope. Surely modern physics and its high technology cannot much longer leave us uncertain about our star and its suspect inconstancy. There are few problems in physical science so intimate and yet so tantalizing as this one. When will the ice come again, and why?

FOOD IN CHINESE CULTURE: ANTHROPOLOGICAL AND HISTORICAL PERSPECTIVES, edited by K. C. Chang. Yale University Press ($20). In Peking dialect to have lost one's job is to have *ta p'o le fan wan,* broken the rice bowl. The bowl of *fan* is indeed the center of every Chinese meal, as it has been for four or five millenniums. But "rice" is too narrow a translation, since *fan* is in fact any staple food made from grain: rice, steamed breads of wheat, millet or maize flour, pancakes, noodles. Each diner has his own portion of *fan*. To "assist" the *fan* every meal should have some *ts'ai,* selections from the overwhelming, flexible variety of dishes of cooked meats, fish and vegetables, those products of "the art of mixture," cut into small morsels and served for the entire table, to be shared through personal selection, often with individual sauces. Chopsticks are

GM

NEW CHEVY MONZA.

FEWER YEN, MARKS, LIRA, FRANCS, OR BUCKS THAN ANY SPORTY FOREIGN HATCHBACK.

'78 Chevy Monza 2+2 Hatchback Coupe.

As a matter of fact, this new Chevy Monza is priced lower than all imported hatchbacks, except Honda Civic, Mazda GLC, Plymouth Arrow, and Renault LeCar. That slick little fastback hatchback shown above, equipped with available sport mirrors and wheel moldings, is priced $1,678* less than a Toyota Celica GT Liftback. And $2,034* less than a VW Scirocco.

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So if you're looking for a sporty car, compare Chevy Monza to the foreign sports. It's quite a car at quite a price. No matter what language you speak.

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"You can't tell a customer we're short of No-nox because of a foggy day in the Azores."

"That doesn't sound like much of a problem, does it?" says Operations Planning Supervisor Wayne Broussard. "A tanker delayed by fog.

"But for any refinery—even one as modern as Gulf's Alliance Refinery—a constant crude oil supply is essential. To meet customer demand for gasoline and fuel oil, it's necessary to have 200,000 barrels per day of crude oil supply.

Uninterrupted supply

"So even if a ship's held up only a few hours, you may be short several hundred thousand barrels of crude. The whole process depends on an uninterrupted supply. So you have to talk to the transportation and supply people to make other arrangements for crude oil delivery.

"And to make sure we meet product quality specifications, you have to refine different crudes or crude mixtures in different ways. That means changing process operations and product blends.

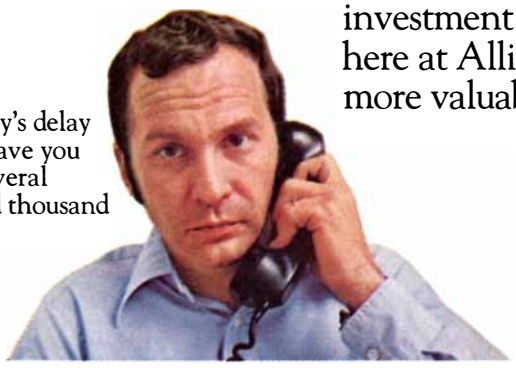
People vs the elements

"There's an enormous investment in hardware here at Alliance, but even more valuable are the people who make it all happen. Bad weather is just one of the challenges our people meet. But every day, all year long, we maintain the crude supply to produce 200,000 barrels of products.

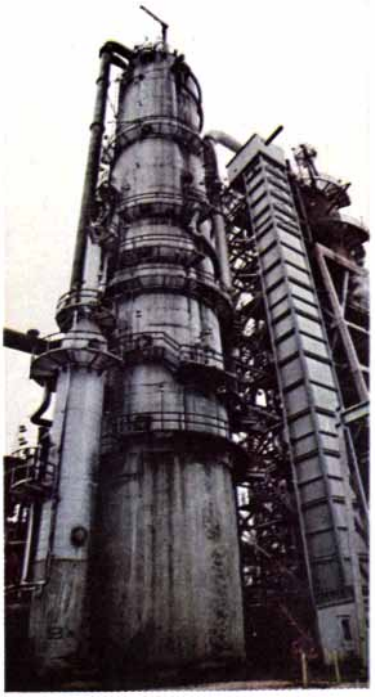
"It's a real challenge—but that's the job: meeting the challenge, and doing it right."

Gulf

Gulf people: meeting the challenge.



"One day's delay could leave you short several hundred thousand barrels."



"You have to refine different crudes different ways to get the same product."

Gulf Oil Corporation

usual, and have been common for 3,000 or 4,000 years. The kitchen always has a cauldron for *ts'ai,* a steamer or boiler for *fan;* the dual principle defines a Chinese meal even more sharply than the familiar ingredients from Chinese farm, field or stream.

That dual scheme is found in the invariable paired utensils in Han digs, in famous Chou texts of Homeric age and every day at a couple of hundred million family tables. The miraculous infant "Lord Millet" began to wail, says the ancient poem; his baby voice was very loud, but soon he showed the people the husbandry of the yellow crop, which "failed nowhere, it grew thick." The Chinese food style is truly an agricultural style. Some wild tribes on their marches ate no *fan* and some other barbarians took uncooked meat, but to be fully Chinese meant and still means eating grain food and cooked morsels, *fan-ts'ai.* Even in the dumplings and filled buns that may appear to mix the grain with its staple meat-and-vegetable accompaniment, the *fan* and *ts'ai* are not mixed but rather put together, the wrapping distinct around the filling.

Eight lively and learned chapters present an informal descriptive history of food in China, dynasty by dynasty, drawing on archaeological, literary, graphic and scientific evidence, seasoned with a good deal of personal experience in contemporary China north and south. The second aim is to interpret the rich material as a part of cultural history, probing the social and ritual implications in a pioneering way that is far from mature but full of interest. The final chapter (by E. N. Anderson, Jr., and Marja L. Anderson of the University of California at Riverside) draws a conclusion of remarkable force. The authors first show persuasively what everyone would concede, that the everyday Chinese cuisine is a "minimax game" making efficient use of land and sun. What then of the festival meals in their variety and splendor? Only here is *fan* made secondary to *ts'ai,* and here too the result is adaptive. Nothing is wasted: the pigs and chickens have converted scraps into high-quality protein, and the production of diverse crops and foodstuffs is encouraged by the habit of feasting.

A Sung dynasty banquet, from **Food in Chinese Culture**

The shared community essential to Chinese life is given tangible expression by the social use of enjoyable food. In China today this experience is more and more widely shared. The polarization of the past—the many hungry, the elegant few—is dwindling, and the old structures of holiday enjoyment remain as public goods. The *ts'ai* dishes are today less expensive but more numerous. Indeed, it is attractive to foresee the future in a world of limited resources, where in any country the scheme of life will not be some wasteful and mediocre hamburger every day but a frugal everyday diet set lower on the food chain and punctuated by a variety of socially sanctioned and highly enjoyable special occasions, yet economical overall. In 1972 Peking one couple of authors enjoyed not only "the best Peking duck we had ever tasted" but also "separate little dishes of sautéed duck's kidneys, sautéed duck's liver and intestines, deep-fried duck's tongue, salt-fried duck's pancreas, smoked duck's brain, and eggs steamed with duck fat."

Here are a few tidbits from this artful mixture of comment. The recent find of the remarkably well-sealed Han tombs (the lady of the Marquis of Tai died in about 160 B.C., but her grave goods and her body are wonderfully preserved) has fully verified the texts. In the tomb many bamboo slips bear meticulous recipes (distinguishing the use of dog flank and liver and of beef lips and tongue). Fermented darkened soybeans came in then, and perhaps bean curd; the great discovery, flowing out of new large-scale grinding technology, was "noodle food" based on wheat flour, attributed by a writer in the third century A.D. to the "invention of the common people."

The T'ang, a time of well-being, an era of cosmopolitanism and intercourse with foreign lands, may perhaps have seen Chinese invention of distilled spirits, which is usually ascribed to the physicians of Salerno in Italy at about the same epoch. In the Sung, a period of population growth, we know that early-maturing rice was introduced from the region of present-day Vietnam, reliev-

ing famine by making possible a second crop and by spreading rice culture to the drier uplands. Tea drinking reached the entire population and sugarcane began to be cultivated widely. China grew and prospered; in the Ming there was iced storage, and refrigerated barges plied the Grand Canal carrying fresh fruit and fresh shad. The 17th century saw new species from America come to nourish many Chinese; maize, peanuts, sweet potatoes (but never widely the white potato) and of course tobacco became major crops, as they still are.

The volume cites gourmets in many eras, one of them of such refinement that he included in the rice water the dew collected from flowers, although the dew from garden roses was too strong in flavor and could not be recommended! Such a pose is far from the honest "classic fare of the everyday Chinese world." In China today a huge bowl of rice, a dollop of bean curd, a dish of cabbage (fresh in season, otherwise pickled), some flavor from fermented soybean and a little rapeseed oil to stir-fry the greens constitute a square meal. The diet has "quality, variety and a nutritional effectiveness" and is able to sustain "more people per acre than any other diet on earth," at least beyond laboratory scale. And New Year's and someone's wedding are sure to come.

ECOLOGY AND BEHAVIOUR OF NOCTURNAL PRIMATES: PROSIMIANS OF EQUATORIAL WEST AFRICA, by Pierre Charles-Dominique. Translated by R. D. Martin. Columbia University Press ($17.50). For 300 or 400 velvet black nights one clever diurnal anthropoid moved unexpectedly around the high-canopied primary rain forest at Makokou, in the interior of Gabon. He was the zoologist-author of this study, and his "ingenuity, versatility and tenacity" are manifest in this readable, much-illustrated and uncompromisingly serious monograph (written in French and well translated by an informed English colleague to appear first in English). He could see in the dark, because he bore a strong headlamp whose probing beam caught bright orange yellow reflections from the crystalline layer behind the retinas of his subjects: our ancient little cousins, the five Gabon species of bush babies and lorisines.

The rain forest houses two worlds of animals, the sunlit and the night-shadowed. The birds long ago staked out the daylight: 96 percent of bird species are diurnal. The mammals chose the night: 80 percent of the mammalian forms in this forest live nocturnally. Rodents, insectivores, bats and the older primates are all night folk. There are exceptions: in addition to the large ground-living hoofed mammals nearly all the squirrels and our monkey kin earn a living by day. They seek arboreal insects and fruits through vision, capitalizing on

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Income may be subject to some state and local income taxes.

color perception, binocular perception of depth and foveal specialization for high-resolution optics; their hands assist in the catch, picking the insect or vegetable foods cunningly out of hiding places in litter or bark. By night, even though the prosimians have those hypertrophied eyeballs, with light-reflecting layers to make the most of the low light level (only 1 percent of the night-sky illumination reaches below the canopy), their insect hunt is done by sound or scent. The sharp, mobile ears of the agile bush babies detect a moving insect; the keen smell of the slow-moving lorisines "can detect an immobile cricket hidden from view at a distance of one meter."

There are two contrasting strategies in this nocturnal primate life. One is for the small and swift: bush babies leap and spin, propelled by long tails and powerful hind limbs. The stout potto and the slenderer angwantibo never leap but climb with a silent, deliberate motion, the former through the canopy and the latter in the undergrowth. The slow movers take slow and often unpalatable or irritant insects—ants and caterpillars—whereas the fast ones get the faster and tastier insects. All the forms prefer insects, but the bigger species, the potto and two bush babies, eke out the meaty diet with fruits or gums. The potto seeks its fruits high in the canopy, crossing from tree to tree on the stoutest branches and lianas of the forest. The angwantibo stays closer to the ground, using small lianas to move about the undergrowth in its hunt for the bristly caterpillars it can stomach. The bush babies all leap remarkably, under good binocular-vision control even on dark nights, sometimes flying two or three meters without loss of altitude. A potto, no mean fighter if cornered, may take two minutes to ooze one meter without rustling the dense leaves. "When extremely frightened, a potto may simply fall to the ground."

The methods of this devoted and penetrating four-year field study are as interesting as the subjects. The author made surveys by headlamp beam, had radio transmitters weighing under an ounce and made stroboscopic-flash photographs. He isolated trees and tree clumps by cutting their branches and lianas to force the animals to choose certain paths and take certain detours, often so that they would actuate switches installed on the vines, thus recording the time and direction of their passage. Taking a careful census of stomach contents, recording the complex calls with a parabolic microphone reaching the ultrasonic range, observing captive animals for long periods, alarming the animals with such stimuli as the skins of snakes and cats—those techniques are perhaps more usual. The richness of understanding that has been gained even of the social life of these nightbound crea-

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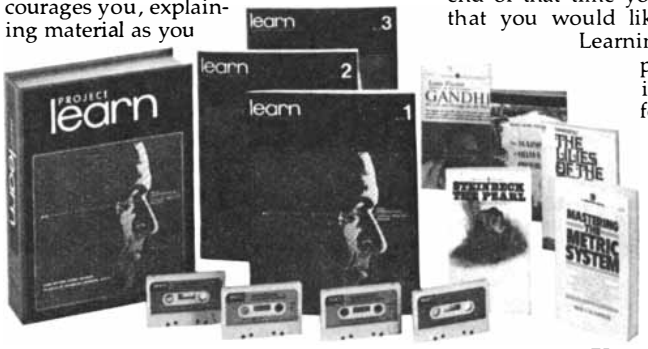

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tures, who signal by sound and scent, is a tribute to the work. (Charles-Dominique is careful to point out to us herded simians that "solitary" is the opposite not of "social" but of "gregarious.")

The bird-reptiles chose daylight 100 million years ago. The first primates were probably like the little fellows in Gabon, nocturnal. The dark night entrapped them all; their few adaptations are admirable, but they have remained in the rain forest almost as they began, since the rain forest itself remains unchanging over the ages. Thirty million years or so back some primates chose the riskier daylight. The eye-hand precision loop, color vision, free ground movement, larger size, wider diet, gregarious existence and in the end even volumes on ethology all appeared along that path of light.

KEY PROBLEMS OF PHYSICS AND ASTROPHYSICS, by V. L. Ginzburg. Translated from the Russian by Oleg Glebov. Mir Publishers, Moscow. Distributed by Imported Publications, Inc., 320 West Ohio Street, Chicago, Ill. 60610 ($2.25). Not many people could have written this book. We are lucky one of them did—a witty, candid, versatile and brilliant theoretical Moscow physicist who, in the spirit of his universal teacher, the late Lev D. Landau, has made stimulating contributions to superconductivity, phase transitions, particle theory, cosmic-ray origins, general relativity, plasmas and much more. Academician Ginzburg has written this little book, a tiny bargain equivalent of about 100 easily read pages, in a unique tone. The three chapters, each with seven to nine distinct sections, deal respectively with macrophysics, microphysics and astrophysics. In each domain he surveys the issues of the day and pronounces on them, firmly enough but with an honest admission that his is but one contribution to a debate, an effort "to argue . . . to be bold in bringing forward suggestions and defending them (but not imposing them)." Only the simplest of formulas (but they are deep ones) and a few key numbers appear in these pages. The argument is not intended for the true novice in physics, but it will engage anyone who has some serious background in the modern subject, even a qualitative one. The "key problems" are those "the answer to which is substantially unclear in character and content." (Biophysics is set aside.)

It is not reasonable to excerpt from such a brief book, but we can cite a few conclusions. Superconductivity at high temperature is bound to be one of the key issues. Thin metal-insulator sandwiches, formed to allow electron interaction through the exchange of electron-hole pairs, seem promising to Professor Ginzburg, who writes that he "would not be too much surprised to read about" such a discovery. We are still waiting. (The references end about three years back; this edition has been somewhat revised to about 1976.) The electron-hole fluid he expects has in fact been seen. Metallic hydrogen is not at hand, or controlled fusion, or the laser analogue for X rays, although the last is close. One can read here a convincing account of why materials with extraordinary properties are often reported, even in respectable publications, but cannot later be confirmed. The theory of phase transitions has been pursued more or less as Ginzburg urges. Superheavy elements remain claims.

Nuclear, or particle, physics appears to the author to be losing the preeminence it held only a generation ago because it now focuses on unstable matter, or matter with almost no interaction here on the earth. Once physics studied everyday things, atoms and their cores; today it deals with the outlandish and the rare. That cannot fault the depth and intellectual sublimity of the discipline, but it does reduce the impact. What was once the "first lady" of the natural sciences is now only the most beautiful; it has merely a subjective distinction, not a socially defined one. "I differ from some of my colleagues in believing that adoration should not be accompanied by neglecting changes in age and character." This was written before charm and other flavors, but it remains pointed.

In astrophysics Professor Ginzburg, obviously no conservative by nature, takes a skeptic's role. Gravitational waves he sees as "pseudodiscoveries" wanting confirmation. The singularities of general relativity, even the black hole dear to popular and scientific authors for a decade, may in fact not be realized, in spite of the classical theory of Einstein and its recent tentative extensions. A new length, somewhere below the present limit of our probing of small distances, may intervene to forbid the startling extrapolations. We do not know. Nor is it clear that the new findings of astronomy—the quasars, pulsars and masers, thermal background and X-ray stars—will demand any similar novelty from physicists. Molecular biology has fallen under the sway of ordinary quantum chemistry, something Bohr, for example, never expected. For Ginzburg new physics may at most be needed in the near neighborhood of the "classical singularities," at the final collapse of matter, or the cosmological analogue.

The book ends with a characteristic few pages in which one seems to hear the lively voice of the author himself. "I just could not write I in a purely scientific paper and it was sometimes with an effort that I wrote so in this book which is, after all, a popular account of my personal views." Surely our scientific literature has gone too far in its laconic and impersonal style; will some able colleague reply to Vitaly Ginzburg's pungent views? We need what he invites: "a debate on the development of science going on in the atmosphere of tolerance and goodwill."

THE ARTICULATE MAMMAL: AN INTRODUCTION TO PSYCHOLINGUISTICS, by Jean Aitchison. Universe Books, New York ($10). "The rabbit is ready to eat." Chef's statement or pet owner's? Two distinct "deep structures" underlie the single plausible sentence, both of which can be transformed by relatively simple rules into the single form cited. Is that how you were able to read the line? For nearly 20 years, under the sustained and penetrating inquiry led by the philosopher-linguist Noam Chomsky of the Massachusetts Institute of Technology, the discipline of psycholinguistics has worried its way into independence. To one side of it lies the apt but stupid pigeon pecking at a picture, to the other the epistemological constructions of Descartes and Kant. Language is so close to thought, so widely and swiftly learned among human beings, so subtle in its complexity that it claims the right to occupy a special place in psychology, a place where the linguist's learning and mathematical bent dispute the experimenter's sovereignty. The controlled experiments of the one and the extraordinary richness of the spontaneous data from the field that is so central to the other have begun to complement each other.

They nonetheless have a long way to go. This cheerful little volume by a linguist at the London School of Economics is an engaging summary at an introductory level of the present status of three grand topical problems: In what way is language genetically programmed into human behavior? How does that internal knowledge find use? How do we in fact understand and produce sentences? With plenty of wordplay, puns, epigraphs from Ogden Nash and others, whimsical terms and even cartoon diagrams, Dr. Aitchison leads us through the literature of the turbulent science. The story begins with the famous review of 1959 in which Chomsky made plain that "language is infinitely more complex and less predictable" than a theory of learned responses can possibly encompass. (Of course, there is some learned-response verbal behavior—people who "invariably say 'Damn' if they drop a raw egg.")

The author leads us through the pseudospeech of mynas to the protospeech of chimpanzees, to a little brain architecture, to the biological preconditions of human speech (for example, how we easily do at least three things at once in speaking), to the way infants utter

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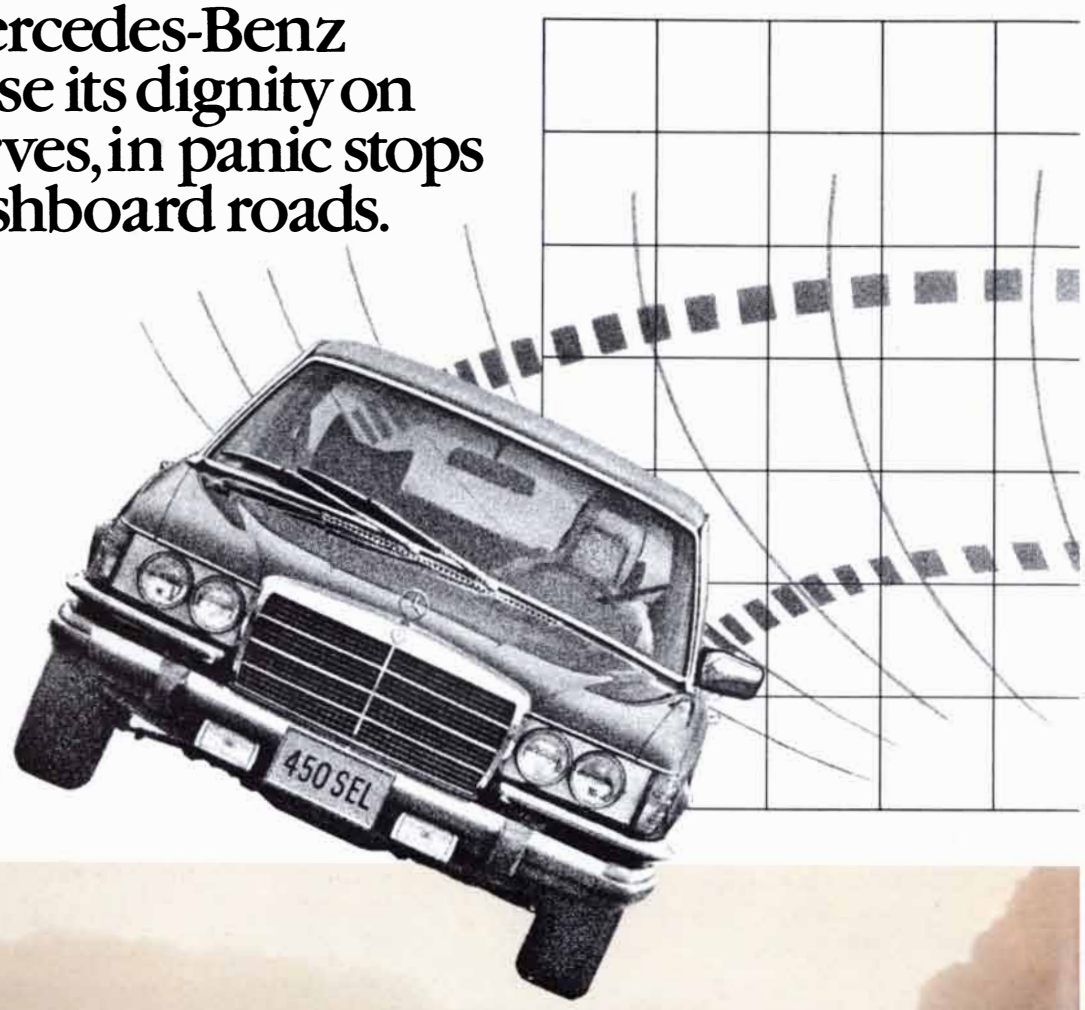

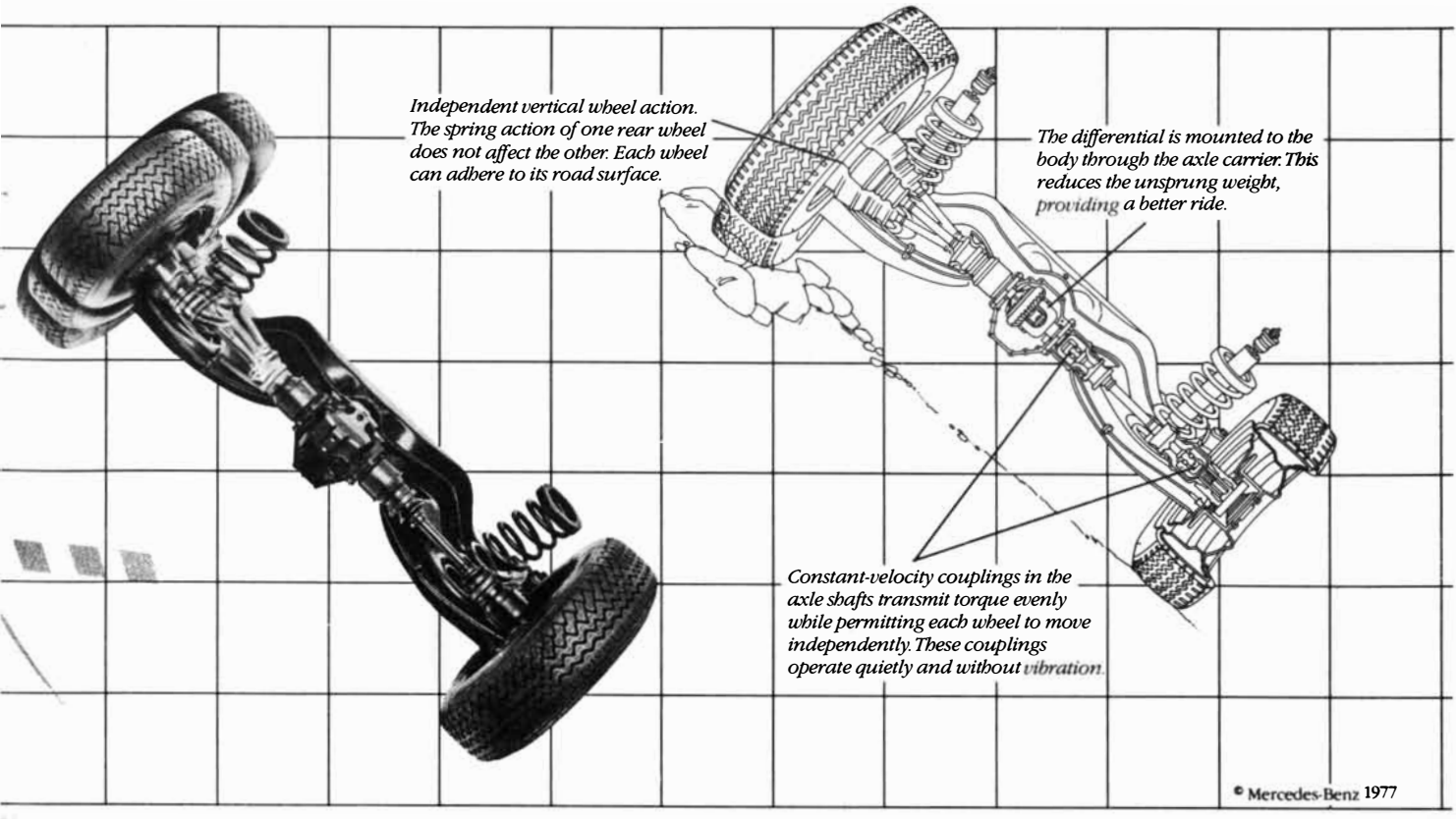

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sounds, to the speech of children and of dysphasics, to the study of mature language structure and comprehension and finally to a close look at the results of the past decade or so of seeking out answers. It is reported that English parents could identify the "messages" of crying Italian and Spanish babies as easily as those of English ones. Chinese infant babbles tend toward the monosyllabic and tonal, distinguishable from Russian or Arabic ones; the result "supports the notion of a 'babbling drift' " in which the infant's babble gradually comes to reflect the speech sounds it hears. Infants cry in no language, but they babble in a familiar tongue. The one-word and two-word stage—found to be full of insight—leads to the chattering flood of children's fluent speech.

The tentative stance with which our guide leaves us is most conformable to the present view of the mind as a whole. What we hear is the "best guess" result of a series of strategies in the space of meaning as well as of syntax, neither a simpleminded search of an impossibly rich store of possibilities nor an open-minded and acute attention to what is said as it is said. People hear to a surprising extent "what they *expect* to hear." (Of course, sight is not much different.) We speak with great speed in spite of the need for a series of overlapping partial plans, made by tone groups, guided in time by a pattern of rhythm. The slips of the tongue that mainly support such a view are fascinating. The Reverend Spooner (whose absent students hissed all his mystery lectures) turns out a little too good to be true.

The biggest issue left unsettled comes down to this: How distinct will language be from the other deep topics of human psychology once the mind is better understood? The lawful English sentence "The cat the dog the man the baby tripped up bit scratched collapsed" is "about as difficult as any sentence could possibly be." It is certainly unexpected, it lacks such clues as "that," its words appear in a strange order, it contains unusual meaning, it strains short-term memory with its impacted subroutines and it has to be worked out in part backward. Any comprehension program at all would be wise to reject it, and indeed most sensible listeners say, "Sorry, it's just not English." Yet it seems to be correct grammatically, unique and simple in deep structure. Here one feels the absence of nearly all quantitative material in this area, except for time-delay studies of various kinds; logical pattern dominates completely. Perhaps a stronger sense of quantity will enter with computer studies, the only relevant domain that is not discussed at all in this admirable book for any general reader able to enjoy (or to put up with) the author's whimsical style.

Established 1845 SCIENTIFIC AMERICAN February 1978 Volume 238 Number 2

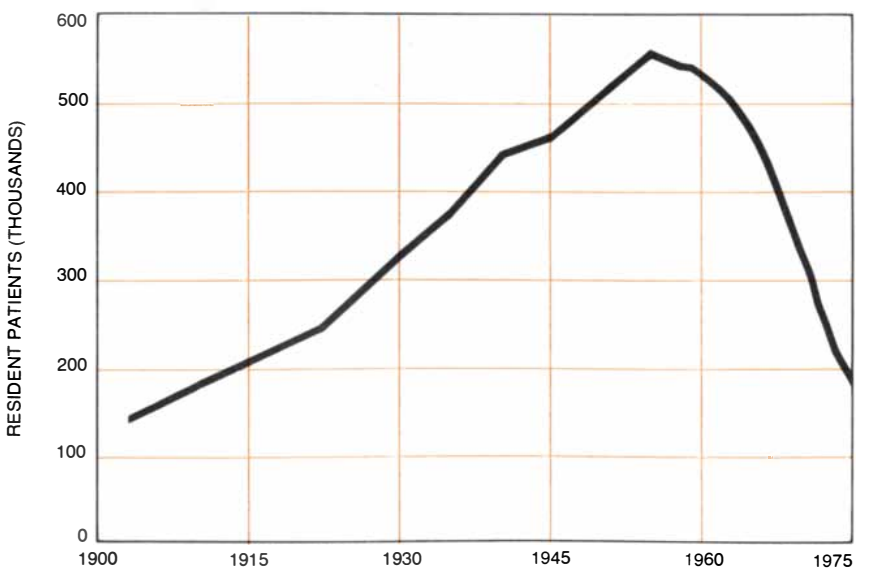
Deinstitutionalization and Mental Health Services

The resident population of large mental hospitals has been reduced by two-thirds in 20 years, but chronic patients are being discharged to a lonely existence in hostile communities without adequate care

by Ellen L. Bassuk and Samuel Gerson

Fifteen years ago the U.S. undertook a massive reform in the delivery of mental health services under the banner of "community mental health." A major objective, urged by a spirit of reform and presumed to be brought within reach by the availability of new psychoactive drugs, was the release from institutions and the rehabilitation within their own community of people with severe mental illness. Today the population of mental hospitals has indeed been reduced by two-thirds. That achievement is offset, however, by huge increases in the rate of admissions to those hospitals (signifying a high turnover of patients through short periods of hospitalization) and in the number of discharged but severely and chronically disturbed former patients consigned to bleak lives in nursing homes, single-room-occupancy hotels and skid-row rooming houses.

Does "deinstitutionalization" represent an enlightened revolution or an abdication of responsibility? It is probably too early for a definitive judgment, but it is not too soon to review the issues raised by this aspect of the community mental health movement and to consider how such a well-intentioned reform as deinstitutionalization could have created so many problems.



INPATIENT POPULATION of state and county mental hospitals rose steadily from the turn of the century until 1955, since when it has decreased sharply. These data do not include private or Federal hospitals, whose population has held fairly constant at between 50,000 and 75,000.

The mandate of those who attend to the mentally ill has always been shaped by the social, economic, religious and philosophical temper of the times, and in no case is that effect more clearly illustrated than in the history of the institutional segregation of people who are labeled "mad." The movement toward institutionalization started with the growth of secularism in the 17th and 18th centuries. As the power of the churches waned, so did the view that disturbed behavior was a symptom of demonological possession, to be dealt with by exorcism or death. In its place came the belief that deviance was a reflection of sloth and moral turpitude, best managed by disciplinary measures and segregation from society. Institutionalization replaced witch-hunting, but the basic objective continued to be to protect society rather than to care for the individual. It was not until the ascendancy of "moral treatment," advocated primarily by Philippe Pinel at the Hôpital Salpêtrière in Paris, early in the 19th century that concern for the welfare of the institutionalized person competed with concern for the protection of society. As inhuman living conditions and harsh punishment began to give way to a more humane approach, there was growing interest in understanding the nature and causes of disturbed behavior from a medical perspective. Concepts of illness replaced concepts of social deviance; medical treatment be-

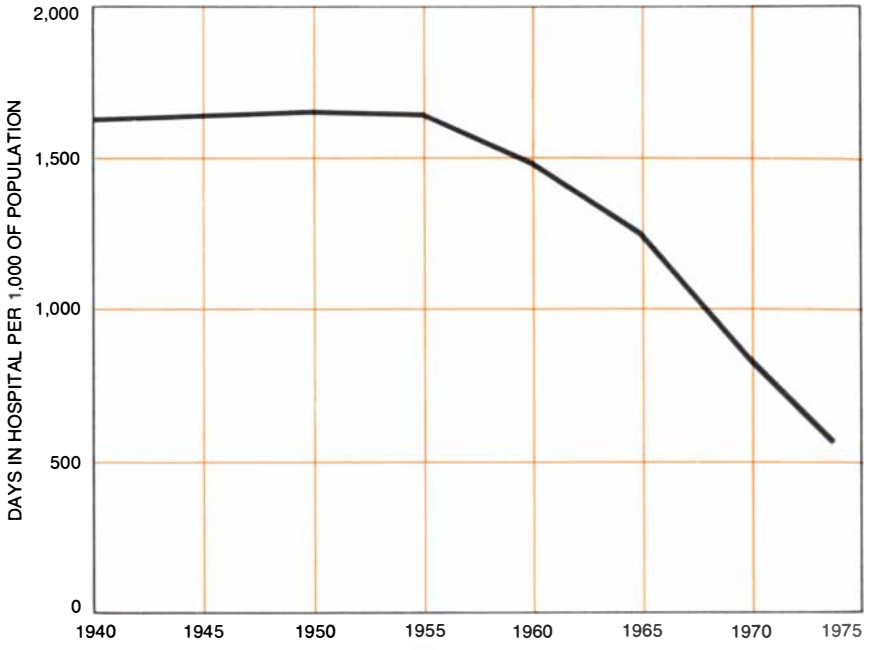
came the new rationale for institutionalization.

In the U.S. parallel efforts to treat disturbed behavior as a medical problem in special hospitals were limited at first to a few large Eastern cities; by the mid-1840's only some 25 such hospitals had been established with a total capacity of perhaps 2,500. The great majority of those who were segregated because they could not function appropriately within the community lived under squalid conditions, sequestered in county homes or almshouses or even in jails with people who were simply poor or old or physically sick—in any case without treatment. In the second half of the 19th century, however, there was a revolution in the care of the mentally ill, brought about by a convergence of social, medical and economic influences. Public attention was drawn to the plight of the severely disturbed by a reform movement led by Dorothea Dix, which coincided with the development of new medical models of disturbed behavior. As the mentally ill began to be transferred from local homes and jails to small county institutions, it became evident to state legislatures that larger state institutions would more economically assuage the reform movement. By 1900 more than 100 new state institutions were built.

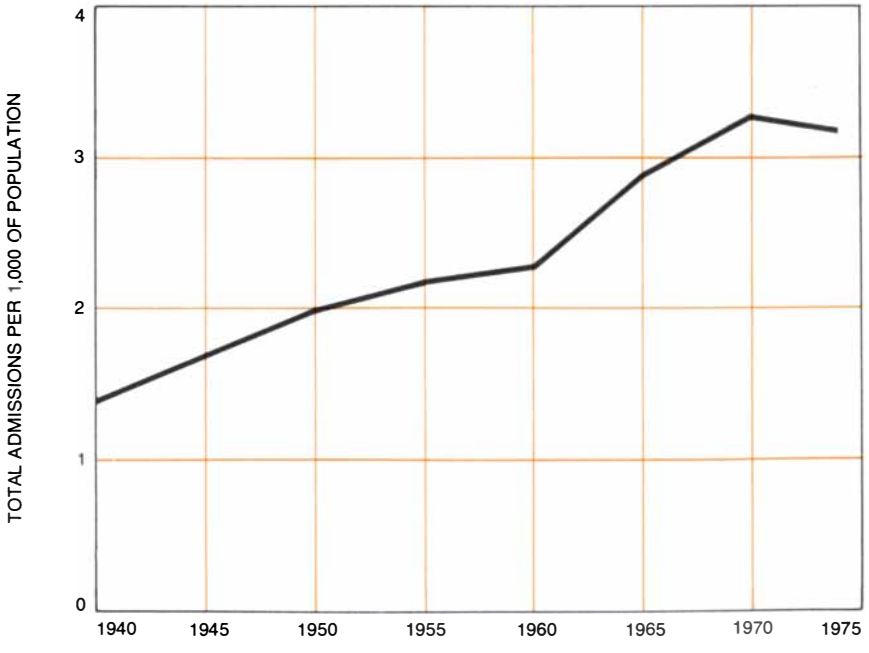
In time the large, cost-effective mental hospitals came to serve as receptacles for a wide range of socially troublesome individuals, including many of the indigent and disturbed—or seemingly disturbed—people among the waves of late-19th-century immigrants. As the proportion of chronically ill patients increased, the hospitals became overcrowded, patient care deteriorated and both psychiatrists and the public lost faith in the possibility of cure and return to the community. The reform movement, having seen its original objectives apparently accomplished, had ceased to be a significant influence. By early in this century the network of state mental hospitals, once a proud tribute to an era of reform, had largely turned into a bureaucratic morass within which patients were interned, often neglected and sometimes abused.

That was the general situation after World War II, when social, economic and medical developments prompted a reassessment of the delivery of psychiatric services. The rejection of large numbers of young men from military service on the ground of diagnosed psychiatric disturbance had made the country aware of the prevalence of mental disorders and of the lack of adequate resources for prevention or treatment. The new awareness led to more funding of research and training programs in the area of mental health. Then came a major medical development: the widespread and effective introduction of antipsychotic drugs in the early 1950's. The possibility arose that thousands of patients previously considered manageable only within the confines of an institution could now be treated as outpatients. That possibility increased the growing pressure for the development of comprehensive programs of community-based treatment. The pressure was further augmented by the desire of state legislatures to reduce the financial burden of state mental hospitals.

These various trends combined to lead Congress to establish in 1955 the Joint Commission on Mental Illness and Health to evaluate services for the mentally ill and to formulate a national mental health program. The commission's recommendations, reported in 1960, provided the groundwork for a landmark address to Congress by President



RATE OF HOSPITALIZATION, or the number of days in the hospital per 1,000 of U.S. population, has decreased by 65 percent in state, county and private mental hospitals since 1940.



RATE OF ADMISSIONS has increased by 129 percent as the resident population and hospitalization rate of mental hospitals have dropped. The drop is the result of shorter average stays.

PORTRAITS OF MENTAL PATIENTS were engraved by Ambroise Tardieu for a two-volume work published in 1838, *Des maladies mentales, considérées sous les rapports médical, hygiénique et médico-légal.* **The author, Jean-Étienne-Dominique Esquirol, was a**

Kennedy urging a "bold new approach" to the management of mental illness, which led in turn to the passage of the Mental Retardation Facilities and Community Mental Health Centers Construction Act of 1963. The legislation and related guidelines from the Department of Health, Education, and Welfare called for the establishment of a new kind of community-based center and promised Federal funding for such facilities if they provided five essential services: inpatient care, outpatient care, emergency treatment, partial hospitalization and "consultation and education." The legislation marked a momentous shift in the ideology of treatment for mental illness and led to radical changes in the delivery of psychiatric services.

The concept of "community mental health" implied a dual promise: treatment and rehabilitation of the severely mentally ill within the community and the promotion of mental health generally. The first promise was to be fulfilled by the development of an extensive support system for the mentally ill, based on community mental health centers and offering comprehensive and coordinated treatment and rehabilitation services. These new and "less restrictive" services were to take over the traditional function of large custodial institutions in caring for chronically disturbed individuals. The quantitative goal set for this deinstitutionalization process was a 50 percent reduction in the patient population of state hospitals for the mentally ill within two decades—a statistic that, as we mentioned above, has already been achieved. The second aim of the program, the broad improvement of the nation's mental health status, was to be accomplished largely by preventive programs originating in the mental health centers, each of which would be responsible for a population of 75,000 to 200,000 people in a geographically defined "catchment" area.

Implicit in these objectives was an expectation that mental illness could indeed be prevented and that even chronic patterns of severely disturbed behavior could be altered. There was a mood of enthusiastic optimism, which in retrospect can be seen to have bordered on blind faith. The shortcomings of the initial legislation, the lack of an adequate system of follow-up care, the hard realities of insufficient funding, the probable impact of patients on communities and even the uncertainties as to effective therapy that continue to plague psychiatry—all of these were largely ignored in the rush to implement the new goals. In some programs established by the legislation ignoring the realities has only made for confusion and waste. For thousands of hospitalized patients released haphazardly to a nonsystem of community aftercare, however, it has meant real hardship and even tragedy.

As of mid-1975, 507 community mental health centers were in full operation; an additional 96 centers had received large grants from the National Institute of Mental Health for construction and staff. (According to NIMH estimates, however, the 603 centers would provide coverage for only some 40 percent of the U.S. population; some 1,500 centers are needed.) Outpatient facilities, which include the community centers, other clinics and emergency rooms, now account for more than 65 percent of all mental health patient-care "episodes," an increase from 23 percent in 1955. (An episode is an entry into care; the total number of episodes in a year is the sum of the inpatient and outpatient rolls and the additions to those rolls in

FIRST STATE HOSPITAL built expressly for the humane custodial care of chronically disturbed patients under medical supervision

pioneer in psychiatry who classified mental illnesses and advocated humane treatment.

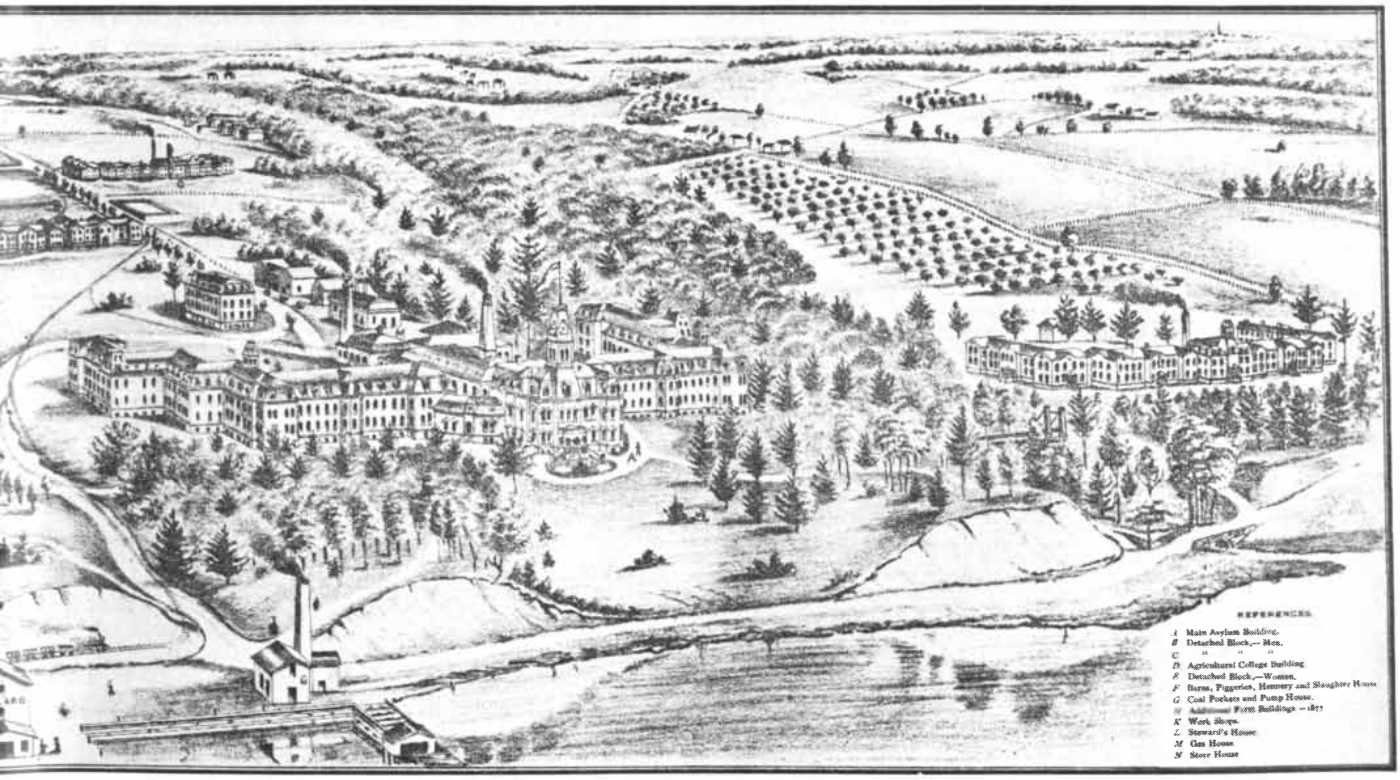
the course of the year.) At the same time that outpatient episodes were more than doubling between 1955 and 1975, there was a 65 percent decrease in the census of resident patients in state mental hospitals, from 559,000 to 193,000.

The deinstitutionalization statistics are illusory, however. Although the annual census was decreasing, admissions to state hospitals increased from 178,000 in 1955 to a peak of 390,000 in 1972 and had declined only to 375,000 by 1974. That trend reflects a new philosophy of short-term hospitalization. Moreover, a growing proportion of the admissions were readmissions (in 1972, 64 percent of them); about half of the released inpatients are readmitted within a year of discharge. Those statistics must surely reflect the lack of a fully effective community-based support system. As a matter of fact, the Department of Mental Health in Massachusetts, where we work (at Beth Israel Hospital and Cambridge Hospital and the Harvard Medical School), has estimated that between half and three-fourths of the readmissions could have been avoided if comprehensive community facilities had existed.

And they generally do not exist. As contemplated in the 1963 legislation and made more explicit in an amendment in 1975, the deinstitutionalized patient was to be supported by a spectrum of aftercare services delivered by halfway houses, family and group homes, therapeutic residential centers, foster-care arrangements and so on, with the local community mental health center as the coordinator. In 1977 a report issued by the General Accounting Office concluded that the centers have not fulfilled their intended function in behalf of patients returned to the community. There are some obvious reasons. One is that the centers developed and have been administered without connection with the state hospitals; the two systems are most often completely unintegrated and frequently not even in communication with each other, so that the discharges are inadequately coordinated with the availability of community facilities. Moreover, in the rush to reduce their census the hospitals discharged patients long before most of the community centers had been established and before supporting programs had been developed.

There are, to be sure, a few centers that have devised innovative programs to enhance the quality of life for chronically ill patients; there are some experimental programs that offer total care for discharged patients in a community setting. Such centers and programs are few, however, and they are the result of efforts by particular individuals or institutions, special funding or other special circumstances rather than of any consistent plan. In part this inconsistency results from a deliberate choice: the development of community services was not based on data collected by systematic research; rather, it was assumed that each center would be shaped by the particular needs of its area as they were perceived by the community itself.

A major problem in gauging the ef-

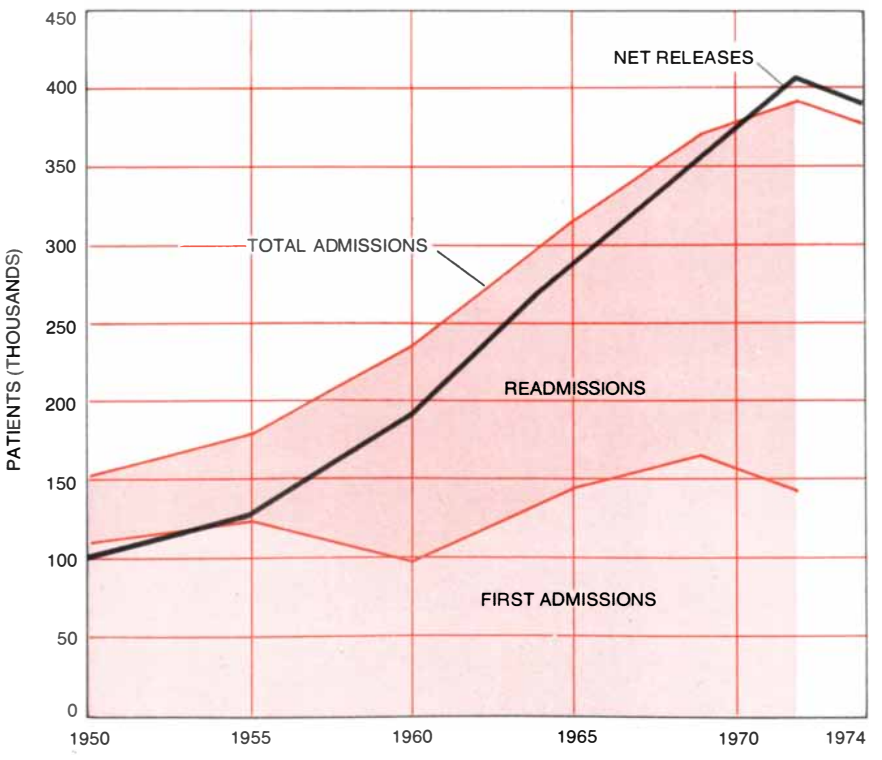


was the Willard Asylum for the Insane, opened in 1869 at Ovid in western New York. Its sprawling plant, which included a central building, farm buildings and "detached blocks" for men and women, accommodated 1,500 patients, many more than any earlier U.S. mental institution. This engraving of the hospital grounds was an illustration in the ninth annual report of the board of trustees, published in 1878.

fectiveness of the community support programs is the paucity of follow-up studies whose data can be generalized and compared and that trace the movement of discharged patients through the labyrinth of psychiatric facilities and living conditions after their release. The existing evidence is clear, however, particularly to those of us who are engaged in the emergency care of severely disturbed people in outpatient departments of city hospitals. Time and time again we see patients who were released from state hospitals after months or years of custodial care; who then survived precariously on welfare payments for a few months on the fringe of the community, perhaps attending a clinic to receive medication or intermittent counseling; who voluntarily returned to a hospital or were recommitted (which in Massachusetts is possible only if the patient is acutely suicidal or homicidal or manifestly unable to care for himself); who were maintained in the hospital on antipsychotic medication and seemed to improve; who were released again to an isolated "community" life and who, having again become unbearably despondent, disorganized or violent, either present themselves at the emergency room or are brought to it by a police officer. Then the cycle begins anew.

The generally ineffective functioning of community mental health centers in caring for discharged patients means that there is an inadequate system of follow-up psychiatric treatment for them, or even of basic guidance in coping with the mechanics of daily living. The failure to establish sheltered housing shunts former patients into nonpsychiatrically oriented facilities. Most patients are placed in nursing homes (a category that includes skilled nursing facilities, intermediate-care facilities, rest homes and homes for the aged), a process the Department of Health, Education, and Welfare has labeled "reinstitutionalization," since most homes have more than 100 beds (and yet offer only custodial care). A national survey in 1974 of skilled-nursing facilities revealed that 22 percent of their 284,000 patients less than 65 years old were diagnosed as being mentally ill or retarded. Of the patients 65 years and over, a third had chronic brain disease and a tenth were diagnosed as being neurotic or psychotic. The inappropriate occupying of nursing-home beds by these former patients means that the beds are not available for patients with chronic physical illnesses, whose stay in general hospitals is therefore unnecessarily prolonged.

Untherapeutic though many nursing homes are, living conditions in most of them are at least tolerable. Conditions may be worse for discharged patients living on their own, without enough money and usually without any possibility of employment. Many of them drift to substandard inner-city housing that is overcrowded, unsafe, dirty and isolated. Often they come together to form a new kind of ghetto subpopulation, a captive market for unscrupulous landlords. Their appearance and their sometimes bizarre behavior may disturb the neighborhood, and they are usually shunned and frequently feared. Even patients who live in recognized residential centers such as halfway houses have been found to have inadequate medical and psychiatric care or none at all, minimal activities and little interaction with people outside the facility. For the significant proportion of ex-patients who return to live with their own families physical conditions may be relatively good, but severe stresses can be placed on both the family and the patient, particularly in the absence of close follow-up treatment; there may be long-term effects, especially on children in the household. Finally, whatever the living arrangement for a discharged patient may be, he is almost sure to find a shortage of vocational rehabilitation, sheltered employment or job referrals, transportation and recreation.



READMISSIONS of patients previously discharged from institutions have exceeded first admissions since 1960; in 1972 they accounted for 64 percent of admissions. Rise in net releases (discharges minus returns from long-term leaves) reflects shorter periods of hospitalization.

It is not enough to review and deplore the plight of the chronically disturbed ex-patient. It is important to see just where deinstitutionalization has encountered difficulties, and that requires some understanding of the dynamics of the program: the complex interaction of financial, professional, political and administrative factors that operate almost independently of the intentions or the legislation that initiated it. Perhaps the most important single element in this case is money—the lack of money in general, the issue of cost ineffectiveness and more specifically the effect of various methods of compensation.

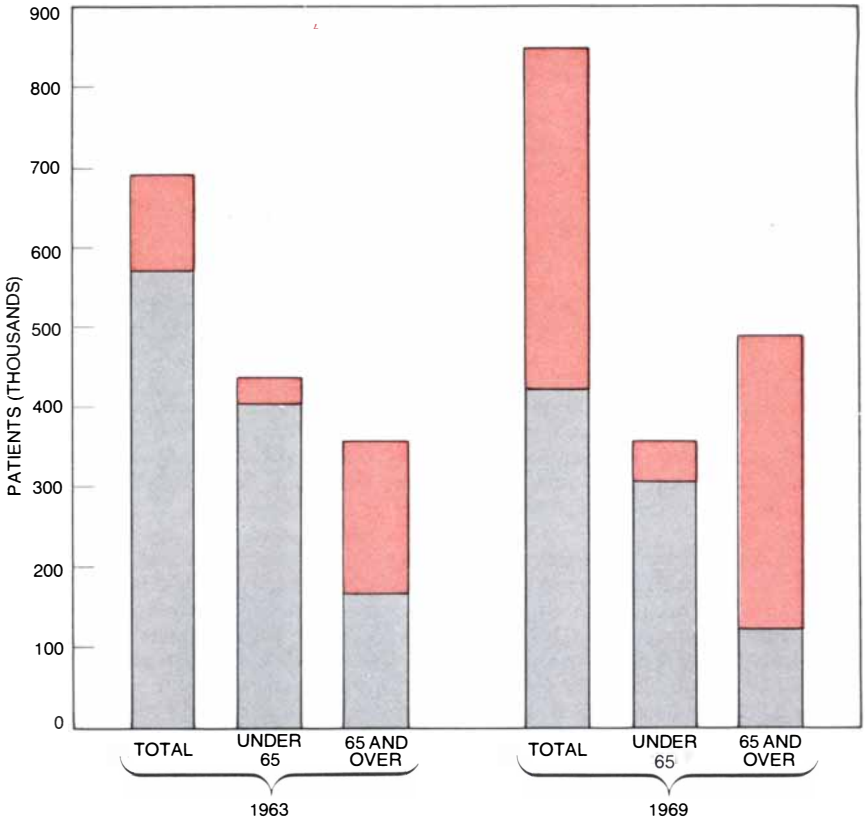
Community mental health centers were constructed and originally staffed by grants of Federal "seed" money, but they were expected eventually to become self-supporting. The idea was that enough income would be generated by individual fees, third-party (insurance) reimbursements and budget expenditures by state and local governments. The expectation of fees turned out to be unrealistic. The great majority of the people who apply for community mental health services are poor; people with money go to private or voluntary hospital clinics or to individual practitioners. In recognition of these facts the Federal Government kept amending the original legislation and now helps to fund the centers for a 12-year period. A major burden is nevertheless placed on third-party reimbursement. Insurance coverage of the mentally disabled has always been incomplete, biased in favor of inpatient care and markedly inferior to coverage for physical illness. (In 1968 a fourth of all physical patient episodes were covered by insurance and only an eighth of all mental-care episodes; re-

imbursement for inpatient treatment is usually more time-limited for mental illness than it is for physical illness.)

The major Federal insurance plans are the Medical Assistance Program, or Medicaid (for the medically indigent), and Medicare (for the elderly), and their specifications have been important determinants of the community mental health centers' growth and activity. Medicaid pays the states between about 50 and 78 percent of the mental health costs of eligible individuals. Each state defines its own benefits, but Medicaid has established some restrictive general guidelines. Mentally ill people between 21 and 65 ordinarily are not eligible for Medicaid if they are hospitalized in facilities that care for mental disorders exclusively, including even residential treatment centers such as halfway houses. Medicaid benefits are available, on the other hand, for inpatient psychiatric care in general hospitals—and for maintenance in most nursing homes. That is why the nursing home, rather than more psychiatrically oriented facilities, has become the principal alternative to the state hospital. Medicaid coverage of outpatient care in mental health clinics is very limited (although there has been a trend toward increasing the benefits), and in most states the coverage for day-care programs is inadequate.

Medicare provides limited inpatient coverage in state hospitals and more extensive coverage in general hospitals. It allows no more than $250 a year for outpatient coverage, a figure that has been frozen since Medicare was initiated in 1965 in spite of marked increases in the cost of psychiatric services. A third source of Federal money that has an impact on mental health care is the Supplemental Security Income program, which provides income-support funds for some mentally ill individuals. It ordinarily provides monthly payments of $167.80 to ex-patients (with some states adding a supplement), but generally not if they live in a halfway house, a group home or a similar institution—actually giving the individual an incentive to choose a welfare hotel or nursing home rather than a psychiatrically oriented facility.

The combined effect of the Federal programs has been to limit development and use of community-based alternatives. Their eligibility requirements have channeled many patients into nursing homes and substandard housing with minimal opportunities for psychiatric services and have undermined the development of a full range of outpatient services and residential treatment programs. (It should be said, on the other hand, that both Medicaid and Medicare have established "utilization review" systems and criteria for adequate treatment and for discharge planning that should in time help to improve the quality of care in mental hospitals.)



NURSING HOMES have absorbed many patients released from hospitals. Bars show population of nursing homes (*color*) and of state and private mental hospitals (*gray*) in 1963 and 1969.

Apart from insurance programs the financial support of community mental health centers and their services has had to come from Federal grants and state and local budgets. At the state and local level funds for community services have had to compete with funds for the traditional mental-hospital system. Between 1968 and 1974 the cost of that system increased from $1.7 to $2.8 billion. There is little indication that the reduction in the population of large institutions has freed funds for less restrictive services. The hope was that the community approach would save money, but it is now clear that effective care requires very large expenditures. The political influence of discharged mental patients is small, to say the least, and appropriations by state and local legislatures are inevitably guided more by political priorities than by clinical concerns.

It is hard to see how the fiscal viability of the community mental health system can be improved except by the passage of some form of comprehensive national health insurance. As such legislation is debated it is important to bear in mind the great potential for shaping public policy that is inherent in the details of the insurance coverage. For example, the Kennedy-Corman Health Security Act, one of the most comprehensive proposals, encourages ambulatory care by providing coverage for unlimited visits to a community mental health center. Yet it would cover only 20 visits per benefit period (which in existing insurance programs is generally one year) to a private practitioner. Inpatient treatment would be covered for up to 45 days in a benefit period. The effect of such coverage would be to make the centers the major source of outpatient care, which may well be desirable, but it would strictly curtail visits to private practitioners and clinics except by the affluent.

In addition to being short of funds the community mental health centers are short of personnel. The demand for services far exceeds the supply. There is a relative lack of well-trained professionals in psychiatry in general, and their concentration in large urban centers compounds the scarcity. In 1975 the National Institute of Mental Health estimated that psychiatrists constituted less than 6 percent of the staffs of the centers and that most of them were engaged in administration. Over the past decade there has been a decrease in the proportion of psychiatrists in the centers and only a small increase in the number of other relevant specialists such as psychologists and social workers.

To make up for the shortage of pro-

fessionals, special programs for the training of paraprofessionals have been instituted, and an attempt has been made to enroll volunteer workers. These trends have resulted in a blurring of professional roles and in controversy over the qualifications and training required to treat severely mentally ill patients effectively. Moreover, the centers' deviation from traditional methods of psychotherapy and their frequent preoccupation with nonclinical issues involving public health, social problems and economics have made many academic professionals reluctant to become engaged in community mental health programs. It is important that specific roles and tasks be defined for the personnel staffing the centers and that adequate recruitment and training programs be developed.

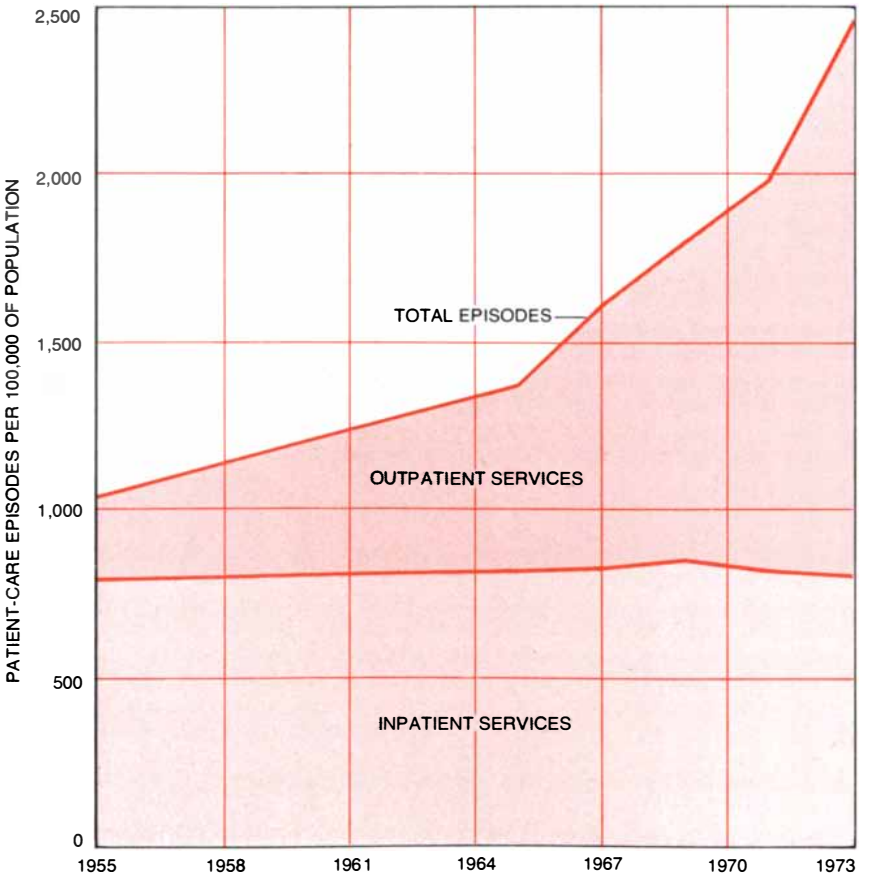
Given the shortage of money and personnel, the allocation of sufficient resources to research is another major problem. The authors of the 1960 report on mental health proposed an increased allocation of funds for long-term basic research in mental illness and for the establishment of mental health research centers. Those goals were broadly accepted, and yet there has been a significant decrease in the availability of funds for such activities over the past 15 years. Knowledge of the origins of severe mental illness, particularly the psychoses, and understanding of complex social-behavioral systems and of effective methods of treatment are still only rudimentary.

Psychiatry still lacks criteria for selecting patients to be treated with most of the various therapeutic methods; the methods themselves are not well defined and there is only a small body of data on the efficacy of particular approaches. It is clear that some patients cannot be treated with any existing technique, so that new approaches need to be developed. The very nature of many conditions psychiatrists attempt to treat is still not well understood. In view of this lack of basic knowledge it is not surprising that there are no accepted guidelines for establishing comprehensive systems for the delivery of mental health care—notably systems for reaching disadvantaged people, who may be subjected to particular stresses and may respond to them in ways requiring specific interventions with which many psychiatrists are not familiar. Systematic basic research is needed if comprehensive and effective treatment is to be provided for varied groups of patients.

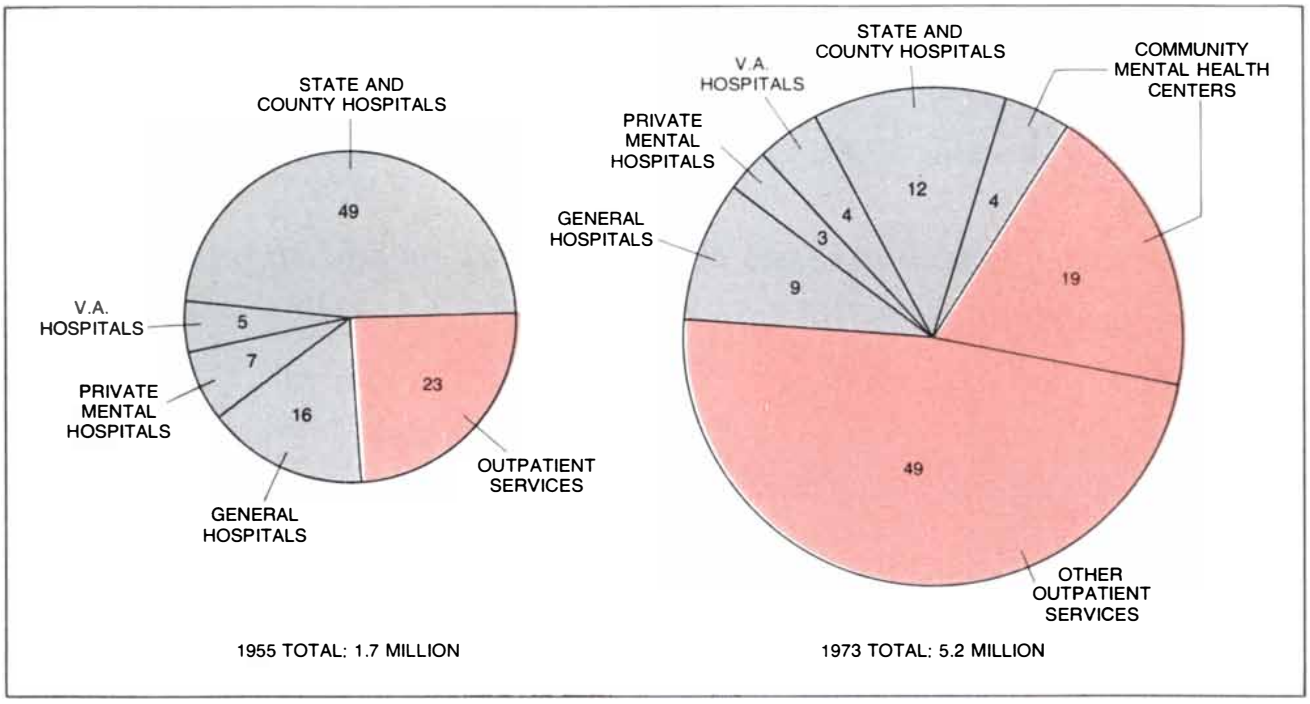
The complex and interrelated tasks of reducing the patient population in state hospitals, providing alternative community facilities and ensuring the best possible outpatient treatment would be difficult ones in any case, and the difficulty is compounded by organizational chaos. The bureaucratic fragmentation, diffusion of responsibility and lack of coordination begin at the Federal level and extend through the state and local mental health apparatus. Eleven major Federal departments and agencies share the task of administering 135 programs for the mentally disabled. Inevitably (as in the case of Medicaid and Medicare coverage) the provisions of one program may undercut the objectives of another. Some agencies have not considered deinstitutionalization a major goal; other agencies have given it a high priority but lack the power to distribute funds or monitor Federally funded programs. At the state and local levels there is a similar fragmentation of roles, and in particular there are lack of coordination, competition for funds and even enmity between the administrators of the old state hospital systems and the managers of community programs.

The problem of conflicting governmental jurisdictions in mental health has been exacerbated in recent years by increased judicial involvement. Significant decisions by courts in several states have asserted the civil liberties of patients and have established a constitutional right to treatment, have defined minimum standards of care and have delineated objective criteria for involuntary commitment. Many of these decisions have advanced the cause of human and civil rights, but in some cases the immediate effect has been damaging to patients. For example, a landmark right-to-treatment case in Alabama, *Wyatt* v. *Stickney,* defined minimum standards of care and stated that unless a hospital could provide specific treatment for a patient's condition it could not hold that patient against his will. Providing such treatment would have required the expenditure of large sums of money. The Alabama state legislature chose not to appropriate the additional funds, thus in effect mandating the release of thousands of patients—who ended up in substandard housing and with still less in the way of psychiatric services.

Officials at the National Institute of Mental Health have recognized that a comprehensive national strategy needs to be adopted, agreed to at all levels of government and carried out in a coordinated manner. The institute is develop-



PATIENT-CARE "EPISODES" (the number of people on inpatient and outpatient rolls plus the number of additions during the year) have risen sharply in proportion to the population. The increase is due almost entirely to the growth in outpatient services. Inpatient episodes have remained constant in spite of the drop in the population of hospitalized patients. These data cover most public and private psychiatric services except for offices of private practitioners.



SHIFT TO OUTPATIENT SERVICES is illustrated by the two pie charts. The numbers give the percent of total episodes accounted for in 1955 and 1973 by various facilities offering either inpatient (*gray*) or outpatient (*color*) services. The community mental health centers that have been established since 1963 account for much of the outpatient increase, but other outpatient facilities have also expanded.

ing what it calls a Community Support Program, which would require coordination of the relevant activities of all Federal agencies and careful delineation of the roles of each and would define responsibility for policy making. A "fiscal partnership" would be established among the various levels of government to develop a genuinely integrated system of direct services to meet the needs of the severely and chronically ill patient. Although some details of the system are still to be worked out, $3.5 million has recently been allotted to 16 states for program development. What is most important is that the NIMH plan asserts the willingness of the Federal Government to accept more responsibility for the mentally ill and that it acknowledges the specific needs of the chronic, severely disabled patient. For the first time in several decades the proposal explicitly affirms the existence of chronic disability, an implied denial of which has permeated the mental health movement, and asserts the importance of supportive and rehabilitative services as well as preventive measures.

The view that a massive shift in the locus and form of treatment can in itself combat mental illness is not new. It was, after all, the view of Dorothea Dix and her supporters 100 years ago, when they urged the development of large state institutions as both sheltering asylums and centers of treatment. Their movement gained impetus from a cult of curability, and the community mental health movement may have been a victim of a similar faith. Although the institutionalization movement of the 19th century and the recent push for deinstitutionalization were nominally opposite in their objectives, they suffered from a similar confusion of goals. In both cases the aims of social reform and of more effective treatment became entangled; the improvement of living conditions or the assertion of civil rights was somehow expected to bring advances in treatment and rehabilitation. Social justice may be a necessary condition for successful treatment, but it is not a sufficient condition.

Even too narrow an emphasis on "treatment" can be inappropriate if it shifts attention from the patient's daily life situation. This is true particularly in the case of the chronically mentally ill, for whom definitive therapies are generally unavailable. Treatment within a community may in concept seem to offer a better chance of rehabilitation than hospitalization does. Actually, however, the quest for treatment may obscure a more basic responsibility: the responsibility to provide living conditions that ensure human dignity and that offer refuge to individuals who seek such refuge themselves or are demonstrably unable to manage their lives independently.

In meeting this responsibility it is important to remember that neither the hospital nor the community approach is inherently the more humane. Some 100 years ago the trustees of the Willard Asylum for the Insane in western New York explained the purpose of their new institution in their first annual report. It would be a home "for those people who have neither home nor friends, and who are without the means financially or capacity intellectually to provide for themselves, with intellect shattered, minds darkened, living amid delusions, a constant prey to unrest, haunted by unreal fancies and wild imagining. They now have in their sore misfortune a safe refuge, kindly care, constant watching, and are as comfortable as their circumstances will allow. This is a result over which every humane and Christian citizen of the state will rejoice." The subsequent failure to maintain and improve institutions with that purpose seems to us to reflect economic, political, administrative and clinical realities rather than any inherent fallacy in the goals themselves.

Priorities must be established. The first task is to provide decent places of habitation—of asylum (which is a humane term in spite of its association with the old label "insane asylum"). New approaches to treatment should be undertaken only after rigorous research, and those approaches must not ignore and thus jeopardize the individual life situation of patients whom the treatment presumes to serve. One must accept the fact that psychiatry is not now able to cure some forms of severe emotional disability, and that psychiatry alone cannot assume the broad responsibilities of a society to care for its helpless fellows.

The Origin of Metal Deposits in the Oceanic Lithosphere

The geochemical processes that give rise to metal-rich minerals are largely localized in mid-ocean ridges: "spreading centers" where new material is added to the plates of the earth's crust

by Enrico Bonatti

For centuries men have searched for deposits of metallic ores in the crust of the earth with little more than past experience as a guide to where they should look. One of the results of the recent revolution in man's understanding of the earth, which is best summarized by the theory of plate tectonics, is the growing realization that most deposits of metallic ores originate in the intense physicochemical activity taking place at the boundaries between the huge plates into which the lithosphere, or outer shell of the earth, is divided. Where the process is currently under way, as it is along active plate boundaries on the ocean bottom, it can be studied. Where it took place at ancient boundaries that are now on dry land, ore deposits of exploitable size either are found or can be searched for with a reasonable expectation of success.

The essence of the geological revolution is that the earth is dynamic rather than static. The lithospheric plates (a dozen major divisions of the lithosphere and several minor ones) move like rafts on the denser, hotter and more fluid rock of the asthenosphere. The activity at the boundaries between plates depends on the type of boundary. At a divergent boundary two plates are pushed apart because hot fluid magma rising from the mantle forms new crust that cools and moves outward in both directions. Such an axis of spreading is one place where metal may be deposited. At a convergent boundary two plates meet; in a subduction zone one plate plunges under the other and returns to the hot asthenosphere; in a region of outright collision parts of the crust are thrust up to become mountains. At parallel boundaries two plates move edge to edge. Important metal deposits are generated also at convergent and parallel plate boundaries.

In most of this account I shall be concerned with metal deposits that are created at spreading centers. Some of the deposits are formed under the sea floor, within the crust and the upper mantle; others are formed at the sea floor. Some of the deposits are termed hydrothermal deposits, for reasons I shall return to. First, however, it will help to set the stage if I describe two other types of metal deposition on the sea floor: hydrogenous and diagenetic.

The term hydrogenous is from the Greek for generated from water. Hydrogenous deposits are formed by the slow accumulation on the sea floor of metallic elements extracted from seawater. Such water contains minute but significant quantities of metals in solution; examples are iron and manganese in concentrations of less than one part per million by weight. The metals are supplied to the ocean partly by streams, which in turn acquire them as a result of the weathering and decomposition of rocks on the continents.

Iron, manganese and most other metallic elements have a very limited solubility in an alkaline and oxidized medium such as seawater, and so they tend to be extracted easily from the water. The extraction occurs mainly through inorganic reactions whereby dissolved iron and manganese, say, are oxidized (by oxygen in solution in the seawater) to form insoluble oxides and hydroxides of iron and manganese. Thus extracted, the metals are deposited on the ocean bottom as tiny particles (a few microns in diameter) or as films and crusts on any solid material outcropping from the sea floor. Certain metals can also be extracted from seawater by living organisms, either planktonic (free-floating) or benthic (bottom-dwelling). After the organisms die the metals are released near the interface of water and sediment, where they can become incorporated in the sediments.

All these processes are slow. The growth rate of hydrogenous deposits, estimated by means of the decay of radioactive elements in them, can be as low as one millimeter or less per 1,000 years. Hydrogenous deposits, including most of the sea-floor concretions known as manganese nodules, are particularly well developed in regions of the ocean basins that receive a minimal inflow of material from the land. Examples include abyssal plains far from the continents and elevated areas of the sea floor such as seamounts and isolated shallow banks. Elsewhere dilution by detrital sedimentation (the steady rain onto the sea floor of clay and other mineral particles derived from the land) prevents the metals from growing into concentrated deposits.

Another source of metal deposits on the sea floor is the water in pores of the sediment. These deposits are called diagenetic after the term diagenesis, which defines all the physicochemical reactions (including compaction and recrystallization) that occur in a sediment after it has been deposited. Diagenetic deposits are formed in the areas of the sea floor where fairly large amounts of organic matter are incorporated in the sediment. In general the areas are below water masses that teem with life.

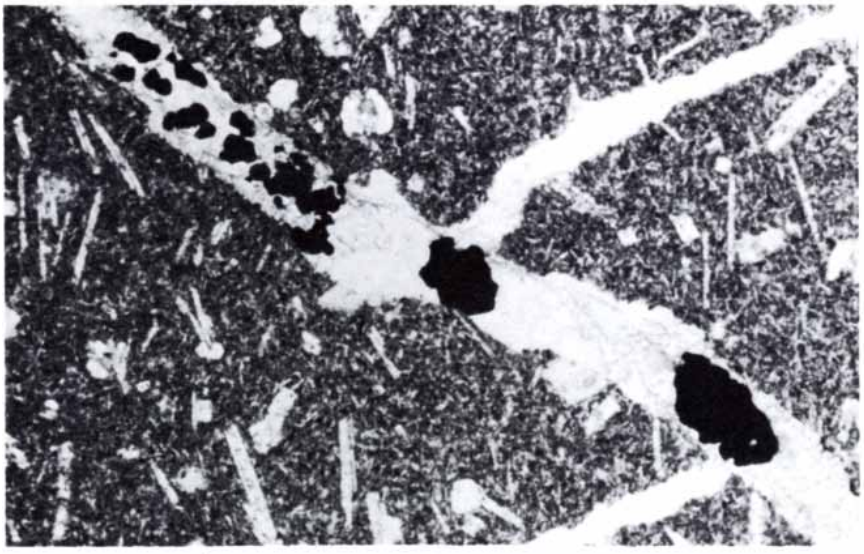
The gradual oxidation and decomposition of organic matter in the sediment deplete the dissolved oxygen in the pore water and create reducing conditions at some level below the sea floor. When the particles of iron and manganese that were formed hydrogenously reach this

APENNINES OF ITALY appear on the opposite page in a photograph made from a Landsat satellite. They have numerous outcrops of the ancient oceanic lithosphere known as ophiolites, many of them rich in metals. In late Mesozoic time, about 100 million years ago, the region was part of the sea floor near a spreading center where new crust is formed. Metals concentrated there by various mechanisms include manganese oxide and copper and iron sulfide. The new crust moved slowly away from the spreading center. Eventually, on colliding with another of the earth's plates, it was thrust up to its present position. Metals have been mined in the region for centuries.

level as they are gradually buried in the sediment, they are dissolved. Iron and manganese then become strongly concentrated in the pore solution of the sediment. Thereafter they tend to migrate upward, mainly by diffusion, and back into the oxidized zone of the sediment, where they are deposited again as solid particles.

The boundary between the oxidized zone and the reduced zone thus acts in effect as a filter for some of the metals; as a result they become concentrated just above the boundary. When the boundary is close to the interface of sediment and water, metal crusts and concretions may form on the sea floor by this process. These diagenetic deposits are different in composition from hydrogenous ones. For example, they have a lower ratio of iron to manganese. Iron is less mobile than manganese in reduced sediments, partly because it can readily be extracted from solution by combining with sulfur to form particles of iron sulfide.

MANGANESE AND IRON minerals were brought up from the West Indian Ocean in 1976 by the research vessel *Vema*, operated by the Lamont-Doherty Geological Observatory. In this sectioned and polished specimen the gray metal is manganese oxide and the reddish metal is iron hydroxide. The deposit was found 4,000 meters below sea level in a fracture zone near the axis of the Mid-Indian Ridge, a spreading center. It is a hydrothermal deposit: its metals were leached from the crustal basalt by circulating seawater and brought up through the sea floor at a hot spring. When such a hot solution enters the cold oxygenated water of the sea floor, metals such as iron and manganese tend to be oxidized and deposited. Iron and manganese separate because iron is less soluble than manganese in seawater and so may be deposited first.



METAL SULFIDES appear in this micrograph of altered basalt dredged from the floor of the Atlantic near the Mid-Atlantic Ridge. The sulfides are the black clusters in the light vein that passes diagonally through the basalt. They are mainly chalcopyrite (copper-iron sulfide) and pyrite (iron sulfide). The sulfides, like the manganese and iron shown in the photograph in the upper illustration on this page, were created by hydrothermal systems. Seawater circulating deep in the earth's crust near the ridge, which is a spreading center, became enriched in metals and sulfur from the basalt. The combination of sulfur with certain metals created insoluble minerals that were deposited under the sea floor. The micrograph is enlarged 45 diameters.

To return to the hydrothermal deposits, they are associated with the active zones of the sea floor, where, according to the theory of plate tectonics, new lithosphere is created. These spreading centers, which are zones of intense seismic and volcanic activity, correspond generally to the axis of the ridge that runs roughly down the middle of an oceanic basin. The processes that lead to the creation of metal concentrations along oceanic spreading centers have stirred considerable interest in the past few years.

In the middle 1960's several investigators, working independently, reported finding geochemical anomalies in wide areas of the sea floor, centered along the axis of the East Pacific Ridge in the southeast Pacific. Kurt G. V. Boström of the Institute of Marine Sciences of the University of Miami and I. S. Skornyakova of the Institute of Oceanology of the U.S.S.R. detected unusually high concentrations of iron and manganese in sediments from those areas. Gustaf O. Arrhenius of the Scripps Institution of Oceanography and I had found in the same region anomalously high concentrations of barium in the form of the mineral barite. At the Institute of Marine Sciences, Oiva I. Joensuu and I studied samples of unusual deposits, obtained right at the crest of the East Pacific Ridge, containing more than 30 percent iron by weight.

All these workers recognized at the time that their discoveries could not be accounted for by detrital sedimentation or by chemical deposition from normal seawater. They agreed that a local source of metals was required to account for the deposits. They suggested that the source might be related to volcanic or hydrothermal activity (perhaps both) centered on the axis of the ridge. Since then the origin, composition and distribution of such deposits have been greatly clarified.

Deposits of this type have been found to outcrop in young sea floor along the active spreading centers of the major oceans and of regions that are becoming ocean, such as the Red Sea, the Afar Rift and the Gulf of Aden. Deep drilling by the research vessel *Glomar Challenger* has revealed that identical deposits are also present in older sea floor, far from modern spreading centers, as a layer buried at the base of the sediment column. The layer lies just above the basaltic crust characteristic of ocean basins.

This distribution suggests that the

processes responsible for the creation of metal deposits at modern spreading centers also operated throughout the past history of the major oceans. The rate of deposition of iron, manganese and other metals has been found to be several times higher along spreading centers than elsewhere on the sea floor, confirming that a local source of metals must exist there. What is the nature of this source?

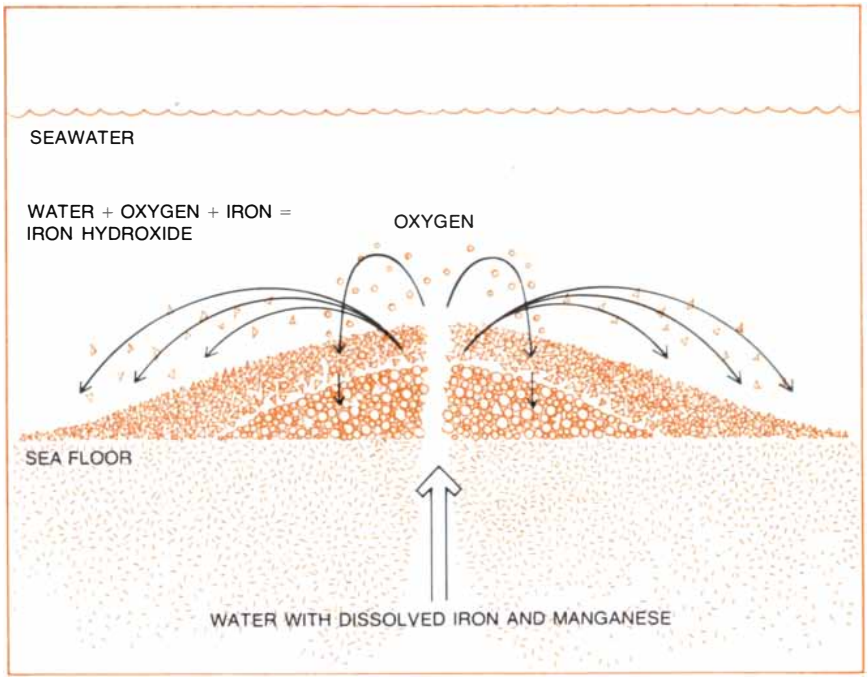
The formation of metal deposits that are similar in composition to those at ocean ridges has been observed directly in shallow water in several volcanic areas: near the island of Thera in the Mediterranean, near Matupi Harbor in the western Pacific and on the submarine volcano Bunu Wuhu in Indonesia. In each place the deposits were seen to form by the precipitation of metals from warm solutions, rich in silica and metal, that were discharged through the sea floor by hydrothermal springs.

This line of evidence and others suggest that metals are supplied along oceanic spreading centers by the discharge of hot springs. Indeed, active hydrothermal springs have recently been observed at the Galápagos spreading center in the eastern equatorial Pacific by groups from the Woods Hole Oceanographic Institution and from Oregon State University, who were riding in a submersible at a depth of 2,500 meters.

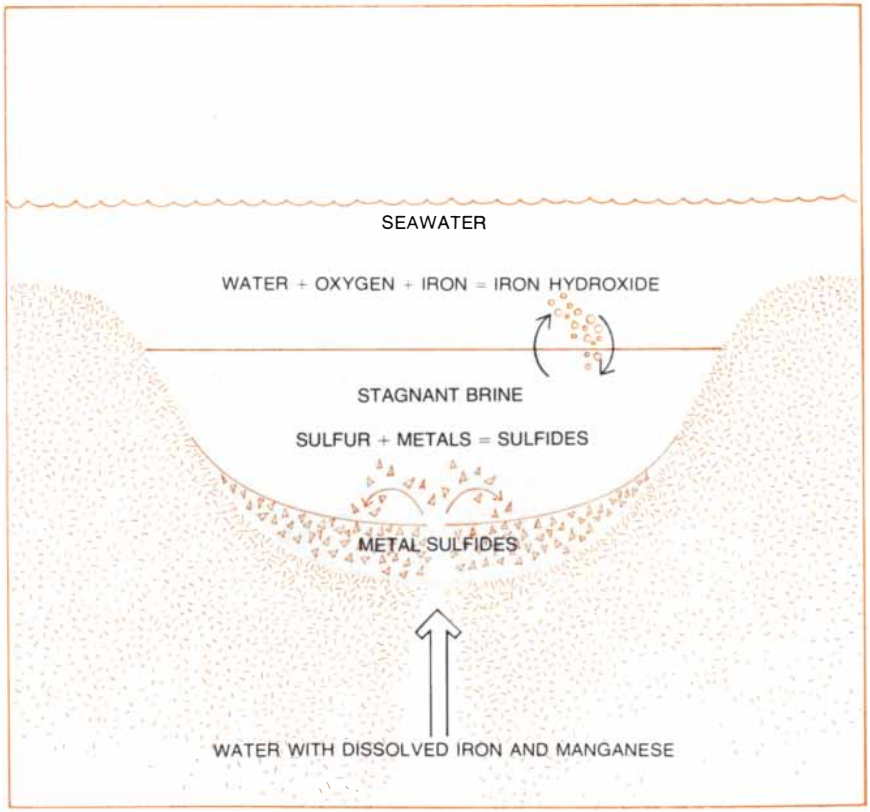
When a hot solution rich in metal and silica emerges from such a spring into cold oxygenated seawater, metals such as iron and manganese tend to be oxidized and deposited. Iron tends to be deposited earlier than manganese, since it is less soluble in seawater. Silica is also deposited, since its solubility decreases sharply with decreasing temperature.

Chemically hydrothermal deposits differ significantly from hydrogenous deposits. The latter contain iron and manganese in roughly equal amounts, whereas the ratio ranges between wider extremes in hydrothermal deposits. Some deposits from the Mid-Atlantic Ridge contain more than 35 percent manganese and less than 1 percent iron, whereas in certain other deposits (from the East Pacific Ridge) the proportion of the two metals is reversed. Samples consisting of an iron-rich layer overlain by a manganese-rich layer have also been recovered. The metals tend to separate because one reacts slower than the other in certain chemical processes such as oxidation (iron tends to oxidize faster than manganese); oxidation is followed by deposition, which therefore occurs at different rates for the two metals.

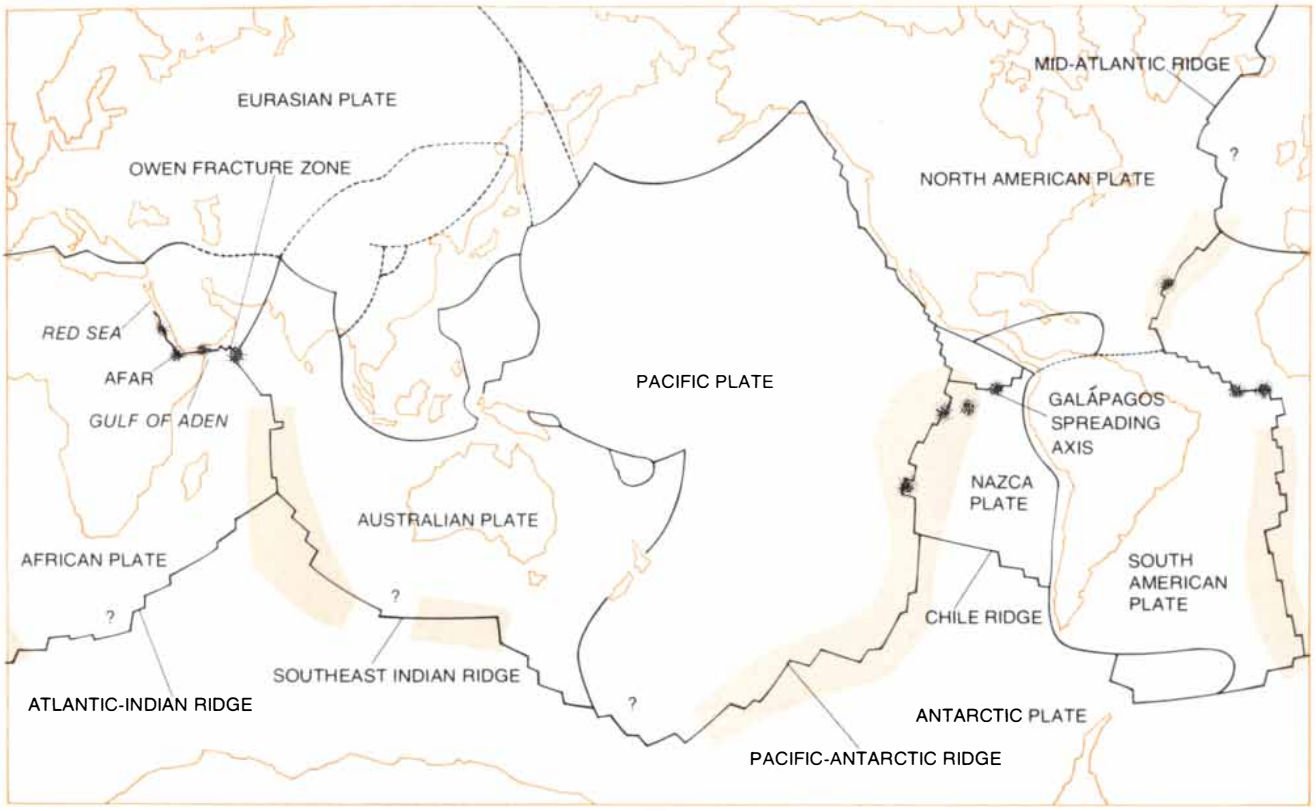
Another difference between hydrothermal and hydrogenous deposits is that the concentration of trace metals (nickel, copper, cobalt, lead, zinc and so on) is lower in the hydrothermal deposits, although it is higher there than it



HYDROTHERMAL DEPOSITION of iron and manganese is depicted. Hot seawater driven by convection from the basaltic rock deep in the crust, where it is able to penetrate and circulate because the rock is fractured, emerges through the sea floor at a vent in a spreading center. The water carries in solution ions of iron and manganese that it has leached from the basalt. In the cold oxygenated water of the sea floor the metals are oxidized and deposited as manganese oxides, which are represented here by triangles, and iron hydroxides, represented by circles.



STAGNANT BRINE POOL on the sea floor also provides conditions for the formation of metal deposits. Such a pool can form if the metal-rich solution that has circulated in the crust is discharged through the sea floor in a topographic setting that prevents mixing of the solution with seawater. Lacking oxygen, the brine favors the combination of iron, copper, lead and zinc with sulfur to form insoluble sulfide compounds. The sulfide minerals are then precipitated onto the sea floor to give rise to metal deposits of the type found at the axis of the Red Sea.



METAL-RICH SEDIMENTS occur along spreading centers at mid-ocean ridges in a distribution indicated by this map. In the shaded areas the sediments have an anomalously high concentration of such metals as iron, manganese, barium, copper and uranium. Concentrated metal deposits have been found in regions marked by clustered dots. Question marks indicate possible metal-rich sediments.

is in normal oceanic sediments. The relatively high rate of deposition of the hydrothermal deposits can explain their low content of trace metals on the assumption that trace metals are largely scavenged from seawater by the particles of iron and manganese oxide and hydroxide. The longer such particles stay in contact with seawater (the lower their rate of deposition is), the more opportunity they have to pick up trace metals and other elements such as phosphorus and uranium through adsorption. The trace metals then become incorporated in the deposits. The high concentration of trace metals, particularly cobalt and copper, in deep-sea hydrogenous deposits is what makes them attractive economically.

A few trace metals, such as copper and zinc, can also be carried by the hydrothermal solutions and are discharged through the sea floor along with iron and manganese. They can become concentrated in deposits formed near the hot springs only when the discharge occurs in a topographic and hydrologic setting that gives rise to the formation of stagnant and reduced pools of brine on the sea floor. The oxygen-free condition of a reduced environment prevents the oxidation of the metals and favors the combination of copper and zinc with sulfur to form insoluble sulfides. One finds such conditions in the Red Sea deposits (where the concentration of copper and zinc reaches a few percent, making the deposits economically attractive) but not in most deposits at mid-ocean ridges, where the bottom waters are oxidized and sulfides cannot form above the sea floor.

The geochemistry of the rare-earth elements provides another means whereby hydrothermal deposits can be distinguished from hydrogenous ones. The rare earths are a group of 15 elements (atomic numbers 57 through 71) with a remarkably similar chemical behavior, so that during most of their geochemical cycle on the earth they tend not to fractionate from one another.

Cerium is one of the rare earths that under certain conditions can behave somewhat independently because its chemical valence can be changed. Cerium, alone among the trivalent rare earths, can be oxidized to the relatively insoluble quadrivalent state. As a result seawater loses cerium more readily than it does the other rare earths. The cerium is gained by the slowly growing hydrogenous deposits.

Hydrothermal deposits usually show a cerium-depleted rare-earth pattern, similar to that of seawater, and a total rare-earth concentration that is substantially lower than the concentration in hydrogenous deposits. Such data suggest that rare earths can be captured from seawater by hydrothermal deposits, although to a limited extent because the deposits accrete so rapidly. Some hydrothermal metal deposits have been shown to have a rare-earth distribution similar to that of oceanic basalts, suggesting that the basaltic oceanic crust is the source for at least some of the elements contained in the metal deposits from spreading centers.

Two pertinent questions emerge from this discussion. Where do the hot solutions that discharge at spreading centers come from, and what is the source of the metals they carry? To answer these questions I need to digress briefly.

According to the theory of plate tectonics, a lithospheric plate slowly cools as it moves away from the axial zone where it was created. Knowing its initial temperature at the axis of creation (about 1,000 degrees Celsius), its thickness and its average composition, one can calculate the vertical conductive heat loss of the aging plate. The curve derived from this calculation matches well the actual values of heat flow measured on the sea floor, with the exception of young lithosphere close to the axis of spreading. There the measured values of heat flow exhibit much variation and are always substantially lower than the theoretical curve.

This discrepancy can be explained if one assumes that close to the ridge axis a substantial fraction of the heat is lost not by conduction but by convection,

that is, the flows set up by the tendency of a hot fluid to rise and a cold fluid to sink. Convective loss would occur where seawater penetrated into the oceanic crust within the sediment-free and highly fractured zone close to a spreading axis.

The permeability of young oceanic crust is such that seawater can probably reach several kilometers below the sea floor. There, in the hot zone where magma is rising in the axis, the water is heated and is driven back up by convection and discharged through the sea floor at hot springs.

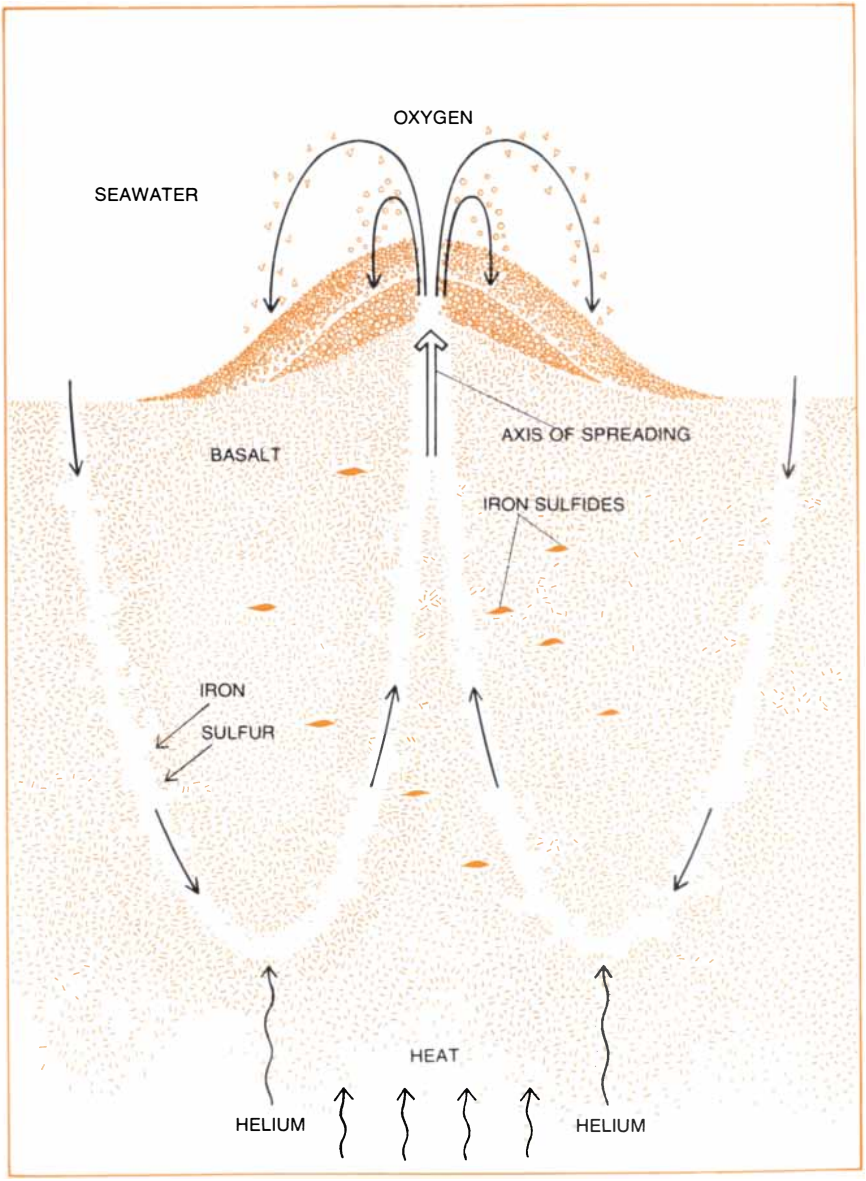
One next wonders what happens during this process to transform a liquid such as seawater, which has an exceedingly low concentration of metals, into a solution that is highly enriched with metals and has a totally different chemistry. The circulation of seawater I have described takes place mainly in rocks of basaltic composition. Therefore it is possible that the observed chemical changes result from reactions between basaltic rocks and heated seawater. These reactions have been studied in the laboratory by several geochemists. Seawater and powdered samples of basalt are made to react with each other under controlled conditions of temperature and pressure for periods of time ranging from hours to years.

A considerable exchange of elements results from these reactions, particularly the reactions conducted at temperatures of a few hundred degrees C. The seawater changes from an oxidized and slightly alkaline solution (the normal condition of seawater) to an acidic and reduced one, highly enriched in silica, calcium, iron, manganese, copper and other elements, all of which have been leached from the basalt. On the other hand, the seawater loses certain elements, such as magnesium, that are acquired by the rock. The composition of the solutions resulting from these experiments is remarkably similar to that of solutions discharged by hydrothermal systems operating in basaltic terrains.

A complementary approach to the same problem is to compare fresh oceanic basalt with oceanic basalt that has been altered by the action of seawater. Large chemical differences are observed between the two kinds of basalt. The metals are again among the elements that have decreased most in concentration in the altered basalts. Several lines of evidence thus support the concept that reactions between hot seawater and basalt, occurring below the sea floor, are a major supplier of metals to the deposits associated with ocean ridges that are or have been spreading centers.

A simplified model can be advanced to summarize the development of metal deposits at oceanic spreading centers. Seawater penetrates below the sea floor in the vicinity of the active zone of lithospheric accretion. It circulates within the zone of young, highly fractured oceanic crust to a depth of up to a few kilometers and is heated to a temperature of up to a few hundred degrees C. The heated water reacts with the basaltic crust; a number of elements are leached from the basalt and carried in solution by the hydrothermal water, which is driven back up by convection and discharged through the sea floor. Iron and manganese are oxidized, partly separated and deposited, together with silica and minor elements. A number of elements, including phosphorus, the rare-earth elements and some trace metals, are captured from seawater and incorporated in the deposit.

The elements contributed to hydrothermal systems by the basaltic crust derive ultimately from the mantle, since ocean-ridge basalts are produced by the partial melting of mantle material at depths of 25 to 50 kilometers. In addition, however, hydrothermal systems at accreting plate margins may provide a medium for the discharge into the ocean of gases derived directly from the mantle. An example of such degassing of the mantle is the discovery of nonatmospheric helium along oceanic spreading centers. The isotopic composition of the



HYDROTHERMAL PROCESS is modeled schematically. Seawater enters the fractured basalt of the crust near a spreading center and penetrates to a depth of several kilometers. Because of the high temperatures in the zone of magma injection along a spreading center, the water is heated to a temperature of a few hundred degrees Celsius. The heated water extracts a number of elements, including metals, from the basalt and also loses a few. Thermal convection drives the now metal-rich water back up to the sea floor, where it is discharged through hot springs. Some of the metals are deposited as sulfides within the crust. The metals remaining in solution are deposited on the ocean bottom. The discovery of mantle-derived helium along oceanic spreading centers suggests that hydrothermal systems also bring gases up.

helium suggests that it came from the mantle. One therefore cannot exclude the possibility that some of the elements incorporated in the deposits associated with oceanic spreading centers may have such a direct origin in the mantle.

It has been estimated that a volume of water equivalent to the total volume of the present oceans has undergone hydrothermal circulation below the sea floor at spreading centers in 100 million years or less. One derives from this estimate a measure of how important these hydrothermal systems are in accounting for the chemistry of seawater and for chemical exchanges between the solid and the liquid layers of the earth.

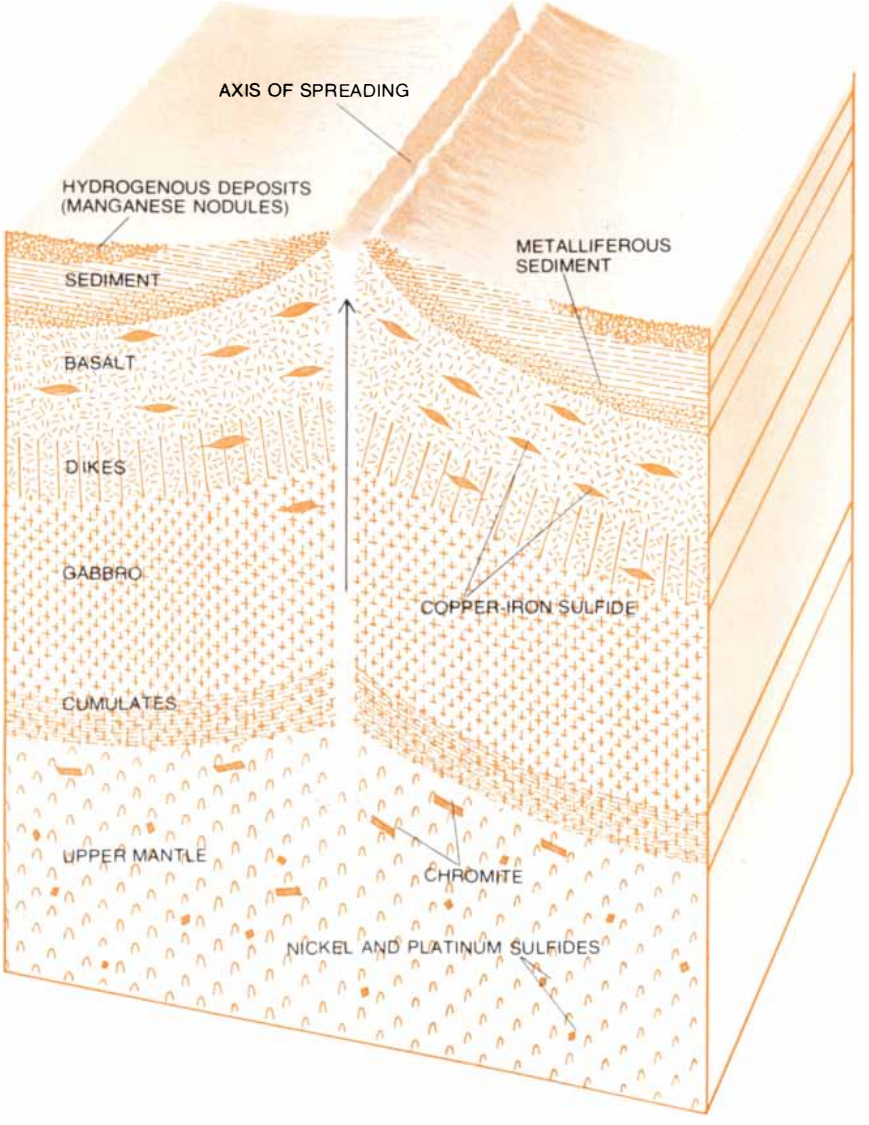
The oceanic crust moves away from the axis of accretion at a speed of one centimeter or a few centimeters per year. Eventually the crust reaches a margin of the ocean basin and becomes involved in such complex geologic processes as subduction and collision. In the course of these processes fragments of oceanic lithosphere may be uplifted and exposed on land at the margins of continents. Fragments of ancient oceanic lithosphere, which are known as ophiolites, have been identified in various parts of the world. Can one recognize in ophiolites metal deposits like those in the modern oceanic lithosphere? Indeed one can.

An example is provided by the ophiolite complexes of late Mesozoic time (about 100 million years ago) exposed on the Apennines of northern Italy. Like similar complexes elsewhere, they consist of an upper sedimentary layer; a layer of basalt, corresponding to the upper part of the oceanic crust; a zone of gabbro (the lower part of the oceanic crust), and an ultramafic layer, corresponding to the oceanic upper mantle. Metal deposits, which are particularly rich in manganese, exist in the ophiolites at the base of the sedimentary pile, just above the area where it was in contact with basalt. This stratigraphy is the same as what has been found associated with the metal deposits of modern oceans, as revealed by the drillings of the *Glomar Challenger*. Moreover, the geochemistry of the Apennine ophiolite sedimentary deposits is identical with that of deposits from modern oceanic spreading centers. Similar results obtained in ophiolite complexes from Cyprus and elsewhere demonstrate that their metal-rich sediments were formed originally by hydrothermal activity at ancient spreading centers.

The study of ophiolites not only confirms the validity of the model of hydrothermal metallogenesis but also suggests that additional classes of metal deposits are formed at oceanic spreading centers. Within the basalt units of the Apennine ophiolites, deposits of sulfides of iron, copper, lead and zinc have been known for a long time, having been exploited by the Romans. The deposits consist generally of large lens-shaped mineralizations, up to about 100 meters across, emplaced between basalt flows or of networks of mineralized veins and disseminated concentrations within the basaltic rock. Similar deposits are known on Cyprus, on Luzon in the Philippines and in most other ophiolite complexes, where they have provided a rich source of copper, lead and zinc.

The realization that ophiolites are fragments of former oceanic lithosphere and the discovery that zones of accretion of the modern oceanic lithosphere are the locus of large hydrothermal systems have shed light on the origin of the ophiolitic metal sulfide deposits. In the course of the circulation of seawater below the sea floor the waters become strongly reduced. They acquire metals and also become enriched in sulfur, partly through leaching from the basaltic rocks and partly through the reduction of sulfate ions in the seawater. These conditions favor the combination of sulfur with certain metals (mainly iron, copper, lead and zinc), which are thus extracted from the hydrothermal solution to form insoluble sulfide minerals.

It is therefore evident that metal-sulfide deposits similar to those observed in ophiolite complexes can be formed at spreading centers within the basaltic oceanic crust by the same hydrothermal systems that give rise to the metal-rich sedimentary deposits found there. The



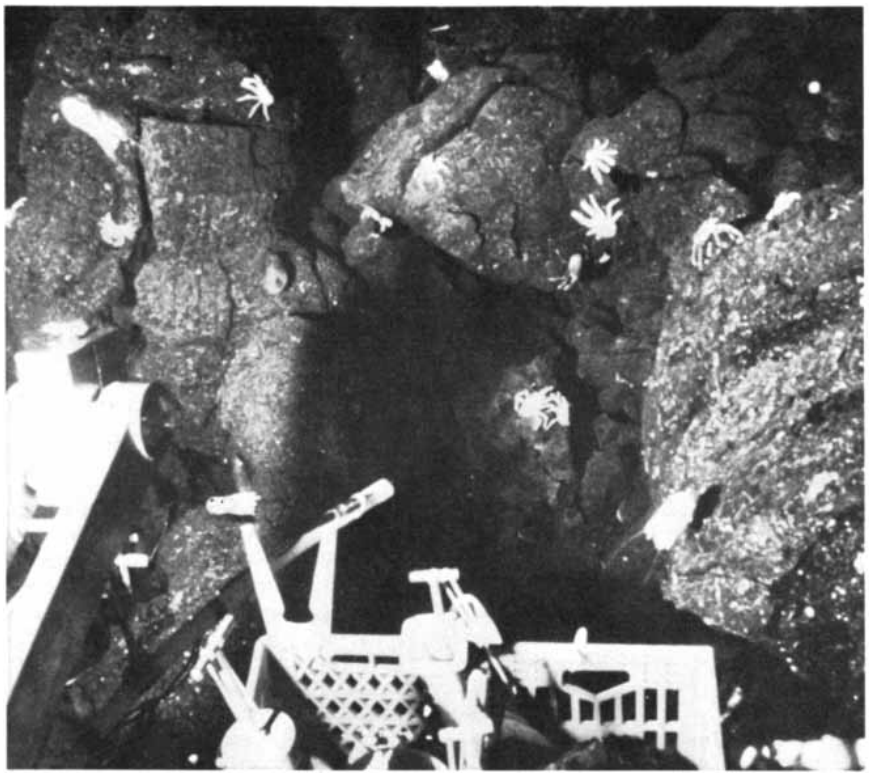
DISTRIBUTION OF METAL DEPOSITS in units of the oceanic lithosphere is depicted schematically. Hydrogenous metal deposits, such as manganese nodules, are found at the summit of the sediment layer. Hydrothermal systems near an axis of spreading give rise to sedimentary metal deposits at the base of the sediment layer and to metal sulfides within the upper (basaltic) part of the crust. Chromite deposits can be formed at the base of the crust, within cumulitic gabbro and ultramafic rocks, and particularly within the upper mantle by segregation from pockets of magma created by partial melting of ultramafic rocks far below the spreading axis. Concentrations of platinum and nickel sulfides can form in magma pockets in the upper mantle. A similar distribution is found in uplifted fragments of former oceanic lithosphere.

extent to which metal sulfides are deposited from hydrothermal systems below the sea floor depends on such factors as the temperature of the hydrothermal solutions, the depth and speed of the circulation of seawater in the hydrothermal system, the concentration of metal and sulfur, and so on. The extraction of certain metals from the solution by sulfide precipitation before the solution is discharged through the sea floor can result in the fractionation of the metals. For example, manganese does not readily form sulfide minerals. It is therefore kept in solution until the hydrothermal water is discharged through the sea floor. Iron, on the other hand, is partly deposited within the crust as iron sulfide. This fractionation might explain in part why some hydrothermal sedimentary deposits on the sea floor are rich in manganese but contain almost no iron.

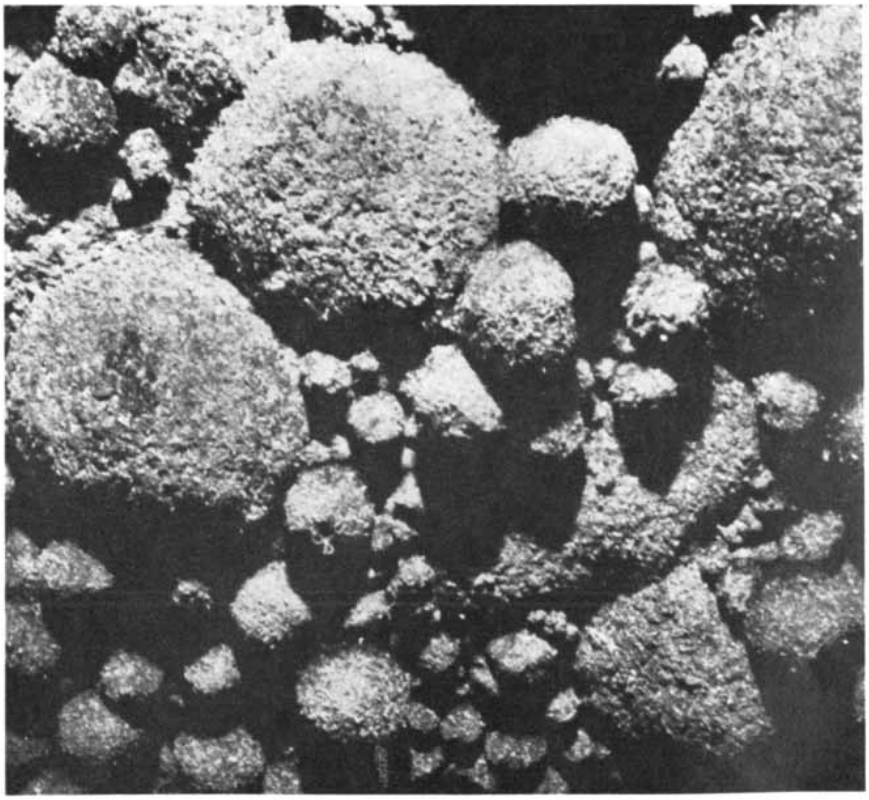
Do modern oceanic basalts offer any evidence of the deposition of metal sulfides by the hydrothermal process? They do. Some hydrothermally altered basalts that have been recovered from the Mid-Atlantic Ridge are extensively mineralized by veins and disseminated concentrations of chalcopyrite (copper-iron sulfide), pyrite (iron sulfide) and other metal sulfides. These mineralizations are identical with the ones that in ophiolite complexes are closely associated with massive deposits of metal-sulfide ores. It is unlikely that a massive sulfide deposit would be revealed by drilling into the oceanic crust, but sooner or later it is bound to happen.

Ophiolite complexes can also provide information on the generation of metals deep in the oceanic crust and upper mantle, below the zone reached by the hydrothermal systems. Some of the largest chromite deposits in the world, many of them associated with concentrations of nickel and platinum, are found in ophiolites within ultramafic rocks, which represent what was formerly the oceanic upper mantle. These concentrations of chromite originally formed 10 kilometers or more below the sea floor by segregation from pockets of magma scattered in the upper mantle along accretionary plate boundaries. Such pockets are probably generated by partial melting of ultramafic rocks in the mantle. The melting is caused by decreasing pressure during the upwelling of mantle material below an axis of spreading.

Mantle-derived ultramafic rocks have been sampled in the oceans where blocks of upper-mantle material have been uplifted and exposed on the sea floor. The oceanic ultramafic rocks contain concentrations of chromite (usually small ones). It is unlikely that anyone in the near future will be lucky enough to sample in the ocean concentrated chromite deposits of the type exposed in the ophiolites of Cyprus and Luzon.



HYDROTHERMAL VENT was photographed at a depth of 2,500 meters near the Galápagos spreading center in the east Pacific by investigators in the submersible *Alvin*. The warmth of the water emerging from the vent has attracted a much larger number of organisms than would be found elsewhere on the sea floor. Hydrothermal vents are associated with metal deposition.



MANGANESE NODULES photographed on the sea floor in the South Pacific represent a hydrogenous process whereby metal deposits are formed in the oceans. In such a process metal that is present in seawater in minute quantities, in part having been brought from land by streams, is extracted from the water by oxidation or by certain organisms living in the sea. Deposits of metal thus built up develop slowly; rate is as low as one millimeter per 1,000 years.

Computer-controlled Assembly

High-volume products are assembled by people or by special-purpose machines. An experimental programmable robot suggests that robots would be cost-effective for the assembly of products in lower volumes

by James L. Nevins and Daniel E. Whitney

Continuing inflation, competition from other countries and record deficits in international trade have created a widespread awareness in the U.S. of the need to increase productivity in manufacturing, which means decreasing the man-hours, materials, energy or capital required to produce industrial goods of all kinds. An additional stimulus for increasing productivity arises from the desire to improve the quality of life, including the life of workers now engaged in stultifying, repetitive and sometimes hazardous tasks. For most of the past century growth in manufacturing productivity has been maintained by the substitution of power-driven machines and new technological methods for labor. Today there are pressures to use power, materials and capital more efficiently. The conventional remedies need to be reexamined and new solutions need to be sought.

Although there are many ways of increasing manufacturing productivity—financial, fiscal and social—we shall focus here on the possibility of raising productivity through the application of science and advanced technology to an old field: assembly. Technology has brought about radical changes in many areas—power generation, transportation, chemical manufacturing, communications and data processing—but it has had only a minor effect on the way the broad spectrum of consumer goods, from electric toasters to automobiles, are actually assembled. Alert to the need for raising productivity, Germany, Japan, Norway and other countries have begun long-term government financing of research on manufacturing methods. In the U.S. the National Science Foundation and a few industrial firms joined forces several years ago to support similar studies, although on a much more modest scale.

Attacking assembly alone will not be sufficient. The fraction of the manufacturing labor force engaged in assembly operations varies widely from industry to industry. It is seldom less than 10 percent, and even in the automobile industry, which has the volume to justify a heavy investment in mechanization, roughly a third of the total work force is engaged in assembly. Thus massive shifts in productivity can come about only if great changes are made in the entire production system, including assembly but extending well beyond it.

At present manufacturing is based largely on experience; it is really an art form. Equipment designers and factory managers prefer to repeat what has worked in the past, which can be taken as evidence that they are struggling with a vastly complicated situation. Such changes as are introduced tend to be small ones. Wholesale shifts in technique are expensive and risky.

At the Charles Stark Draper Laboratory in Cambridge, Mass., with support from the National Science Foundation and industry, our goal is to contribute to a base of manufacturing knowledge from which new theories, experimental techniques and assembly methods can emerge rather than to develop devices of limited value one at a time to meet specific factory problems. With guidance from our industrial partners we have developed economic models of the role of assembly in manufacturing. In this way our studies can be focused on the problems most in need of solution at the same time that we are acquiring the basic knowledge for solving them.

One lesson learned from this approach is that certain problems addressed in the past are of little interest to industry. For example, highly complicated robot-arm computer systems, guided by television "eyes," that will pick up parts arriving in any orientation and mate them to other randomly oriented parts, although intellectually challenging, do not tackle the core problems of assembly. What happens when parts touch each other? How can close-tolerance parts be mated when there is no way to see into the hole where wedging and jamming actually take place? What should a computer-controlled assembly machine "know" in the way of general assembly skills and what should it be taught "on the job" in order to perform a particular task on the factory floor? What industrial products lend themselves to robot assembly? One must be able to answer these questions and similar ones on a firm factual basis if assembly technology and other manufacturing technologies are to advance.

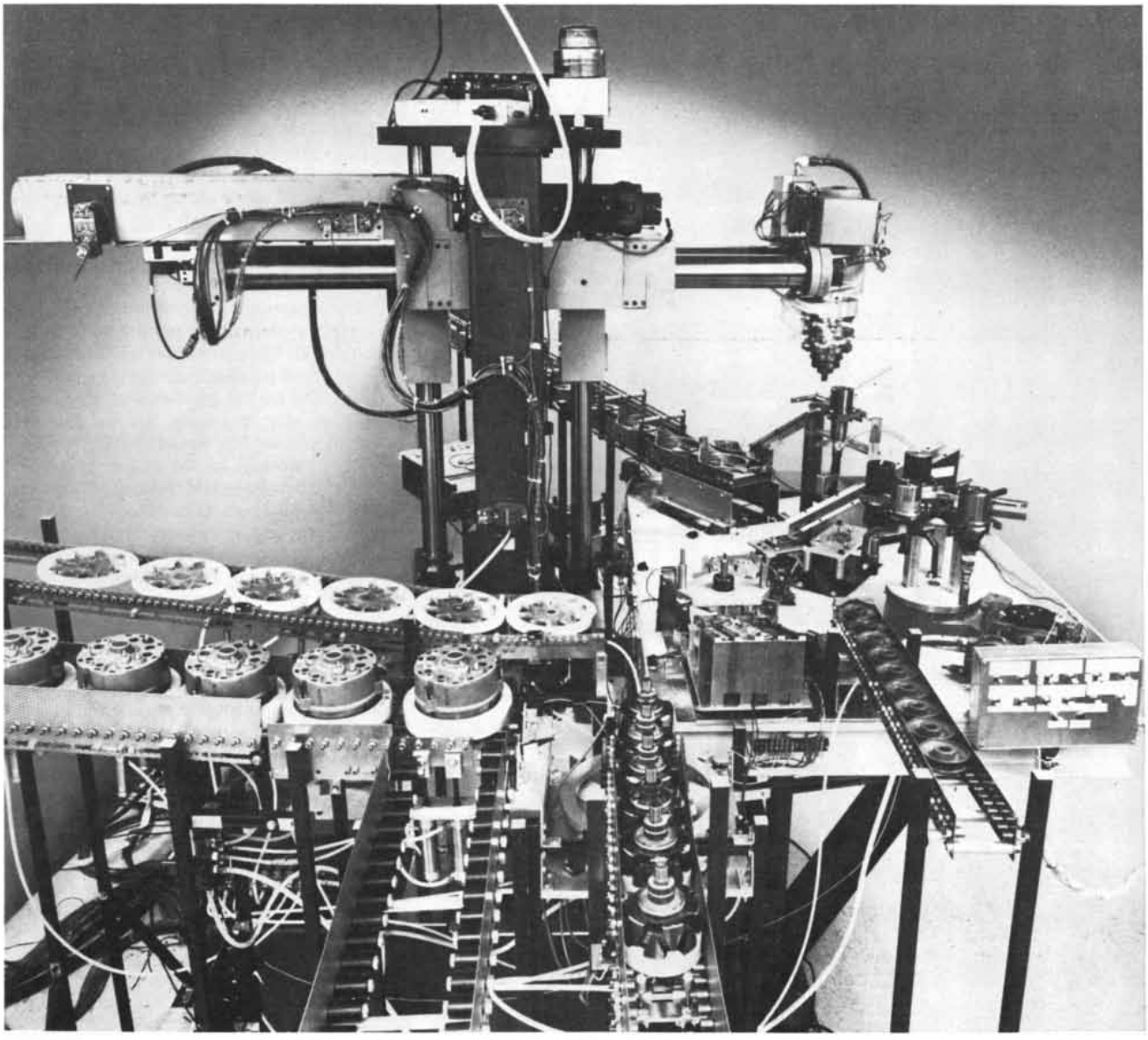
At present assembly is performed by people and, when the production volume is high enough, by special-purpose machines. People are readily taught new tasks, and they adapt to changing conditions (such as slight variations between one part and the next), to different models of the same product on the same assembly line and to major changes in product design. They make skillful use of sight and touch both to move objects around and to carry out the fine tasks required for assembly. As a result they have little need for special tools and parts holders (generally called jigs and fixtures). On the other hand, people are subject to fatigue and the inability to perform a task exactly the same way time after time. These limitations often lead to substantial problems in quality control.

Special-purpose machines are very efficient, give reproducible performance and are not subject to fatigue, but they consist almost totally of jigs and fixtures built to perform one task, or a closely related series of tasks, on one product. They cannot easily be altered to accommodate different models on the production line or changes in product design. Such machines do not have sensors to guide or monitor the assembly process, although they can perform simple tests on the assemblies. Each machine is usually one of a kind, expensive and laboriously tuned to the accuracy necessary to handle one set of parts. Slight variations in the parts can cause such machines to jam as much as a third of the time. The high cost of special-purpose machines and their inability to handle new tasks

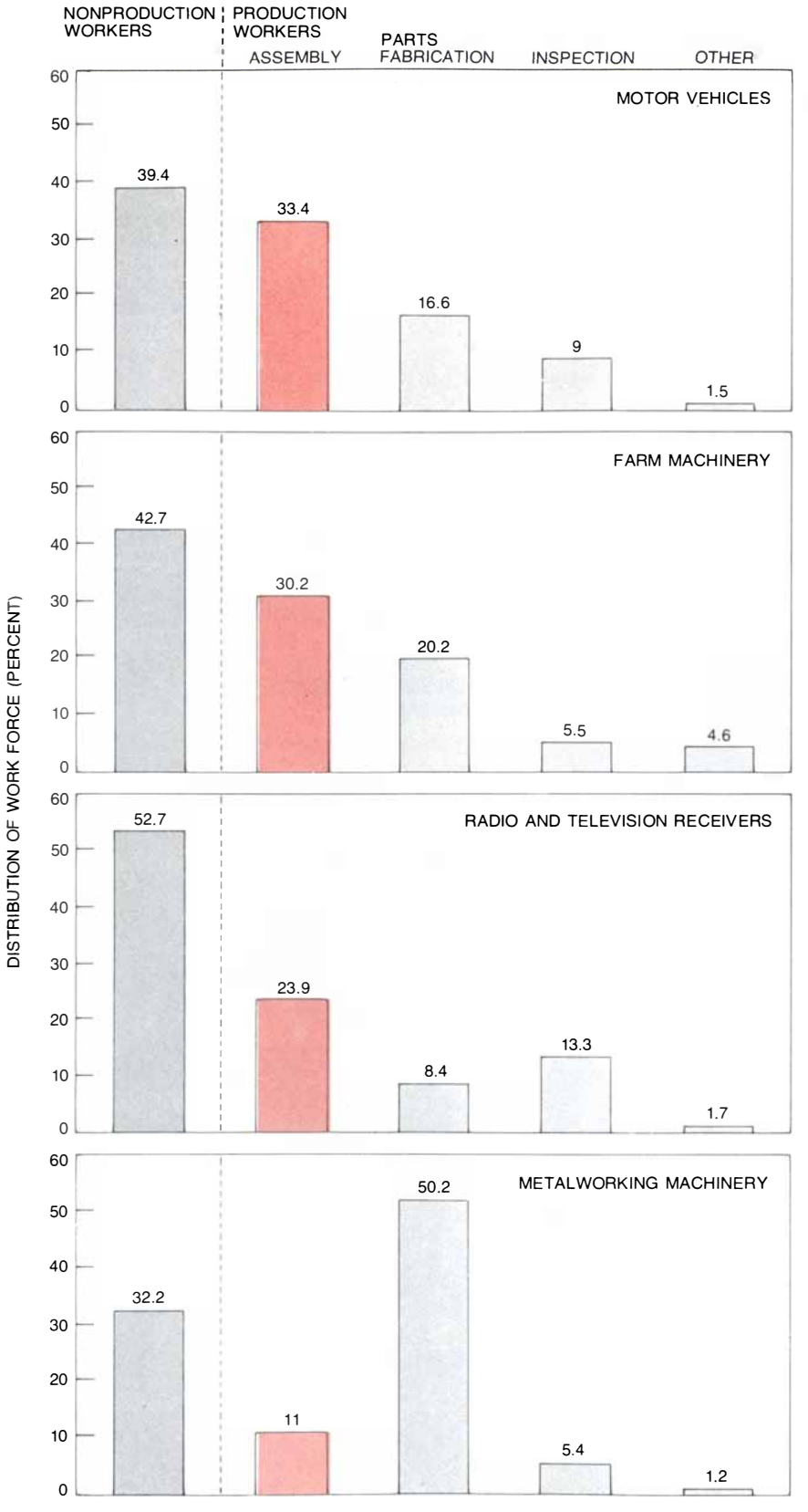
or products limit them to applications where millions of identical units are made each year for several years. It has been estimated that such high-volume production characterizes only 5 percent of all goods manufactured.

Most products are manufactured in batches with wide style variations, in quantities too small or a design life too short to justify investment in a special-purpose machine. In addition many items are not designed with sufficient attention to assembly problems, partly because assembly phenomena are not well enough understood to allow precise requirements to be placed before the product designers. Moreover, assembly-line workers do more than just put parts together. They often make spot repairs and perform many vital inspection tasks. It is for these reasons that most assembly is still done by people. It is unlikely that completely unmanned factories will ever exist, because people will always be needed to supervise and repair the machines.

Our research group at the Draper Laboratory has been examining the hypothesis that low-volume batches of a product (a few hundred thousand items or fewer per year) and mixed batches of similar models of a product can be assembled profitably by machines that are adaptable and programmable. An adaptable machine is one that can perform an assembly task as it accommodates itself to relative position errors between the parts. Such errors arise from the usual tolerances within which all manufactured parts are allowed to vary and from the lack of perfectly repeatable performance by the assembly machine itself. It is these errors that cause parts to jam rather than go together smoothly. Adaptability is therefore central to successful assembly. A programmable machine is one that can be taught, with minor alterations, to perform a new assembly task or that can perform several tasks in sequence. This capability is essential if assembly ma-



PROGRAMMABLE ROBOT ASSEMBLY STATION built at the Charles Stark Draper Laboratory can assemble the 17 parts of a commercial automobile alternator in two minutes 42 seconds. At the far right is a control box through which the robot can be taught a sequence of moves that can then be recorded in the memory of a minicomputer. The robot serves as a test bed for exploring theories, techniques and costs of computer-controlled assembly systems capable of being reprogrammed for various comparable tasks. The alternator was selected for the assembly experiment because it is an actual industrial product and thus requires mating of component parts that have standard industrial clearances. Alternator was also chosen because it is a "stack" product: all the parts can be added from a single direction.



DISTRIBUTION OF LABOR in four major durable-goods industries demonstrates the large role that manual-assembly labor still plays, even in the highly mechanized motor-vehicle industry. The different distributions are characteristic of the industries, for example the intensive use of labor in fabricating precision parts of metalworking machinery and in inspecting radio and television receivers. The data for the chart are taken from the 1970 U.S. Census.

chines are to be economic for low-volume manufacturing.

Before setting out to design an adaptable and programmable assembly machine one must answer a number of questions. What assembly tasks will the machine face, or what tasks are appropriate? What should the machine's performance capabilities be in terms of speed, size and accuracy? Should it be capable of all the possible motions a human arm can execute, or of more or fewer—including both gross motions and fine ones? Should the machine be provided with efficient but inflexible fixtures or with an elaborate reteachable sensing capability to enable it to find the exact locations of parts? If the machine is to be programmable, it cannot be built from the start to do its assigned task; how then is it to be "taught" what to do? Should one machine be expected to assemble an entire product or should the assembly tasks be distributed among several machines that pass partially completed work along as in a conventional assembly line?

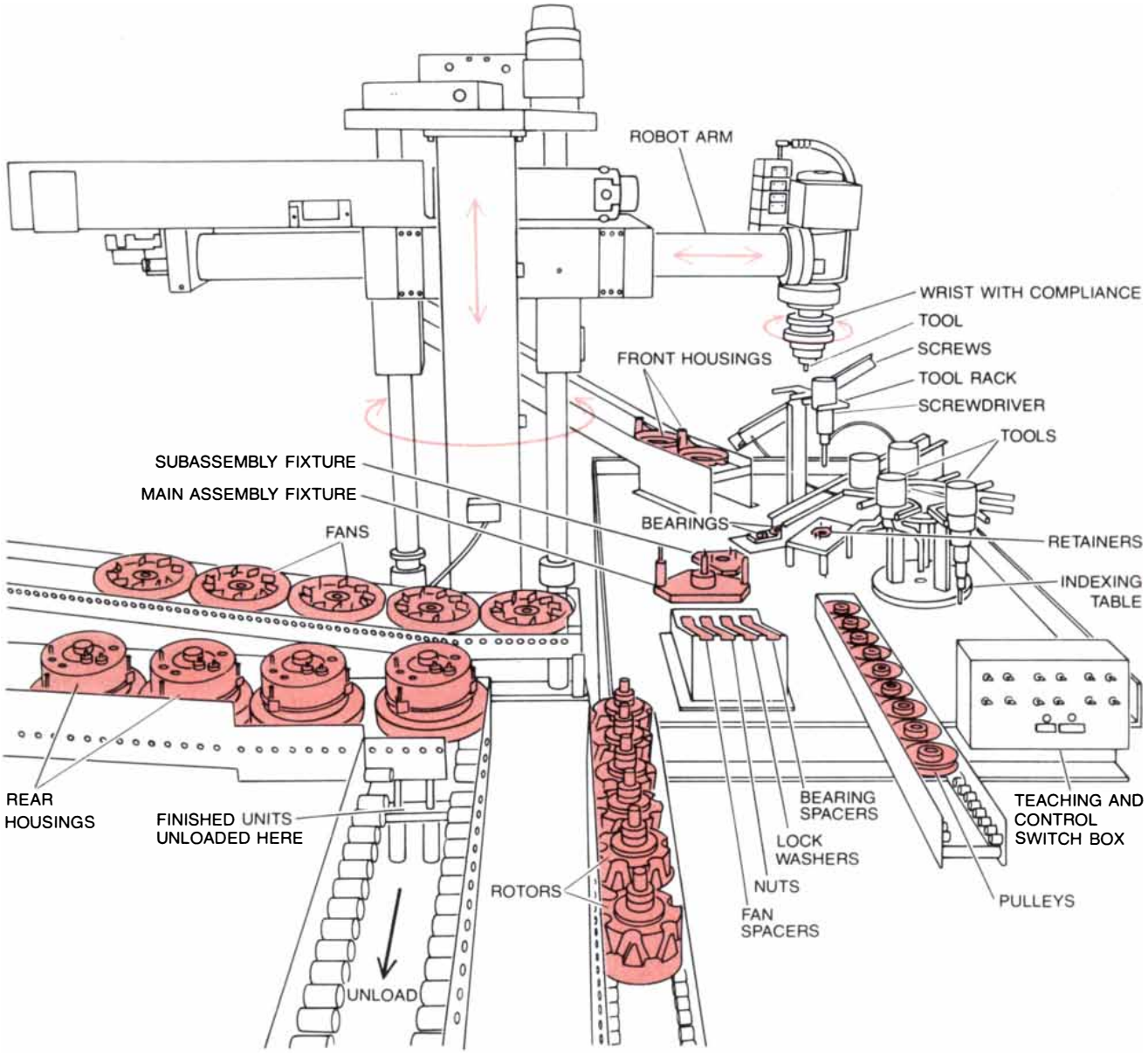
These questions have plausible but conflicting answers. Our approach has been to divide the problem into two segments: parts-mating phenomena and assembly systems. The mating of parts involves all the events that occur as parts touch and go together. Such events are governed by the geometry of the parts, particularly including the amount of clearance (or free space) between them after assembly, by the degree to which they are misaligned laterally and angularly when they first touch and by the influence of contact and frictional forces between them as they slide together. In order to understand the mating of parts we have studied idealized tasks, formulated hypotheses and verified them experimentally.

When we began this work five years ago we had several further assumptions, some of which have survived and others have not. We postulated machine systems with several work stations, each of which incorporated an "arm" something like today's conventional industrial robot [see "Robot Systems," by James S. Albus and John M. Evans, Jr.; SCIENTIFIC AMERICAN, February, 1976]. Such devices repeat a sequence of taught moves, combined with the opening and closing of grippers, that enable them to transfer objects from place to place. Current industrial robots do not have sophisticated controls or sensors to allow modified behavior in case of difficulty, although they can detect trouble and stop before damage is done. Neither are they accurate enough to perform assembly. Many of these limitations are being overcome or soon will be by research and redesign. At present, however, the robots are too big and too expensive for most assem-

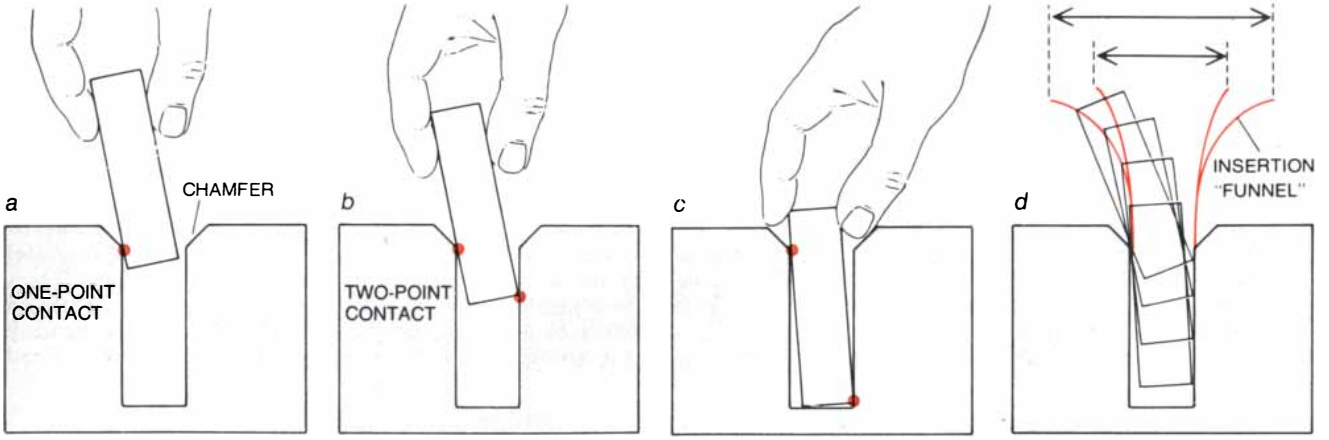
bly applications, and it is questionable whether assembly applications require all the motions they are capable of.

We further postulated that the arm at each work station should be capable of executing both gross motions for the transfer of parts and fine motions, measured in fractions of a centimeter, for the assembly of parts. In order to guide the fine motions we proposed placing in the arm's "wrist" a sensor capable of detecting both forces and moments. We concluded early that the spatial information necessary to put close-fitting parts together could be sensed as physical forces much more readily than it could be acquired by viewing mechanisms such as television.

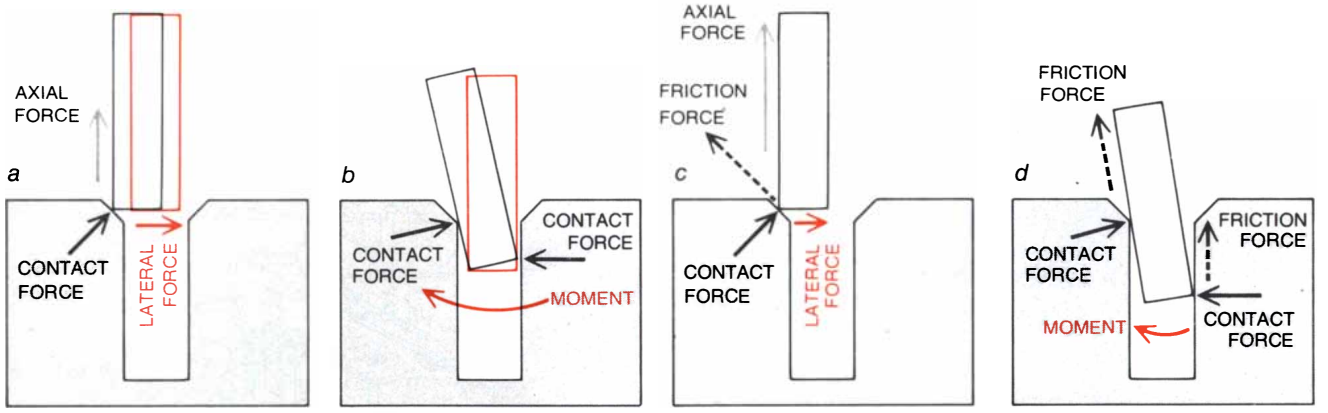
Whether parts will mate successfully in any given instance depends on the relative error between the parts as they touch for the first time. If the parts touch with some relative error, a contact force will arise, causing the parts or the grippers and jigs to deform slightly. The deformation has the effect of altering the path along which the arriving part moves, with results that are either adverse, beneficial or neutral. If the relative error is small, mating can proceed without difficulty, but adverse effects are increasingly likely as the errors get larger. If the addition of expensive and inflexible fixtures is to be avoided, our mating mechanisms must be able to tolerate errors larger than those tolerated by existing machines. This requirement means not that the contact forces merely be allowed to work their will on the motions but rather that a strategy for producing beneficial responses and



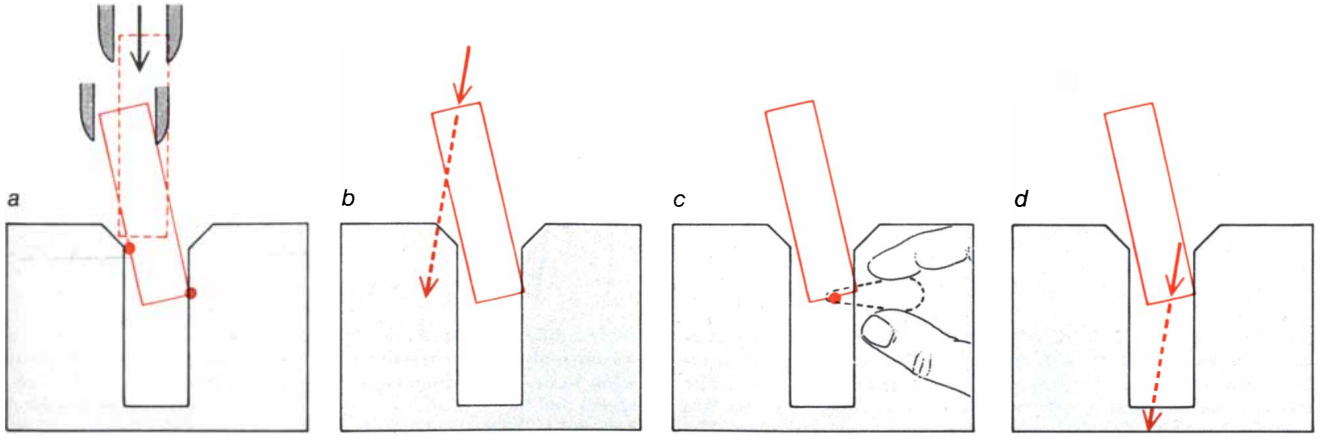
LAYOUT OF ROBOT ASSEMBLY STATION shown in the photograph on page 63 places tools and parts within easy reach of the robot's arm, which has four degrees of freedom (*colored arrows*). The assembly task requires six different kinds of tools, held on a table that "indexes," or turns, to supply the proper tool for each operation. The alternators's 17 parts are fed by gravity from 12 feeders. (The 17 parts include three screws, which have only one feeder, and three long bolts, fed together with the rear housing.) The assembly is performed on two different fixtures, one for the main assembly, the other for a subassembly. The robot is operated by a computer that drives the four joints to designated stopping points at designated speeds. The points, speeds and tool operations are programmed with the aid of a control box and a simple keyboard language. The language names and sequences the points and tool operations. A major feature of the robot is a wrist-and-gripper mechanism that responds compliantly so that parts can be inserted into close-fitting openings without jamming.



INSERTION OF A PEG IN A HOLE, a typical assembly task, is basically a problem in positioning. Holes are usually chamfered (beveled around the edge) to aid insertion. As the peg slides down the chamfer and enters the hole (*a*) it touches one side of the interior first (one-point contact). If the angular misalignment is large (*b*), the peg will soon touch the opposite side of the hole as well (two-point contact), with danger of jamming. In manual assembly vision can help to find the chamfer, but after the peg enters the hole one must rely on the ability to sense the resisting forces in order to maneuver the peg to the bottom (*c*). The geometry of the peg and the hole keeps the peg within the insertion "funnel" (*d*), the path that is traced by the top of the peg at successively deeper stages of the two-point contact. The smaller the clearance between the peg and the hole, the narrower the insertion funnel and the more difficult the insertion task.



CONTACT FORCES BETWEEN PARTS can be used to guide corrective motions of the "wrist" of an assembly robot's arm. In the absence of friction (*a*) the contact force at the chamfer is sensed as two equal reactions, one vertical and the other lateral. The lateral force can serve as a cue to the desired corrective motion (*colored arrow*). Later (*b*) contact forces create a moment around the tip, which provides a cue to the desired corrective motion (*colored arrow*). When there is friction (*c*), the upward reaction at the chamfer is exaggerated, reducing the useful lateral reaction. Friction also reduces the useful information about moment (*d*). The ratio of the friction force (*broken arrows*) to the contact force, in other words the coefficient of friction, is about 0.2 for steel parts and 1.0 for aluminum ones.



IF COMPLIANT GRIPPERS are used to hold a peg, a lateral error becomes an angular error as the peg slides down the chamfer and enters the hole (*a*). Continued application of force at the top of the peg (*b*) creates a torque that can lead to jamming. If the peg could be grasped compliantly at its tip (*c*), insertion could be accomplished in spite of substantial angular error. The same force that would lead to jamming if it were applied at the top of the peg would tend not to cause jamming if it could be applied at the bottom of the peg (*d*).

avoiding adverse ones be determined in advance.

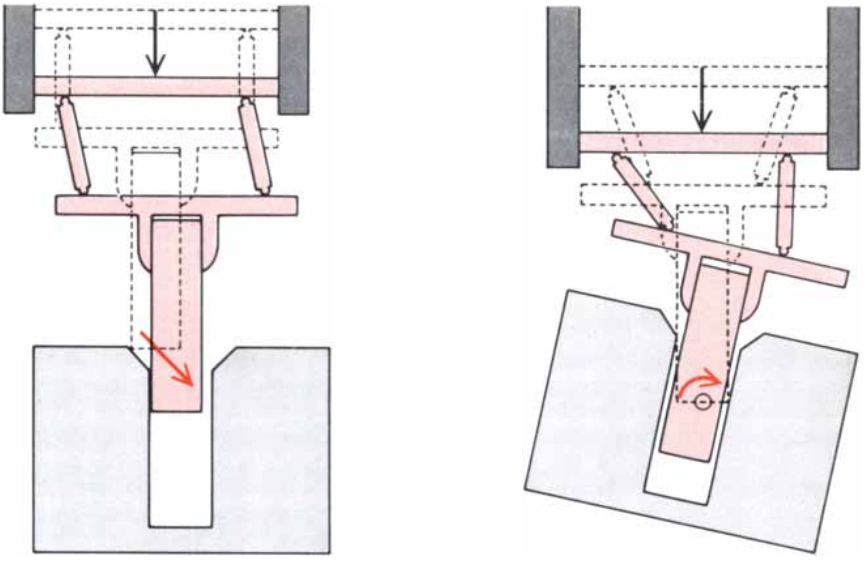
One of us (Nevins) proposed that the force sensor on the wrist could be used to measure all the components of the vector of the contact force. The sensor would be designed to measure three components of force along three mutually perpendicular axes, *x*, *y* and *z*, together with three components of torque around the same axes. Thus we proposed to perform assembly as a blind person might, by measuring the forces and executing appropriate motions in response to what was felt, thereby correcting errors in steps until the parts were successfully mated. One of us (Whitney) then formulated a general strategy for force feedback that generates a vector of motions (three *xyz* translations and three rotations about the *xyz* axes of the tip of the entering part) in response to the sensed vector of the contact force.

We analyzed and experimentally verified this technique on two different computer-controlled robots and in the process learned a great deal about harnessing sensory feedback for assembly. The technique has many of the characteristics of a closed-loop control system, which operates as follows. The wrist force sensor detects the contact-force vector. The assembly strategy, residing in the arm's controller, will call for a certain response motion whose direction depends on the direction of the contact force and whose magnitude depends on the magnitude of the force. This motion, when it is executed, will change the deformation of the parts and the grippers, thereby changing the force. New force gives rise to new motions, which give rise to new force and so on in a loop.

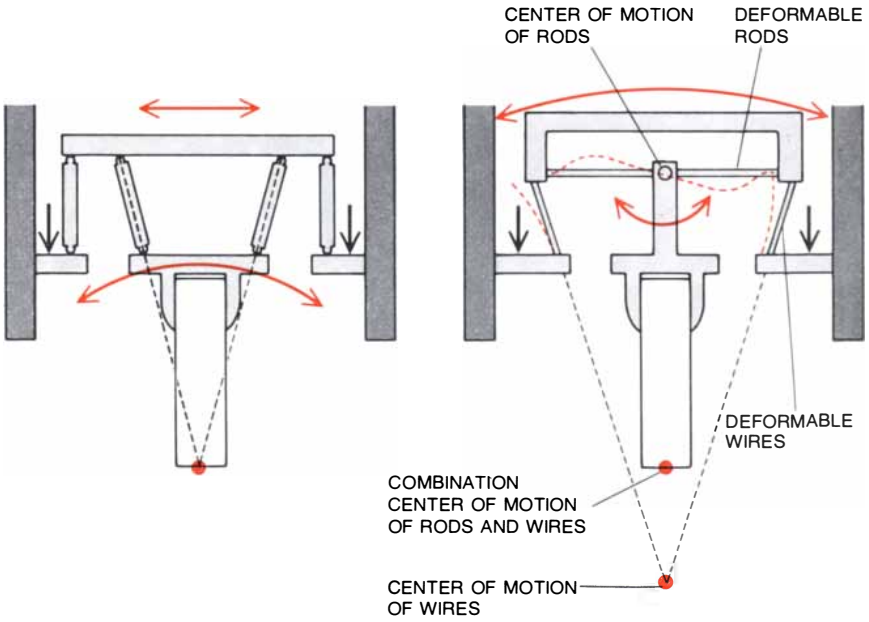
Care must be taken in designing the strategy so that the right amount of motion is called for in response to the felt force. Too much motion will cause the arm to react as a person does when he touches a hot surface; too little motion will let large contact forces build up to a damaging level. The less stiff (more compliant) the parts and the grippers are and the lighter the arm's moving components are, the easier it is to obtain rapid, stable and effective responses with low contact forces. When low stiffness and rapid response motion cannot be built into the apparatus (because, for example, it is too heavy or the workpieces it is holding are), the only remedy for avoiding large contact forces is to make all the closed-loop motions slowly. This alternative is an unattractive one from an economic point of view.

One conclusion of this work was that assembly is best understood in terms of the forces and moments acting on the tip of the part, where it touches its mate during assembly. Another conclusion was that devices capable of fine assembly motions must be small, light and fast. Arms capable of gross motions cannot meet these criteria, indicating that in future assembly systems fine- and gross-motion devices, like the human hand and arm, will be separate entities.

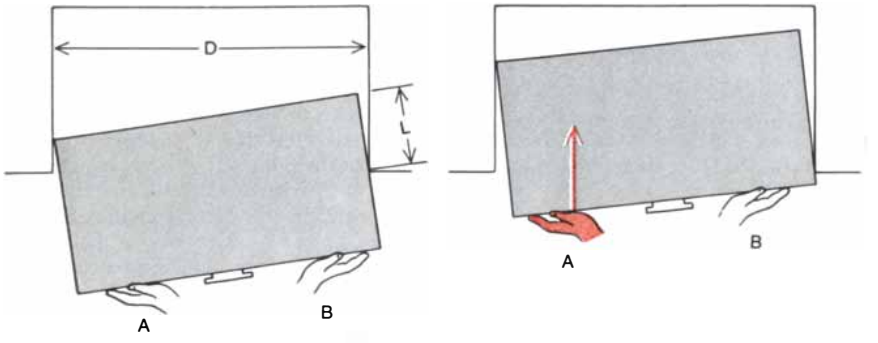
A third conclusion was that friction can mask the force data needed to guide the strategy and can cause the parts to jam rather than slide together. Our coworker Sergio N. Simunovic has demonstrated mathematically that there are really two distinguishable phenomena: wedging and jamming. Wedging involves deformation of the parts themselves and occurs only if the entering part, such as a peg, enters a hole at such a sharp angle that it touches opposite sides of the hole before it has penetrated very far. More specifically, wedging occurs when the ratio between the depth of insertion and the diameter of the hole is smaller than the coefficient of friction;



GRIPPERS WITH LINKAGE SUPPORTS can provide the proper response to an error either in lateral position (*left*) or in angular position (*right*) but not in both. The first linkage allows a laterally misaligned peg to slide down a chamfer and enter a hole without rotating. Second linkage allows a misaligned peg to become aligned by rotating at the tip without moving sideways.



GRIPPERS WITH COMPOUND COMPLIANCE can correct for both lateral and angular misalignment. The "remote center compliance" at the left combines the two types of linkage depicted in the upper illustration. If a lateral force is exerted at the tip of the peg, it will translate (move sideways) without rotating. If a torque is exerted at the tip, the peg will rotate without translating. The device shown at the right can correct for misalignments by a suitable arrangement of deformable rods and wire springs, which are used in place of linkages. The relative stiffness of the rods and wires determines the location of the combined center of motion.



DIFFERENCE BETWEEN WEDGING AND JAMMING was clarified during the development of compliant-gripper mechanisms. When, for example, a bureau drawer becomes wedged (*left*), it is literally locked. Any further application of force will deform the drawer or the bureau or both. Theory shows that wedging arises when the drawer is inserted at such an off angle that the ratio of *L/D* is less than the coefficient of friction (μ) when two-point contact first occurs. The only remedy is to pull the drawer out and start again. If, however, the ratio *L/D* is larger than μ at the time of initial two-point contact (*right*), wedging cannot result, although further movement can be impeded by jamming. The remedy is to break the two-point contact by pushing at *A*, thereby changing the direction of both the applied force and the applied moment. Compliance devices on preceding page apply forces in accord with this theory.

the ratio is typically less than 0.2. There is no known remedy for wedging except to pull the peg out and try again.

Jamming, on the other hand, arises principally from the relation between the insertion force and the frictional forces. It can be remedied by changing the direction of the vector of the applied insertion force. Simunovic has derived a quantitative strategy that has been verified experimentally; it calls for sensing the applied forces and moving the arm under computer control to satisfy certain relations between the components of applied force. This approach is an effective and general one, but it could be expensive to implement in an assembly device. We and many other investigators have nonetheless found it useful in coping with balky drawers and window sashes in the home.

We conducted another illuminating experiment, using conventional industrial robots with no force feedback and relying only on their ability to repeat a taught sequence to within half a millimeter. Donald S. Seltzer of our group taught a robot to insert a crankshaft and a gear into the housing of a small gasoline engine, with clearances of about .05 millimeter, a tenth of the robot's accuracy. At first we were surprised by his success, but closer examination revealed the explanation. When a peg is partway into a hole, it can wobble back and forth a good deal farther than the clearance itself. Because of an incidental and unappreciated compliance in the arm and the grippers this wobbling was allowed to occur and the pieces went together. The contact forces were undoubtedly large.

Can all simple peg-and-hole insertion tasks be accomplished in this way? The answer is "Yes, but...." An engineer wants to be sure his machine will work. In this instance he wants to know how much wobble he can expect and how to arrange the compliances so that jamming will not occur. He cannot depend on the accidental compliance provided by the grippers. In order to improve our understanding of these effects we undertook an experimental and theoretical program of geometrically analyzing assembly tasks, combining the results with the jamming analysis. The aim was to create a passive compliant wrist that could execute the fine motions required for close-clearance insertions without the use of active sensors and actuators. The investigation was guided by Paul C. Watson, Samuel Drake and Simunovic.

Traditional time-study methods distinguish "easy" and "difficult" manual insertion tasks qualitatively, but we needed a description that was quantitative. We found it by determining how much a peg could wobble in a hole as a function of the depth of insertion, the diameter of the hole and the clearance. The results of the analysis are expressed in terms of ratios so that they will apply to all sizes of pegs and holes. The difficulty of the task is expressed in terms of the clearance ratio (the clearance divided by the diameter). We found that most parts of a given kind (washers or bearings, for example) are designed for a particular clearance ratio almost independently of their size.

This finding enables us to predict the difficulty of insertion for many industrial assembly tasks. A clearance ratio of .001 is typical of a fairly difficult insertion. In this instance a peg inserted to a depth equal to one diameter can wobble back and forth about .06 degree. The same peg, just entering the hole, can wobble about 1.5 degrees. We compared this result with the angular accuracy required to start screws into threaded holes without mismatching the threads on opposite sides of the hole and determined that a larger wobble was permissible. We concluded that machines accurate enough to perform most insertions can also install screws.

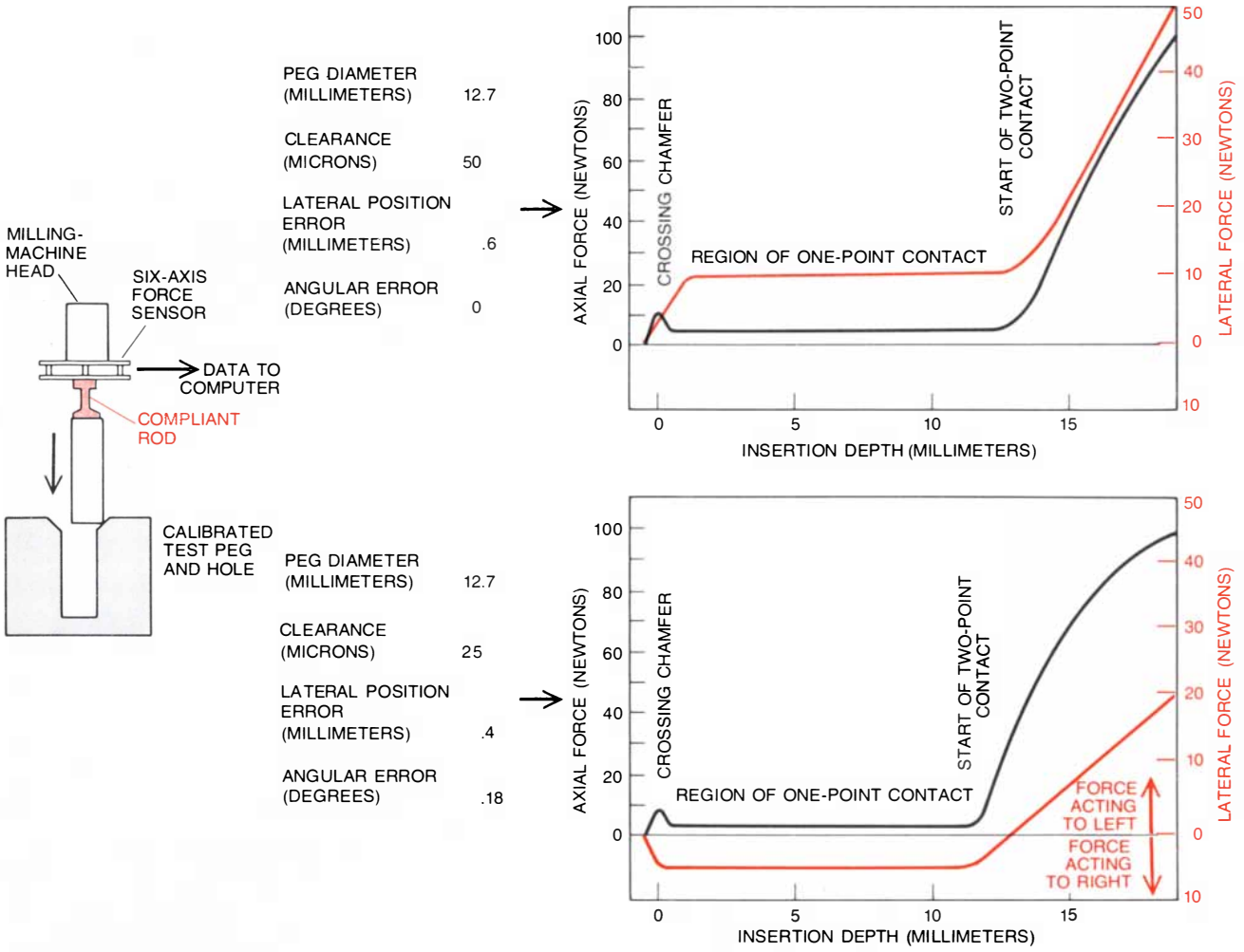
To test the geometric and friction analyses Drake, with the aid of Seltzer, conducted a series of controlled experiments with carefully measured round metal pegs and holes. The peg and the hole were mounted in a milling machine so that during the insertion of the peg precise relative errors could be imposed. The peg was attached to a sensor that measures forces and torques along three axes at the tip of the peg. To provide a known amount of compliance the top of the peg was attached to the sensor by a thin metal rod.

The experiment showed the need to improve the compliant rod in two ways. With the peg pivoted from its top there is a tendency for lateral error to become angular error as insertion proceeds. This tendency gives rise to two-point contact, and further insertion is possible only if the top of the peg can move laterally. The compliant member must be flexible enough to allow such lateral movement, otherwise large contact forces will be exerted on the tip of the peg and on the walls of the hole. When the rod is made too flexible, however, it tends to buckle and collapse.

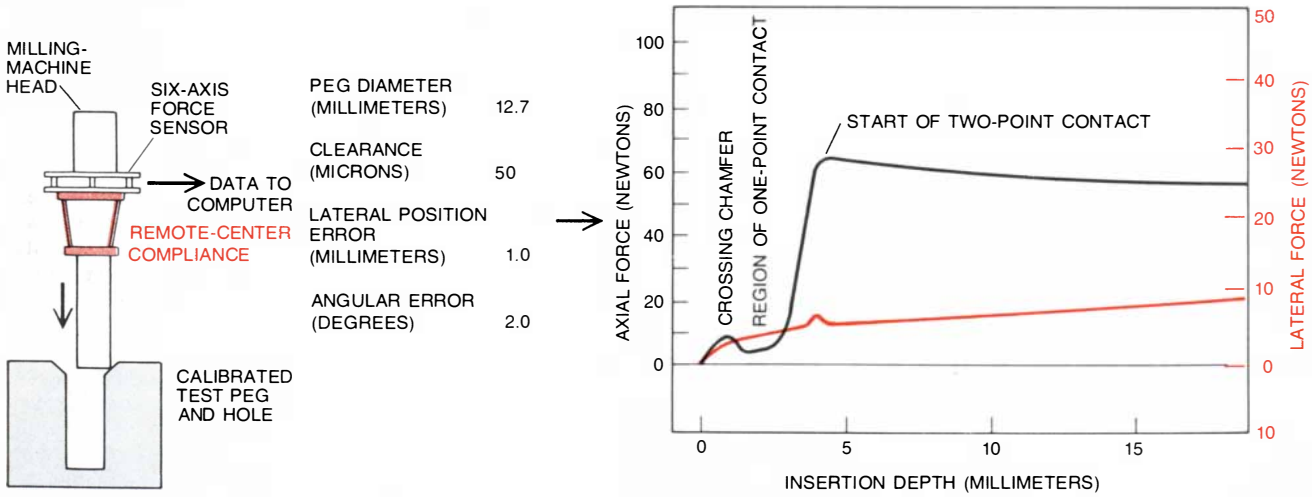
The first step in solving such problems involved constructing a linkage device called a remote-center compliance, which allows the peg to rotate about its tip if it is angularly misaligned with the hole. A second linkage cascaded with the first allows the peg to move from side to side to correct a lateral error without introducing unwanted rotation.

The mathematical analysis of jamming can show that jamming is least likely, and insertion forces are lowest, when the peg is allowed to rotate about its tip. The combination of desirable properties—lateral motion, when it is needed, and rotation about the tip—have been built into a compliant mechanism of improved design that is not subject to buckling collapse. The new device, the first practical passive compliance, is now part of our laboratory assembly machinery and is being studied by several industrial firms. With it we have performed once-difficult assembly tasks, such as putting a bearing into a housing with a clearance ratio of .0004 in a fifth of a second, starting from a lateral error of one millimeter and an angular error of 1.5 degrees. The new device is clearly applicable to special-purpose automatic equipment and to programmable assembly systems.

The only other fine-motion device of which we are aware that can achieve close-clearance insertions is the Hi-Ti-Hand, developed by Hitachi, Ltd., in Japan. It is an active motorized unit that inserts pegs into holes by deliberately



PART-MATING EXPERIMENTS depicted in this illustration disclose the forces that are developed when a steel peg is inserted into a hole under carefully calibrated conditions of clearance and misalignment. The forces and moments are detected and sent to a computer by a six-axis force sensor attached to the head of a milling machine. A simple compliant rod provides a limited amount of compliance between the force sensor and the test peg. In this pair of experiments the axial forces increase sharply by about the same amount after two-point contact takes place. The behavior of the lateral force in the second experiment (first pushing to the right and then to the left) is characteristic of combined lateral and angular error. The results of the part-mating experiments conformed to theoretical predictions.

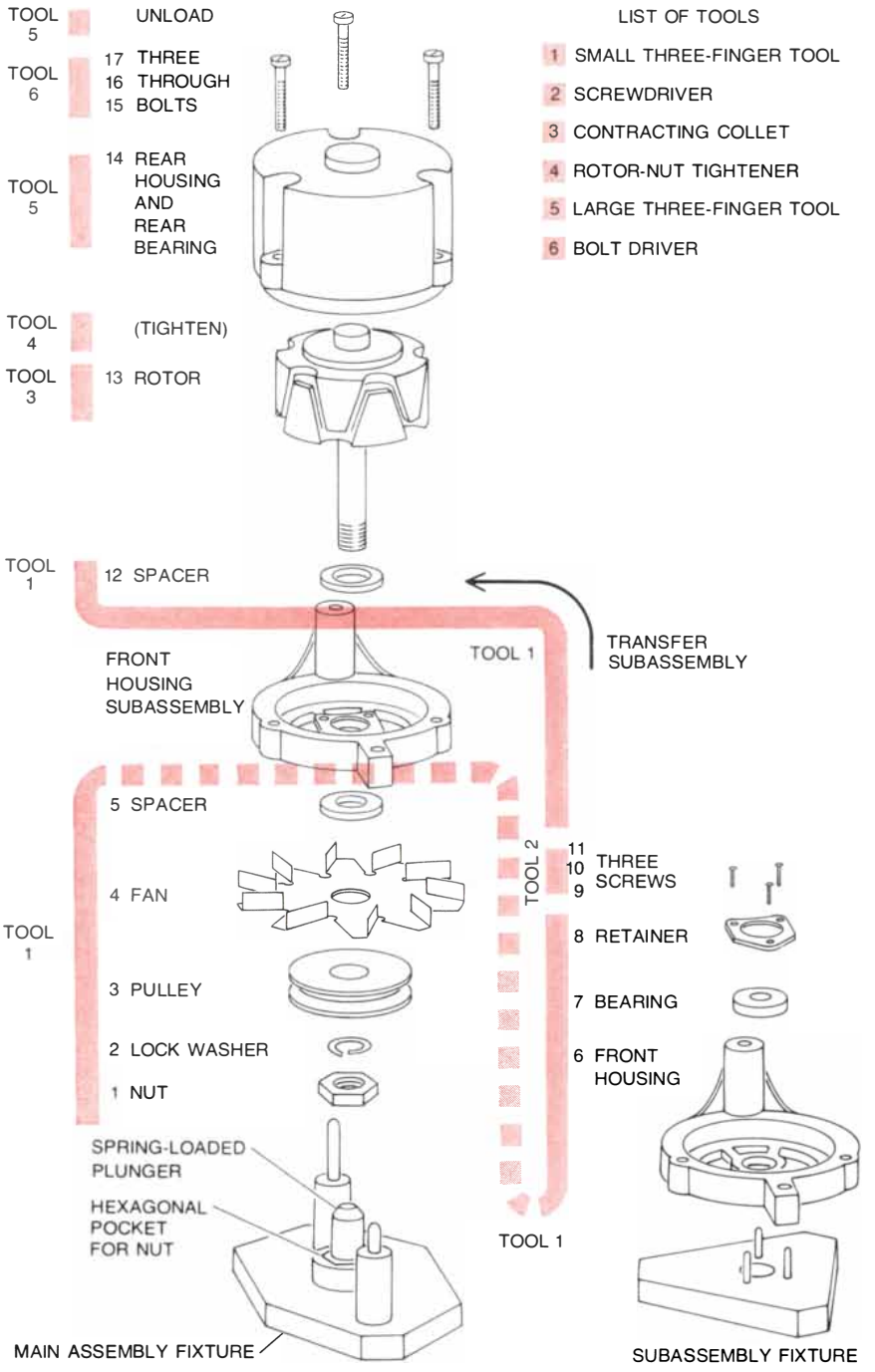


MUCH LARGER MISALIGNMENTS between a peg and a hole are tolerated and generate smaller axial and lateral forces when the peg is held by the newly developed remote-center compliance instead of by a rod. In this experiment the initial error in lateral position is about twice the value of the error in the compliant-rod experiments. The angular error of two degrees is more than five times greater than it is in the second rod experiment. The virtue of the new compliance scheme is that it allows the peg to rotate about its tip as it meets resistance entering the hole. The peg does not jam even though the two-point contact between it and the hole is made near the top of the hole.

moving the top of the peg from side to side and sensing with force sensors when, as a result of two-point contact, no further side-to-side motion is possible. In this way the device finds the boundaries of an imaginary funnel outside the hole defined by all the positions limited by two-point contact. Another version of the Hi-Ti-Hand pushes the peg down until two-point contact is made and then searches for a free area inside the funnel. The control system for detecting contacts and changing the peg's direction of motion is subject to the same constraints we established in our force-feedback studies. The gripper holding the top of the peg must be provided with compliant springs, and search speeds must be kept low to limit the contact forces. Current models of the Hi-Ti-Hand are able to perform only vertical insertion tasks and need several seconds to accomplish the kinds of insertion our remote-center compliance device does in a fifth of a second.

One other commercial system, developed by Olivetti, S.p.A., also incorporates force-sensing for assembling parts. The Olivetti system measures the forces along three axes as pieces come in contact with each other and makes what amounts to a sequence of binary decisions (part present or absent, hole present or absent) until mating is either complete or abandoned. The system has two arms and has been used for the machining and assembly of small parts.

The passive compliance assembly mechanisms designed in our laboratory represent the confluence of three endeavors: the assembly strategy based on sensing force vectors, the geometric analysis of assembly tasks and the theory of wedging and jamming. It seems to us that comparable studies of tasks other than insertions will lead to still other devices for aiding assembly. Let us now take up the kinds of problems that must be considered in designing a complete assembly system.



EXPLODED VIEW OF THE ALTERNATOR shows the sequence in which its 17 parts are assembled by the authors' programmable robot and identifies the tools that perform each task. The center rod in the main assembly fixture is a spring-loaded plunger. The collar at the base of the rod contains a hexagonal cavity that firmly holds part *1*, the nut. When the rotor (*13*) is inserted, the plunger is depressed, enabling the rotor's threaded shaft to engage the nut. The rotor is then spun by tool *4* in order to thread the shaft tightly into the nut. The authors calculate that time now required by entire operation, two minutes 42 seconds, could be reduced to one minute five seconds if changes were made in design of tools, fixtures and the alternator.

Assembly systems are collections of assembly machines capable of putting together one or more products. To design machines that can be widely applied in industry and to combine them into efficient systems requires an understanding of what industrial products are like, what assembly tasks arise, how small the clearances between parts are, how many models of one product are made and so on. It is also necessary to understand how assembly lines are arranged efficiently so that, for example, one machine does not lag behind the others. Finally, choosing products amenable to automatic assembly calls for thorough economic studies of what performance the new methods can provide and at what cost compared with present methods.

The first design decision is whether to use a manual system, a special-purpose machine or a programmable assembly machine, or perhaps some combination of all three. This problem is essentially an economic one as long as technically feasible designs can be formulated. It is common practice in industry to make such evaluations (between manual systems and special-purpose machines at present, of course) on a case basis, but we decided to devise a mathematical formulation of the important factors. Such a formulation makes it possible to name variables, to establish the relations between them and to explore the conditions, if any, that favor the use of

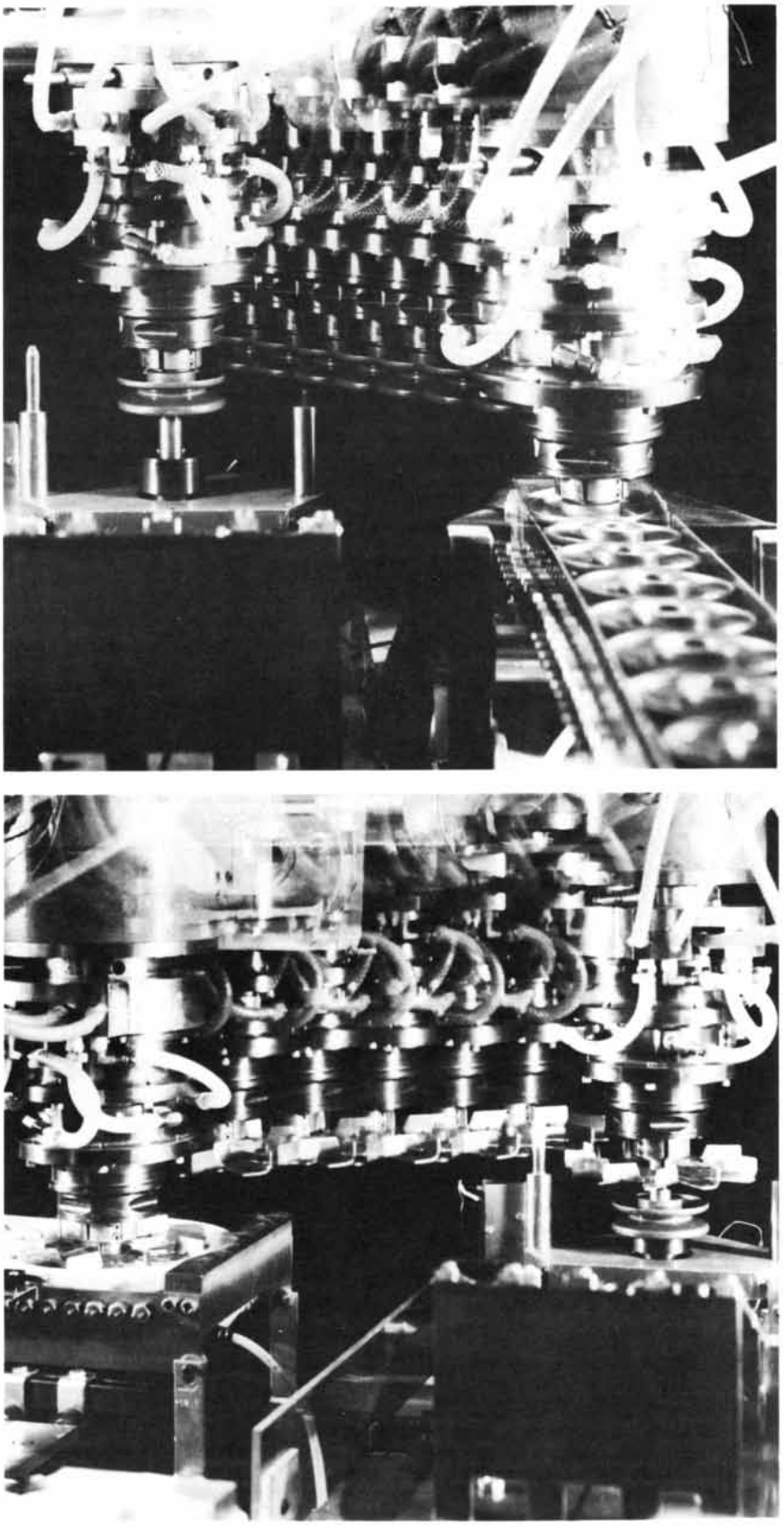
programmable assembly machines. We particularly wanted to find out whether our original hypothesis about the applicability of programmable assembly machines in low-volume manufacturing was correct. This effort, carried out in collaboration with Paul Lynch, resulted in our economic model of assembly alternatives.

Before we had formulated our model we were beset by conflicting opinions and rules of thumb. A common opinion, the result of years of studying particular cases, is that an automated assembly process is more economic than manual assembly only if at least a million assembled units are needed each year for several years. How then could "low-volume programmable automated assembly" be economic?

Another opinion is that robot assembly arms should have six powered joints, since fewer joints would prevent the arm from making all possible rotational and translational (back and forth) motions as it positioned an object. Arms with fewer than six joints would inevitably be specialized; the manufacturer would have to make several stock types or he would always be building expensive special units rather than one mass-produced inexpensive arm that could "do everything." But should the customer pay for joints he does not need when mass-production quantities of robot arms are not likely to be achieved for many years? Without an economic model and a quantitative study of assembly tasks such arguments can continue indefinitely and inconclusively.

Let us take up the problem of economic modeling first; it will help to clarify the question of how many joints an arm should have. Our approach is necessarily simplified, but the main considerations are not greatly changed if the complexity is increased. Industry normally judges an investment (the purchase of a piece of equipment) in terms of how much money can be saved and how rapidly the savings pay back the investment. A straightforward way to evaluate the economics of an automatic assembly system is to compare the cost of assembling one unit manually with the cost of assembling the same unit automatically. The major cost in manual assembly is the hourly wage. This cost can readily be combined with the hourly production rate, the number of parts in the unit and the time it takes a person to add each part to the unit, from which the cost of assembling the complete unit can be found.

Since machines do not collect wages, a different approach must be taken with them. There are many such approaches, but a simple one will illustrate the principle. The company's management establishes a minimum period over which the machine must pay for itself, with



TYPICAL ASSEMBLY OPERATIONS are shown in these multiple-flash photographs taken in the authors' laboratory. At the top the robot arm is performing the third step in the assembly sequence in the illustration on the opposite page. With the aid of tool *1* (small three-finger tool) the robot is picking up a pulley from the feeder line at the right and is lowering it onto the plunger of the main assembly fixture. In the photograph at the bottom the robot, using the same tool, is picking up a fan from the feeder line at the left and placing it on top of the pulley.

shorter periods being the more desirable. Each of the units assembled during the selected payback period is allocated an equal share of the initial investment, thus creating what amounts to a "cost to assemble one unit." That cost will be higher if the payback period is made shorter. If the cost is less than the present or projected cost of manual assembly, it will be economic to buy the machine. Although other factors—taxes, interest rates, maintenance costs, salvage values and so on—enter in, this is the essence. It follows that if an economic model is to predict whether or not a given type of machine will be economic, the model must be able to predict the amount of the initial investment. This requirement in turn calls for modeling the amount of work that must be done to assemble each unit.

For the three broad alternatives—manual assembly, special-purpose-machine assembly and programmable-robot assembly—we have measured the amount of work simply by counting how many parts make up one unit. The investment for special-purpose machinery is assumed to be proportional to the part count, since each part calls for a separate dedicated work station. For small parts a station might cost $6,000; for large parts it might cost $200,000. This cost breaks down into three categories roughly as follows: machine parts and materials, 25 to 35 percent; design and construction, 30 to 50 percent, and adjusting the machine after it has been set up, 15 to 45 percent. The number of stations for a given job does not depend on the required production volume unless the volume is so large that several machines are needed. Hence economies of scale are realized if production volume is large, but the "cost to assemble one unit" is large if production volume is small.

The investment for a programmable machine, in contrast, is expected to depend significantly on the required production volume, because one station can perform several assembly tasks on one unit. Thus low production volumes can be met, with low investment, by a few stations each of which puts many parts on one unit. Larger volumes can be met by many stations each of which puts on a few parts. To be sure, grippers and feeders are needed to handle each part, so that some of the costs do not depend on production volume. Simple equations relating the cost of a robot station, the average time required to attach one part to a unit and the cost of tools and fixtures can predict the required investment and hence the unit assembly cost for a given payback period.

The models of the three assembly methods relate most of the recognized quantities: the work content of the task, the cost of the various techniques and their speed, the cost of labor and the required annual production. When we insert reasonable numerical estimates for these factors into our equations, we get curves of the type shown in the illustration on page 74. Although the curves represent a theory so far unverified, they do appear reasonable in several respects. First, they reproduce the conclusion that special-purpose machines become economic compared with manual assembly when production runs exceed a million units per year. Second, the curves show the economic benefits of programmability: the curve for programmable machines falls below that of special-purpose machines because fewer work stations are needed at low production volumes. This creates a range of production volumes below mass production where programmable machines have economic promise. Since the machines are reprogrammable, it is feasible to apply them to the assembly of products manufactured in families of models. The production volume of each model may be small, but the aggregate will be large enough to justify programmable assembly.

The equation for the costs of programmable assembly also resolves an old argument: whether to achieve economy by making assembly arms that are fast or to achieve it by making assembly arms that are cheap. The equations show that only the cost of the arm multiplied by the time needed to add one part is important. An equal percentage change in either factor has the same effect. Further study of specific arm designs has also shown that the most effective way to reduce the product of the two factors is to make a small, lightweight arm that has as few joints as possible.

This brings us back to the unanswered question of how many joints an arm should have, which is part of the larger question of matching the arm to the job. To obtain some basic information on assembly tasks our colleague Anthony S. Kondoleon took apart and reassembled a number of typical products, such as a bicycle brake, a refrigerator compressor, an electric jigsaw, a small electric motor and an electric toaster-oven. A key question concerned what might be called choreography: In what sequence are the parts attached to the product and from what directions do they arrive? The arrival direction is determined by the part's location on the product, how it fits into a hole, over a pin or into a slot, and what other parts block its path.

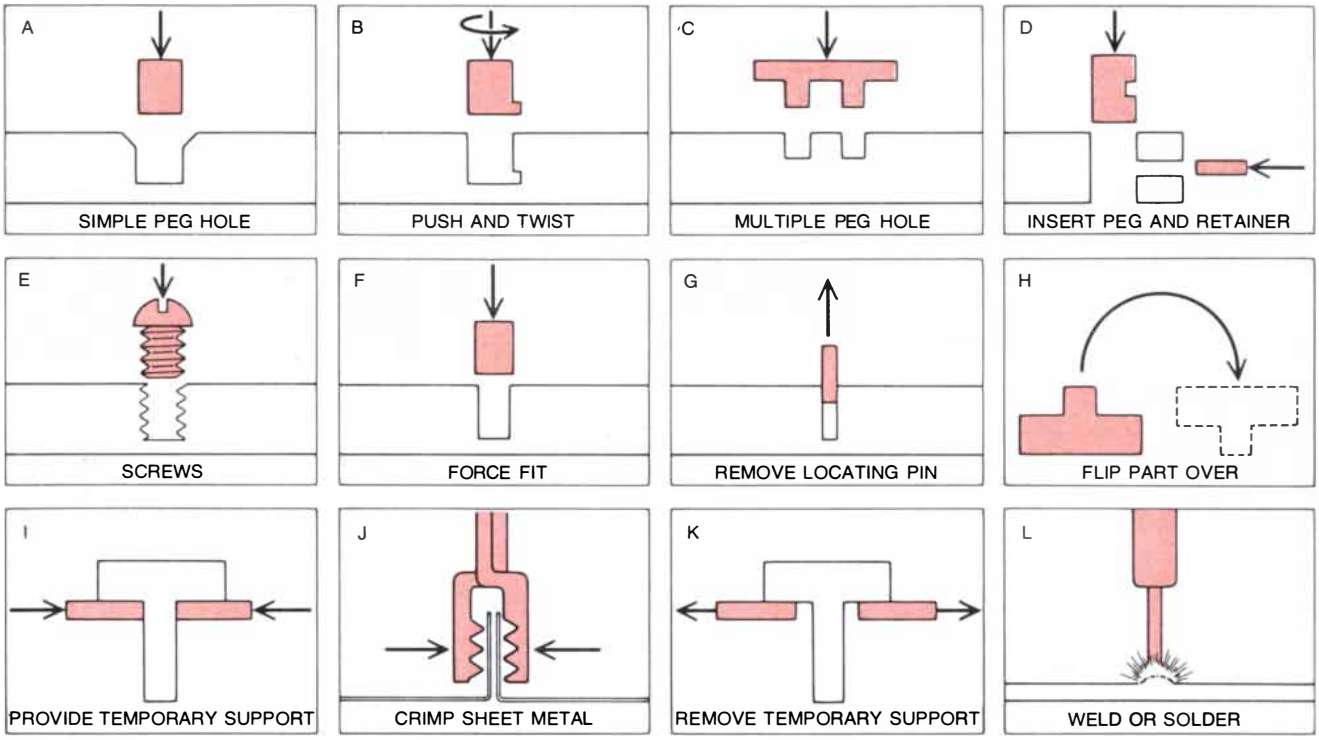
Kondoleon found that in all but one of the items he inspected about 60 percent of the parts arrived from one direction, 20 percent more arrived from a second direction opposite to the first, 10 percent arrived in a plane perpendicular to the first two planes and the remaining 10 percent arrived from various other directions. This means that the products are essentially stacks. They are made of cast, machined or molded materials and consist of a main body or frame to which parts are added. The only exception in the admittedly small sample of products Kondoleon studied was the toaster-oven, which was made of sheet metal, plastic and wires. Here no one arrival direction predominates and the interlocking wires and sheet-metal pieces make the product difficult to assemble.

Kondoleon also catalogued the various kinds of assembly tasks required for each product, their relative frequency and the directions of approach of the parts associated with those tasks. Simple peg-hole insertion tasks were not only the most frequent overall but also the most frequent along the dominant direction of approach. The installation of screws was the second most frequent task, but interestingly enough most of the screws were inserted in directions perpendicular to the dominant one. Many other tasks were identified, but none was dominant in any particular direction.

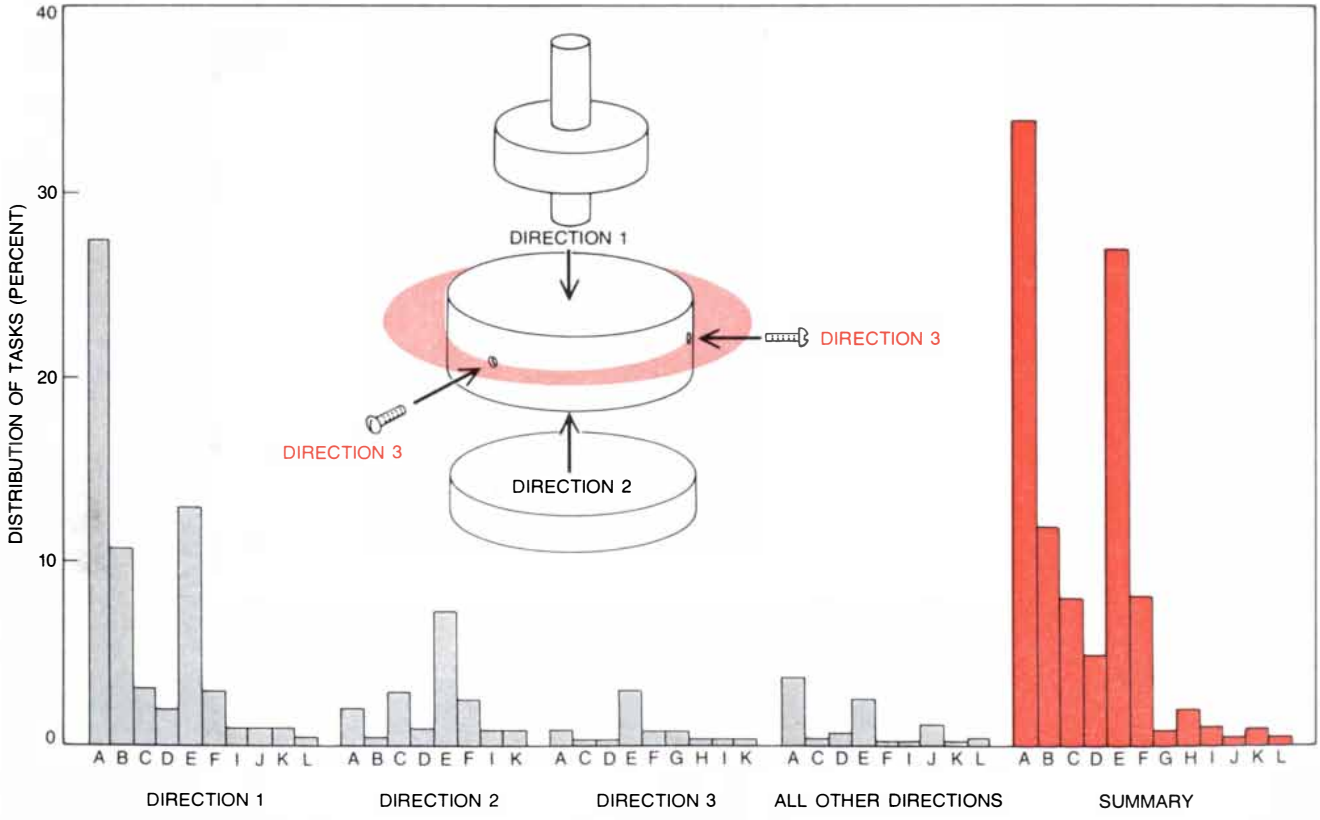
Since the dominant directions form an *xyz* right-angled coordinate system, it can be concluded that an arm with just enough joints to move along three perpendicular directions can perform all the gross motions required to move parts together for typical "stack" products. Of course, additional degrees of freedom, although they could be limited to fine motion, would still be needed to carry out the total assembly task. When this general finding is combined with the compromises in arm cost and speed indicated by the economic analysis, our conclusions are that stack products offer a promising area in which to apply programmable assembly and that arms whose gross motions follow rectangular or cylindrical coordinates would be well suited to the task.

As part of our program we have recently built and operated an adaptable programmable assembly system in our laboratory. It consists of a computer-controlled industrial assembly robot with four degrees of freedom. The wrist of the robot contains an advanced version of our passive-compliance insertion device. The system has been taught to assemble a Ford automobile alternator, using six interchangeable tools. The alternator has 17 parts, all of which can be inserted from one direction with the aid of two assembly fixtures.

The system was built in order to obtain data on adaptable programmable assembly and to test our parts-mating concepts on an actual industrial prod-



TYPICAL MANUFACTURING TASKS were identified by taking apart and reassembling a variety of products and their components, including a refrigerator compressor, an electric jigsaw, an induction electric motor, a toaster-oven, a bicycle brake and the automobile alternator used in robot assembly project. All the items could be assembled with various combinations of 12 operations depicted.



DIRECTION OF ATTACHMENT OF PARTS was analyzed in the study that classified the types of operation required. The inset diagram defines the three principal directions of attachment. Direction *1* is dominant, followed by direction *2* and direction *3*. Direction *3* is any direction perpendicular to the other two. The bar graph correlates attachment direction with type of task involved according to the identification in the illustration at the top. Simple peg-and-hole tasks (*A*) outnumber all others, followed by insertion of screws (*E*).

uct. The alternator is a good experimental subject because it is a stack product and its assembly calls for several tight-clearance peg-hole insertions and screwdriving operations. The experiment was not designed to show whether alternators should be assembled by robots: nearly two million alternators are made each year by the Ford Motor Company, indicating that a special-purpose machine would be a better choice.

The experiment has shown that the compliant wrist is an extremely valuable device. The roughness of the outer surfaces of the parts made it difficult to hold them in their feeder tracks or on the assembly fixtures in precisely known and repeatable positions and orientations. Position errors of one millimeter are typical and unavoidable. The compliance device overcomes such errors, picking up parts of various sizes, placing them on fixtures and inserting close-tolerance parts successfully to assemble a complete alternator. The flexibility of the compliance device also greatly reduces the time required for adjusting the feeders and fixtures.

The complete assembly operation takes two minutes 42 seconds. Better engineering of the tools and fixtures, together with a simple design change, could reduce the time to about one minute five seconds. The biggest saving would be in reducing the time needed for changing tools, which now takes about 30 percent of the total. One route to this end would be to assemble several alternators at once, so that the robot could carry out the same operation on several units before changing to the next tool.

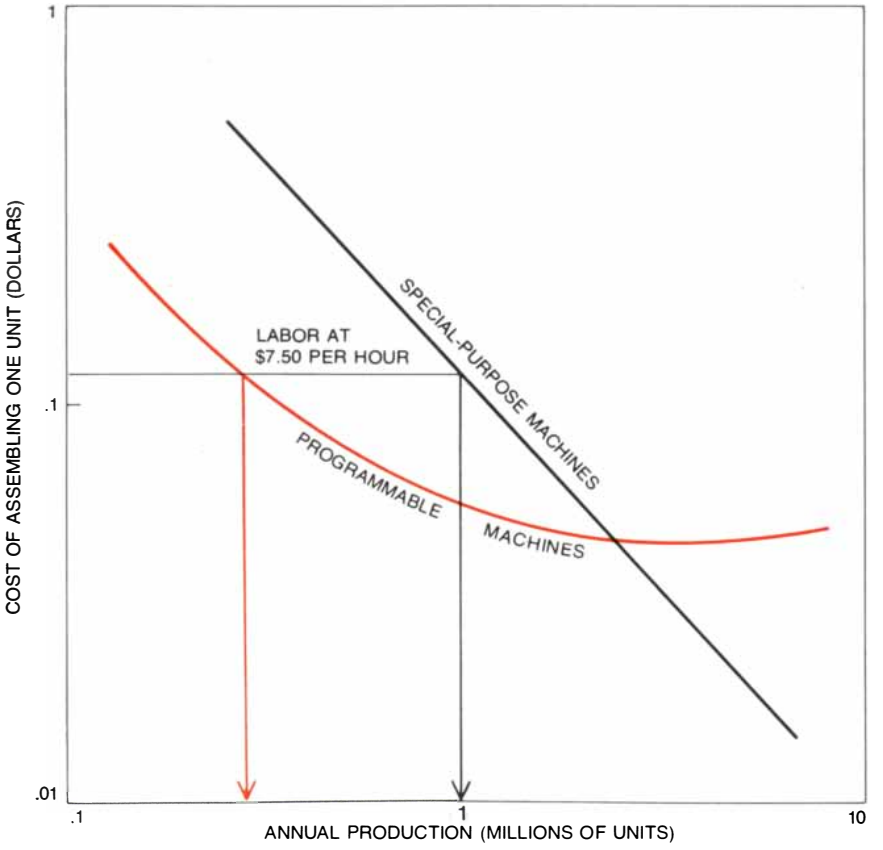
A detailed study of how the robot spends its time also revealed the relations among gross motions, fine motions and a third category: interface motions. Between gross and fine motion there is an interface region where the robot lines itself up for an insertion move before the parts have actually begun to touch. Trajectories must be executed carefully in this region, which is close to the parts. We found that the gross motions take up only 33 percent of the total time and the fine motions less than 20 percent. The rest of the time is taken up by interface motions. This fact suggests that increased assembly speed might be better sought by improving interface motions (perhaps with an independent interface-motion device) than by trying to speed up the gross motions, as many robot manufacturers are currently doing.

The experiment has demonstrated the feasibility of assembling a stack product with a robot capable of moving along four axes only. It is important to note that the alternator may represent a special case. Most stack products have some parts that arrive from eccentric directions, which means that a single four-axis robot could not assemble the entire product.

In any case our economic analysis shows that a one-arm assembly system would be satisfactory only for products of low annual volume (perhaps fewer than 50,000 units), assuming that the robot arm, like the human one, would need three to five seconds to add each part. At higher production volumes several arms would be needed. Each arm could be put to work with complete sets of parts-feeders and tools for assembling finished products. Tooling and feeding expenses would be much lower, however, if the arms were grouped into an assembly line with each of them adding a few of the parts. Then only one complete set of tools and feeders would be needed and the arms could be simpler.

For most products the designer of assembly systems has some freedom in choosing the sequence in which parts are added to the product. He can take advantage of such freedom to group tasks with similar directions and tool requirements at one station on the line and assign an arm with the appropriate number of axes to perform the tasks. Balancing the line (giving each arm about the same amount of work) is also part of the designer's aim, and achieving all these goals is not easy. Along the way the designer may discover that a few simple design changes in the product itself will make assembly easier, quicker or less expensive. Much work remains to be done in this area.

A start has been made in understanding assembly on a scientific basis. It is our hope that this work, together with other studies funded by the National Science Foundation, will find profitable application in American industry. It should also be noted that the application of our investigations is not limited to industrial assembly. People perform many tasks in hazardous or difficult environments with the aid of mechanical manipulators. Examples include conducting experiments with radioactive chemicals, inserting fuel rods into nuclear reactors, cleaning or inspecting tubes in steam boilers and exploring the sea floor for minerals or oil. The application of the knowledge and devices we have described here could make all such tasks easier to accomplish.



ECONOMIC-TECHNOLOGICAL MODEL leads to cost curves such as this one. As long as programmable general-purpose machines are not an option a manufacturer must choose between manual assembly and special-purpose machines. If labor costs $7.50 per hour, the model estimates that the break-even point for special-purpose machines is a production volume of about a million units a year, assuming a two-year period for paying back the investment. When programmable robots are sufficiently developed, they should be economically attractive for volumes as low as 300,000 units per year of one product or a group of products and should remain cheaper than special-purpose machines until the volumes approach three million units.

Now, Lois, about who will be wanting these two new photography works . . .

The key word in the one title is **theory;** in the other title it's **practical.** Both are encyclopedic, though the one on theory is all in a single 714-page volume organized not alphabetically but like the Kodak Research Laboratories, whose people wrote it.

For a sample of the kind of folks who might want that one, one might visit the photographic science department of the University of Moscow. In the department's conference room with its portraits of distinguished photographic scientists, one notes that a prominent place is occupied by portraits of S. E. Sheppard and C. E. K. Mees. To these scientists without beards the present volume owes its origin. They were both 21 in 1903 when they published their first papers. On the strength of eleven subsequent papers published as "Investigations on the Theory of the Photographic Process," they were jointly awarded the degree of Doctor of Science by University College, London in 1906. After a few years they settled in Rochester, N.Y., where Mees founded and directed the Kodak Research Laboratories.

By 1942 he felt that the Laboratories' progress with the theory, quite walled off from all that had been accomplished on the proprietary side, justified knocking off the first two words of the old title for the title of a new book. Now, with 36 more years of sophistication in chemistry, solid-state physics, and related disciplines, succeeding generations of Kodak scientists share their deepened understanding with colleagues everywhere for whom photography is more than a way to get pictures. The completely rewritten Fourth Edition of *The Theory of the Photographic Process* issues from Macmillan Publishing Company's College and Professional Division.

It is equally appropriate to have American Photographic Book Publishing Company (AMPHOTO) as our partner on the 14 volumes that will have appeared by the end of this year for people who want to keep within arm's reach relatively brief explanations of just about anything that comes up in talking photography and doing it—explanations that can be followed without anything like the background of study expected in the orals toward a doctorate. The whole comes to some 2800 pages splashed with many an exemplary photograph in color or b&w. To help judge scope, here are the topics in the first volume:

Contents
Volume 1

A
A and B Roll Editing
Abbe, Ernst
Aberration
Abney, Sir William de Wiveleslie
Acetic Acid
Acetone
Achromatic
Acid
Actinic
Action Photography
Acutance
Adams, Ansel
Additive Color Synthesis
Adurol
Advertising Agencies
Advertising Photography
Aerial Fog
Aerial Perspective
Aerial Photography
Aftertreatment
Ag
Agencies, Picture
Agitation
Airbrush
Albada, Liewe Evert Willem van
Albumen
Alcohol, Denatured
Alcohol, Ethyl
Alcohol, Isopropyl
Alcohol, Methyl
Alkali
Alkaline Salts
Alum, Chrome
Alum, Potassium
Ambrotype
Amidol
Ammonium Chloride
Ammonium Persulfate
Ammonium Thiocyanate
Ammonium Thiosulfate
Anaglyph
Anamorphic Systems
Anastigmat
Andresen, Momme
Animal and Pet Photography
Animation
Anschütz, Ottomar
ANSI
Antifoggant
Aperture
Apochromatic
Archer, Frederick Scott
Architectural Photography
Archival Processing (B & W)
Arc Lamps
Armat, Thomas
Art, Photography of
Artificial Light
ASA, ASAP Speeds
Aspheric
Astrophotography
Atmospheric Haze
Audiovisual Planning
Automatic Exposure Systems
Available-Light Photography

B
Baby and Child Photography

To help decide whether to order the whole set, photo stores and book stores have information on which topics are in the other volumes.

This is for people deeply committed to photography as a profession, an art, a business, or an engrossing hobby rather than as an interdisciplinary science.

Kodak

SCIENCE AND THE CITIZEN

Declaration

American scientists, like other citizens, tend to disagree among themselves on a wide range of public issues, but on certain subjects and at certain times they can speak virtually with one voice. The present status of the nuclear arms race has created such an occasion.

This impression is strongly conveyed by a document titled "Declaration on the Nuclear Arms Race," which has been circulating through the scientific community in recent months. The text of the declaration was prepared last August under the auspices of the Union of Concerned Scientists, a group that has played an active role in promoting public opposition to the U.S. nuclear-power program. What is unusual about the statement, however, is that it has been signed so far by (among others) some 12,000 scientists, engineers and other professionals, many of them leaders in their fields, representing a broad spectrum of opinion not only on nuclear power but also on many other controversial topics.

Where there is agreement among the diverse signers is on the "critical need" for the U.S. to "take the initiative" in halting the nuclear arms race. The declaration makes two specific recommendations toward that goal. The signers join in urging that:

"1. The United States announce that it will halt underground testing of nuclear explosives provided that the Soviet Union follows suit within a reasonable time.

"2. The United States announce that it will not field test or deploy *new* strategic nuclear weapons, nuclear weapons systems or missile defense systems for a period of 2 to 3 years provided that the Soviet Union demonstrably does likewise."

In support of the two recommendations the scientists' statement emphasizes that "these measures, carried out with due care, *do not jeopardize our security.* The recommendations do not stem from blind faith in the good intentions of the Soviet Union. We already can detect Soviet tests of nuclear weapons smaller than the Hiroshima bomb with existing seismic sensors and clearly distinguish them from earthquakes. Hence underground tests of strategic warheads cannot escape detection. Our satellites already inspect Soviet missile launches, missile-site construction and submarine arrivals and departures; thus we would know if the Soviet Union were not following our lead. Should the recommended initiatives not bear fruit, the interruption in testing would hardly degrade our security. It takes many years to develop and deploy strategic-weapons systems and our strength is such that a short delay of the sort we recommend cannot put the U.S. at risk."

The "key to a safer future" embodied in the recommended measures, the statement continues, is that they "*can restrain the technological arms race.* Without underground tests there is not enough confidence in the new warhead designs to allow deployment. New missiles also depend on more accurate guidance systems, and these can only be tried and perfected in repeated test firings. By reducing the number of missile test firings to those needed for maintenance a major hurdle to new deployments would be created."

Such moves, the signers of the statement believe, would come at a propitious moment. "We are, once again, at a turning point in the nuclear arms race. Because SALT I succeeded in placing ceilings on the number of missile launchers, it stimulated an intense race toward more accurate and powerful missiles, and more warheads per launcher, the development of new and more potent bombers and submarines to replace existing fleets. Most important, President Carter has displayed a more penetrating understanding of the dangers of the arms race than the previous leaders of the U.S. and the U.S.S.R. and has indicated a readiness to consider imaginative policies."

The reason the U.S. should take the initiative now, the statement adds, arises from the fact that "the U.S. lead in new weapons technology in the nuclear era is a reflection of our overall superiority in creating new technologies and sophisticated industries. Under these circumstances we cannot expect the U.S.S.R. to take the initiative."

In conclusion, the declaration calls on the Carter Administration "to demonstrate its dedication to arms control by initiating the unilateral, reciprocal steps we have recommended, which represent the first steps leading to gradual disarmament. These actions, if carried out by the United States, would represent a policy of restraint of the greatest political significance and yet, for an interim period, be devoid of military risk. Should the Soviet Union reciprocate—and they, like the United States, have much to gain in so doing—a great step forward would be taken to diminish the threat of nuclear war."

The 21 sponsoring signers of the Declaration on the Nuclear Arms Race were Hans A. Bethe, Mary I. Bunting, Owen Chamberlain, Bernard T. Feld, J. William Fulbright, John Kenneth Galbraith, Donald A. Glaser, Donald F. Hornig, Carl Kaysen, Henry W. Kendall, James R. Killian, Jr., George B. Kistiakowsky, Salvador E. Luria, Eugene McCarthy, J. Carson Mark, Linus Pauling, George W. Rathjens, Herbert Scoville, Jr., Albert Szent-Gyorgyi, Victor F. Weisskopf and Jerome B. Wiesner. The complete list of signers includes 27 Nobel prizewinners and some 400 members of the National Academy of Sciences.

Split Genes

A structural gene is defined as a segment of chromosomal DNA that codes for the sequence of amino acids in a single protein or polypeptide chain. Such a gene is expressed in two stages: the sequence of nucleotides in the DNA is transcribed into the complementary sequence of messenger RNA (mRNA), which is in turn translated into the specific sequence of amino acids. It has been known for some time that many structural genes, together with the regulatory genes that control their expression, are separated from one another along the chromosome by segments of DNA called "spacers," which are not transcribed into mRNA. Now a group of French investigators has discovered that segments of untranscribed DNA may also be inserted into structural genes, disrupting the linear continuity of the coding sequence. Remarkably, the complementary mRNA strand transcribed from such a "split" gene has the continuous coding sequence for the protein, meaning that the inserts have been somehow omitted in the transcription. These surprising findings have raised new questions about the arrangement of genes along the chromosomes of eukaryotic cells (cells that have a nucleus, including the cells of all higher organisms) and how they are transcribed into mRNA.

Writing in *Nature,* R. Breathnach, J. L. Mandel and P. Chambon of the Faculty of Medicine at Strasbourg describe how they inadvertently discovered the untranscribed inserts within the structural gene of chickens that codes for ovalbumin, one of the principal proteins of egg white. The finding arose from a discrepancy between the structure of the ovalbumin gene prepared by one method and the structure of the same gene prepared by another method. There is only one copy of the ovalbumin gene in the entire gene complement of chicken DNA, so that in order to obtain enough of the gene for analysis it must be mass-produced.

One method is to synthesize the ovalbumin structural gene in the test tube from a template of purified ovalbumin

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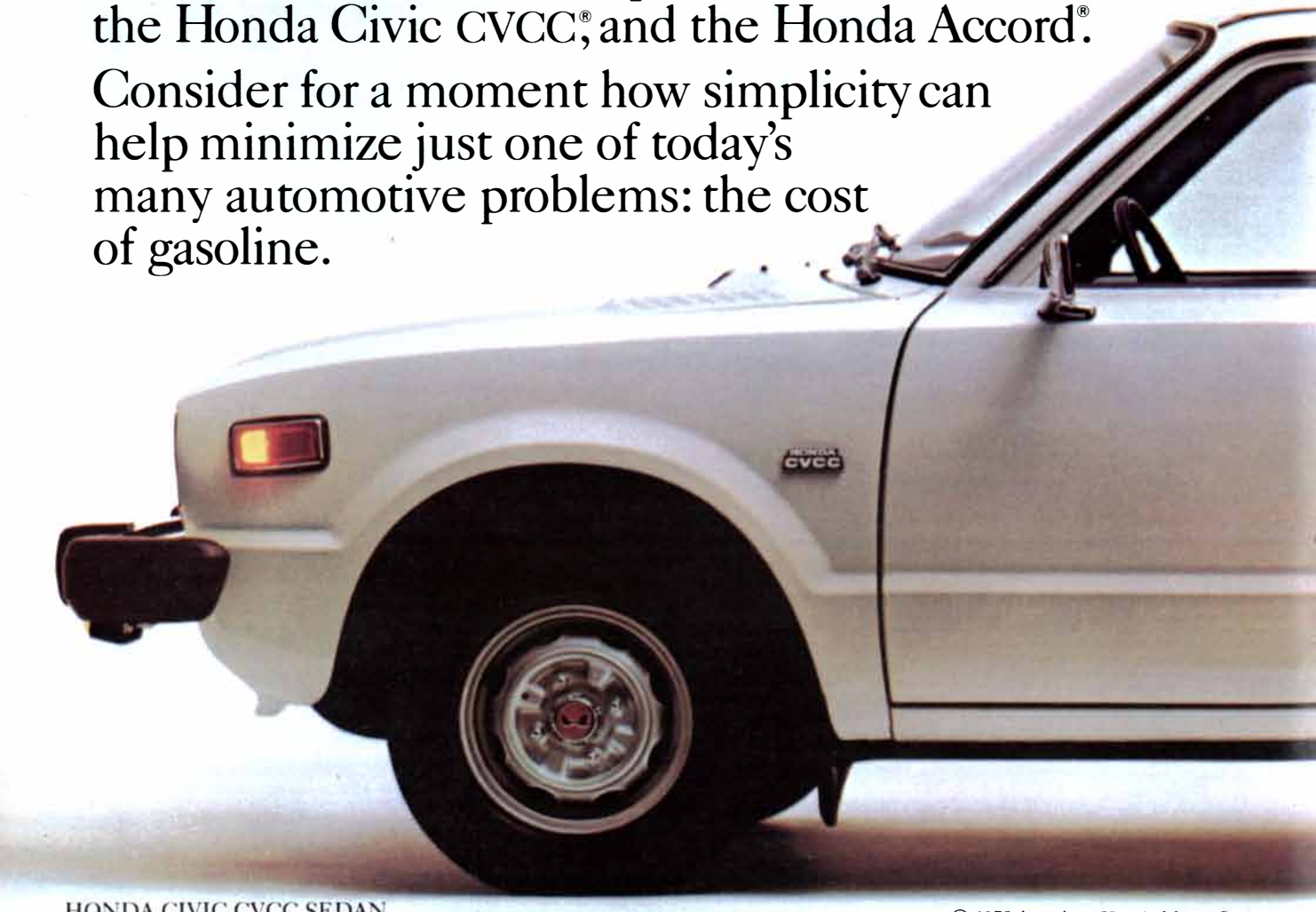

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mRNA. In the tubular-gland cells in the oviduct of a laying hen 40 percent of the mRNA manufactured by the cell is transcribed from the single ovalbumin gene. As a result the ovalbumin mRNA is plentiful and can be easily purified. A DNA copy of the purified mRNA can be made in the test tube by means of the viral enzyme reverse transcriptase. The copies of the synthetic gene obtained by this method therefore represent only those parts of the original gene that were transcribed into mRNA.

The alternative method for producing large quantities of the ovalbumin structural gene is to isolate the segment of the chromosome incorporating the gene from chicken cells and insert it into a bacterial plasmid: a ring of DNA separate from the bacterial chromosome. The plasmid is then taken up by bacterial cells, and the foreign gene is replicated many times over by the bacteria's own synthetic machinery.

Chambon and his colleagues prepared the ovalbumin DNA by both of these methods, assuming that the resulting genes would be identical in structure. But when they exposed the ovalbumin gene made in the test tube and the ovalbumin gene made by bacteria to certain restriction enzymes, which recognize specific nucleotide sequences on the DNA and cleave the DNA chain at those sites, they got strikingly different results. The test-tube ovalbumin gene was not cleaved by the restriction enzymes, since it did not contain the correct recognition sequences. The ovalbumin gene replicated in bacteria, on the other hand, was cut into several pieces by the enzymes. The investigators concluded that the original ovalbumin gene in the chicken chromosome incorporated nontranscribed inserts of DNA containing recognition sequences for the restriction enzymes. Because the inserts were not transcribed into mRNA, however, they did not appear in the test-tube ovalbumin gene made from the mRNA template. The inserts in the ovalbumin gene are quite extensive: one of them is at least 7,000 nucleotides long.

At about the same time that Chambon and his colleagues made their finding other laboratories were obtaining similar results. An insert 93 nucleotides long was found in the gene coding for the variable region of the antibody molecule in the mouse, and longer inserts were discovered in the gene coding for the beta chain of the hemoglobin molecule in both mice and rabbits. "It seems, therefore," the French investigators write, "that the splitting of genes within the protein-coding sequence may have some generality in eukaryotic cells." Although the function of the DNA inserts is not known, it is conceivable that they perform some regulatory function, perhaps one related to the conformation of proteins in the chromosome during the process of transcription.

Chambon and his colleagues have proposed three different mechanisms by which a split gene could be transcribed to yield a single continuous strand of mRNA. The first possibility is that the inserts "loop out" from the rest of the chromosomal DNA in such a way that the enzyme RNA polymerase, which synthesizes the complementary mRNA strand, can "jump across" the looped-out inserts and transcribe the structural-gene regions sequentially. The second possibility is that the entire DNA sequence, including the inserts, is transcribed, after which the inserts are cut out of the mRNA by special enzymes and the segments of the mRNA corresponding to the structural gene are joined together by another enzyme called a ligase. The third possibility is that the various portions of the ovalbumin mRNA are transcribed independently and are joined at a later processing stage. In that case the inserts might or might not be transcribed. Moreover, the segments of the structural gene would not have to be in the "correct" order along the chromosome, because the mRNA transcripts could be rearranged before being joined together by the ligase.

In any case the discovery of the split-gene type of organization in eukaryotic chromosomes may present new problems for studying the molecular genetics of higher organisms in the test tube with recombinant-DNA techniques. Because it is unlikely that bacterial cells possess the specialized enzymatic machinery that would apparently be required for the transcription of split genes into continuous mRNA's, it may prove extremely difficult to insert an entire eukaryotic gene and its regulatory elements into a bacterial plasmid and then study its expression. Progress in this field may therefore have to be based on the linking of known bacterial regulatory elements to synthetic eukaryotic genes incorporating the continuous protein-coding sequence.

Philadelphia Story

At the end of July, 1976, there was an explosive outbreak in Pennsylvania of a severe pneumonialike disease of unknown origin. In less than a month 182 cases had been reported; 147 patients were hospitalized and 29 died. Most of the victims had just attended a state American Legion convention in Philadelphia, and so the illness was quickly dubbed "Legionnaires' disease." The sudden and mysterious epidemic attracted widespread coverage by news media and immediately became the subject of investigation by local and state health departments and teams from the

Center for Disease Control of the U.S. Public Health Service. The symptoms and tissue pathology seemed to be those of a bacterial pneumonia, but no bacteria could be detected in diseased lungs or cultured from lung tissue. The epidemic's association with a convention and with a particular hotel led to speculation that the cause might be food or water poisoning or the spread of a toxic gas or heavy metal by the air-conditioning system. Some of the speculation was fed by prematurely publicized laboratory reports.

Now the first full investigative reports on the epidemic and its cause have been published in *The New England Journal of Medicine,* recording what an editorial by Edward H. Kass of the Harvard Medical School calls "a brilliant example of scientific achievement." The agent was indeed a bacterium, which has been cultured, visualized in lung samples and shown by serological tests to have been responsible for Legionnaires' disease and some similar outbreaks. The organism has yet to be precisely identified, however; its source, how it spreads and why it struck virulently at a particular place and time are still not known.

One report, by David W. Fraser and a large group of colleagues at the Center for Disease Control, describes the course of the epidemic and the results of exhaustive epidemiologic surveys designed to establish the time, place and nature of exposure to the causative agent. The investigators tracked down the 182 cases of what they defined as Legionnaires' disease (a disease that fit the clinical description in a person who had attended the convention between July 21 and 24 or who had for other reasons entered the hotel after July 1) and also 39 cases of what they called "Broad Street pneumonia" (the same clinical conditions in a person who was not at the convention or in the hotel but had been within a block of the hotel after July 1).

The shape of the epidemic curve, with a rapid upswing and an incubation period of from two to 10 days, suggested a continuing common-source exposure. There was no evidence of person-to-person spread; for example, there was no clustering of cases among roommates and patients' families were not infected. The primary site of exposure was apparently within and in the immediate vicinity of the convention hotel. More specifically, there was a strong correlation between time spent in the hotel lobby and the incidence of the disease. (The fact that hotel employees seemed not to have been affected was puzzling, but an explanation was to emerge later.) There was no such correlation for attendance at particular convention functions or presence in a particular hotel room. The disease agent seemed not to have been

Ansel Adams made the image, "Cherubs, Mission San Xavier del Bac." It was exhibited at an Adams retrospective at New York's Light Gallery. Adams used the finest instant photographic system available: Polaroid's® SX-70® Land camera, the world's only folding single-lens reflex camera, and SX-70 film. This system is used by millions of photographers everywhere. With its unique metallized dyes, SX-70 film has the qualities important to photographers: vivid colors, sharp detail and permanence. Polaroid instant photography, selected by Ansel Adams for the expression of his art.

This Polaroid SX-70 photograph by Ansel Adams was exhibited at a major New York gallery.

associated with any food or drink, including the hotel water. The agent was therefore almost surely airborne.

In a companion paper Joseph E. McDade and his colleagues at the Center for Disease Control present the laboratory results. Careful comparison of tissues from patients and controls failed to show the presence of any unusual substances or levels of toxins that could explain the disease. The first microbiological studies showed various organisms in lung tissues but no consistent pattern. Electron micrographs of lung tissue did reveal thin-walled bacteria, but they could not be stained by fluorescent antibodies to any of 13 known agents. It was not until early last year that the agent was finally isolated by infecting guinea pigs with lung specimens from three patients with Legionnaires' disease and one patient with Broad Street pneumonia. The guinea pigs died. Tissue from the animals was injected into embryonated eggs; the embryos died. A stain was found that revealed rod-shaped bacteria (bacilli) in the yolk sac of the embryos. Eventually the same organism was isolated directly from patients' lung tissue; fluorescent-antibody tests showed that the blood serum of convalescing patients contained antibody to the organism.

Meanwhile strong evidence that the isolated bacterium was responsible for the disease had been obtained by testing the yolk-sac material with blood serum from a large number of patients by the indirect fluorescent-antibody technique. The yolk-sac material was incubated with serum samples. Any antibody to the organism that was present in a patient's serum became fixed to the yolk-sac material and was then stained by fluorescent rabbit antibody to human immunoglobulin. In most cases serum that had been taken at different stages of the disease showed an increase in the level of the specific antibody (seroconversion); in others (where there was either only one serum sample or no change) the antibody level was very high (a seropositive result). Stored serum from several earlier outbreaks of unexplained, clinically similar diseases showed similar results, thus defining the outbreaks as Legionnaires' disease. Tests of serum from long-term hotel employees showed a high level of antibody, suggesting that the employees had become immune to the organism as the result of intermittent exposure over a period of years.

Even after the organism had been isolated it remained impossible to demonstrate its presence visually in the lung tissue of patients through the application of conventional stains. Finally, according to a report by Francis W. Chandler, Martin D. Hicklin and John A. Blackmon of the Center for Disease Control, staining with the Dieterle silver-impregnation method was found to reveal the small, blunt bacilli, thereby providing a diagnostic tool for any future outbreak of the disease.

Jets

When two marbles collide head on at the same speed, they do not simply stop, even though their total momentum is zero; instead they rebound along back-to-back paths. A similar kind of "hard scattering" provides a high-resolution image of the inner structure of the proton and of the many related subatomic particles known as hadrons. When hadrons appear among the debris of head-on collisions between particles, they are often emitted in well-defined beams, or jets, that radiate from the point of collision. The formation of jets suggests that protons and other hadrons are made up of smaller particles, which have the properties expected of the hypothetical entities called quarks.

Jets were first observed in collisions between electrons and antielectrons (positrons). Electrons and positrons are not hadrons and they are not made up of quarks, but when an electron and a positron annihilate each other, hadrons can be formed from the energy liberated. The hadrons are often emitted at a large angle to the axis of the colliding beams; indeed, the most favored angle is perpendicular to the beams. When several hadrons are emitted, there is a high probability that most of them will be detected in two narrow jets (or occasionally more than two).

These observations can readily be explained in the quark theory. When hadrons are created by the annihilation of an electron and a positron, the initial products are thought to be a single quark and a single antiquark, which fly apart with equal but opposite momentum. Through subsequent interactions both the quark and the antiquark can give rise to a large set of hadrons, but the momentum of the original pair must be conserved. Hence all the hadrons that are daughter particles of the quark or the antiquark follow approximately the same trajectory.

Jets have also been observed in the aftermath of collisions between protons, notably in experiments conducted with the intersecting storage rings of the European Organization for Nuclear Research (CERN) in Geneva. Collisions between hadrons are more complicated than those between electrons and positrons because the colliding particles themselves have an internal structure. One consequence of the complication is that the jets are not always arrayed back to back around the point of collision. Such asymmetry can be explained by assuming that the quarks are in motion within the hadron, so that a given quark would not be expected to have the same net velocity as the proton as a whole. If the event could be observed in the frame of reference of the colliding quarks, then the jets of particles would appear to be back to back.

Quarks have not been seen in isolation, and it does not seem possible to extract a quark from a hadron. The formation of jets is therefore one of the few phenomena in which the properties of an individual quark are exhibited. From the angular distribution of the jets the intrinsic spin angular momentum of the quarks can be deduced; it appears to be 1/2 unit. From the charges of the daughter hadrons the quark charges can be estimated. In proton-proton collisions the hadrons observed in jets have a large excess of positively charged particles. Protons are thought to be composed of two positively charged quarks and one negatively charged quark, so that the observed charge distribution could reflect the higher probability of collisions between positively charged quarks.

Chinese Fireworks

At 3:00 P.M. on March 8, 1976, a ball of fire brighter than the full moon flashed across the sky of China. It was one of the largest—possibly even the largest of all—meteorite falls ever witnessed by man. The body entering the earth's atmosphere traveled 400 kilometers and broke into pieces that fell to the ground in the northern part of the province of Kirin. Within three days the Joint Investigation Group of the Kirin Meteorite Shower had been formed by the Kweiyang Institute of Geochemistry, the Institute of Geology, the Institute of Mechanics, the Purple Mountain Observatory of the Academia Sinica, the Peking Planetarium and Peking University and had begun conducting a two-month on-the-spot investigation. The results of the investigation were published in *Scientia Sinica,* an English-language journal of Chinese science published by the Academia Sinica in Peking.

The Kirin meteorite fall had been seen by thousands of people along its path. The Joint Investigation Group began its work by interviewing some 1,000 eyewitnesses, taking fixes on the meteorites' landing sites, excavating for fragments buried in the ground, reconstructing the fall's history and analyzing the fragments for their chemical composition. "The firsthand observational data given by the broad cadres and masses provided the group with rich and accurate research information," reported the Joint Investigation Group. According to eyewitness accounts, the main fireball was twice as large as the apparent disk of the sun, reddish white in color and rimmed with blue. It gave off dazzling rays, a brilliant trail of light and whirling clouds of smoke and dust. Over the Chinchu People's Commune on the outskirts of the city of Kirin the fireball exploded with a violent thunderclap, and

DP Dialogue

Notes and observations from IBM that may prove of interest to the engineering community

Steel from the basic oxygen furnace at Ford is poured into ingot molds. An IBM 5937 Industrial Terminal helps the furnace operators control the amount of costly alloying materials they add during the heat.

Terminal Stands the Heat at Ford Steel

Computer equipment has now moved right up to the mouth of the fiery furnace. At River Rouge, Ford Motor Company's sprawling complex of industrial plants in Dearborn, Michigan, IBM 5937 Industrial Terminals adjacent to two huge steelmaking units — a basic oxygen furnace and an electric furnace — guide operators in the crucial step of measuring alloying ingredients into the molten metal. Because the 5937 is tolerant of extreme heat, vibration and corrosive atmosphere, it can be installed where no ordinary computer terminal would work for long.

Ford Steel Division makes and processes over 10,000 tons of steel a day. In its completely integrated River Rouge facility, the division smelts ore and performs a wide variety of steel-making and finishing operations. An online computer tracks every slab of steel from the furnace right up to shipment to the customer, using data acquired through sensors in the processing machinery.

Closing the Loop

The two IBM 5937 Industrial Terminals close the loop from the metallurgical laboratory back to the furnace operators. The loop begins at the furnace, where a small sample of the molten steel is drawn and sent to the laboratory — in another building—through a pneumatic-tube delivery system. The lab promptly analyzes the sample, and the results pass automatically from the analytical instruments to the IBM System/370 Model 148.

"When the operator is ready to add alloying ingredients," explains Earl O'Shaughnessy, general superintendent of basic oxygen furnace melting operations, "the computer flashes a chemical analysis to him that shows just how much of each additive to use."

It is this analysis that tells the furnace operator how much manganese, aluminum, carbon, silicon or other alloying material must be added to make the type of steel required of each melt.

"Before we had the 5937 terminals, the operators had to walk to a typewriter terminal in a protected environment some distance away to see the analysis," O'Shaughnessy says. "Or, if time was short, they simply added excessive amounts of these costly materials, to make sure the specifications were met.

"Putting a rugged terminal like the 5937 right out on the floor with the operators has meant significant direct dollar savings in steelmaking costs."

CADAM®: Interactive Graphics for Design Engineers

Producing a modern aircraft can require more mechanical drawings than rivets.

Traditionally, engineers sketch, then draftsmen draft. Then engineers discover needed changes or improvements, and draftsmen draft some more. A lot more. Move a stiffener or bracket, say, two inches to the left, and a chain reaction of changes riffles through the entire set of drawings.

But now the computer has opened up a new way to meet design engineering needs with speed and reliability for a broad range of products, from high-performance aircraft to complex integrated circuits. Computer-Graphics Augmented Design and Manufacturing (CADAM), a set of interactive programs available from IBM, allows the designer to sketch directly on the screen of a graphic terminal. He defines lines and contours by pressing keys and positioning a light pen, and the computer displays what he has expressed.

Curve fitting, or reducing the design to a set of control equations, is completed iteratively at the terminal, eliminating coding, card punching, and repeated computer batch runs. Then CADAM converts the preliminary design to a dimensioned drawing with auxiliary views.

If something needs fixing — if, for example, the dimensioned drawing reveals a problem of component or subassembly compatibility — the pieces can be moved around with the light pen and CADAM will revise all of the affected drawings. And do it automatically.

CADAM encourages doodling, an important source of design inspiration. The user can translate or rotate any graphic element. Or change its scale. Or stack parts, separate them, or watch moving parts move.

CADAM stores the design as it is developed, displays any element on demand, then generates the final detailed drawings. It supports complete design of the part, including structural members and such elements as ribs, stiffeners, lightening holes and fasteners. Once a design is stored in the system, CADAM analysis programs can calculate its weight or determine its structural properties. Any frequently used design element or drawing symbol can be stored and reproduced automatically wherever it is needed.

As its name implies, CADAM includes a direct link to manufacturing. It can generate a "part program" (path of travel) for the cutter of an automatic machine tool.

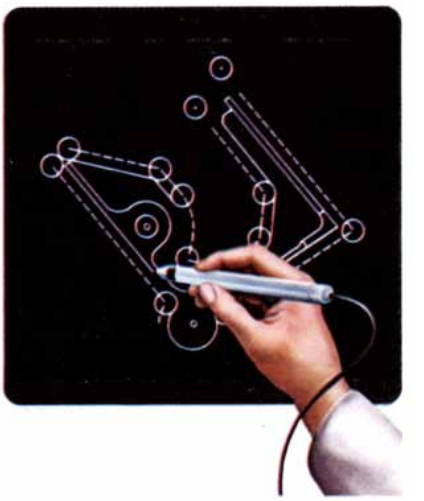
CADAM has cut drafting manhours drastically for engineering departments — by as much as 90 percent or more on a few special tasks. It helps prevent and correct errors and improves the quality of the engineering product. One user's experience is described below.

Productivity Up

Northrop Corporation is one of the world's largest manufacturers of high performance jet aircraft. Today, Northrop engineers design complex aircraft parts with CADAM in a fraction of the time once spent at drafting boards.

® CADAM is a trademark of Lockheed—California Corp.

Engineers at Northrop Corp. use computer graphics to speed the structural design of high-performance jet aircraft.



CADAM converts freehand sketches, made directly on the CRT screen with a light pen, into fully defined and dimensioned graphics.

Says Northrop's Aaron Feder: "In addition to the time savings, we can identify improvements in design quality. Because changes are so easy to make at a CADAM terminal, we can keep up with changes traditionally required during the design development of an aircraft part and still release the drawing on time." Feder is manager of technical computer graphics at Northrop's Aircraft Division in Hawthorne, California.

"Before installing CADAM," Feder points out, "we ran a number of carefully controlled tests. When we saw productivity gains ranging from four to one to as high as 17 to one, for changes to a drawing, we saw the potential for CADAM and decided to adopt it.

"We compared the manhours required to prepare several types of drawings using CADAM with the time requirements using our established manual systems.

"This involved a broad sampling of different types of drawings, including layouts, structural and electrical drawings. We saw productivity gains of four to one or better on every one of 14 test problems. Even though productivity is lower in the hectic, day-to-day development design world, CADAM has still proven cost-effective.

"Once a tentative design is in the computer," Feder adds, "we can run CADAM engineering analyses: calculating weights and determining the capabilities of the design aircraft and the dynamic behavior of its structure.

"The data required for this kind of analysis is already in our System/370 as a byproduct of the graphic design effort. That means another major savings in manhours, the elimination of a significant source of error, and the assurance that all departments are working from the same data."

Fast Answers to Tough Energy Questions

"Suppose the government made major changes in national energy policy," speculates Prof. John J. Donovan of MIT. "What would be the economic impact on each region of the U.S.? How would the economy change if the fuel supply were to be altered? If prices were to change? What effective actions can be taken by homeowners, industry and public policymakers?"

To help provide prompt answers to such questions, the Generalized Management Information System (GMIS) was jointly developed by IBM, MIT Sloan School of Management and the MIT Energy Laboratory. IBM provided staff support and the use of a System/370 Model 158 at its Cambridge Scientific Center. GMIS has been used to analyze conservation strategy in, for example, the consumption of energy for residential heating across the United States. And it has been used to produce programs and a data base for energy policy analysis in New England. Called the New England Energy Management Information System (NEEMIS), this application was developed through a collaborative effort among MIT, the New England Regional Commission (a Federal-New England states partnership) and IBM.

What can the homeowner do? According to Donovan, an associate professor at the Sloan School: "An econometric model shows that, for a homeowner in the Northeast or upper Midwest, a thermostat setting of 65 degrees (daytime) and 55 at night—or 63 around the clock—will save 15 percent of his energy costs.

"Other computer models produced using GMIS suggest measures for commercial buildings. For some institutions in the Boston area, these models identified ways to reduce energy costs by 40 percent (of which 20 percent required no capital improvements).

"To answer questions like these," he continues, "the Energy Laboratory has collected data and computer programs from government research, professional and technical groups, and university research efforts. A user can scan the data base interactively to locate and define the needed data and select a suitable modeling system.

Most homeowners today want to keep warm without wasting energy. At MIT, computer simulation has shown that a 24-hour thermostat setting of 63 degrees saves as much fuel as a night setting of 55 degrees.

"GMIS is a universal bridge to this diverse collection of data: Whatever type of analysis is to be used—a simulation or a regression analysis, for instance—GMIS provides the interface between the required language and the data."

Users with terminals in their offices are now working out solutions interactively. Using programs created under GMIS, engineers in the government of the state of Maine are conducting studies to determine the best use of the money available for energy conservation.

GMIS data has helped the New England region avert a proposed oil tariff by demonstrating its negative economic effects there.

"Sound public and private policymaking and resource management require prompt, accurate information on many such issues," Donovan says. "GMIS is designed expressly as a tool to provide that information."

FORTRAN and Logic Programming Aids

Three program products available from IBM simplify the programming of engineering and scientific applications:

1. FORTRAN Interactive Conversion Aid facilitates the conversion of non-System/370 FORTRAN dialects into System/370 FORTRAN IV executable source code.

2. APL Decision Table Processor (DTABL) converts a decision table (a powerful method of notation for complex logic) into an executable program.

3. FORTRAN Interactive Subroutine Library (FISLIB) makes FORTRAN a truly interactive tool for any application that requires human judgment during the course of the program.

For more information on these and other IBM program products, contact your local IBM branch office or write to the Editor of DP Dialogue at the address on the right.

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**Survey conducted among owners of new cars bought in May, 1977.*

VOLVO. A CAR YOU CAN BELIEVE IN.

three smaller fireballs continued traveling toward the southwest in procession.

The largest of the three smaller fireballs, later named Meteorite No. 1, fell in the village of the No. 10 production team of the Kaoshan Production Brigade of the Huapichang People's Commune, 65 meters from the nearest house and only 30 meters from three commune members and three children. The six witnesses reported that they heard what sounded like a sonic boom, and a grayish mass "like a huge jar" hit the ground with "an appalling roar." The shock wave from the impact shattered windows, caused clay to fall from ceilings and pushed open unlatched doors. The main body of the meteorite excavated a slightly elliptical crater some two meters across, drilling its way six meters into the ground and scattering lumps of frozen soil and meteorite fragments as far as 150 meters. A dense cloud of yellow dust and smoke rose from the crater to a height of 50 meters, forming a small mushroom cloud.

The Joint Investigation Group reported: "Under the unified leadership of the Kirin Municipal Party Committee, the workers from electrical industry, communication and transportation and construction departments, and local poor and lower-middle peasants, dug the crater of Meteorite No. 1." The total weight of the pieces collected in the crater was 1,770 kilograms; the main specimen was almost a cubic meter in volume and weighed 1,170 kilograms. Over the next few months additional fragments of the shower were gathered from an elliptical area 72 kilometers long and 8.5 kilometers wide; the total weight of the fragments recovered was about four metric tons.

Analysis of the path of the meteorite shower indicates that it stemmed from one large meteorite that overtook the earth from behind in the direction of the earth's revolution around the sun. The velocity of the meteorite with respect to the velocity of the earth was about 10 kilometers per second. The object plunged into the atmosphere from the east at a shallow angle. Friction with the air soon heated it to incandescence (some 10,000 degrees Celsius) and slowed its fall. The resulting thermal and compressional stresses broke the body apart some 17 kilometers above the Chinchu People's Commune, creating the three smaller fireballs and a series of rolling, thunderlike echoes lasting four to five minutes that were audible to perhaps a million people over an area of 200 square kilometers. By the time the fragments struck the ground they had been slowed to less than 300 meters per second and had cooled to between 50 and 80 degrees C. Chemical analysis of the fragments revealed that the Kirin object was a stony meteorite; specifically it was an olivine-bronzite chondrite. The largest specimen of Meteorite No. 1 is the largest stony meteorite known.

R_{317} Is Prime

An area of particular importance in number theory, the branch of mathematics concerned with the properties of integers, is the analysis of prime numbers: any number that can be exactly divided only by itself and 1. Although primes have been studied since the time of Euclid, there is still no efficient way to recognize and prove that a large number is prime. Of course, dividing the number by all smaller prime numbers will show whether or not it is prime, but even with today's fast computers that procedure is prohibitively time-consuming for large numbers. Therefore it is of special interest that Hugh C. Williams of the University of Manitoba has discovered a new prime number. The number is 11,111,111,111,111,111,-111,111,111,111,111,111,111,111,111,-111,111,111,111,111,111,111,111,111,-111,111,111,111,111,111,111,111,111,-111,111,111,111,111,111,111,111,111,-111,111,111,111,111,111,111,111,111,-111,111,111,111,111,111,111,111,111,-111,111,111,111,111,111,111,111,111,-111,111,111,111,111,111,111,111,111,-111,111,111,111,111,111,111,111,111,-111,111,111,111,111,111,111,111,111,-111. It is called R_{317} for short.

The new prime is a member of an elite group of numbers; it is a rep-unit number, that is, all its digits are 1. Each rep-unit number, R_n, is equal to $10^n - 1$ divided by 9, and so n is the number of 1's in R_n. For example, R_1 is equal to 1, R_2 is equal to 11 and so on. It is easy to see that if R_n is prime, then n is equal to a prime number, p. (If a divides n, then R_a will divide R_n exactly.) R_p is not, however, necessarily prime. In fact, until Williams discovered R_{317} last year there were only three known rep-unit primes: R_2, R_{19} and R_{23}. Almost 50 years had elapsed since the last discovery of a rep-unit prime.

Williams did not set out to find the fourth rep-unit prime but gave a computer problem to Eric Seah, an undergraduate student. Seah was to run a pseudoprimality test on all the R_p's for which p is less than 1,000. The test, based on the work of the 17th-century mathematician Pierre de Fermat, consists in looking at the expression $13^{R_p - 1}$ to see whether it is equal to 1 modulo R_p, that is, whether the remainder is 1 when $13^{R_p - 1}$ is divided by R_p. The procedure is called a pseudoprimality test because if an integer fails the test (if the remainder is not 1), then the integer is definitely not prime, but if the integer passes the test (if the remainder is 1), then the integer is probably prime.

It seemed that nothing new could be expected from Seah's testing of the R_p's because they had all been tested before.

John D. Brillhart of the University of Arizona and John L. Selfridge of Northern Illinois University had tested all the rep-unit numbers from R_1 to R_{358} and had determined that all except the three known primes were composite numbers. Other mathematicians had extended the list past $R_{1,000}$.

Seah began with a preliminary sift of the R_p's, dividing each one by every prime smaller than 1,000 and discarding those R_p's that divided exactly. Next he ran the pseudoprimality test on the remaining R_p's. Surprisingly, four rep-unit numbers passed the test: R_2, R_{19}, R_{23} and R_{317}. Seah's results convinced Williams that R_{317} was indeed prime. "If a number passes one pseudoprimality test," he said, "in your heart you know it is prime." Even so, Williams retested R_{317} for pseudoprimality with three different computer programs and 50 variations of the pseudoprimality test. Each time R_{317} turned out to be a pseudoprime. "The real problem," Williams said, "was to prove that it was prime."

It is extremely difficult to prove that such a large number is prime. Williams chose to prove that R_{317} is prime by finding several factors for the number $R_{317} - 1$. The discovery of each factor of $R_{317} - 1$ places strong restrictions on the possible factors of R_{317}. Therefore if R_{317} is prime, when a sufficient number of factors have been found for $R_{317} - 1$, no possible factors remain for R_{317} (except, of course, itself and 1). Williams was unable to factor $R_{317} - 1$ sufficiently, and so he sent the problem to Brillhart and also to D. H. Lehmer of the University of California at Berkeley, who had access to the powerful computer ILLIAC IV. Brillhart responded first, saying that Samuel S. Wagstaff of the University of Illinois had discovered a large divisor of $10^{79} + 1$, one of Williams' remaining composite factors. Two weeks later Williams received a letter from Lehmer, who had computed the same divisor. With this new information Williams completed the proof that R_{317} is prime.

Williams asserts that his discovery of R_{317} involved "a lot of luck." Primality testing is difficult because at present all primality-testing algorithms involve factoring numbers, which is very hard to do in a reasonable amount of time. On the other hand, recent developments in the techniques of factorization and primality testing are bringing larger numbers within the scope of modern computers. The discovery of R_{317} provides no information about the existence of other rep-unit primes, but there is no reason to believe there are not more of them. The mistake in the work of Brillhart and Selfridge was probably the result of human error in typing rep-unit numbers, but assuming that the rest of the pseudoprimality testing that has been done is valid, the next candidate for a rep-unit prime is $R_{1,031}$.

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A couple of years ago, calculators took a step forward. Programmability transformed the slick slide-rule calculator into an advance scientific machine.

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The check symbol for ⊟, for example, is F. So if, as you step through the program, the display shows

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puts machine into 'learn' mode. **the correct step**

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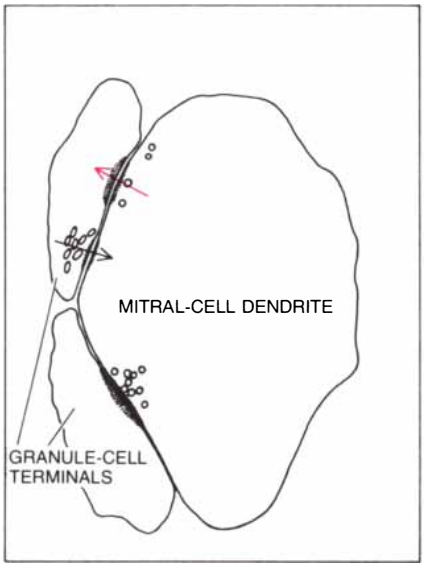
Microcircuits in the Nervous System

Nerve circuits are usually analyzed in terms of the axon, the long fiber of the nerve cell. It now appears that there are many circuits involving only the nerve cell's shorter extensions, the dendrites

by Gordon M. Shepherd

For nearly a century the investigation of the physiological basis of behavior has been dominated by the concept that the nervous system is composed of centers and pathways. Within the centers groups of neurons, or nerve cells, subserve specific functions such as the processing of sensory information and the control of movement. Some of these cells give rise to single long, thin fibers called axons, which transmit information from one center to another in the form of electrochemical impulses. Behavior therefore involves the continual transmission of impulses in the axons of different pathways.



SIMPLEST MICROCIRCUIT in the brain is the reciprocal synapse, a specialized junction between two nerve cells that transmits both excitatory and inhibitory signals. The electron micrograph on the opposite page, made by Joseph L. Price in the laboratory of T. P. S. Powell of the University of Oxford, shows reciprocal synapses between two types of nerve cells (mitral cells and granule cells) in the olfactory bulb of the rat. The large oval structure at the center of the micrograph is an extension of the mitral cell, seen in section; at the left are two terminals of the granule cell. The reciprocal synapse (*top left*) consists of two synaptic contacts that are side by side. The paired synapses have opposite polarities, that is, they conduct information in opposite directions. Moreover, one is excitatory (*colored arrow on map*) and the other is inhibitory (*black arrow*). The junction functions as an inhibitory feedback loop. The magnification is 77,500 diameters.

This traditional view has naturally focused attention on the nerve impulse and the axon. Neurophysiologists have elucidated how the nerve impulse is generated and neuroanatomists have traced the trajectories of the axons. Such investigations have been brilliant chapters in the development of neuroscience. Yet they have left unanswered a central question: What controls the activity in the axons? The answer appears to lie in the intimate organization of the centers themselves. Recent studies of the connections and interactions between nerve cells within the centers—the microcircuits of the brain—have begun to provide the basis for a deeper understanding of the neural mechanisms underlying behavior.

Dendrites and Synapses

Within each center, nerve cells give rise to dendrites: short, branching strands that terminate in the vicinity of the cell. The lengths and branching patterns of the dendrites are many and varied. Some dendrites branch sparingly, others profusely; some radiate in all directions, others are confined to single trunks or tufts. Dendrites may extend for less than a tenth of a millimeter or as far as several millimeters. The various types of dendritic branching pattern are characteristic of the nerve cells in each of the many specialized regions within the central nervous system.

In the 1950's the electron microscope revealed the intimate junctions that connect nerve cells: the synapses. At these junctions information is transferred from one neuron to another, usually by means of the chemical messengers known as neurotransmitters. A synapse between an axon and the soma (the cell body) of a neuron is called axosomatic; one between an axon and a dendrite is called axodendritic. For many years it was assumed that these were the only possible types of synapse and hence that the neuron was functionally polarized, receiving signals with its dendrites and cell body and transmitting them through its axon. As we shall see, the nervous system is much more resourceful in putting together synaptic circuits.

The effect of a synaptic input is to induce a postsynaptic potential: a slow change in the voltage across the outer membrane of the receiving neuron. Depending on the type of neurotransmitter involved, the postsynaptic potential is either excitatory or inhibitory. Whereas a nerve impulse traveling down an axon is an all-or-nothing phenomenon, the excitatory and inhibitory postsynaptic potentials are graded: the amplitude of the response depends on the intensity of the input. In neurons that have a long axon, if the sum of the excitatory potentials reaches a certain threshold, the cell will "fire," or send an impulse down its axon. If, on the other hand, the excitatory input does not reach the threshold, or if it is opposed by an inhibitory input, the cell will not fire. Thus the relative activities of the excitatory and inhibitory synapses impinging on a neuron determine the frequency of impulses transmitted through the cell's axon to other regions.

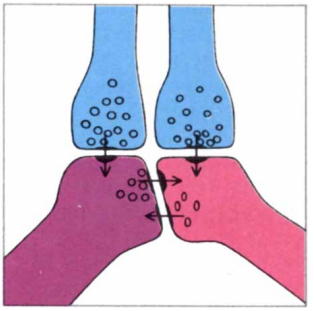
Investigation of synaptic inhibition showed that it can be mediated by axons projecting from neurons in distant centers or alternatively from the axons of neurons whose cell bodies are in the immediate vicinity. For example, the axon of a motor neuron in the spinal cord gives off a collateral branch that makes excitatory synapses onto a small short-axon cell called a Renshaw interneuron; the interneuron then makes inhibitory synapses back onto the motor neuron.

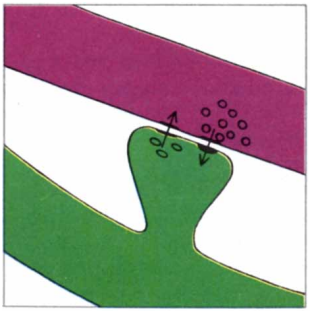
This inhibitory feedback loop, postulated by Birdsey Renshaw of Rockefeller University, was found in 1954 by John C. Eccles, Paul Fatt and K. Koketsu of the Australian National University. Since the Renshaw interneuron is confined to the same region of the spinal cord as the motor neuron it inhibits, the circuit is local compared with the long axonal pathways that connect one nervous center to another.

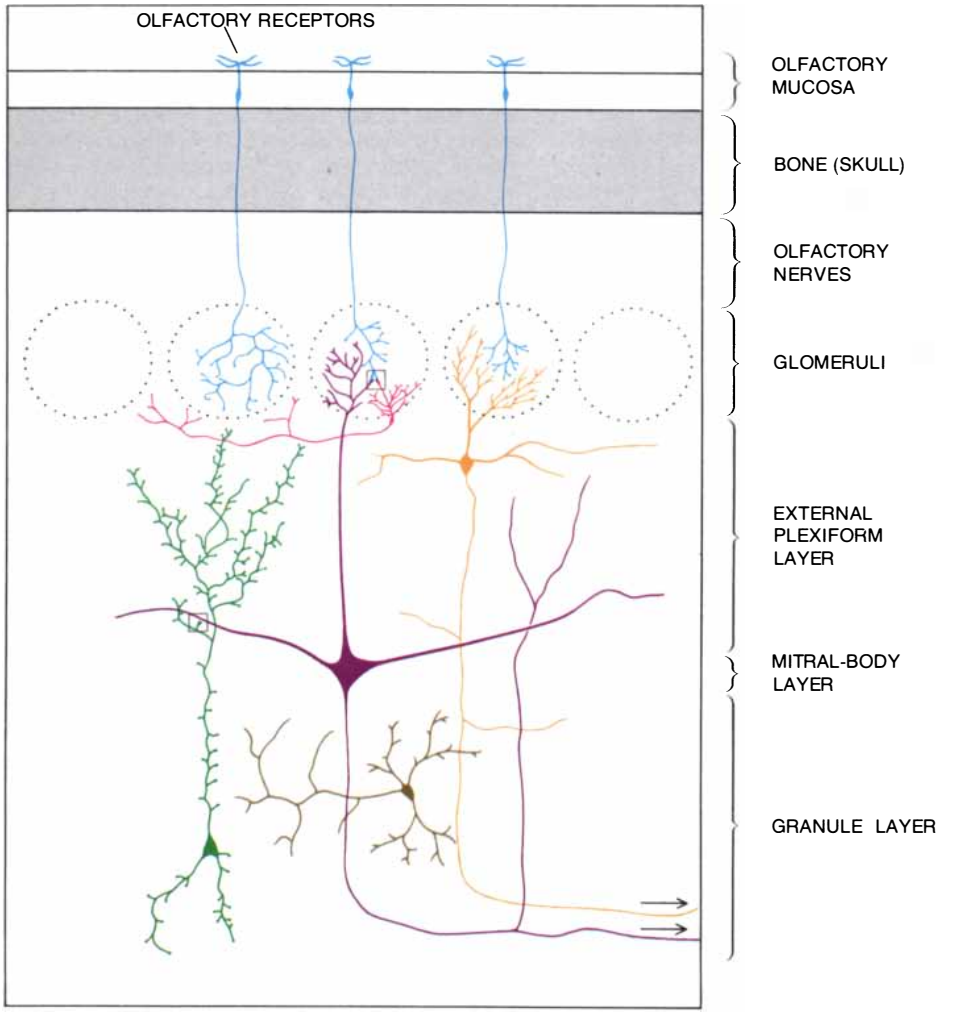
The Olfactory Bulb

In 1959, when I began my own research in the laboratory of Charles Phillips at the University of Oxford, the Renshaw inhibition pathway was the only type of local feedback circuit that had been well studied. Phillips was interested in determining whether similar circuits might be found in other parts of the central nervous system. To this end we, together with T. P. S. Powell, decided to study the organization of the neurons in the olfactory bulb, an oval structure attached to the front part of the brain that serves as a relay station between the olfactory receptors in the nose and the olfactory cortex in the brain.

The advantages of the olfactory bulb for neurobiological investigation are several. First, the input and output pathways of the bulb are separate: the axons from the olfactory receptor cells all enter the surface of the bulb, and the output axons arise from a different layer and leave through the depths of the bulb to connect to the olfactory cortex. This clear separation is quite rare in the nervous system; it is of great value to the experimenter, who can activate the pathways specifically. Second, the three major types of nerve cells in the olfactory bulb are arranged in discrete layers, which makes it possible to easily correlate anatomical and physiological studies. The principal neuron in the bulb is the mitral cell, which has a long axon projecting to the olfactory cortex. Its dendrites are of two types: branched secondary dendrites that extend laterally from the cell body and a long trunk-like primary dendrite that terminates in a tuft of branches. The dendritic tuft of each mitral cell receives incoming axon terminals from olfactory receptor cells





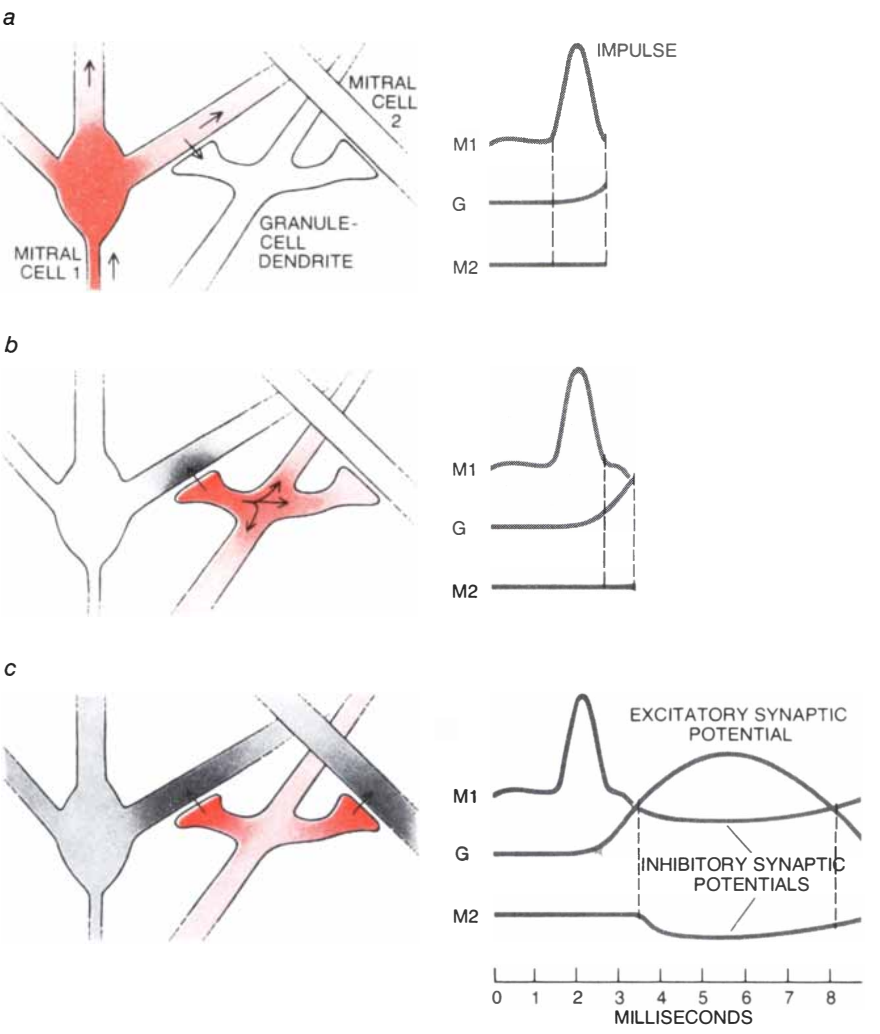


OLFACTORY BULB, a relay station linking the sensory receptors in the nose to the brain, contains numerous microcircuits that transmit and process olfactory information. In many of these circuits the nerve cells communicate directly through their dendrites (the short, branching extensions of the cell body) rather than sending an impulse down the axon (the nerve fiber). This diagram shows the various types of nerve cells in the olfactory bulb as revealed by treating the tissue by the Golgi method, which darkens only a few cells but does so throughout their extensions. The bulb is divided into discrete layers. Within the semispherical glomeruli the axons from the olfactory receptor cells (*blue*) make synapses with the dendrites of the periglomerular cells (*red*) and the dendritic tufts of the mitral cells (*purple*). Other types of neurons, including tufted cells (*orange*), also extend their dendrites into the glomerulus. In the external plexiform layer the horizontal secondary dendrites of the mitral cells make synapses with the "spines," or protruding terminals, that cover the dendrites of the granule cells (*green*). The deep granule layer of the olfactory bulb contains the output axons of the mitral cells, which project to the brain, and short-axon interneurons (*brown*). Insets at the left show main types of synaptic connections in glomeruli (*top*) and the external plexiform layer (*bottom*) as revealed by the electron microscope. Reciprocal synapses between dendrites are present in both regions.

within a small spherical region called a glomerulus, which acts as a kind of miniature relay station within the bulb.

The other two types of neurons in the olfactory bulb have all their processes confined within the bulb, and by that definition they are interneurons. One type, the periglomerular cell, sends a small dendritic tuft into a glomerulus and gives rise to a short axon that terminates nearby. The other type, the granule cell, sends out in opposite directions two long vertical dendrites that are covered with tiny cytoplasmic "spines." As long ago as 1875 the Italian neuroanatomist Camillo Golgi noted that the granule cell lacks an axon. This observation left the function of the cell entirely enigmatic: if, as the classical doctrine required, the output of a neuron is through its axon, what could be the output of a neuron without an axon?

Our initial studies showed that following an electrical stimulus to the axon of the mitral cell a nerve impulse is conducted along the axon to invade the cell body. (In this experimental situation the impulse travels in a direction that is the reverse of the normal one.) The spread of the impulse into the dendrites of the mitral cell is followed by a period of inhibition. Although the impulse lasts for only a millisecond or two, the subsequent inhibition lasts for up to several hundred milliseconds, which is quite long on the time scale of neurophysiological events. We hypothesized that the inhibition of the mitral cell was due to the action of the granule cell. How a cell without an axon could function as an inhibitory interneuron, however, remained a tantalizing mystery.



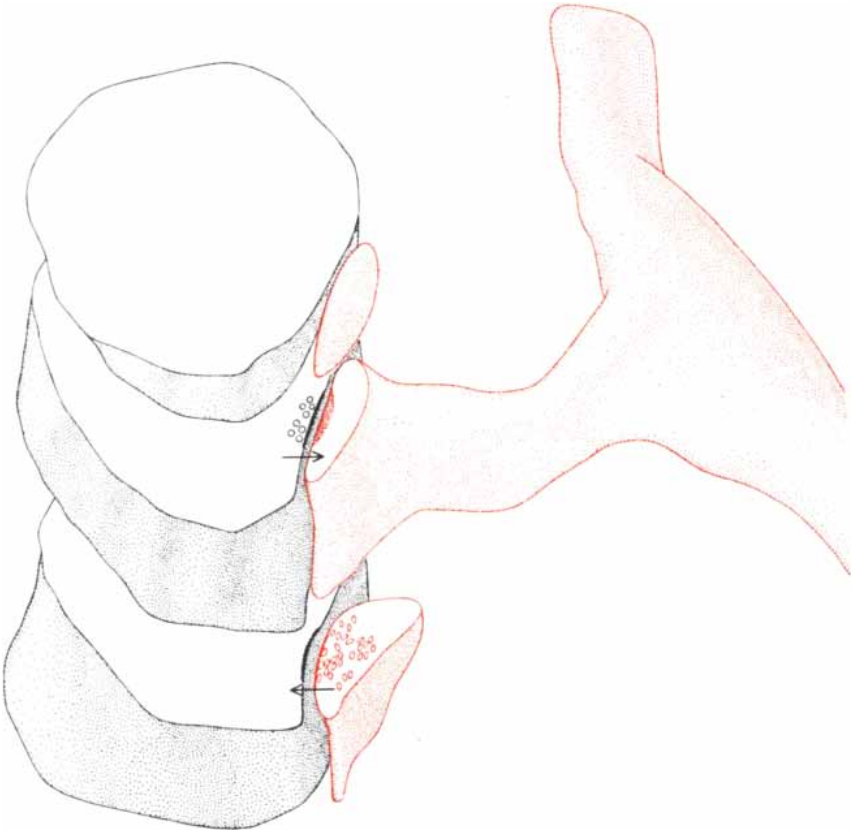
FUNCTION OF THE MICROCIRCUIT between the mitral cell and the axonless granule cell in the olfactory bulb was deduced by interpreting the results of physiological experiments with the aid of computer simulations. Here the activity in the circuit during a typical experiment is diagrammed. First the mitral-cell axon is electrically stimulated, triggering an impulse that is conducted backward up the fiber to the cell body. The impulse travels throughout the secondary dendrites of the mitral cell, activating excitatory synapses onto the dendritic spines of the granule cell (*a*). The excitation of the granule cell in turn activates inhibitory synapses from the granule-cell dendrite back onto the mitral-cell dendrite (*b*). As a result of this feedback loop the initially excited mitral cell is inhibited from firing. Moreover, because of the passive spread of current in the granule-cell dendrite, inhibitory synapses in other parts of the dendrite act to inhibit additional mitral cells (*c*). Normally, of course, the initial impulse in the mitral cell is triggered not by electrical stimulation but rather by input from the olfactory receptor cells.

Dendrodendritic Synapses

The mechanism of action of the granule cell was still unknown in 1962, when I moved to the laboratory of Wilfrid Rall in the Mathematical Research Branch of the National Institute of Arthritis, Metabolism, and Digestive Diseases. Rall was one of the first to recognize the importance of dendrites in the synaptic integration of neuronal activity, and his most important finding was that the electric currents set up by synapses onto the dendrites flow throughout the dendritic tree. These "electrotonic" currents are the functional link between the sites of synaptic input on the dendrites and the site of impulse generation, if there is one, in the cell body of a neuron. Rall showed that the electrotonic currents and the potential changes associated with them could be rigorously described by taking account of the electrical properties of the dendrites and the geometry of their branching. His methods have now become the accepted basis for analyzing and understanding synaptic integration in dendrites throughout the nervous system.

Our work together was mainly concerned with constructing computer models of the mitral and granule cells that realistically represented their electrical and geometric properties. Beginning with the impulse conducted backward up the mitral-cell axon and into the cell body, we modeled the spread of activity in the dendrites of the mitral and granule cells, modifying our simulation as we went along so that it agreed with the physiological recordings Phillips, Powell and I had obtained at Oxford. The sequence of events that fit the experimental data was an unexpected one. According to our computer model, the arrival of an impulse in the mitral cell triggers the activation of excitatory synapses from the secondary dendrite of the mitral cell onto the spines of the dendrite of the granule cell. This excitatory synaptic input depolarizes the granule cell (that is, it discharges the voltage across its outer membrane) and activates inhibitory synapses back onto the mitral cell to produce the observed long-lasting inhibition. The graded depolarization is conducted electrotonically throughout the dendritic tree of the granule cell, so that inhibitory synapses onto neighboring mitral cells are activated as well.

This scheme was highly unorthodox



RECONSTRUCTION OF A RECIPROCAL SYNAPSE in three dimensions shows a granule-cell spine (*color*) forming a junction with the secondary dendrite of a mitral cell. Within the single ending are two synaptic contacts with opposite polarities. The synapse from the mitral cell to the granule cell (*top*) has round vesicles and a fuzzy thickening of the postsynaptic membrane characteristic of an excitatory synapse, whereas the synapse from the granule cell to the mitral cell (*bottom*) has flattened vesicles characteristic of an inhibitory synapse. The reconstruction was done by Thomas S. Reese and Milton W. Brightman at the National Institute of Neurological Diseases and Stroke by tracing a series of electron micrographs of 23 consecutive sections through the junction; no sections are omitted in showing the cut surfaces.

in that it postulated the existence of inhibitory and excitatory synaptic interactions between dendrites, for which there was no precedent at the time. By good fortune, however, we were in frequent contact with Thomas S. Reese and Milton W. Brightman, who were studying the structure of the olfactory bulb with the electron microscope in a nearby laboratory at the National Institute of Neurological Diseases and Stroke. It was an exciting moment early in 1965 when we learned that synapses between the dendrites of mitral and granule cells actually exist. The discovery of such dendrodendritic synapses, together with our functional model, contradicted the classical doctrine that the nerve cell could only receive signals with its dendrites and cell body and transmit them through its axon, since it suggested that neurons can communicate with each other through their dendrites without the intervention of an axon or a nerve impulse.

The careful studies of Reese and Brightman made it possible to reconstruct the dendrodendritic synapses in the olfactory bulb in three dimensions and to clearly identify them with the dendrites of the mitral and granule cells. The most striking aspect of the structure was that the excitatory and inhibitory synapses were arranged in reciprocal pairs oriented in opposite directions, and hence they were appropriate for mediating the postulated sequence of an excitation proceeding from the mitral cell to the granule cell followed by an inhibition proceeding from the granule cell to the mitral cell.

Anthony Pinching and Powell at Oxford and Edward White in Reese's laboratory subsequently found that the short-axon periglomerular cells also make connections with the dendritic tuft of the mitral cell inside the glomerulus through reciprocal dendrodendritic synapses. Moreover, in my laboratory at the Yale University School of Medicine, Thomas V. Getchell and I have obtained physiological evidence that the periglomerular cells are inhibitory in their synaptic actions. Thus the two types of interneurons in the olfactory bulb share basic features in their interactions with the mitral cells.

For many research workers the existence of dendrodendritic circuits has been difficult to reconcile with traditional notions of neural organization based on circuits formed by axons. The dendrodendritic circuits have been termed "primitive," "nonusual" and "unconventional." The available evidence indicates, however, that dendrodendritic synapses are similar in basic respects to the synapses made by axons. It is now apparent that they are a logical and economical way to organize synaptic interactions in the minimum space. The reciprocal synapse between dendrites is the most compact synaptic circuit yet identified in the nervous system. We can therefore consider it to be a microcircuit, at the opposite extreme from the macrocircuits between nerve centers made through long axonal pathways.

Sensory Functions

How is the operation of microcircuits through dendrites related to the sensory function of the olfactory system? One important property of sensory systems is their sensitivity. We and others have found that molecules of odorous substances can be detected at extremely low concentrations in the air, a finding that implies a high degree of sensitivity in the circuits of the olfactory bulb that transmit under these conditions. Actually the situation is somewhat more complex. Computer simulations I have recently carried out in collaboration with Robert K. Brayton of the Thomas J. Watson Research Center of the International Business Machines Corporation suggest that different microcircuits of the olfactory bulb differ markedly in the sensitivity of their synapses to electrotonic current flow. For example, the synapses made by the secondary dendrites of the mitral cell appear to have a relatively low sensitivity, since they are activated by the spread of the impulse generated in the cell's primary dendrite by input from the olfactory receptor cells. In contrast, the synapses made by the granule-cell dendrites seem to have a relatively high sensitivity, since they are activated by graded synaptic potentials. High-sensitivity synapses may also be present in the olfactory glomeruli. More needs to be known about the electrotonic properties of dendrites, however, before the sensitivities of the dendrodendritic synapses in the olfactory bulb can be characterized quantitatively.

Recently John S. Kauer and I have been analyzing the responses of mitral cells in the olfactory bulb of the salamander to various olfactory stimuli, using pulses of odorous substances at carefully controlled levels of concentration. It is clear from our work so far that inhibition is important in shaping the responses of the mitral cells, and we are currently trying to identify the specific contributions of the circuits through periglomerular and granule cells to this inhibition. It seems safe to say that the ability to distinguish one odor from an-

other depends on interactions between excitatory and inhibitory activity in the dendritic circuits of the olfactory bulb.

An entirely different approach has been to correlate the activity of the circuits in different parts of the olfactory bulb with different olfactory stimuli. To this end Frank R. Sharp, Kauer and I have utilized a new biochemical technique developed by Louis Sokoloff and his associates at the National Institute of Mental Health. Because nerve cells that are physiologically active consume glucose for fuel, they can be identified by providing them with a chemical derivative of glucose that is taken up like glucose by active cells but that cannot be further metabolized; the substance is therefore trapped in the tissue. The glucose derivative is labeled with atoms of a radioactive isotope, so that its location is revealed by its radioactivity. The radioactivity is detected by slicing the tissue into thin sections and placing them on photographic film; after a week's exposure the radioactive cells have darkened the emulsion of the film in proportion to their physiological activity.

With the aid of this technique we have found that odor stimulation is associated with spatial patterns of activity in the olfactory bulb. The foci of activity are located precisely in groups of glomeruli, which have a high density of dendrites and synapses. In collaboration with William B. Stewart and our colleagues in the Neurosurgical Research Laboratories at Yale we are currently analyzing the distribution of these active sites in relation to different odors, including pheromones, the chemical substances that coordinate social activity in insects and mammals. The glucose method is one of a growing battery of biochemical techniques available to neuroscientists, and it promises to be of great service in correlating synaptic organization with sites and levels of functional activity.

Distribution of Microcircuits

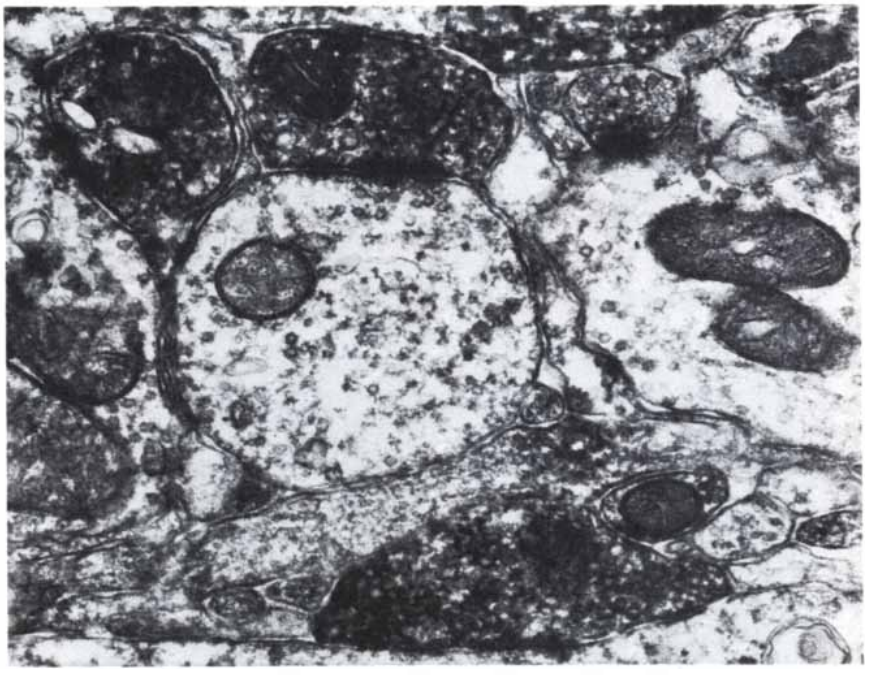
Are dendrodendritic synapses perhaps found only in the olfactory bulb? This possibility never arose, because as we were studying the bulb independent investigations by John E. Dowling, who was then at Johns Hopkins University, in collaboration with Brian B. Boycott of the University of London, showed the presence of similar synaptic arrangements in the retina of the eye. One type of interneuron in the retina, the amacrine cell, was known to lack an axon, and in this respect it presented the same puzzle that the granule cell in the olfactory bulb did. Dowling and Boycott helped to solve the puzzle by finding reciprocal synapses between the dendrites of the amacrine cells and those of neurons known as bipolar cells. Subsequent work by Frank S. Werblin and Dowling in 1969, and by many others since then, has shown that most of the cells in the retina generate slow synaptic potentials serving as both the synaptic response and the synaptic output, a situation analogous to the ones we have seen in the olfactory bulb.

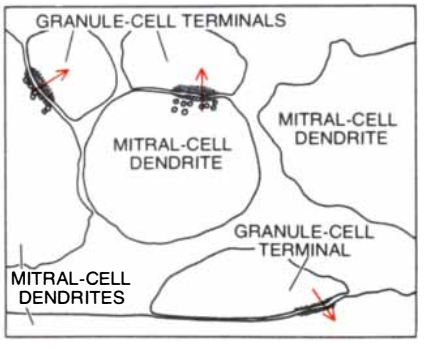
Over the years since the early work on the olfactory bulb and the retina much evidence has accumulated for similar types of synaptic circuits through dendrites in other parts of the nervous system. The evidence was slow to come at first; most neuroanatomists were trained to think of synapses as being made only by axons onto cell bodies or dendrites, and they had to retrain themselves (and in some cases revise earlier conclusions) to include synapses made by dendrites. Now, however, the list of synaptic circuits through dendrites is quite long, and it can be said that such circuits have been found in most of the major parts of the nervous system.

For example, the synaptic connections of the trigeminal nerve to the brain stem have been studied by Stephen Gobel at the National Institute of Dental Research. This nerve carries sensory information from the face, and it feeds into a complicated microcircuit that appears to be essential for integrating the information and transferring it to the brain. Several types of synaptic arrangements have been identified in this region: single and reciprocal axodendritic synapses, single dendrodendritic synapses and even axoaxonic synapses, in which an axon receives synapses from another axon. This variety of synaptic arrangements suggests the existence of many small computational units that provide for a highly localized and specific processing of information.

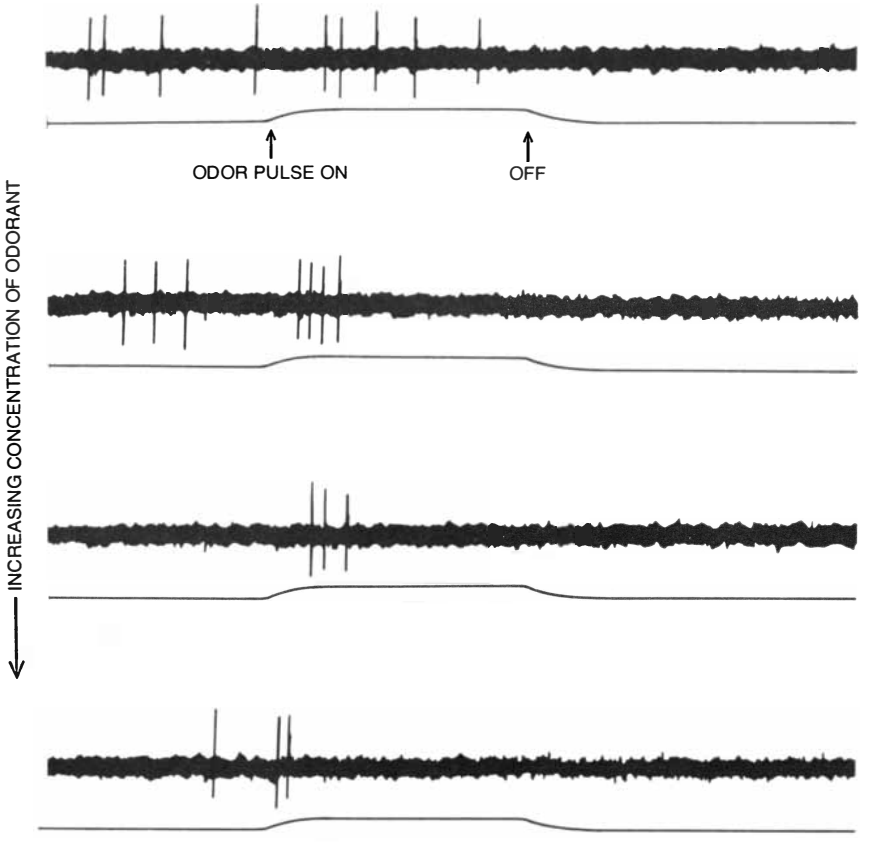
One of the important sensations mediated by the trigeminal nerve is that of pain. There is currently an enormous range of investigations of pain, including studies of the neuronal mechanisms of normal pain, of the dysfunctions responsible for states of intractable pain, and of the localization of opiate receptors in the nervous system. It is likely that our understanding of such problems will require precise knowledge of the dendritic circuits that process the inputs from the spinal and trigeminal nerves.

Another brain region in which dendritic circuits have been identified is the thalamus, the final relay center for sensory pathways to the cerebral cortex.

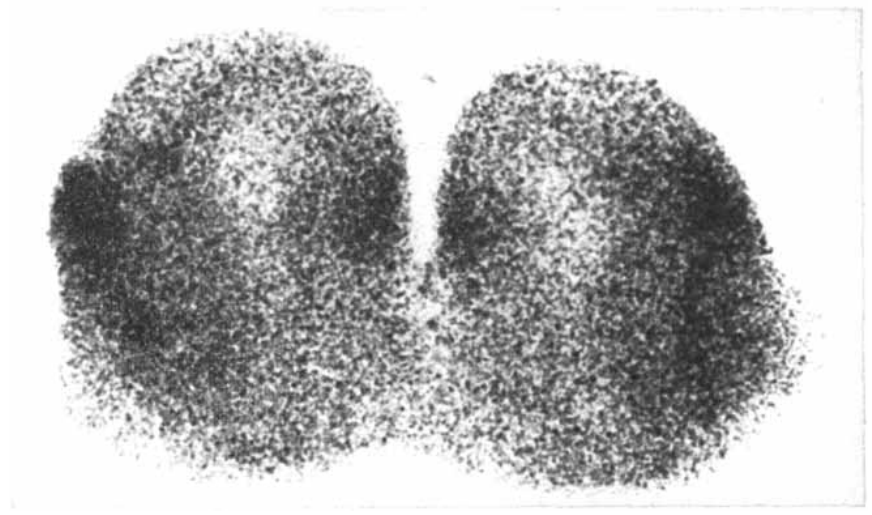




TYPE OF NEUROTRANSMITTER that is released at the inhibitory synapse from the granule-cell dendrite to the mitral-cell dendrite was identified by a cytochemical study conducted by Charles E. Ribak, James E. Vaughn, Kihachi Saito, Robert Barber and Eugene Roberts at the City of Hope National Medical Center in Duarte, Calif. In this electron micrograph the terminals of the granule cell contain a precipitate: a positive test for the enzyme glutamate decarboxylase, which converts the amino acid glutamic acid into the neurotransmitter gamma-aminobutyric acid (GABA). This finding suggests that GABA is released from the granule cell. Magnification of the micrograph is some 37,000 diameters.



PATTERNS OF IMPULSES generated by mitral cells in the olfactory bulb in response to pulses of an odorous substance were recorded with an extracellular microelectrode by John S. Kauer and the author at the Yale University School of Medicine. The substance they used was amyl acetate, which to human beings smells like bananas. (The odor pulse is represented by the lower trace, beginning at the arrow.) At a low concentration of amyl acetate (*top*) there was an impulse discharge in the mitral cells that lasted through most of the odor pulse. At higher concentrations the impulses fired faster and the discharge was cut short by a long-lasting inhibition. This interplay of excitation and inhibition appears to underlie processing in olfactory bulb.



AUTORADIOGRAPH OF A THIN SECTION through the olfactory bulb reveals the focal activity of the synaptic circuits in response to a specific odor. To make this image Frank R. Sharp, Kauer and the author injected a rat with a radioactively labeled sugar, deoxyglucose, and then exposed the animal to air containing a vapor of amyl acetate. The nerve cells in the bulb that were most active in detecting and discriminating the odor preferentially took up the radioactively labeled sugar from the blood. When sections of the bulb were placed on X-ray film, the nerve cells darkened the film in proportion to their radioactivity, providing an activity map of the bulb. Here the darkest regions are located precisely over the olfactory glomeruli.

Within the thalamus incoming axon terminals make synapses onto the dendrites of both long-axon relay neurons and interneurons; the interneurons then make both dendrodendritic and axodendritic synapses onto the relay neurons. It therefore appears that much of the information flowing into the cerebral cortex is processed by microcircuits at the thalamic level. Dendrodendritic synapses have also been found in regions that regulate movement in monkeys, such as the motor area of the cerebral cortex and the basal ganglia of the cerebrum and the midbrain, which have been implicated in the derangements of movement that occur in Parkinson's disease. These regions are difficult to study, however, and the quantitative importance of dendrodendritic and other types of circuits found in them has yet to be established.

A final example is the suprachiasmatic nucleus, a tiny region in the forward part of the hypothalamus above the optic chiasm (the region where the optic nerve from one eye meets the optic nerve from the other). Fritz H. Güldner and J. R. Wolff of the Max Planck Institute for Biophysical Chemistry in Göttingen have shown that dendrodendritic synapses are a distinctive feature of the synaptic organization of the suprachiasmatic nucleus. Reciprocal synapses have also been observed there. What little is known about the region suggests that it plays an important role in slow cyclic behavior, such as the daily physiological cycles of the body, by controlling the release of certain hormones. It therefore appears that dendrodendritic synapses may be related not only to rapid information processing but also to slow activity measured in hours or days.

Invertebrate Systems

So far I have focused on the nervous system of vertebrate animals. In invertebrate animals information recently obtained suggests a striking parallel with the findings in vertebrates. The nervous system of invertebrates is characteristically organized in a chain of ganglia, or small nerve centers. Within a ganglion the nerve-cell bodies lie at the periphery; the dendrites arise from the axon and branch and intermingle in the center of the ganglion, at some distance from the cell bodies. This separation has greatly complicated the identification of the cells from which the dendrites arise. Recently, however, David King of the University of California at San Diego has been able to reconstruct the dendritic terminals within the ganglion of the lobster and has found that a given terminal can have both sending and receiving synapses. These results and others appear to confirm that the basic types of dendrodendritic synapses are present in

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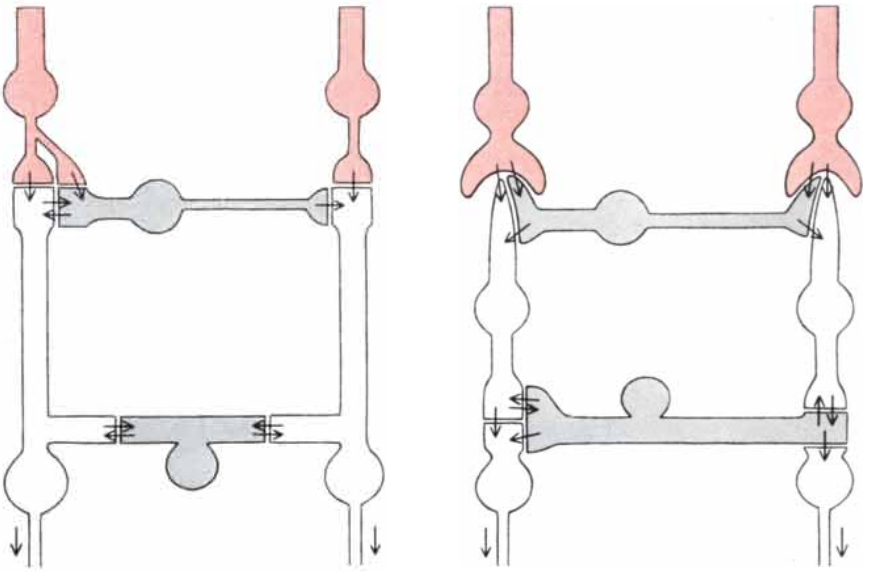

SIMILARITY BETWEEN THE SYNAPTIC ORGANIZATION of the olfactory bulb and the retina is shown in this schematic diagram. Both regions are way stations between the sensory receptor cells (*color*) and the brain. Both have a framework of vertical pathways (*open*) for straight-through transmission combined with horizontal pathways (*shaded*) for lateral interactions. The horizontal connections are organized in two main layers and involve single and reciprocal synapses that operate by combinations of slow graded potentials and impulse activity.

the invertebrate nervous system, and that some of the patterns of interconnection are similar to those found in the vertebrate nervous system.

Neurophysiologists have often taken advantage of the relative simplicity of the nervous system of invertebrates to explore the fundamental properties of nerve cells. As early as 1959 the electrophysiological activity of a number of different types of neurons in invertebrate ganglia had been recorded by impaling individual cells with thin glass electrodes. In reviewing these studies Theodore H. Bullock, who was then at the University of California at Los Angeles, concluded that the normal functions of many of the small neurons in the invertebrate ganglion might be mediated by graded potentials rather than by the generation of all-or-nothing nerve impulses. Evidence to support this hypothesis was difficult to obtain in invertebrate neurons because of the separation between the cell body, where the recordings are made, and the dendritic terminals, where the synapses occur. Recently, however, several examples of neurons have been found that communicate only through graded potentials.

Particularly striking are the results obtained by Keir Pearson and C. R. Fourtner at the University of Alberta with the nervous system of the cockroach. The legs of the cockroach arise from the thorax, and walking is controlled by alternating bursts of impulses in the nerves from the thoracic ganglia to the flexor and extensor muscles in the legs. The rhythmic and reciprocal nature of this activity arises in the ganglia themselves, and Pearson and his colleagues have shown that nonfiring neurons there are responsible for generating the motor pattern [see "The Control of Walking," by Keir Pearson; SCIENTIFIC AMERICAN, December, 1976].

Other Local Interactions

In this account of microcircuits I have emphasized dendrodendritic interactions, but I could also note a number of locations where interactions between axons (axoaxonic synapses) have been found or suspected. Similarly, I have focused on the role of graded potentials in microcircuits, but all-or-nothing nerve impulses do occur in short axons, in axon collateral branches and in some dendrites. In addition, although most synapses operate by releasing chemical neurotransmitters, there are a number of specialized regions called gap junctions where transmission is mediated by the direct flow of electric current. Finally, there are interactions between neurons that take place independently of specific points of contact; they include the continual flow of substances within nerve cells and across their membranes, and the electric fields that are set up when populations of nerve cells are active in concert. All these phenomena contribute to functional operations within the microenvironments of the nervous system.

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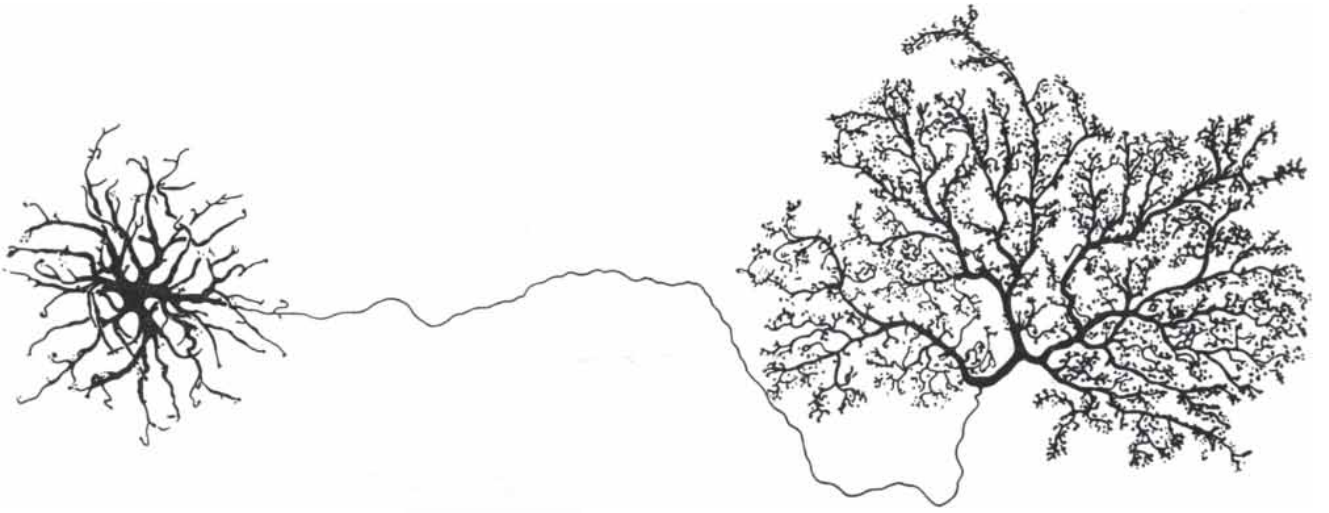
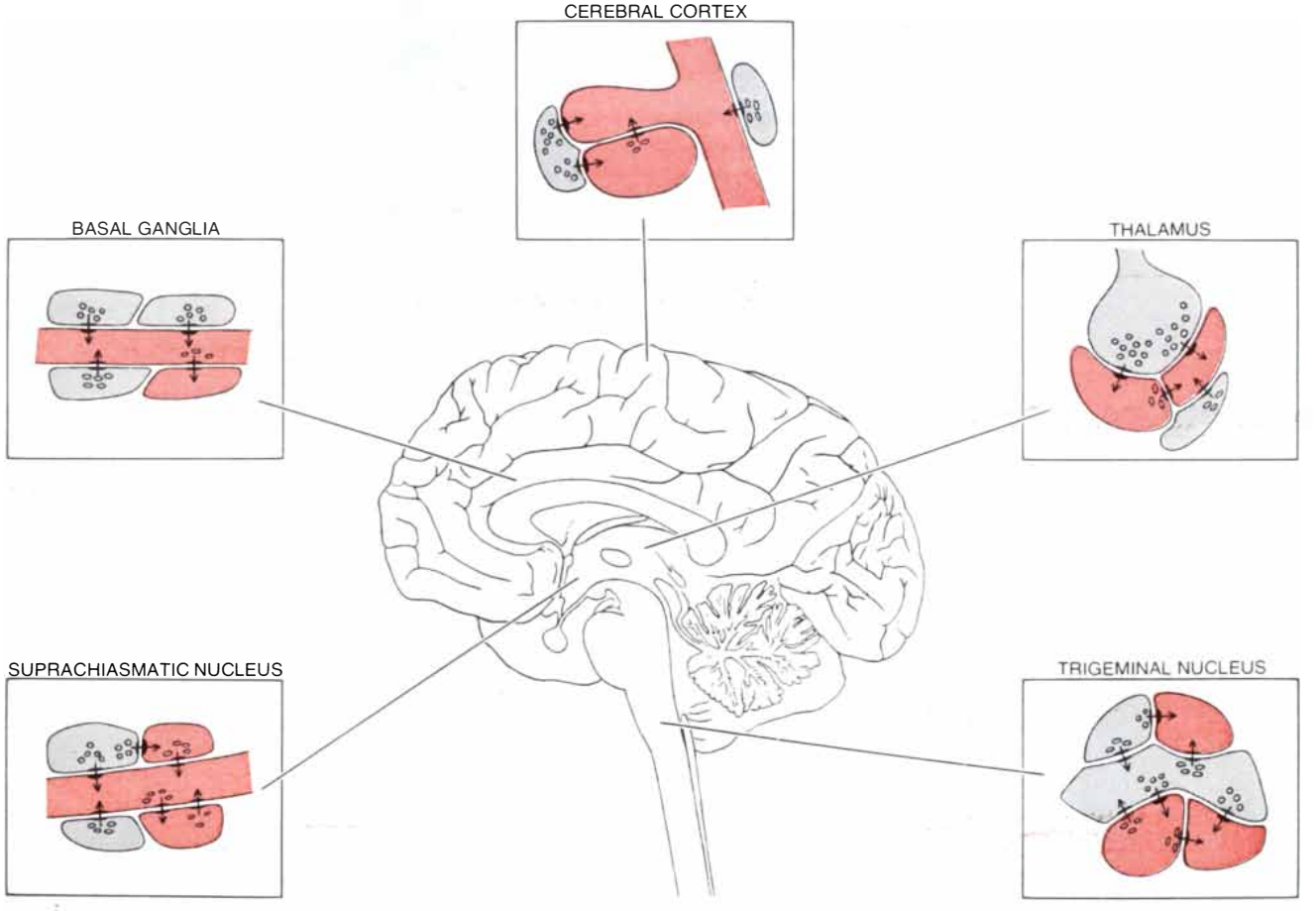


HORIZONTAL CELL FROM THE RETINA of a cat was visualized with the Golgi method by Brian B. Boycott of the University of London. The cell is divided into two highly branched regions connected by a thin fiber. Dendrites associated with the cell body (*left*) receive signals predominantly from the color receptor cells (cones), whereas the terminal arborization (*right*) receives signals primarily from the light-intensity receptor cells (rods). The axonlike process connecting these two regions neither generates impulses nor allows significant passive conduction between them. Instead it appears to serve to electrically isolate the cell body from its terminal arborization while maintaining a nutritive link. In some mammals this arrangement apparently restricts the interactions between the rod and cone systems, which have different dynamic ranges of function. The advantage of having single nerve cells with electrically isolated regions is that the number of independent integrating units within the brain can be increased without the need for augmenting number of individual cells.



TYPICAL MICROCIRCUITS in different regions of the brain are diagrammed. The insets represent in schematic fashion the outlines of terminals and the sites of synapses; dendrites are shaded in color and axons in gray. The synaptic connections in the thalamus and trigeminal nucleus are organized in clusters as shown; the connections in the other regions are more diffusely distributed than is indicated here. The circuits are involved in functions ranging from rapid processing in the thalamus to the generation of long-term rhythms.

Neurosciences Research Program, an interdisciplinary organization that conducts scientific meetings to explore current problems in the neurosciences, the new work on synaptic organization was reviewed. In this session, organized by Francis O. Schmitt of the Neurosciences Research Program and chaired by Pasko Rakic of the Harvard Medical School, the term "local circuits" was used to describe the pathways confined within nerve centers. The pathways through dendrites that occur in the olfactory bulb and other regions may be regarded as the prototypes of local circuits, characterized as they are anatomically by local connections and physiologically by local potentials.

Microcircuits and Behavior

How are investigations at this microscopic level of nervous organization related to the large-scale actions that characterize behavior? The simplest types of microcircuit are concerned with the properties of synaptic excitation and inhibition and with sequences of these activities. In many instances, as in the olfactory bulb or the retina, the patterns in which the synapses are organized are complicated but stereotyped, which suggests that some microcircuits might be organized into more complicated microprocessing units, each with a particular operation to contribute to local integration.

From considerations such as these it is becoming evident that the nervous system is built up of hierarchies of functional units of increasing scope and complexity. The traditional concept of the single neuron, receiving information by way of its dendrites and sending it out through its axon, can now be seen to represent only one type of functional unit within these hierarchies. The new findings indicate that a single neuron may comprise many functional units in terms of its individual synaptic relations. In addition any given neuron is only one small component of larger functional units made up of multineuronal assemblies.

At the highest levels of organization such functions as perception, memory, learning and complex behavioral acts call for coordination of many centers. In this coordination a microcircuit and a macrocircuit are not separate entities; one is indissolubly embedded in the other. Thus whether one starts with an interest in the biochemical aspects of behavior or in the electrical activity that underlies it one is led to a common focus: the synaptic circuit through dendrites. Although an understanding of the neural basis of behavior is still remote, some clues have now been given, and it seems clear where the search is most likely to be rewarded.

Carnivorous Plants

The luring, capturing and digesting mechanisms they have evolved to devour insects augment their supply of mineral nutrients and enable them to survive in habitats where few other plants can live

by Yolande Heslop-Harrison

Green plants gain their energy from the sun, their carbon from the atmosphere and their water and mineral elements from the soil. The atmospheric carbon (in the form of carbon dioxide) and the soil nutrients are replenished from the wastes of microorganisms and animals, and in this way plants and animals are complementary in the general economy of nature. A few plants, however, have evolved the capacity of feeding directly on animals, supplementing their nutrition by capturing and digesting animal prey. By adopting this habit they have gained the ability to survive in nutrient-poor environments, although in some instances at the expense of being unable to exist in richer habitats in competition with species that have a more usual life-style.

Those flowering plants that have evolved the carnivorous habit can be divided into two groups according to their methods of catching prey: active trappers and passive trappers. Of the active trappers *Dionaea muscipula,* the Venus's-flytrap, is one of the most familiar. In nature this species is found only in certain habitats on the coastal plains of North and South Carolina. Now, however, it is also widely cultivated and can even be seen on sale as a novelty at the checkout counters of supermarkets. Its natural prey are mainly hopping or crawling insects and spiders. Prey touching the leaf agitate tactile hairs; the action triggers a closing mechanism and the hinged leaf snaps shut.

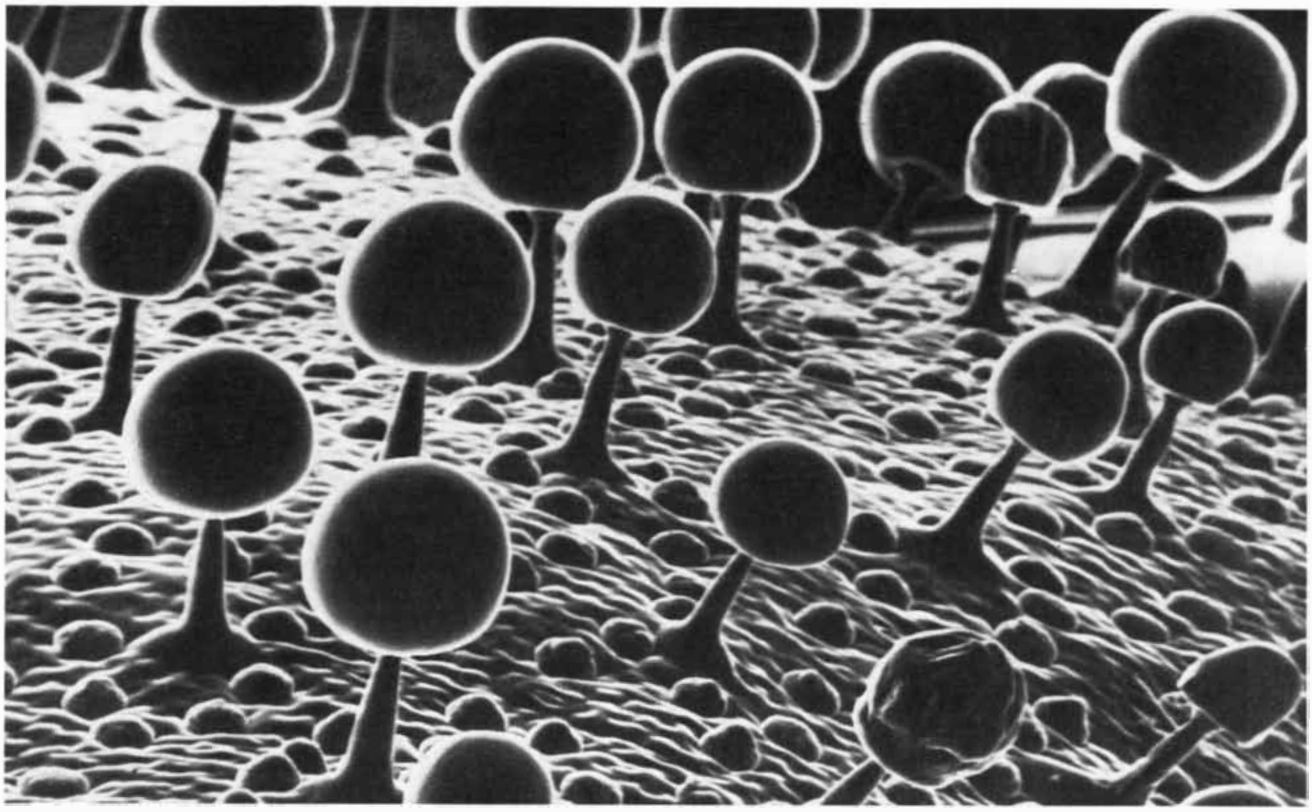
A closely similar mechanism of trapping, although on a diminutive scale, is found in another genus of the same plant family: *Aldrovanda,* the waterwheel plant. As its common name indicates, *Aldrovanda* is an aquatic plant. The genus includes only one species, *A. vesiculosa,* but it has a widespread distribution, occurring in central and southern Europe and eastward across Asia into Japan and parts of India and Australia. The commonest of all the active trappers belong to the genus *Utricularia,* which includes some 150 species. In the aquatic or semiaquatic species of this genus the traps take the form of small elastic-walled bladders, hence the common name bladderwort. When the bladder is "set," it is flattened, and the entrance to it is sealed by a flap of cells. The prey are swept into the bladder with the current of water produced when the walls spring apart following the opening of the entrance flap, an action that is triggered by tactile hairs near the entrance.

The passive trappers include the pitcher plants, where the prey is captured and digested in pitcherlike structures formed by modification of the entire leaf, as in the North American genus *Sarracenia,* or by an extension of the leaf tip, as in the genus *Nepenthes* of the eastern Tropics. The prey are enticed to enter the pitcher by colors and scents, much in the way that pollinating insects are attracted to flowers, and they are then drowned and digested in the pitcher fluid. A different strategy is seen in plants with flypaperlike leaves, as in the species of *Pinguicula,* the butterworts, and *Drosera,* the sundews. In these genera glands on the leaf surface secrete adhesive droplets. The prey, usually a flying insect attracted by odor or color or perhaps by the brilliant refractions of the droplets, is trapped by the adhesive when it alights. It becomes more firmly attached to the leaf surface as its efforts to escape bring it into contact with more glands.

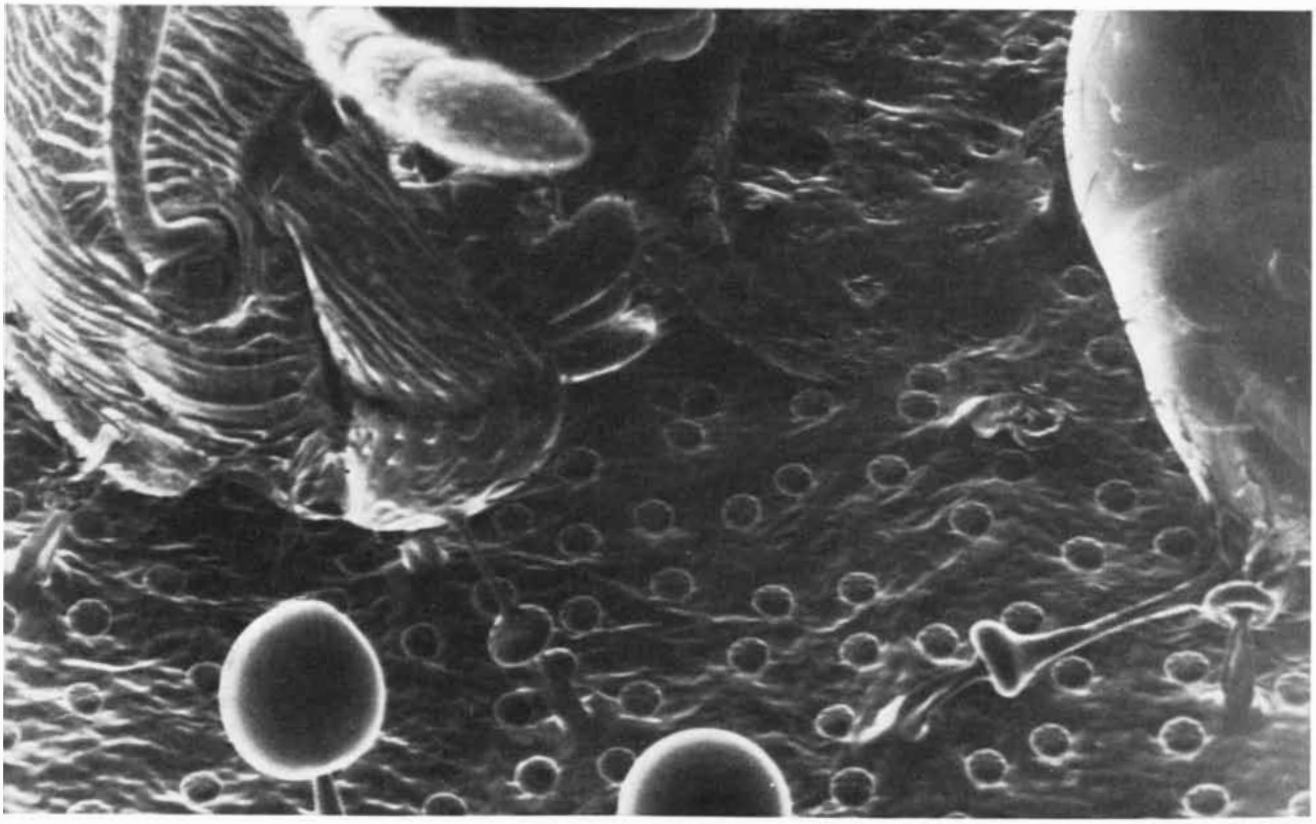
The effectiveness of carnivorous plants as predators has been well documented for several species, and the published lists of animal species captured are remarkably long. The prey are usually quite small, but mice have been found in the pitchers of *Nepenthes,* probably the victims of a chance fall, and the remains of small tree frogs have been found in the pitchers of *Sarracenia.* Bladderworts sometimes catch small fishes and tadpoles, but the bladders are never more than a few millimeters wide and are more adapted to the capture of rotifers, copepods and the aquatic larvae of such insects as mosquitoes.

The quantity of prey captured is sometimes quite large. In the pitcher plants the pitchers usually survive for several months, and they may be virtually filled with the decaying remains of their catch. In plants with more ephemeral traps, such as the species of butterworts in which the effective life of a leaf may be only five days, the total catch of a growing season is more difficult to assess. A butterwort such as *Pinguicula grandiflora* grows one new leaf about every five days, so that a total of 400 square centimeters of catching surface may be produced in a single season, even though the diameter of the leaf rosette never exceeds eight centimeters. Carnivorous plants also occasionally form dense stands. Some 30 years ago Francis W. Oliver of University College London described a sward of sundews extending over an area of more than two acres near Barton Broad (not far from the Norfolk coast in eastern England) that had captured vast numbers of butterflies, most of them cabbage whites trapped when they settled after a migratory flight from the Continent. Oliver found four to seven butterflies adhering to each plant and estimated the total number of trapped insects to be about six million.

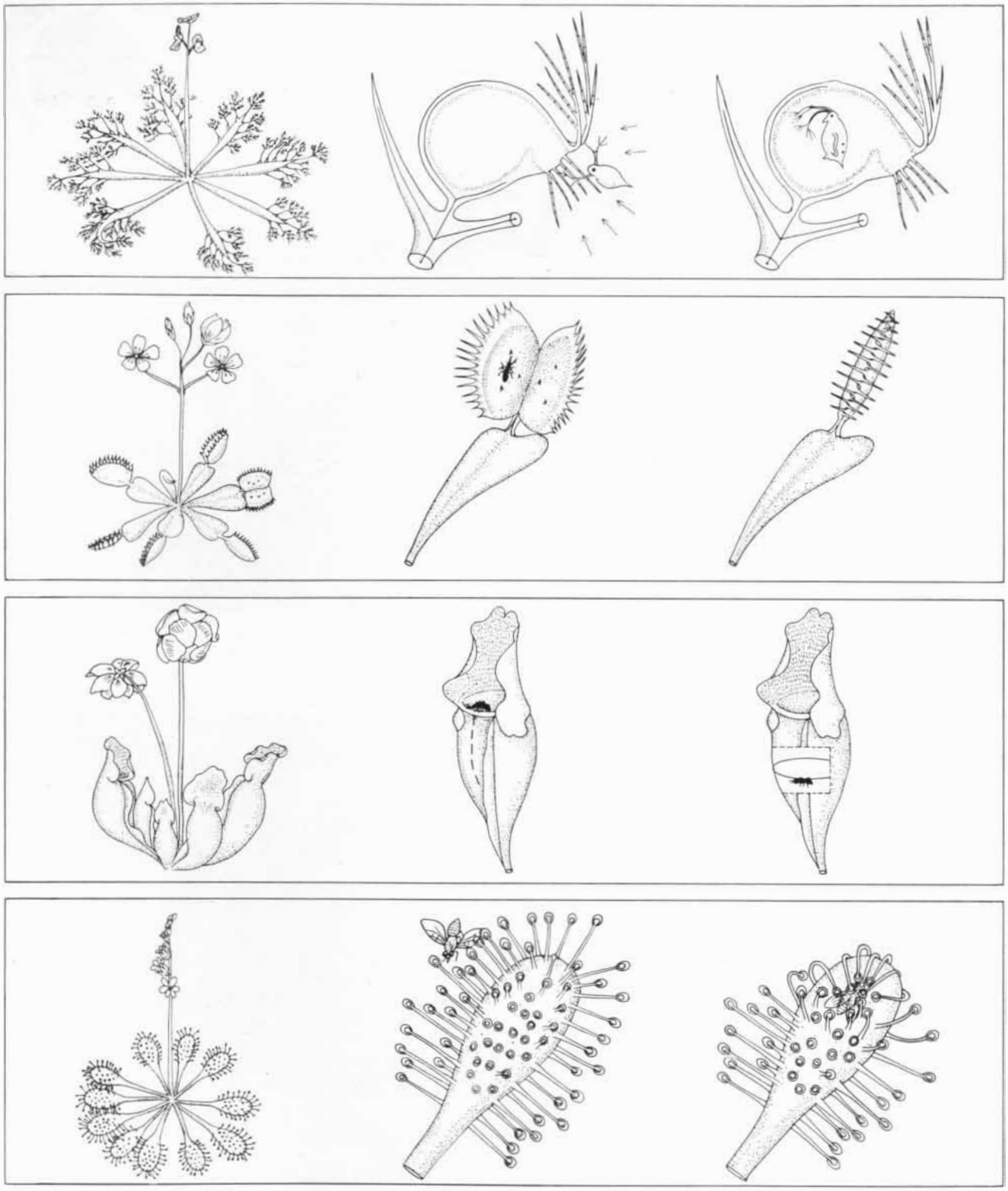
What, then, is the value of the carnivorous habit in plants? Charles Darwin, who was one of the pioneers of work on the physiology of carnivorous plants, addressed himself to the question a little more than a century ago. With his son Francis he showed convincingly that sundews in cultivation that had been fed artificially by applying insects to their leaves were more vigorous, produced more flowers and set more seed than those denied such fare. More recently Richard Harder of the University of Göttingen and others have shown that butterworts, sundews and bladderworts cultivated in controlled environments with carefully regulated access to nutrients perform better when provided with prey, confirming the Darwins' results. They have also found that butterworts make use of pollen carried in the atmo-



ARRAY OF GLANDS in the leaf surface of a butterwort, *Pinguicula grandiflora,* appears in this scanning electron micrograph. The prominent stalked glands trap insect prey. The many small semi-recessed glands spread over the leaf surface are the digestive glands; after an insect has been captured they emit enzyme-rich fluid that forms a pool. The same glands later resorb the digestion product.



TRAPPED ANT is firmly attached to the leaf surface of a butterwort, held by strands of the mucilage secreted by the stalked glands of the leaf. Untouched stalked glands appear in the foreground of this scanning electron micrograph. The ant's head (*left*) has one of the adhesive strands attached to a mouthpart and another attached near the right antenna; a third strand is attached to the thorax (*upper right*) and two others secure the tip of the abdomen (*lower right*). The smaller, stalkless digestive glands have not yet started to secrete.

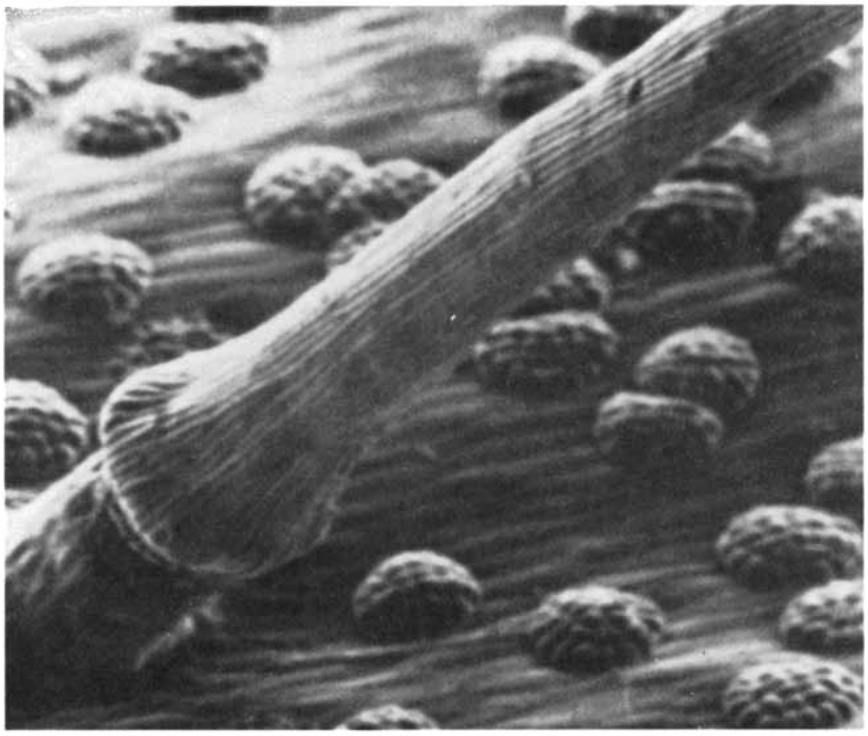


ACTIVE AND PASSIVE TRAPPERS among carnivorous plants are exemplified by four species. At the top is the bladderwort *Utricularia inflata,* a widespread American species that has "float leaves" at the base of the flower stalk. The bladders are submerged suction traps. When swimming prey, for example the small crustacean of the genus *Daphnia* shown here, touch the trigger hairs around the mouth of the bladder (*center*), the flap of tissue that forms the door springs open and the bladder expands suddenly to draw in both water and prey (*right*). Second from the top is another active trapper: the Venus's-flytrap, with its basal rosette of hinged leaves. When a visiting insect or spider touches one of the trigger hairs on the leaf surface, the two sides of the leaf move quickly together, closing the trap. Third from the top is a passive trapper: the pitcher plant *Sarracenia purpurea,* shown with its basal array of pitcher-shaped leaves that form pitfall traps. The prey is lured to the pitcher's slippery edge by a trail of nectar (*broken line*), falls into a pool of digestive fluid and cannot climb out. In this particular species the plant itself may not contribute much to the digestive properties of the pitcher fluid; the main digestive action is due to a commensal bacterial flora. In other pitcher-plant species glands below the surface of the pitcher fluid secrete enzymes into the fluid, at least early in the life of the trap. At the bottom is another type of passive trap: an adhesive trap exemplified by one of the sundews, *Drosera intermedia.* Small flying insects that alight on the attractively colored leaf surface touch the secretion globules that are carried on the stalked glands. These glands secrete the digestive enzymes, and later they resorb the products of digestion.

sphere, digesting it much as they digest insects.

The nutrients derived from captured prey enter the leaves with surprising rapidity. Some years ago Bruce Knox and I used algal protein labeled with the radioactive isotope carbon 14 in order to follow the movements of the products of digestion in the plant. The leaves of butterworts were fed minute quantities of the labeled protein, and the breakdown products were traced by means of autoradiographs. We found that the amino acid and peptide products of protein digestion moved into the leaf in two or three hours and then passed into the stem and on toward the roots and growing points in less than 12 hours. The main pathway through the leaf was the xylem, the water-conducting tissue of the plant.

Recently John S. Pate and Kingsley Dixon of the University of Western Australia have labeled fruit flies by feeding them on yeast containing the isotope nitrogen 15 and have used the flies as a diet for *Drosera*. In the sundews growth arises from corms formed during the preceding season, and much of the nitrogen reserve in the corms is in the form of the amino acid arginine. Pate and Dixon found that at the end of their experiment some 40 percent of the arginine in the corms of the experimental plants contained nitrogen 15, a striking demonstration of how important the supplemental nutrients obtained from the prey must be for the survival of the species in nature.



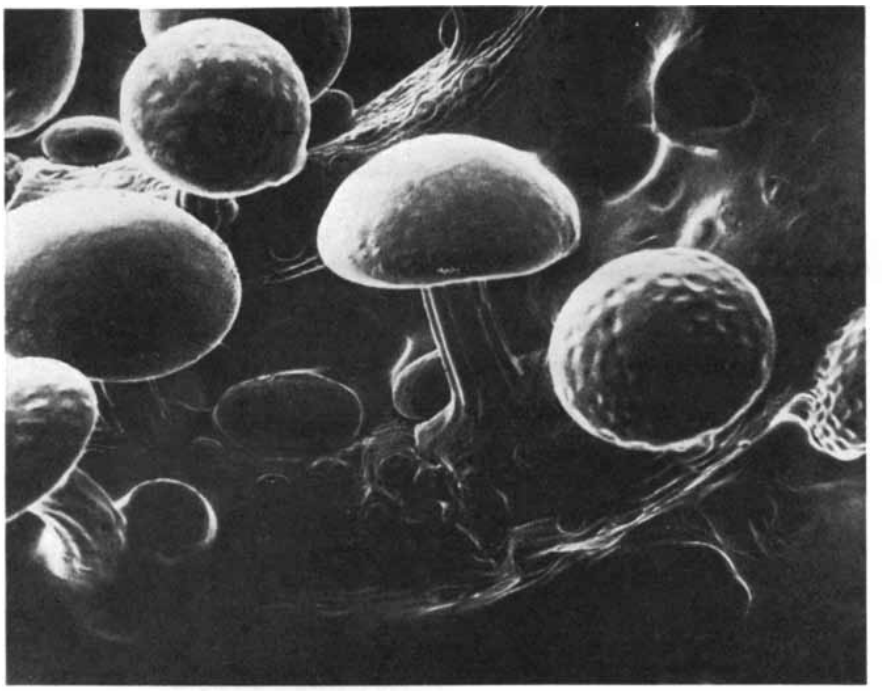
BASE OF A TRIGGER HAIR on the surface of a Venus's-flytrap leaf appears in this scanning electron micrograph. The low mounds are the glands that secrete the digestive fluid and then resorb the digestion products after the trap closes. The flow of secretion does not automatically follow the springing of the trap but depends on chemical stimuli provided by prey.

About a quarter of a million species of flowering plants exist on the earth today, and of them some 400 are known to be carnivorous. They belong to 13 or so genera of six families. Some of the families are quite diverse, with members on every continent. If the main function of the carnivorous habit is to provide scarce nutrients, one might expect the plants to inhabit the kinds of environment where such supplementation would be most beneficial. That is just what is found. The plants are most often encountered in nutrient-poor communities: on heaths or in bogs, on impoverished soil in forest openings and occasionally on marl, the crumbly clay soil associated with weathered limestone. Often two or three different genera of carnivorous plants will be found growing together in such localities. For example, in the Pine Barrens of New Jersey several species of sundew, pitcher plant and bladderwort coexist.

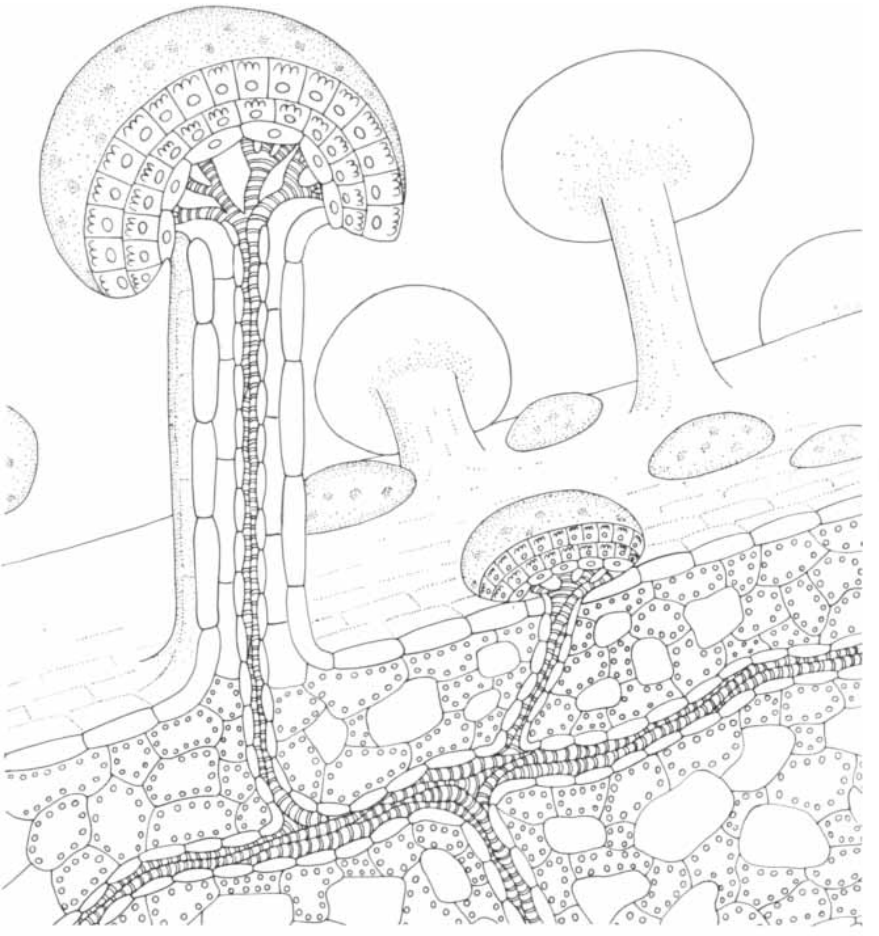
At the same time some carnivorous species occupy remarkably narrow ecological niches. Certain bladderworts of South America are found only in the pools of water that accumulate in the natural basins formed by the leaf rosettes of bromeliads, members of the pineapple family. In this environment they are essentially free from competition. Species of the pitcher-plant genus *Heliamphora* provide another example. They occur in nature only in the remote mist zone high in the mountains along the border between Guyana and Brazil, and their environmental requirements are so peculiar that the plants can be maintained in greenhouse cultivation only with difficulty. Still another example is the cobra plant of North America, the only species in the pitcher-plant genus *Darlingtonia;* its distribution is limited to mountain slopes and coastal bogs in Oregon and California.

A number of the carnivorous plants are able to survive in quite extreme environments. *Sarracenia purpurea,* one of the nine North American species of this pitcher-plant genus, is found from Florida northward to British Columbia and Newfoundland. At the northern limit of its range the bogs where it grows may be frozen for several months each winter. In Australia (where more sundew species are found than are found anywhere else in the world) some of the sundews native to the northwest are exposed to near-freezing night temperatures during the wet winter months when they are actively growing and become dormant during the summer dry season, when the daytime temperatures in the shallow depressions in granitic rocks where they live may exceed 50 degrees Celsius (120 degrees Fahrenheit). The dewy pine of the western Mediterranean, a passive trapper and the only species in the genus *Drosophyllum,* is relatively drought-resistant during its main growing period Found on the dry, sandy coastal plains of Portugal and Morocco, it depends on sea mists for a part of its water supply

Contemplating the range of adaptations found together in the plant carnivores, one can readily appreciate Darwin's absorption with them as examples of evolutionary virtuosity. The trapping mechanisms themselves represent elaborately modified leaves or leaflike organs, and they are usually associated with lures and guides that tempt and direct the prey into or onto the trap. Specialized glands secrete the digestive enzymes, and the same glands or others retrieve the products and pass them back into the plant for distribution through the conducting tissues to the sites of growth. None of the individual features—the traps, lures, odors, directional guides, secreting glands and absorbing glands—is itself peculiar to the carnivores. Many plants have leaf parts capable of rapid movement, for example *Mimosa pudica,* the sensitive plant; others have elaborate insect-trapping mechanisms associated with pollination, and plants of many families have glands capable of secreting water, salt, mucilage, sugars, proteins and other products. It is the assemblage of features that gives carnivorous plants their unique character, the bringing together of so many individual adaptations into a functional combination directed to an end so unusual for a photosyn-



STALKED AND STALKLESS GLANDS of the dewy pine *Drosophyllum* appear in this scanning electron micrograph. Two kinds of glands, one for capture of the prey and the other for digestion, are present as in the butterworts, although plants belong to different families.



ANATOMY OF THE GLANDS of the dewy pine is shown in this drawing based on the original study by C. A. Fenner. Both the stalked glands that secrete the adhesive trapping mucilage and the stalkless glands that release enzymes after prey is trapped and then resorb products of digestion are connected directly with leaf's vascular system, or system of conductive vessels.

thetic plant that it seems grotesque and even macabre.

Students of plant morphology have long been interested in the special features of the carnivorous plants. Notable among them in Britain, besides Darwin, was Joseph Dalton Hooker, at that time director of the Royal Botanic Gardens at Kew, and his assistant, William Thiselton-Dyer, who succeeded Hooker as director. In Germany they included Karl I. E. von Goebel, a leading plant morphologist and anatomist, and C. A. Fenner. In North America, Francis E. Lloyd later contributed many detailed observations, notably on the trap of the bladderworts and its firing mechanism. Lloyd published his classic study, *The Carnivorous Plants,* in 1942; it is still a standard in the field today.

Little could be added to the remarkably precise work of these earlier observers until the advent of electron microscopy. The transmission electron microscope has revealed many features of subcellular structure connected with the processes of secretion and absorption in carnivorous plants, and in the past decade the scanning electron microscope has provided revealing new views of the traps and their associated glands.

The traps of the different types of carnivorous plants have several kinds of surface glands, some concerned with capture and digestion and some with other functions. Certain glands produce nectar as a lure for prey, much as the nectar-secreting glands in flowers that attract insect pollinators do. In *Nepenthes* such glands are around the lip of the pitcher; in *Sarracenia* glands of this type may form an "ant-guiding" trail up the outer surface of the pitcher.

In the butterworts the glands that secrete the viscous globules of the "flypaper" leaf surface are specialized for that function only. In the sundews, however, the stalked glands secrete not only the adhesive but also the enzymes that digest the captured prey. The sundews also possess many minute stalkless glands, which are visible only with the microscope; these glands are scattered over the upper surface of the leaf and on the stalks of the larger glands. The function of the stalkless glands is not known, but it seems possible they are concerned with the movement of the larger stalked glands. The larger glands, which earlier observers saw as "tentacles," move in the direction of the prey when they are stimulated. The movement results from the loss of turgor in groups of cells along the side of the stalk closest to the stimulus. The stalkless glands may be responsible for the withdrawal of fluid that causes the loss of turgor.

Glands of a similar type may serve the same function in the butterworts when the leaf rolls up to enfold a captured insect, forming what Darwin called a temporary stomach. Evidence that cer-

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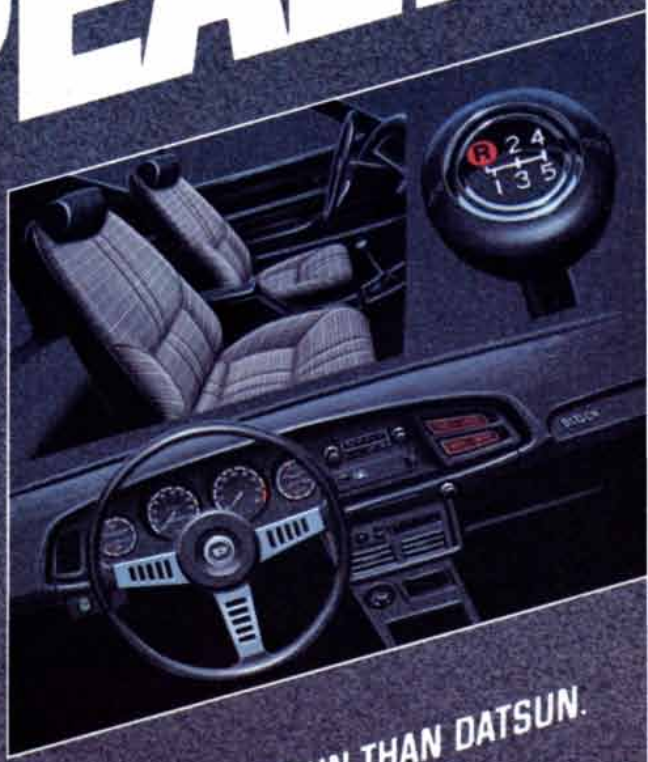

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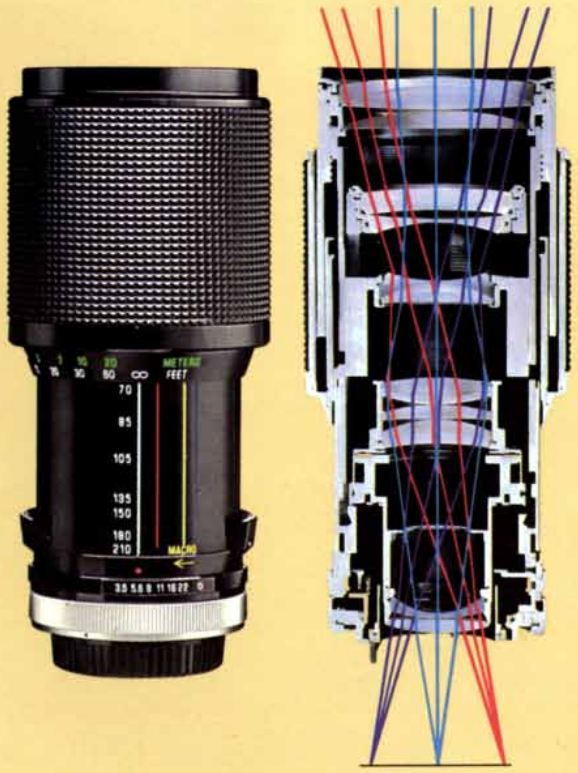

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tain glands perform this kind of function in the bladderworts has been presented recently by P. H. Sydenham and G. P. Findlay of Flinders University in Australia. The glands involved are on the outside of the bladders, and Sydenham and Findlay showed that the glands are concerned in the active transport of ions from inside the cavities of the traps to the bathing water outside. By setting up an osmotic gradient the ion movement generates an outward flow of water from the interior of the bladder. In the bladderworts such an outward flow is needed for the resetting of the trap. In the related genus *Genlisea* the prey moves along what is virtually a digestive tract, on the outside of which are glands similar to those found on the outside of the *Utricularia* bladder. Here they probably function to generate a flow of fluid along the tract.

The digestive glands of the carnivorous plants function under different conditions in the various genera according to the nature of the trapping mechanism. In *Nepenthes* the glands in the lower third of the pitcher become totally immersed in their own secretion fluids as the trap matures and before any prey is captured. In the larger species the accumulation of fluid can be as much as a liter. In the four other genera of pitcher plants smaller quantities of fluid collect, in some cases scarcely enough to immerse the glands, but here again it seems that the presence of prey is not necessary to stimulate secretion.

In contrast, the digestive glands on the leaf of the Venus's-flytrap remain dry until the prey is captured. If the trap is sprung with a pencil or a glass rod, the digestive glands remain dry and the leaf soon reopens. When an insect is trapped, however, the glands become active and a secretion pool builds up between the closed lobes of the leaf. Evidently the onset of secretion depends on chemical stimulation rather than mechanical. Although the glands in the bladders of the bladderworts are permanently immersed in water, it seems that they too do not secrete enzymes until they are stimulated by prey.

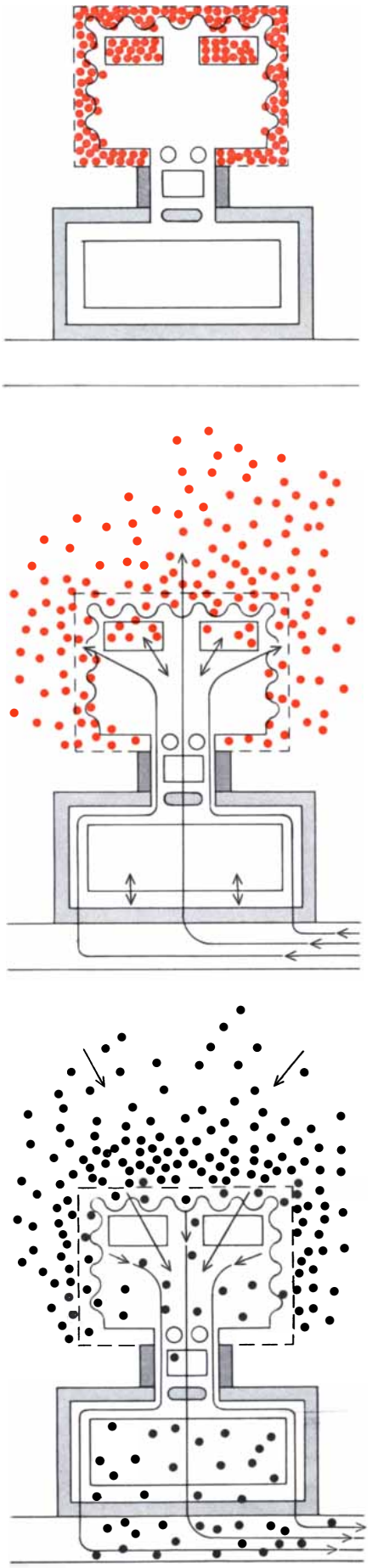
The sundews are different. Here the viscid secretion droplets accumulate on each gland head as the leaf matures; the load is held until the gland is touched by prey, and then still more secretion is released. The butterworts and the dewy pine *Drosophyllum* in some respects combine the features of the Venus's-flytrap and the sundews. In these genera there are two classes of glands on the leaf surface: stalked glands that carry secretion droplets at maturity and are mainly concerned with catching prey, and stalkless ones that remain dry until they are stimulated, when they pour out a less viscid secretion containing the digestive enzymes.

In Darwin's experiments on the sundews and butterworts he found that secretion could be stimulated by many sources of combined nitrogen but not, for example, by sugar or sodium carbonate. Insects excrete many nitrogenous products, but it has recently been suggested by Richard Robbins of the University of Oxford, who was studying the Venus's-flytrap, that the main stimulant may be uric acid, which is abundantly present in all insect excreta.

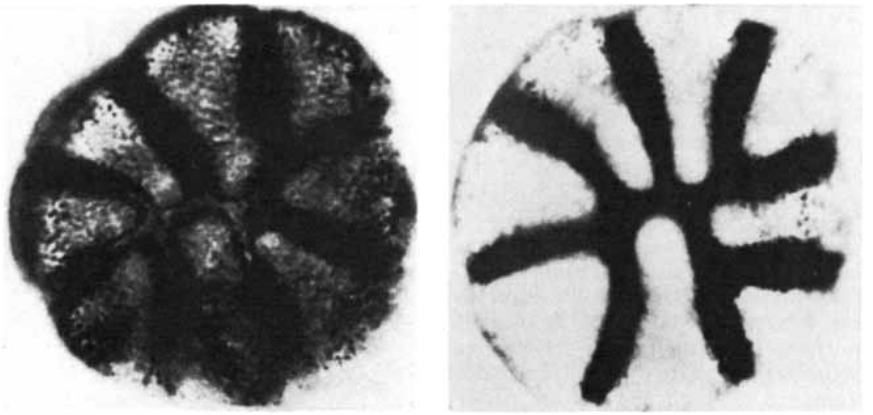
The digestive glands of the carnivorous genera vary considerably in their morphology. In the pitcher-plant genus *Nepenthes* the glands are some 60 micrometers in diameter and are partly sunk below the inner epidermis of the pitcher, where they are protected by an overlying flap of tissue. In the sundews the heads of the digestive glands are borne on multicellular stalks. The glands of the butterworts, both the stalked glands specialized for insect capture and the sessile ones concerned with digestion, are smaller and consist of many fewer cells than the glands of the other genera.

Notwithstanding such structural variations, a common architectural theme can be traced in all the digestive glands. Indeed, the theme is one that recurs in many other classes of plant-surface glands. In all cases it is the secretory cells that form an outer cap or layer one cell or a few cells thick, which lies directly over a specialized single cell or a pavement composed of several such cells side by side. This second layer is either in direct contact with the conducting vessels of vascular tissue or is separated from such tissue by two or three large "reservoir" cells.

The secretory outer cells of the gland are epidermal cells specialized for their function of enzyme synthesis, and they show many features reminiscent of those found in animal cells with similar functions. The network of cytoplasmic membranes known as the endoplasmic reticulum is well developed, and sometimes the elements are stratified, as they are in the cells of the animal pancreas. The endoplasmic reticulum is some-



DIGESTIVE SEQUENCE is traced diagrammatically, based on the author's studies of butterworts. At the top is a digestive gland in its resting phase. Colored dots in the rectangular upper vacuoles and in the invaginations of some of the cell walls represent the stored digestive enzymes. In the middle the stimulus of prey capture induces an osmotically driven outward flow of fluid. This flow flushes out the stored digestive enzymes, which reach the surface of the leaf through discontinuities in the cuticle, the otherwise impermeable layer coating the cell wall. At the bottom, after digestion is complete, the secretion pool on the surface of the leaf is resorbed, and the products of digestion (*black dots*) are transported through the cell wall and are distributed to the other parts of the plant through the plant's vascular system.



SITES OF ENZYME STORAGE in a butterwort digestive gland are revealed in these two light micrographs in different focal planes. The activity of the enzyme ribonuclease has been made visible by a cytochemical reaction that produces a dark product. At the left the focus is at the surface of the cells in the head of the gland; the dark granules of the reaction product show that the enzyme sites are clustered at the surface of the eight cells of the gland head. At the right the level of focus is at the center of gland. Most of the granules are associated with cell walls.

times associated with colorless plastids. Plastids are a type of organelle not found in animal cells, the most familiar example being the green chloroplast of the photosynthetic apparatus. In the secretory cells they may be concerned in some manner with the synthesis of protein, but so far there is little evidence on this point.

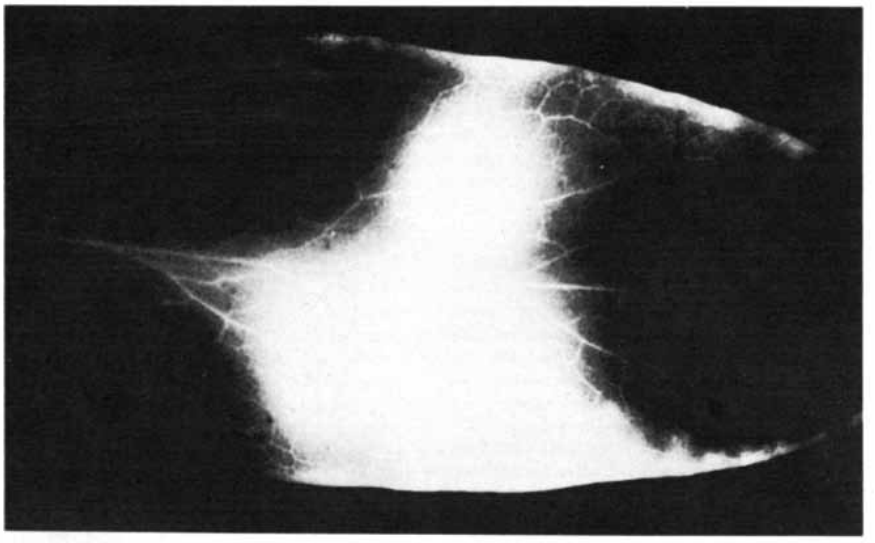
The secretory cells of carnivorous plants are comparable to those of animals in still other ways. The vacuoles of the secretory cells, formed as inflated bays of the endoplasmic reticulum, are sites of enzyme storage; they are therefore comparable to the lysosomes of animal cells. Furthermore, in some instances the nuclei of the secretory cells of the gland head contain more DNA than most body cells. This is a feature of such animal glands as the salivary gland of the fruit fly. And finally one can see a parallel in the luxurious development of the Golgi apparatus in those glands concerned with mucilage secretion on the leaves of the sundews and butterworts. Many types of animal gland show a similar development of this cytoplasmic system, which is concerned with the packaging of various synthetic products and their passage out of the cell.

The cells of animal glands have an outer membrane but do not have a cell wall of the kind found in plants, and many of the adaptations of the gland cells of the carnivorous plants are unique in that they have to do with the structure and function of the cell wall. The outer walls of the secretory cells are coated with a water-resistant, cutinized layer, but this layer is perforated by distinct pores or less well-defined discontinuities through which the secretions can reach the outer surface of the cell. The walls themselves are often modified for the storage and transfer of secretion products. Some are thickened irregularly to form extensive embayments or labyrinthine ramifications; the cell membrane follows these convolutions, so that the interface between the cell wall and the cytoplasm is greatly increased in area. For example, in the butterworts the interface may be enlarged by at least one order of magnitude. In the mucilage-secreting cells of the glands of the butterworts and the sundews the precursor products accumulate in the vesicles of the Golgi apparatus and discharge outward by fusing with the cell membrane, whence they pass across the cell wall and accumulate on its outer face. The vigor of this activity can be judged from the fact that the glands secrete several times their own volume of the mucilage during their active life.

The digestive glands secrete enzymes by other methods. In some instances the enzymes seem to diffuse directly through the plasmalemma, the outer membrane of the cytoplasm. In others, as in the sundews, the transfer involves a local disruption of the plasmalemma during the period of rapid secretion that follows the capture of the prey.

The cells of the layer underlying the secretory cells show some of the characteristics of those of the endodermal layer of the root, a sheath of cells that separates the root cortex from the inner conducting tissues. The side walls of the cells are heavily cutinized, and in them the plasmalemma is fused with the cell wall. Water cannot pass through the side walls, and so it is constrained to move through the cytoplasm.

Because the glands of the different genera of carnivorous plants function under widely different circumstances it is only to be expected that the processes of secretion and resorption should vary accordingly. My own observations of such "flypaper" trappers as butterworts and sundews suggest that these plants have secretory and resorptive mechanisms that are quite different from the ones likely to operate in pitcher plants. Among the butterworts some enzymes, notably amylases, are secreted by the stalked glands whose sticky exudate captures the insect prey, but it is the stalkless glands at the surface that furnish the main outflow of digestive fluid. Before stimulation the stalkless glands hold in reserve a supply of proteases, nucleases, phosphatases, esterases and other digestive enzymes, stored both in the spongy cell walls and in the vacuoles of the secretory cells. Stimulation induces an outpouring of fluid, and this flush-



MOVEMENT OF DIGESTED MATTER from a leaf surface back into the plant is traced in this autoradiograph of a butterwort leaf. A small amount of protein labeled with the radioactive isotope carbon 14 was placed on the surface of the leaf at one side of the midrib. After eight hours the radioactive digestion products (amino acids and peptides) had spread over much of the leaf surface (*large bright areas*). Movement of products in vascular system of leaf, mainly toward stem but also toward leaf margin and tip, is indicated by thin bright lines.

es the stored enzymes out onto the surface of the leaf.

One can follow the activity of the enzymes that build up in the pool of secretion on the leaf surface. The pool extends and deepens to engulf the prey, and then, after the digestion is completed, the fluid is resorbed. Generally speaking, the size of the pool is related to the size of the prey. A small captive insect induces only a modest flow of digestive fluid, and in the butterworts after such a catch the pool may reach its maximum size in an hour or so. A large insect may stimulate so much secretion that surplus fluid will drip off the edges of the leaf. Under such circumstances the secretion may go on for several hours, and its volume may exceed the entire volume of liquid originally held in the leaf, showing that the flow is supplemented by the passage of water from elsewhere in the plant through the vascular system. Overstimulated leaves do not complete the digestive cycle. Resorption does not take place, and the leaf begins to rot, a victim, so to speak, of plant indigestion.

If the digestive cycle is normal, the period of resorption is only a little longer than the period of initial outflow. Knox and I found in our tracer experiments that the labeled end products of the digestion of algal protein passed from the secretion pool back into the leaves of butterworts through the same glands that had supplied the digestive fluid. The spongy gland walls where the digestive enzymes had been stored became the channels for the inward passage. The products of digestion then passed through the endodermal cells into the vascular system of the leaf, where autoradiography detected them in the xylem vessels.

In other experiments we added a marker substance, colloidal lanthanum nitrate, to the secretion pools on butterwort leaves just as resorption was beginning. The marker is opaque under the electron microscope. As in the experiments with radioactive tracers, the substance could be tracked entering the gland cells through discontinuities in the cutin layer of the cell walls and moving on into the endodermal cells.

The protoplasts of the butterwort gland cells show striking changes during the process of digestion. In the secretory half of the cycle the vacuoles shrink and eventually become ill-defined. At the same time the plasmalemma, which is normally in continuous contact with the sinuous inner surface of the cell wall, loses this contact. As the glands enter the resorption phase of the cycle the cytoplasm condenses, the nucleus of the cell becomes clumped and the labyrinthine invaginations of the cell walls become blurred, probably through a partial dissolution of the wall structure.

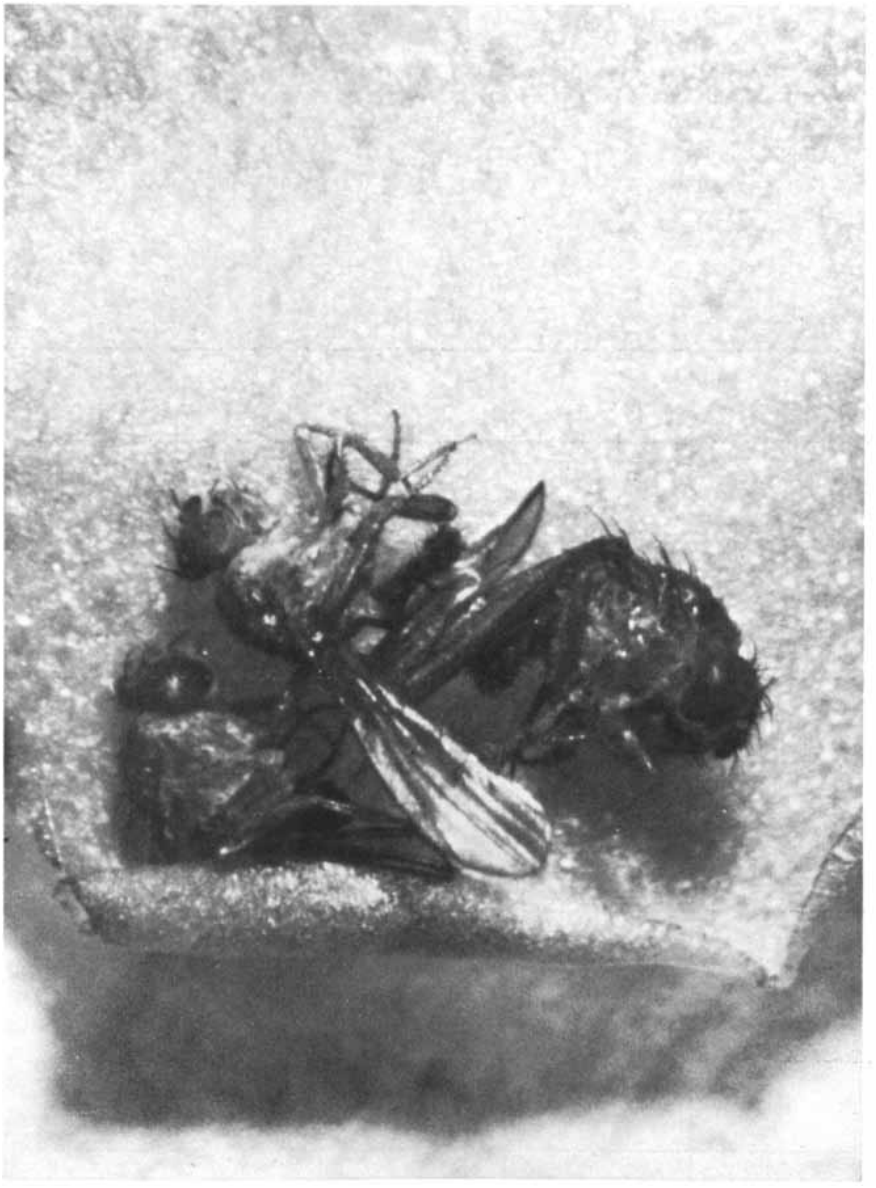
In a detailed electron-microscope study of Venus's-flytrap glands during the digestive cycle D. Schwab, E. Simmons and James Scala of the Owens-Illinois Corporate Technology Technical Center in Toledo, Ohio, found corre-

FAMILY AND GENUS	NUMBER OF SPECIES	RANGE	TRAP: ACTIVE: SUCTION	TRAP: ACTIVE: SNAP	TRAP: PASSIVE: PITFALL	TRAP: PASSIVE: ADHESIVE	DIGESTIVE ENZYMES: PEROXIDASE	RIBONUCLEASE	LIPASE	ESTERASE	ACID PHOSPHATASE	AMYLASE	MALTASE	INVERTASE	CHITINASE	PROTEASE	UREASE
NEPENTHACEAE																	
NEPENTHES	60 SPECIES	BORNEO AND NEARBY				X		?	+	+	+	+	–			?	+	
SARRACENIACEAE																	
SARRACENIA	9 SPECIES	NORTH AMERICA				X				?	–		?	–	+		+	–
HELIAMPHORA	4 SPECIES	NORTHEAST SOUTH AMERICA				X												
DARLINGTONIA	1 SPECIES	CALIFORNIA, OREGON				X				–			?	–	?		+	–
CEPHALOTUS	1 SPECIES	SOUTHWEST AUSTRALIA				X							–				+	
DROSERACEAE																	
DROSERA	90 SPECIES	COSMOPOLITAN					X	+		–	+	+	–				+	
DROSOPHYLLUM	1 SPECIES	WESTERN MEDITERRANEAN					X	+			+	+	–				+	
DIONAEA	1 SPECIES	NORTH AND SOUTH CAROLINA			X						+	+					+	
ALDROVANDA	1 SPECIES	EUROPE, AFRICA, ASIA			X						+	+					+	
LENTIBULARIACEAE																	
PINGUICULA	30 SPECIES	NORTHERN HEMISPHERE					X	–	+		+	+	+			–	+	
GENLISEA	15 SPECIES	SOUTH AMERICA	X								+	+					+	
UTRICULARIA, BIOVULARIA, POLYPOMPHOLYX	150 SPECIES	COSMOPOLITAN	X								+	+					+	
BYBLIDACEAE																	
BYBLIS	1 SPECIES	AUSTRALIA					X											

TRAPPING ACTION of 13 genera of carnivorous plants belonging to five plant families is indicated by an *X* in this table. The presence (+) or absence (–) of 11 enzymes in the digestive fluid of each genus is given at the right. A question mark indicates that the enzyme may be present; a blank, that there is no information on whether it is present. The bladderwort genus *Utricularia* is sometimes subdivided into three genera on the basis of its flower forms, but the bladder trapping mechanism of the plant is the same in all of them.

sponding changes in the fine structure of the cell walls. In the secretory half of the digestive cycle the invaginations of the cell wall became eroded and the plasmalemma took on a smoother profile. In the butterwort, where each gland functions only once, the changes are irreversible. In the Venus's-flytrap, however, the walls of the secretory cells can be rebuilt and the cells can return to their former state before the leaf reopens to catch new prey.

The butterworts, and probably other genera of carnivorous plants with the same pattern of digestive-gland function, have thus evolved a definite digestive cycle. The secretion and resorption phases, respectively associated with massive movements of fluid first outward and then inward through each gland, are geared to far-reaching changes in the gland cells. There appears to be no such cycle in the pitcher plants. In this group the early period of secretion is followed by a prolonged interval when the pitcher holds a more or less constant amount of fluid. Trapped insects accumulate in the fluid, and the digestion products are withdrawn continuously from the pitcher into the main body of the plant. In a number of ingenious experiments Ulrich Lüttge of the Darmstadt School of Technology in West Germany has demonstrated that the same glands responsible for the secretion of pitcher-fluid enzymes also participate in the uptake of the digestion products. The process is essentially the same as in the butterworts except that resorption is achieved not through a wholesale uptake of fluid but through the selective inward passage of specific molecules and ions.



"TEMPORARY STOMACH" of the butterwort, as Charles Darwin called it, is seen unrolling in this photograph after the digestion of three fruit flies. No enzyme that can digest the chitinous external skeleton of the flies is present in the digestive fluid of butterwort glands, so that the bodies of the flies remain as empty shells after their inner tissues have been digested.

Lüttge found that the rates of uptake differ with the substance involved. For example, the amino acid alanine moved into the gland faster than phosphate ions, and phosphate ions were transported faster than sulfate ions. To explain these varying rates it is necessary to assume that participating in the uptake are "pumps" with different specificities. The pumps would be driven by the metabolic processes of the plant, and such an assumption is supported by the fact that transfer is partially paralyzed when metabolic inhibitors are present. Just where the pumps are located is not known, but it is significant that the large digestive glands of the *Nepenthes* pitcher possess the equivalent of an endodermal layer. Here, because of the thickening of the side walls of the cells, the fluids must move through the protoplasts. The metabolically driven transport systems may be incorporated in the membranes of the endodermal cells, if not in the membrane of the secretory cells themselves.

In the butterworts it is scarcely possible to explain the events of the digestive cycle in terms of selective pumping. The system involves mass flow in both directions. I have suggested that the initial outflow of digestive fluid following the capture of the prey is driven osmotically. If one supposes the stimulus of capture induces a rapid breakdown of the cell-wall polysaccharides, this could be the source of soluble sugars that could promote rapid fluid transfer into the gland cells by osmosis. In the initial period this flow would be through the intact membranes of the endodermal cells, water being abstracted first from the adjacent reservoir cell and then, through the contiguous vascular elements, from the rest of the plant. One can visualize the flow's reversing at the end of the secretion phase because control is lost by the now irreversibly altered endodermal cells. Resorption from the leaf surface would then be a matter of reverse flow through the gland and into the vascular system in response to diffusion gradients set up elsewhere in the plant.

The uptake mechanism Lüttge has proposed for the *Nepenthes* pitcher is distinctly similar to the mechanism assumed to be responsible for the normal uptake of soil minerals by plant roots. It is as though in each pitcher the plant were creating its own enriched soil solution and abstracting from it the minerals it needs. The analogy seems even apter when one considers that after the pitcher has been open for some time its fluid becomes infected with a commensal flora, mostly bacteria, that quickly as-

sumes most of the burden of digesting the captured prey.

At this stage the pitcher fluid has become distinctly alkaline—and distinctly malodorous. The plant enzymes may now play little part in the digestive process; the digestive glands act mainly as organs of absorption, selectively taking up and concentrating useful products. To carry the analogy even further, it is possible that pitcher plants rooted in the ground may benefit at the beginning of each season's growth from a temporary local enrichment of the soil by nutrients released by the decay of the preceding season's dead pitchers and their partially digested contents. Here the useful products of predation would be taken up in the usual plant fashion: through the roots rather than the leaves.

It seems clear that the supplemental nutrients available to carnivorous plants offer them special advantages, particularly in environments where certain kinds of nutrients are scarce. It has commonly been supposed the principal benefit of the capture and digestion of animal prey by a plant is a supplemental supply of nitrogen. Current research indicates, however, that supplementary phosphorus is equally important and perhaps in some circumstances even more important. The presence in the digestive-gland secretions of nuclease and phosphatase enzymes may well be related to this requirement. In habitats where plant growth is limited by deficiencies of major nutrient elements such as phosphorus—or of one or more of the other elements required only in trace amounts—the advantages to be gained by acquiring contributions from animal prey would be substantial.

So much for the advantages of the carnivorous habit. Are there counterbalancing costs? Most plants live in competitive circumstances; is the carnivorous plant's energetic investment in the synthesis of digestive enzymes and other secretion products, not to mention the investment in the plant's elaborate structural adaptations, cost-effective? The intriguing conclusion of this line of thought is simply that any energy balance sheet is scarcely relevant. In all but a few instances the carnivorous plants are found in places where an abundance of sunlight, adequate carbon sources and unlimited access to water during the growing period place no limit on photosynthesis, the primary energetic resource of the plant. Thus the energetic cost of capturing an atom of nitrogen or of phosphorus, or of whatever else may be the principal growth-limiting element, is not significant. If the capture of such vital nutrients enables the plant to survive in places where no noncarnivorous competitor can intrude, then it is proved that, whatever the energetic cost may be, the investment is justified.

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Our new speakers color sound.

Anybody's do.

Should they tell you otherwise, they speak with forked frequency response.

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But it would hardly change the frequency response—or any other measurements.

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But we stuck it out. Applying the age-old technique of trial and error.

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So we did the only logical thing.

We built a plant. Which does nothing but produce—under outrageously close control—the components for our speakers.

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Improvements that are heard and not seen.

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The SSU-3000 and SSU-4000. Great speakers like these deserve an audience.

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Carbon fiber is light and strong. Light, so our speaker needs less power to operate it, and is therefore more efficient.

Light, so our speaker cone reacts quickly to stops and starts in the signal. The result: improved transient response.

Strong, so the cone won't bend out of shape in the high frequency range.

Moreover, carbon fiber won't resonate much. It has a low Q, and it took someone with a high IQ to realize it would absorb the unwanted vibration.

Unwanted vibration is also reduced by our cast aluminum basket, which is superior to a cheap stamped metal one.

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At which point, far from heckling our speakers, you'll be tempted to give them a standing ovation.

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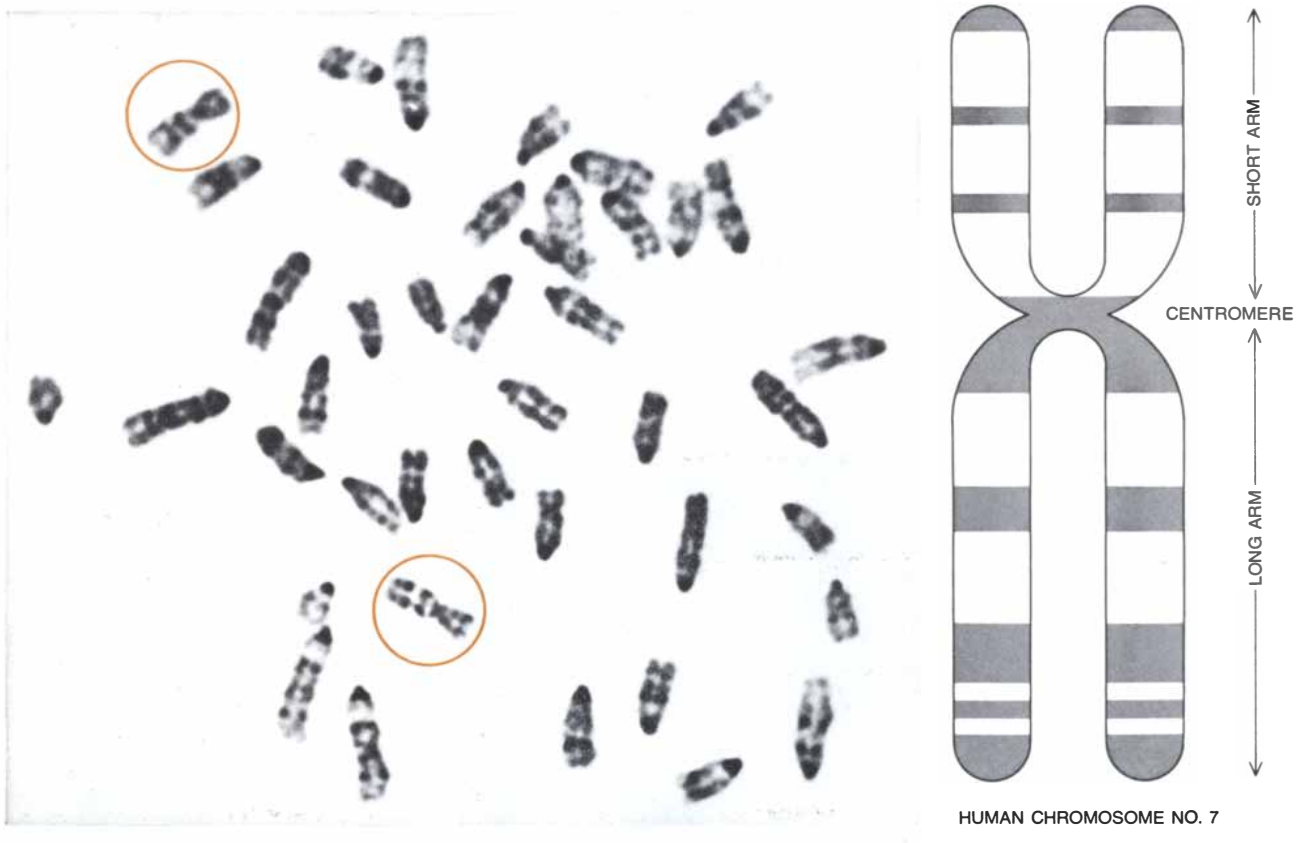
The Genetics of Human Cancer

A new experimental approach makes it possible in certain cases to identify the specific human chromosome involved in the transformation of a normal cell into a tumor cell

by Carlo M. Croce and Hilary Koprowski

The evolution of the modern view of cancer as a disease that arises from the transformation of the genetic material of one or more of the body's normal tissue cells, leading to the uncontrolled proliferation of descendant cells, can be traced back in part to the pioneering theoretical studies of the German zoologist Theodor Boveri, who in 1914 formulated his "somatic mutation" hypothesis of the origin of cancer. According to Boveri's theory, which in modified form is widely accepted by cancer investigators today, the "primordial cell" of a malignant growth is a somatic cell (any cell other than a germ cell) that "contains as a result of an abnormal process a definite and wrongly combined chromosome complex." He was referring, of course, to the array of rodlike bodies into which the genetic material is marshaled for part of the life cycle of the cell. He added: "This is above all the cause of the tendency to rapid cell proliferation, which is passed on to all descendants of the primordial cell."

Boveri, who also recognized the importance of environmental factors such as chemical carcinogens and ionizing radiation as triggering agents in malignant transformation, went so far as to speculate on the identity of the presumed can-



HUMAN CANCER CHROMOSOMES are indicated by the colored circles in the photomicrograph at the left. All the chromosomes shown were obtained from the nucleus of a hybrid cell formed by fusing a human tumor cell with a mouse cell. The human cell had been transformed into a malignant cell in the laboratory by infecting it with the tumor-inducing virus designated SV40 (simian virus 40). The hybrid cell contains 40 mouse chromosomes (*not circled*), the entire complement of the parental mouse cell. The two human chromosomes present (out of a normal complement of 46) can both be identified on the basis of their distinctive pattern of dark and light bands as human chromosome No. 7. The banding pattern is accentuated in the photomicrograph by the addition of a special stain to the preparation. A diagram of human chromosome No. 7 appears at the right. The presence of chromosome No. 7 in tumorigenic hybrid cells of this type, coupled with its absence in the nontumorigenic hybrids, is taken as strong evidence that No. 7 is the human chromosome integrating the genetic material of the SV40 virus, thus making it responsible for the malignant transformation of normal human cells grown in culture.

cer chromosomes. "It is conceivable," he wrote, "that there is for a definite kind of cell only a single abnormal chromosome combination that gives the cell the quality of malignity."

Over the past two decades, thanks to the advent of a number of powerful new laboratory techniques, it has become possible to detect nonrandom chromosomal changes in association with several types of human cancer. More recently, however, a new method has been devised for identifying what Boveri called the "single abnormal chromosome combination" responsible for the transformed cell's "quality of malignity." The principal technique on which the new approach depends is the fusion, or hybridization, of transformed human somatic cells with the cells of other animals. Here we shall describe how present-day cell biologists, including our group at the Wistar Institute of Anatomy and Biology in Philadelphia, have exploited these techniques and others to advance the line of inquiry begun by Boveri more than six decades ago.

Can a predisposition to cancer be inherited? It is now well established, mainly on the basis of the familial distribution of various types of cancer in a given population, that certain types are indeed heritable. For example, it is possible to demonstrate a hereditary predisposition in several comparatively rare cancers that originate in the human embryo and appear during infancy or early childhood. One such hereditary tumor, retinoblastoma, has been studied more intensively than any of the others. Retinoblastoma is a condition that affects the retina of both eyes (bilateral) or one eye (unilateral). It is usually detected after a child's vision becomes impaired during the first few years of life. The disease occurs at a frequency of one child in 25,000, accounting for almost 1 percent of the total number of cancer deaths in infancy and for 5 percent of the cases of childhood blindness. All bilateral retinoblastomas and a small percentage of unilateral retinoblastomas are transmitted within families as autosomal-dominant traits, that is, as diseases caused by the presence of a single dominant gene on one of the parents' autosomes, or nonsex chromosomes. (Another manifestation of the disease, sporadic unilateral retinoblastoma, is apparently not inherited.) Polyposis of the colon, a condition characterized by the appearance of small benign growths, or polyps, in the wall of the intestine, can also be inherited as an autosomal-dominant trait.

Individuals with inherited tumors such as familial retinoblastoma or polyposis of the colon appear to be predisposed to develop tumors in other parts of the body as well. For example, patients with familial retinoblastoma tend to develop bone tumors, leukemia, kidney tumors and muscle tumors more often than other people. In addition they are more likely to develop tumors in areas of the body exposed to radiation therapy. Bone, brain and skin tumors have also been found at a greater than average frequency in patients with inherited polyposis of the colon.

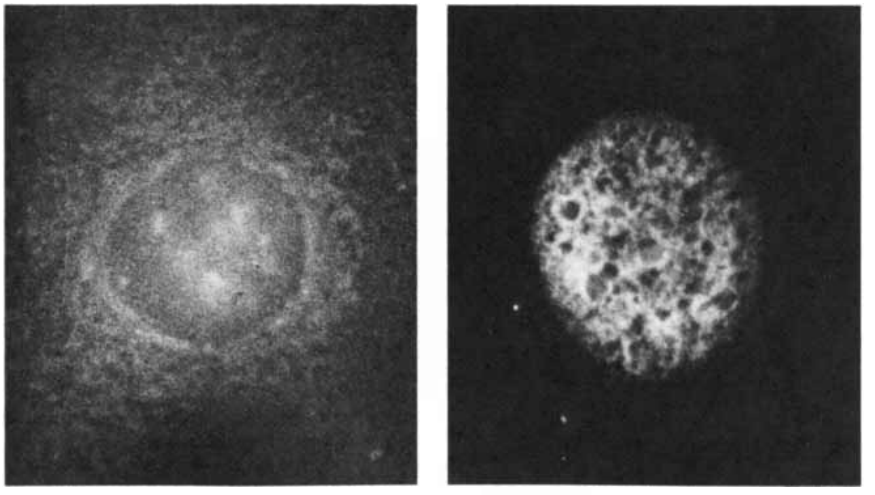
The one characteristic common to all tumor cells is their uncontrolled proliferation. Tumor cells somehow escape the restrictions the body imposes on normal cells that limit either their rate of multiplication or the number of times they can divide. The cells of certain malignant tumors also tend to migrate more freely through neighboring tissues than normal cells, thereby infiltrating distant organs to form metastases, or secondary tumors. Boveri's somatic-mutation theory of the origin of cancer postulates that whatever the cause of a particular tumor is—environmental factors or hereditary predisposition—it is basically a change in the genome, or full complement of genes, of a normal tissue cell that initiates the sequence of steps leading to the growth of the tumor.

If, however, the inheritance of the genes for retinoblastoma and polyposis of the colon were the only event responsible for the development of these particular tumors, one would expect all the epithelial cells of the retina and the colon to be tumorigenic. That is not what is observed. On the contrary, the number of tumor cells in the affected tissues is generally quite small, and the great majority of the cells remain normal.

To account for the development of inherited tumors of this type Alfred G. Knudson, Jr., of the University of Texas Graduate School of Biomedical Sciences suggested in 1971 that there must be an additional precipitating event. According to Knudson's hypothesis, such tumors will result only if a second mutation affects the retinal cells or the colon cells of individuals already carrying the genes for retinoblastoma or polyposis. If the additional mutation (or mutations) takes place in the cells of tissues other than the retina or the colon, that would account for the secondary tumors sometimes observed to arise in such gene carriers either spontaneously or after irradiation.

In the case of familial retinoblastoma one or more tumors of the eye typically appear at the age of 14 months, whereas in sporadic unilateral retinoblastoma (the nonfamilial form of the disease) the single tumor is usually not discovered until after the age of 30 months. Because of the time disparity and because of the lower overall frequency of sporadic retinoblastoma Knudson proposed that the two mutations required for the appearance of this tumor must both occur in the same retinal cell, which then gives rise to malignant progeny. It is not known at present whether two or more mutations are required to convert a normal cell into a tumor cell in any other type of cancer.

Boveri's assumption of the unicellular origin of cancer has been challenged recently on the basis of findings arising from a new experimental approach to the problem developed by Philip J. Fialkow of the Veterans Administration Hospital in Seattle. With the aid of a technique based on the ability of tumors to produce one form or both forms of a certain sex-linked human enzyme Fialkow has been able to show that although many types of tumor do originate in a single "primordial" cell, other types are clearly multicellular in origin.



MALIGNANT TRANSFORMATION of human cells by SV40 viruses results in the production of a characteristic tumor antigen (known to biologists as *T* antigen) within the nucleus of the transformed cell. The presence of this antigen can be detected by means of a fluorescent antibody serum. In photomicrographs the transformed, or antigen-positive, cells have bright nuclei (*right*), whereas the untransformed, or antigen-negative, cells have dark nuclei (*left*).

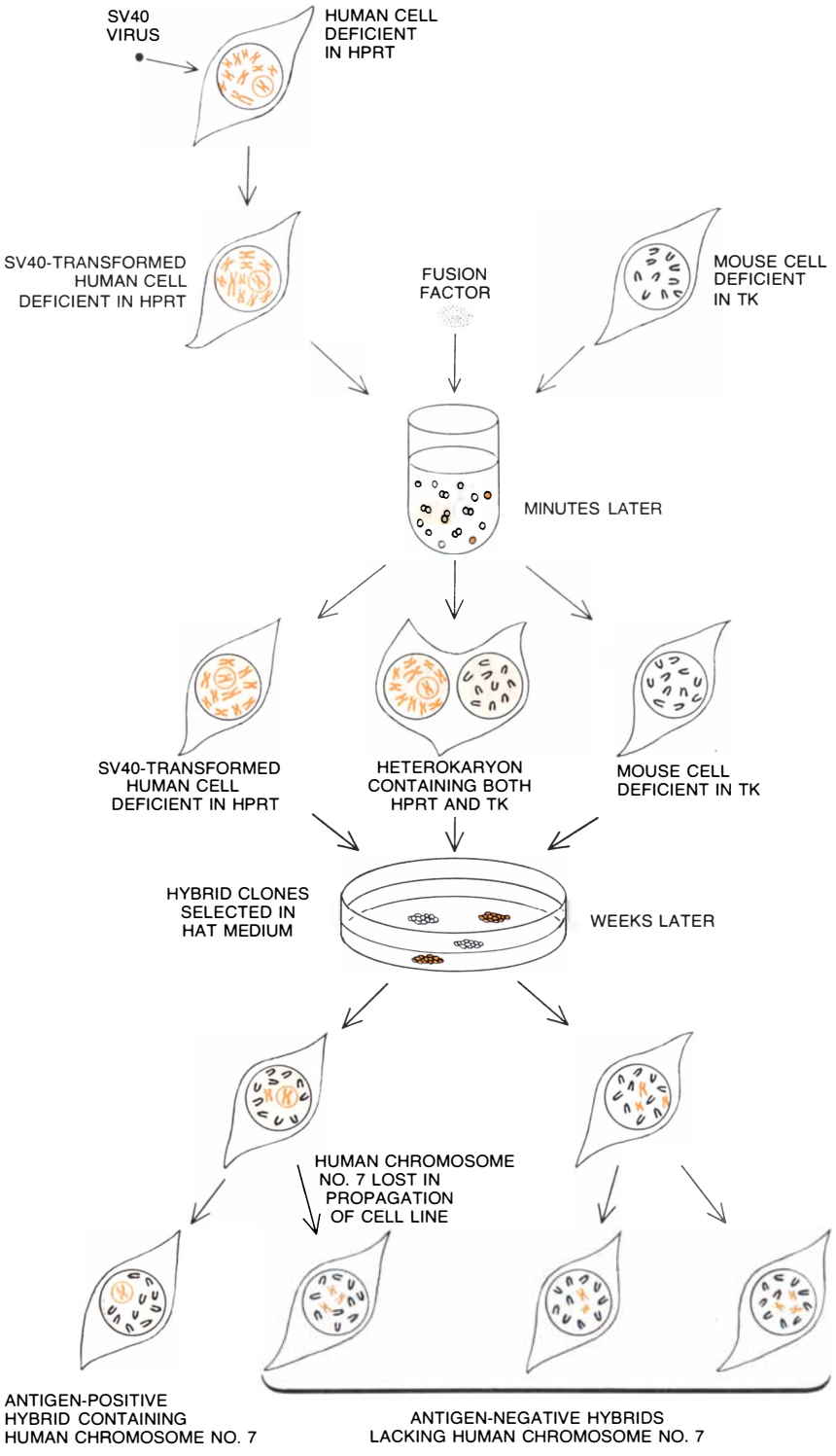
How can cancer chromosomes be identified? Beginning in 1960 various investigators have succeeded in associating specific chromosomal changes

with different types of tumor. Peter C. Nowell and David A. Hungerford of the University of Pennsylvania School of Medicine, for example, observed nonrandom chromosomal aberrations characterized by the deletion of the long "arm" of the human chromosome designated No. 22 in abnormally proliferating white blood cells derived from patients with chronic myelogenous leukemia. Janet Rowley of the University of Chicago later found that in this case the long arm of chromosome No. 22 is specifically transferred to chromosome No. 9. Nonrandom chromosomal changes have been observed in other types of leukemia, including the acute version of myelogenous leukemia. More recently Rowley found a doubling of chromosome No. 1 in 34 patients suffering from blood disorders such as acute nonlymphocytic leukemia and polycythemia vera (a rare disease characterized by the abnormal proliferation of red blood cells).

In addition J. Mark and his co-workers at the University of Lund have reported that in tumor cells obtained from patients with meningiomas (benign tumors of the brain) one end of chromosome No. 22 is deleted, and it does not appear to be transferred to any other chromosome. In the case of familial retinoblastoma it was shown by K. P. Lele, L. S. Penrose and H. B. Stallard of University College London that the chromosomal abnormality involves the deletion of the long arm of human chromosome No. 13.

Although many other chromosomal aberrations have been observed in cells obtained from a variety of benign and malignant tumors of man, there remain many cases in which one can find no such evidence of chromosomal abnormality in association with a tumor. In general, therefore, it has not been possible to say whether a specific chromosomal change invariably results in a given type of human malignancy. Moreover, tumors induced in the laboratory by means of physical, chemical or viral mutagens might not result in morphologically observable chromosomal changes. It is in these cases that the new experimental method for identifying human cancer chromosomes has proved most valuable.

The experimental use of viruses to transform normal human cells into cancer cells was first demonstrated more than 15 years ago by one of us (Koprowski) in collaboration with a group of coworkers at the Wistar Institute. In such a biological system the DNA of the virus becomes integrated in some way into the DNA of the host cell, and the transformed cell can be propagated indefinitely in standard tissue-culture glassware. The descendant cells exhibit permanent hereditary changes: they proliferate continuously; they form clones, or



HYBRIDIZATION TECHNIQUE employed by the authors and their colleagues at the Wistar Institute of Anatomy and Biology in Philadelphia is illustrated here. SV40 viruses were first used to transform human cells obtained from patients with a deficiency in the enzyme hypoxanthine phosphoribosyl transferase (HPRT). The transformed human cells were then fused with mouse cells deficient in the enzyme thymidine kinase (TK), a process that is facilitated by the addition of a chemical fusion factor. The mixture of fused and unfused cells is next put in a culture medium containing three other substances: hypoxanthine, aminopterin and thymidine (HAT). Cells that are deficient in either HPRT or TK die in the HAT medium, but the fused heterokaryon cells (cells with more than one type of nucleus) survive because they contain both enzymes: HPRT from the TK-deficient mouse cell and TK from the HPRT-deficient human cell. The hybrid cells, each of which carries the full complement of mouse chromosomes but only a few human chromosomes, grow into cell colonies, called clones, in the HAT medium. Hybrid clones that retain human chromosome No. 7 are antigen-positive, whereas those that retain combinations of human chromosomes other than No. 7 are antigen-negative. Antigen-positive cells that later lose chromosome No. 7 become antigen-negative.

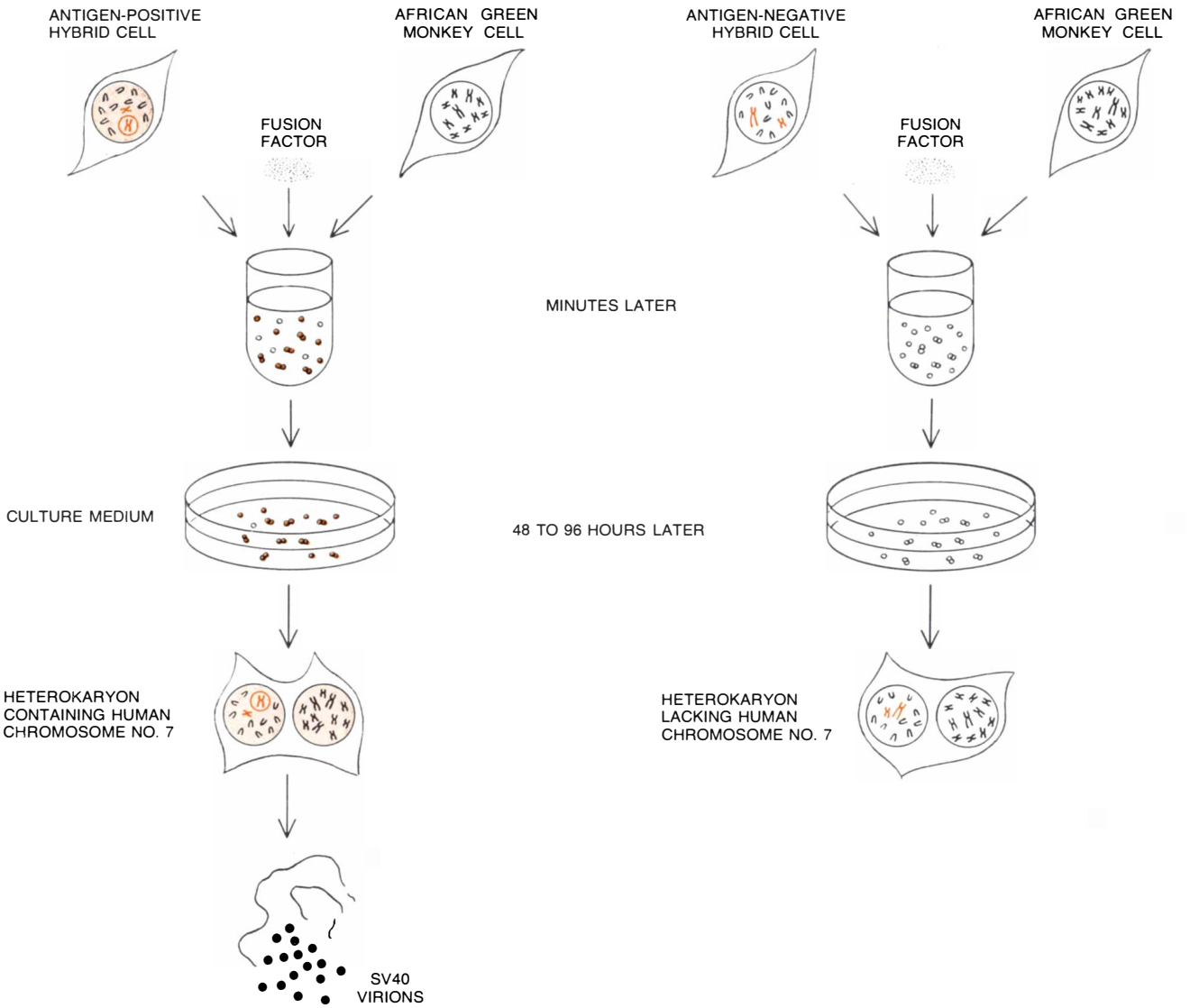
identical-cell colonies, in a semisolid growth medium, and they are able to induce tumors after being injected into experimental animals [see "The Induction of Cancer by Viruses," by Renato Dulbecco; SCIENTIFIC AMERICAN, April, 1967].

In a recent series of experiments conducted with Anthony J. Girardi at the Wistar Institute we made use of the technique of somatic-cell hybridization to determine whether such a tumor-inducing virus is in fact integrated into a specific human chromosome, and therefore whether the chromosome identified in this way is responsible for the malignant transformation of the cell.

For our purposes the most important aspect of the technique of somatic-cell hybridization is the fact that a large part of the normal human complement of 46 chromosomes (22 pairs of autosomes and the two sex chromosomes) is typically lost in the hybrid cells formed by fusing human cells with mouse cells. Hence by repeatedly testing the fused cells for particular characteristics, one can in principle determine whether or not a specific human chromosome is retained in the hybrid.

In one such experiment we employed the virus strain designated SV40 (simian virus 40) to transform human cells obtained from a patient suffering from Lesch-Nyhan syndrome, a sex-linked disorder characterized by a deficiency in the enzyme hypoxanthine phosphoribosyl transferase (HPRT). Cells with this particular enzyme deficiency cannot live in a culture medium that contains a mixture of three other substances: hypoxanthine, aminopterin and thymidine (known as the HAT medium). As it happens, mouse cells deficient in the enzyme thymidine kinase (TK) also die in the HAT medium. Hybrids formed by fusing these two types of cell, however, can grow in the HAT medium [see "Hybrid Somatic Cells," by Boris Ephrussi and Mary C. Weiss; SCIENTIFIC AMERICAN, April, 1969].

After we eliminated all but the fused cells from our test cultures by passing them through such a selective medium we obtained two different populations of hybrids: one of them expressed the characteristic tumor antigen associated with SV40 transformation; the other did not [*see illustration on preceding page*]. The antigen-positive hybrid clones (those that showed the presence of the SV40 tumor antigen) always retained the human chromosome designated No. 7,



SV40 VIRIONS (virus particles) can be recovered from SV40-transformed hybrid cells by fusing them in turn with African green monkey kidney cells, which are known to produce factors that promote the replication of SV40. In this experiment both the antigen-positive hybrids (which contain human chromosome No. 7) and the antigen-negative hybrids (which contain human chromosomes other than No. 7) were fused with the monkey kidney cells. When the new hybrids were later assayed, it was found that SV40 virions could be detected only in those heterokaryons derived from the antigen-positive hybrid clones and not in those derived from the antigen-negative hybrid clones, thus confirming that the genome, or full set of genes, of the SV40 virus is indeed integrated into human chromosome No. 7.

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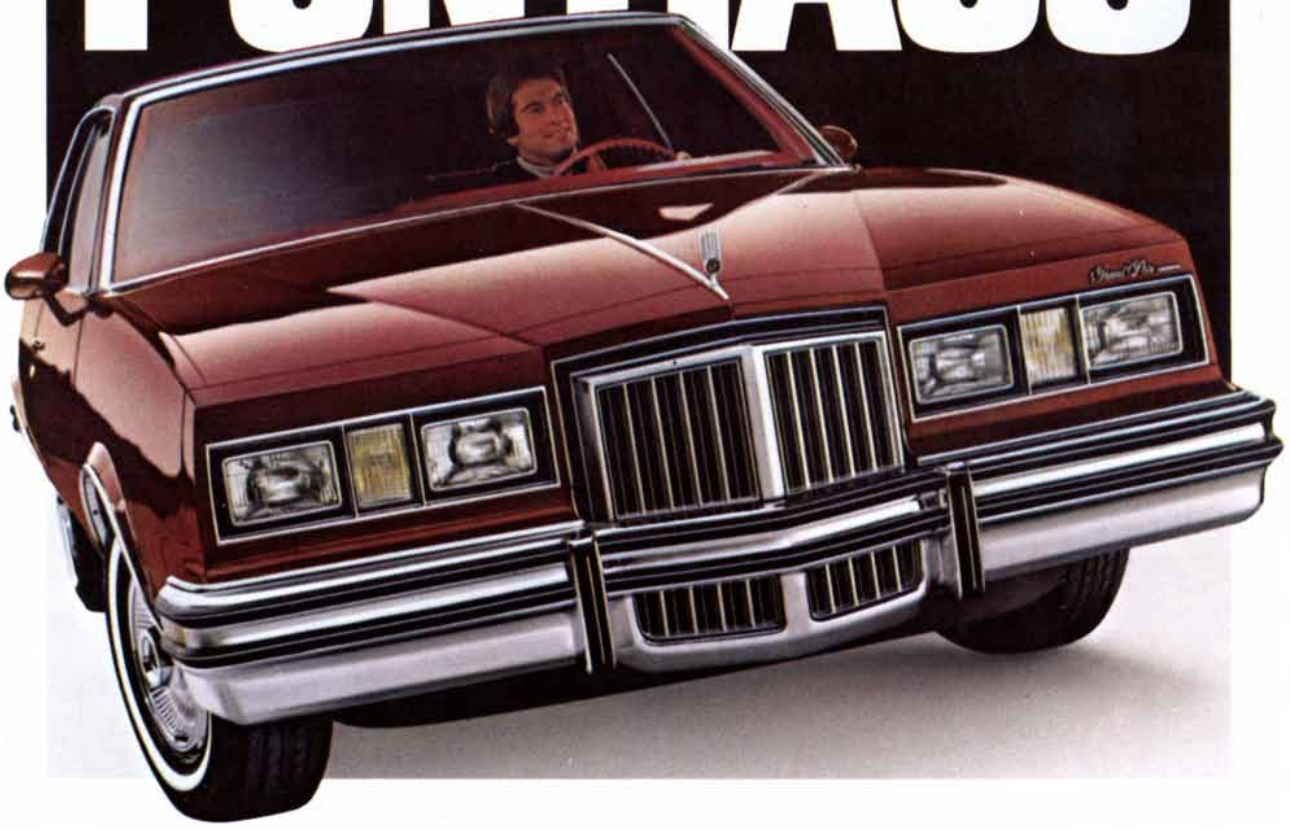

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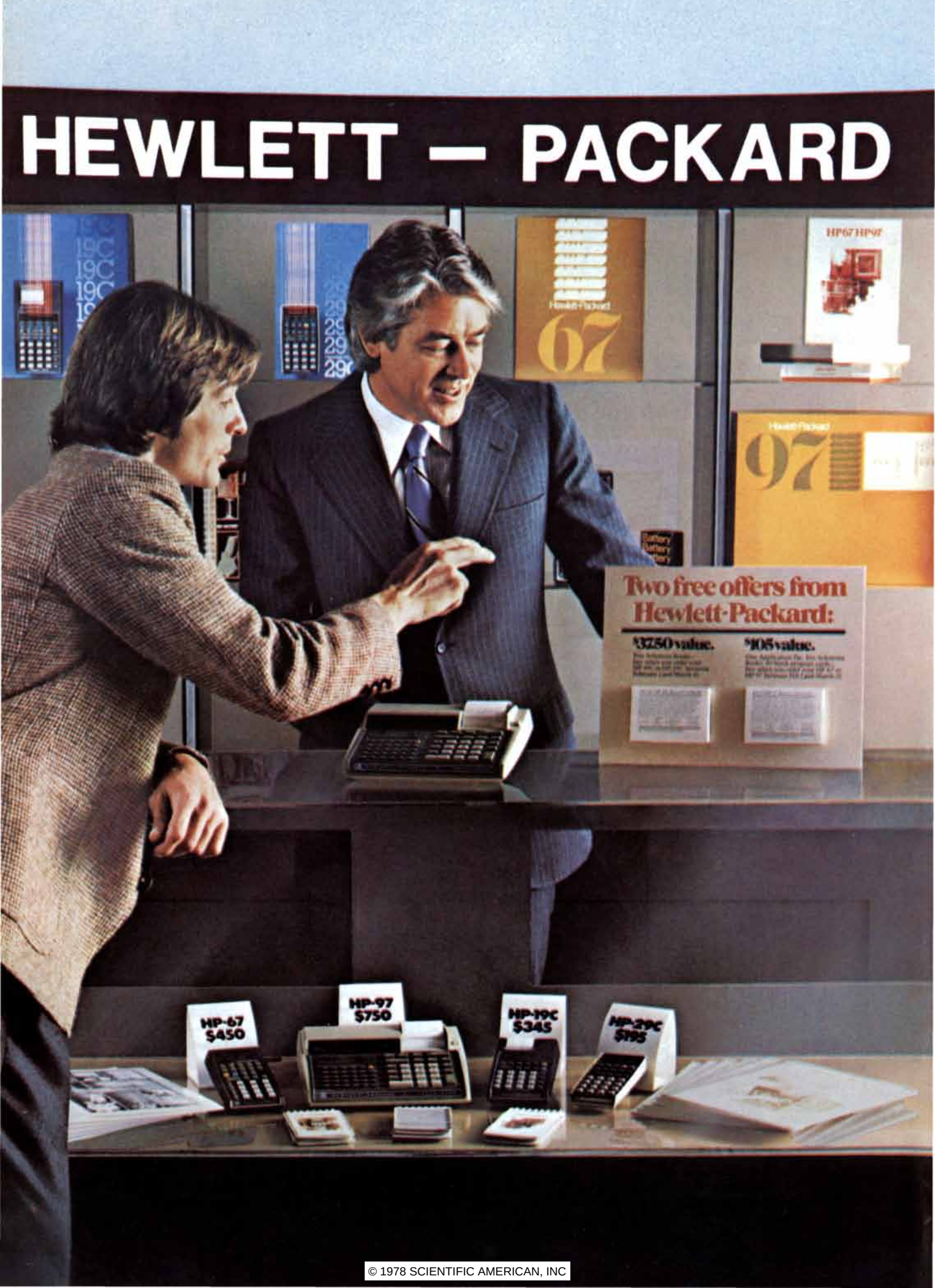

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On Photographing the Invisible

To the naked eye, it was a Swedish 80-ore postage stamp. A rarity, and very valuable.

The camera, however, told quite another story. The stamp was a counterfeit.

Faint traces of tampering that were hidden to the naked eye were revealed by the camera. Someone, somewhere, had ingeniously altered the stamp by chemically removing a surprint. The stamp was worthless.

To the naked eye (left), the stamp was genuine. To the camera (right), it was a counterfeit. Note the faint, dark traces of tampering now revealed in the upper section.

What manner of exotic camera was this that could "see" the invisible?

The lens: one of the 20 in the Hasselblad arsenal, the 105mm Zeiss UV-Sonnar f4.3. Designed for photographywithin the ultraviolet portion of the electromagnetic spectrum, its costly quartz elements can detect radiations that are unseeable by the human eye.

It has peered at objects in outer space, examined forgeries, laid bare the secrets of counterfeit money. Not a lens for everyone, obviously, but an indication of just how awesomely comprehensive the Hasselblad System is.

The camera: an otherwise perfectly standard Hasselblad 500C/M, normally fitted with an 80mm Zeiss Planar f2.8 multi-coated lens.

This is the basic model that allows you to tap into the vast Hasselblad System. It is one of the most bewilderingly versatile cameras the world has ever known. Yet so marvelously simple to operate that it often plays the part of the family snapshot camera.

A True System.

The Hasselblad System is a prodigious array of 4 cameras, 20 lenses, 8 viewfinders, 9 film magazines, and over 300 other accessories. Choose the right pieces, and your 500C/M would be equipped for sports, aerial, architectural, and fashion photography.

And portrait, landscape, medical, underwater, and news photography.

And wildlife, laboratory, industrial, and child photography.

And you would always have the right film in the camera at the right time. You can shift from color to black-and-white and back again to color—and resume shooting at precisely the right frame—by popping in the protective dark slide and switching film backs.

The Camera with Nine Backs.

There is a small button on the film back of every Hasselblad 500C/M. Slide it sideways with your thumb and the back will come away in your hand.

The standard back holds 12 exposures. Each frame of film is 2¼ inches square, *almost four times the area of a 35mm frame.* (See box, below right, for actual size.)

This is only the beginning. There are eight other backs available: Backs that let you change to a 6 x 4.5cm format...or a 4.5 x 4.5cm superslide format for showing in any 35mm projector. Backs that give you a choice of 1, 12, 16, 24, 70, or 500 exposures. A back that is a sheet-film adapter. Even two backs for Polaroid film, so you can check composition, lighting, and exposure ahead of time.

You begin to realize why eight out of ten top commercial photographers surveyed name Hasselblad as the medium-format camera used in their work.

Retained Value vs. Obsolescence.

In an age when machines spew out cameras in the tens and hundreds of thousands, when flashy new models thrust last year's marvels into early obsolescence, Hasselblad goes its own way.

Planned obsolescence is taboo at Hasselblad. All but two of the accessories for the 500C/M will fit every Hasselblad made since 1957 (except the Super Wide C)...and will fit every future Hasselblad.

The greater part of a year is spent on building each camera, much of it crafted by hand. And fully one quarter of the work force devotes its time to nothing but quality control.

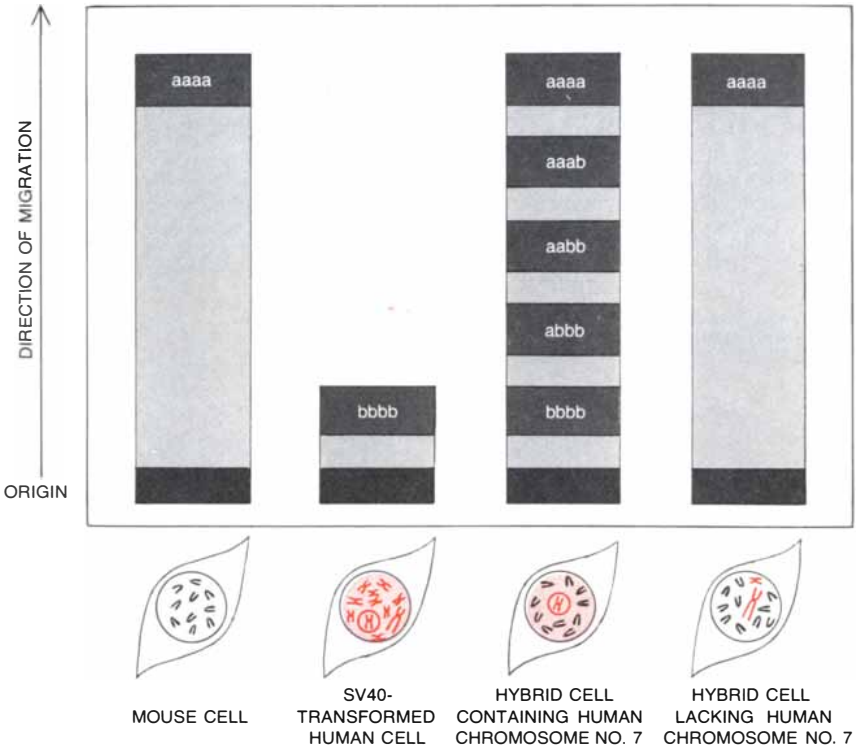
Little wonder, then, that a preowned Hasselblad commands such a high price...if its owner can be persuaded to part with it at all.

sometimes alone and sometimes with other human chromosomes. The antigen-negative clones, in contrast, retained various combinations of all the other human chromosomes, but they did not retain No. 7. In instances where the antigen-positive clones subsequently lost human chromosome No. 7 it was possible to show that those clones also became antigen-negative. It follows that the gene for the expression of the SV40 tumor antigen must be part of human chromosome No. 7. We were able to recover SV40 virions (virus particles) only from those hybrid cells that contained human chromosome No. 7, thus confirming our earlier finding and proving that the SV40 genome is indeed integrated into human chromosome No. 7 [*see illustration on page 120*].

In further tests conducted with George Khoury of the National Institute of Allergy and Infectious Diseases we extracted the double-strand DNA from both the antigen-positive and the antigen-negative hybrid clones and separated the strands by heating them to a high temperature. The DNA from SV40 virions was also separated into single strands by heating, and the resulting single strands were then "annealed" with the cellular DNA at a lower temperature. The speed of the annealing reaction between viral and cellular DNA depends on the amount of viral DNA initially present in the DNA obtained from the hybrid cells. This method enabled us to determine the number of SV40 DNA molecules already present in the hybrid cells. The results of this experiment indicated that the SV40 DNA was integrated only into the cellular DNA of those hybrid cells containing human chromosome No. 7, and that the number of SV40 DNA molecules per hybrid cell was the same as the number of No. 7 chromosomes present in the hybrid cells. Moreover, SV40 DNA molecules were not detected in those hybrid cells in which human chromosome No. 7 was not present.

In order to determine whether or not the cellular genes in the human chromosomes carrying the genome of the SV40 virus were functional in the hybrid cells, we screened the antigen-positive and antigen-negative hybrid cells for the presence of the enzyme beta-glucuronidase, the gene for which is known to be part of human chromosome No. 7. Only those hybrid cells that expressed the SV40 tumor antigen and also contained human chromosome No. 7 were found to express the human form of this enzyme.

Additional tests were then undertaken to determine whether the presence of human chromosome No. 7 in the hybrid cells would result in their being able to form tumors. As in the preceding experiments SV40-transformed human cells were fused with mouse fibroblasts, a normally propagating type of connective-tissue cell that under ordinary circumstances is unable to form colonies in a semisolid culture medium. This time, however, the transformed human cells were also fused with mouse macrophages, nondividing cells obtained from the peritoneal cavity of the animal. All the cells were then grown in a HAT medium, which resulted in the selection of a variety of hybrid clones [*see illustration on next page*].



PARENTAL CELLS AND HYBRID CELLS were analyzed by means of an electrophoretic technique for the presence of the enzyme beta-glucuronidase, the gene for which is known to be part of human chromosome No. 7. Extracts of both parental cell lines (normal mouse cells and SV40-transformed human cells) and of both hybrid cell lines (antigen-positive and antigen-negative) were placed in slots at the base of a cellulose acetate membrane and were exposed to an electric field in which the mouse and human forms of the enzyme migrate at different speeds. Both forms of the enzyme have a four-part structure, denoted here by the letters *aaaa* for the mouse form and *bbbb* for the human form. Therefore in the hybrids that carry the gene for beta-glucuronidase one would expect to find in addition to the two pure parental forms of the enzyme (*aaaa, bbbb*) three different combined forms of the two parental forms (*aaab, aabb, abbb*). As it happens, the hybrid clones that retain human chromosome No. 7 and are antigen-positive produce both the parental forms of the enzyme and the combined forms, whereas the clones that lack human chromosome No. 7 and are antigen-negative yield only the mouse form. This test served to demonstrate that the normal cellular genes in the human chromosome carrying the SV40 genome were functional in the virus-transformed hybrid cells.

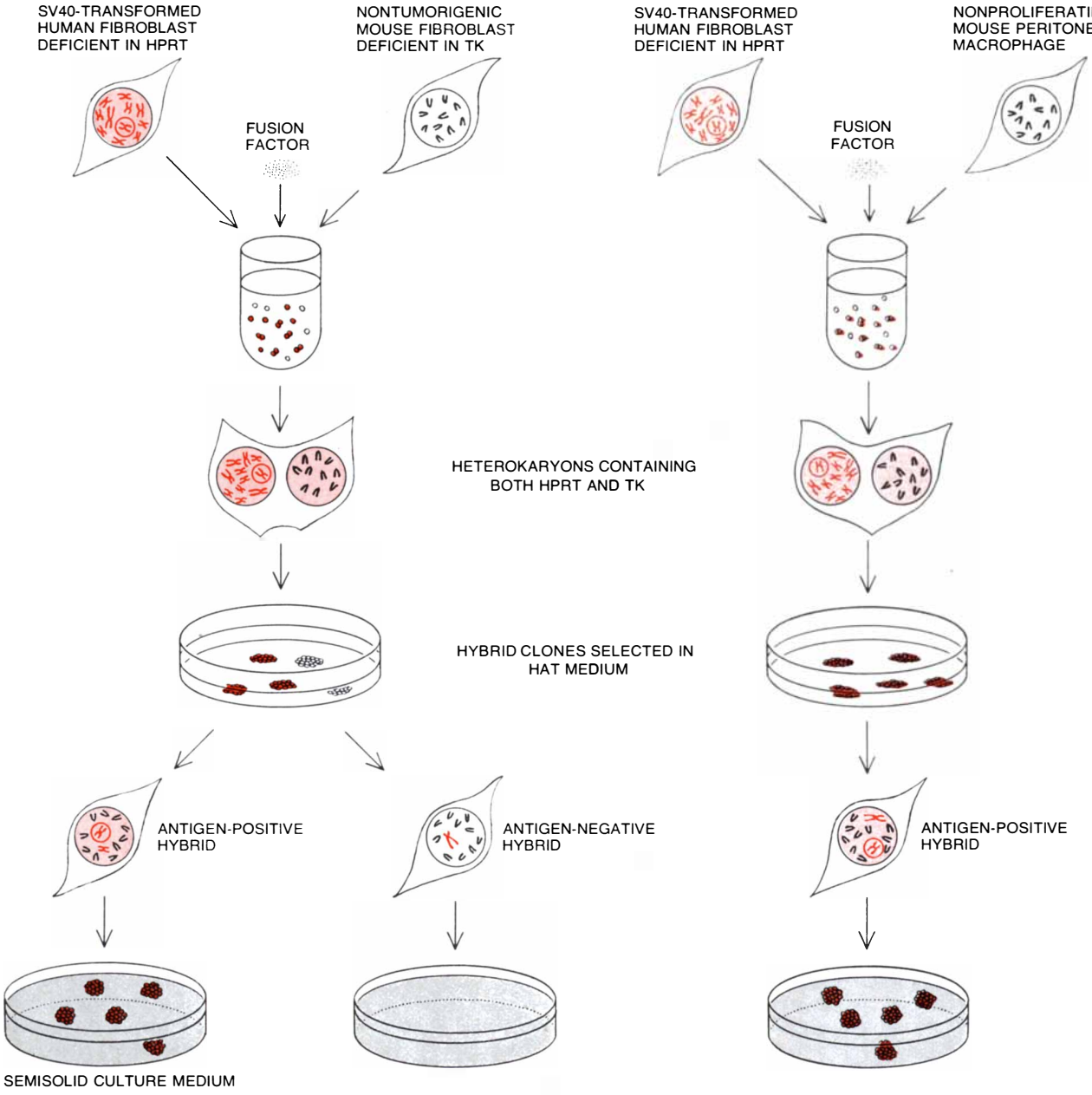
The hybrid clones resulting from the fusion of the virus-transformed human cells with the mouse fibroblasts either retained human chromosome No. 7 and expressed the SV40 tumor antigen or retained human chromosomes other than No. 7 and did not express the SV40 tumor antigen. All the hybrid clones resulting from the fusion of the virus-transformed human cells with the mouse macrophages, on the other hand, contained human chromosome No. 7 and expressed the SV40 tumor antigen; in some of these clones No. 7 was the only human chromosome present. The proliferation of the hybrids of the human cells with the mouse macrophages indicates that human chromosome No. 7, containing the SV40 genome, contributes one or more factors that result in the replication of these otherwise nonproliferating cells. All the hybrid clones that expressed the SV40 tumor antigen could form colonies in a semisolid culture medium, one of the key tests for distinguishing transformed cells. In contrast, the hybrids formed by the fusion of the human cells with the mouse fibroblasts that had lost the ability to express the SV40 tumor antigen were unable to form colonies in a semisolid medium.

The hybrid cells that both contained human chromosome No. 7 and expressed the SV40 tumor antigen were subsequently found to induce tumors when they were injected into "nude" mice, a hairless laboratory strain often used as a host in such experiments because they lack a thymus gland and therefore are unable to reject transplants of foreign tissue [*see illustration on page 123*]. In contrast, nude mice that were injected with cells that lacked hu-

man chromosome No. 7 and were antigen-negative did not develop tumors. Cells derived from the tumors induced in nude mice and transferred to tissue-culture vessels were found to contain human chromosome No. 7 and to express the SV40 tumor antigen.

(In a related experiment we observed that when SV40-transformed human cells derived from a patient with another kind of enzyme-deficiency disease, galactosemia, were fused with either mouse fibroblasts or peritoneal macrophages, it was human chromosome No. 17, not No. 7, that was retained by all the antigen-positive hybrid clones and was therefore responsible for the expression of malignancy in the hybrid cells. Moreover, it is possible that integration sites for SV40 DNA may be found on human chromosomes other than No. 7 and No. 17 in other kinds of SV40-transformed human cells.)

Because hybrid cells containing the entire complement of 40 mouse chromosomes (19 pairs of autosomes and two sex chromosomes) along with the human chromosome (or chromosomes) carrying the viral genome were always

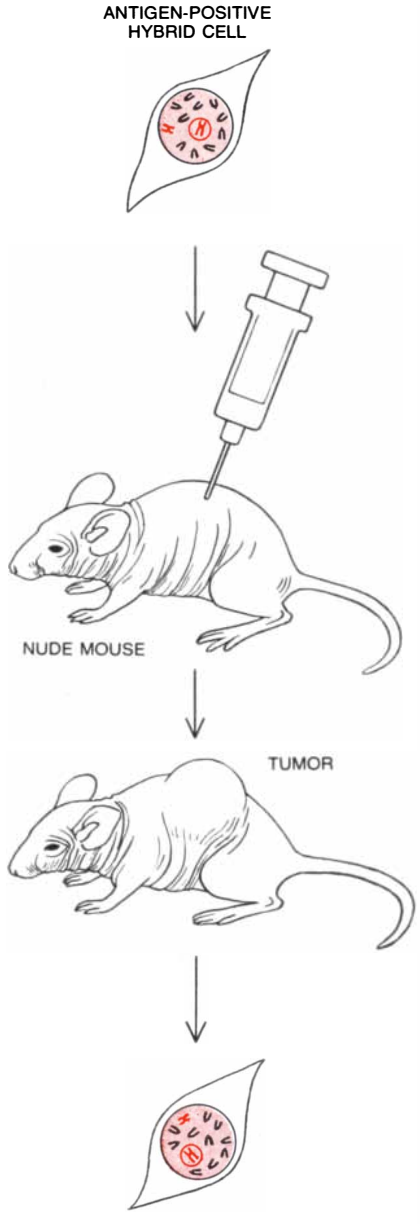


FURTHER EVIDENCE that the genome of the SV40 virus, including one or more factors responsible for its replication, is integrated into human chromosome No. 7 in SV40-transformed human cells was obtained with the aid of this experiment. This time SV40-transformed human cells deficient in HPRT were fused not only with mouse fibroblasts, a normally propagating type of connective-tissue cell, but also with mouse macrophages, nondividing cells obtained from the peritoneal cavity of the animal. All the cells were then grown in the HAT medium, which resulted in the selection of several different hybrid clones. The hybrids derived from the fusion of the mouse fibroblasts with the virus-transformed human cells either retained human chromosome No. 7 and were antigen-positive or retained human chromosomes other than No. 7 and were antigen-negative. The surviving clones derived from the fusion of the mouse macrophages with the virus-transformed human cells, on the other hand, invariably retained human chromosome No. 7 and were antigen-positive. (Mouse-macrophage-derived hybrids that contain human chromosomes other than No. 7 presumably fail to multiply and disappear.) It therefore seems that human chromosome No. 7 is responsible for the proliferation of these otherwise nonproliferating cells. Both types of surviving hybrids could be propagated further in a semisolid culture medium, provided that they continued to be antigen-positive and to contain human chromosome No. 7. Growth in such a semisolid medium is considered to be a key characteristic of transformed cells.

found to be tumorigenic, it became evident that the characteristic of tumorigenicity is inherited as a dominant trait in the SV40-transformed cells. Since human cells can be similarly transformed by certain RNA-containing viruses, it seemed reasonable to expect that the chromosomal location of the genome of the RNA tumor viruses can also be investigated in transformed human cells by means of the cell-fusion technique. This possibility arises from the fact that RNA tumor viruses contain a remarkable enzyme called reverse transcriptase, which was discovered in 1970 by Howard M. Temin of the University of Wisconsin and David Baltimore of the Massachusetts Institute of Technology. This enzyme is able to transcribe the RNA of the virus into complementary DNA, which then becomes integrated into the cellular DNA in the transformed cells. We found that the fusion of these cells with normal mouse cells results in the formation of hybrids that are tumorigenic when they are injected into nude mice. The tumorigenic hybrid cells contain the entire chromosome complement of the mouse but not more than five human chromosomes. Hence the ability of RNA-containing viruses to form tumors also seems to be inherited as a dominant trait.

The hybridization of mouse cells with human cells transformed by either DNA or RNA tumor viruses introduces new ways of identifying the human chromosomes responsible for the expression of malignancy in certain types of human cancer. This approach also makes it possible to determine whether the integration of tumor-virus genomes into the cellular DNA takes place at specific or preferential chromosomal sites or is a random event. The loss of part of the normal human complement of chromosomes is the key to the success of these studies.

An exception to this general rule has been found in the case of hybrid cells formed by the fusion of human cells derived from a fibrosarcoma (a highly malignant human connective-tissue tumor) with mouse macrophages or other cells obtained directly from living mice [*see illustration on next page*]. In this case all the hybrid cells were found to be tumorigenic in nude mice. The hybrids preferentially lost mouse chromosomes, however, while retaining the entire complement of human chromosomes. In contrast, somatic-cell hybrids formed by fusing the same type of human fibrosarcoma cells with normal mouse fibroblasts maintained in laboratory cultures were found to lose human chromosomes preferentially, as in the case of the hybrids between mouse cells and SV40-transformed human cells. The hybrid cells in both of the latter cases segregate into clones, some of which are tumorigenic and some of which are not. In short, by using human fibrosarcoma cells in a hybridization experiment it should be possible not only to identify the human chromosome (or chromosomes) responsible for the expression of malignancy but also to determine the location of genes on the mouse chromosomes.

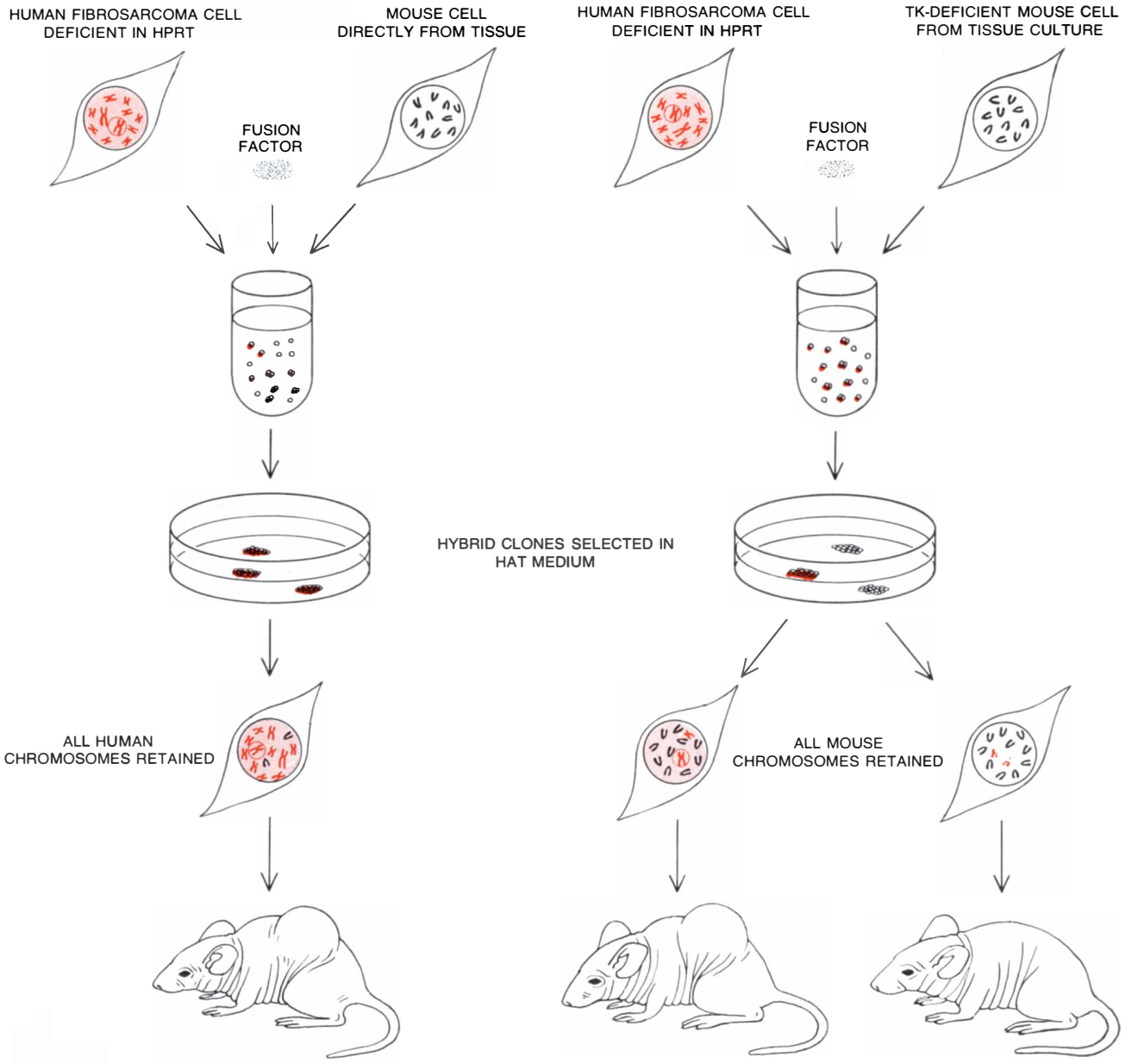


TUMOR WAS INDUCED in "nude" mouse (a specially bred laboratory strain) by injecting the mouse with antigen-positive hybrid cells containing human chromosome No. 7. Nude mice that were injected with antigen-negative hybrid cells lacking human chromosome No. 7 did not develop tumors. Subsequent analysis of cells obtained from the tumors showed that all were antigen-positive and contained human chromosome No. 7.

Boveri postulated that in addition to the "single abnormal chromosome combination that gives the cell the quality of malignity" there may be "inhibiting

chromosomes." He added that "cells of tumors with unlimited growth would arise" if these inhibiting chromosomes were eliminated. Based on the observation that somatic-cell hybrids between normal and malignant mouse cells are malignant only when there is a loss of mouse chromosomes, several investigators have suggested in recent years that normal cells must contain genes capable of suppressing the cells' ability to induce tumors; the loss of the "inhibiting chromosomes" carrying these genes would therefore result in the expression of malignancy. Our results, obtained through the use of interspecies hybrids formed by fusing either virus-transformed human cells or human fibrosarcoma cells with normal mouse cells, indicate, on the contrary, that malignancy is dominant. Moreover, hybrids formed by the fusion of human fibrosarcoma cells and normal human cells behave like tumor cells, even though they retain the entire complement of chromosomes from both parental cells.

So far we have discussed how a variety of environmental triggering agents, including viruses, can induce human cancers either through mutations of the cellular DNA or through the integration of viral genomes into the cellular DNA. Are there any examples of malignancy caused by changes in gene function rather than changes in gene structure? There are. One such malignancy is the teratoma, a tumor that principally affects the gonads. Teratomas contain many different tissues, including skin, muscles, fat, glands, hair and teeth, all derived from "totipotent" cells: cells that by definition are capable of developing into all types of body tissue. Teratomas can be induced in experimental animals by im-



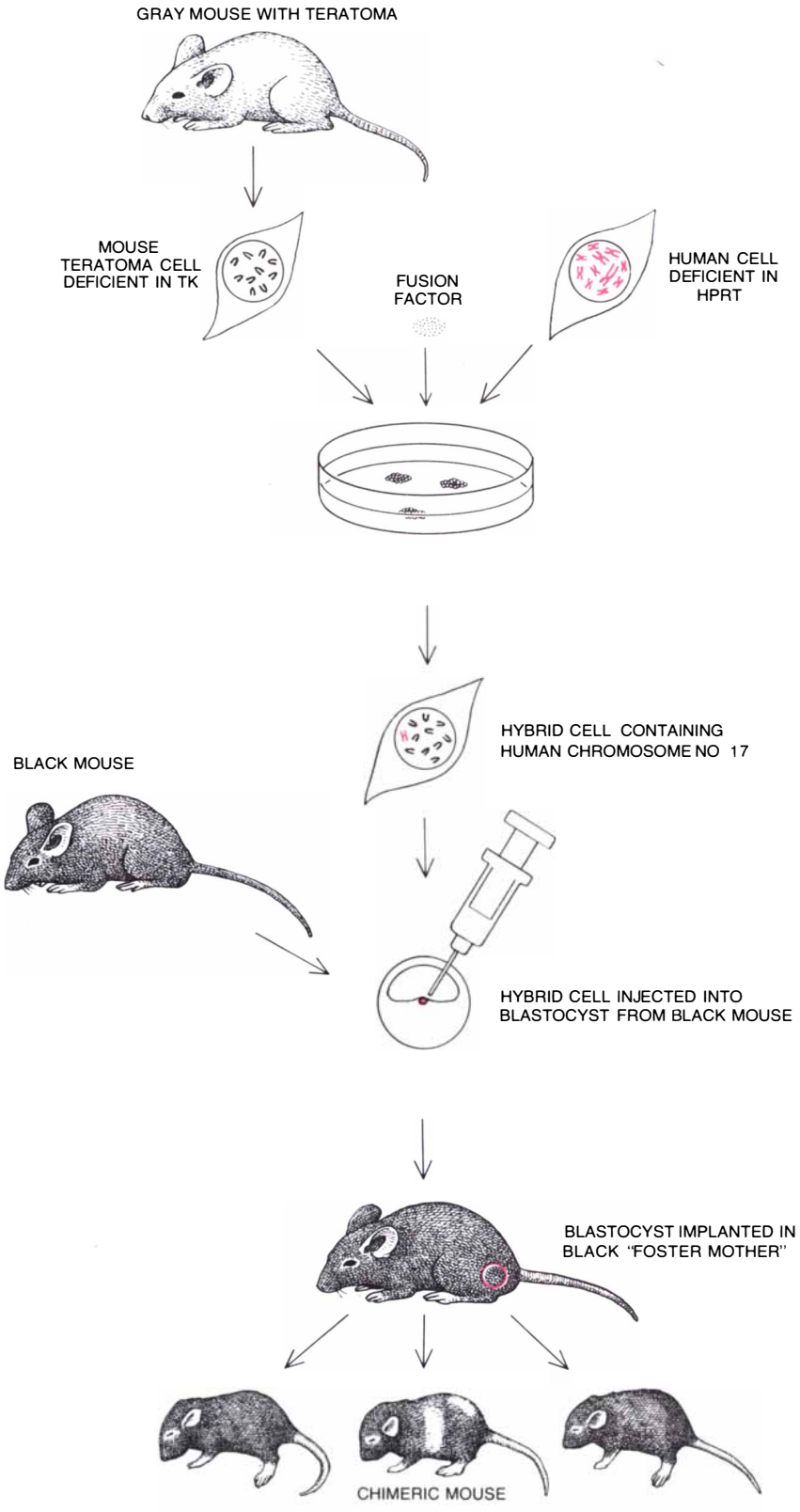
PREFERENTIAL LOSS OF CHROMOSOMES is unusual in the case of hybrid cells formed by fusing human cells derived from a fibrosarcoma, or connective-tissue tumor, with mouse cells obtained from mouse tissue. Unlike the hybrids formed in the preceding experiments, these hybrids tend to lose mouse chromosomes while retaining the entire complement of human chromosomes. All the resulting hybrid cells were found to cause tumors in nude mice (*diagram at left*). In contrast, hybrids formed by fusing the same type of fibrosarcoma cells with normal mouse fibroblasts maintained in laboratory cultures were found to lose human chromosomes preferentially. Hybrid cells in the latter case segregate into clones, some of which are tumorigenic and some of which are not (*diagram at right*).

planting an early embryo at an abnormal site in the animal's body, typically under the kidney capsule.

In two recent experiments Ralph L. Brinster of the University of Pennsylvania School of Veterinary Medicine and then Beatrice Mintz and Karl Illmensee of the Institute for Cancer Research in Philadelphia injected totipotent cells derived from teratomas into the cavity of a blastocyst (an early embryo) obtained from a normal mouse belonging to a strain that was different from the one from which the teratoma cells were derived. The teratoma-containing blastocysts were then surgically implanted in the uterus of mouse "foster mothers." After the normal development of the embryos from the implanted blastocysts the mice that were born turned out to be chimeric, that is, they had in their normal tissues cells that had been derived from both the blastocyst and the teratoma. Moreover, tissue-specific gene products, such as hemoglobin and immunoglobulin, were found that were specific for the strain of mouse from which the teratoma was derived. Since the teratoma cells had become perfectly normal and had developed into normal tissues when they were placed in the proper environment (the blastocyst), it can be concluded that teratomas are caused by changes in gene function and not by mutations of the cellular genome.

Taking advantage of the fact that totipotent mouse teratoma cells can be grown in tissue culture, we have produced TK-deficient mouse teratoma cells that are able to differentiate into normal mouse tissue after being injected into mouse blastocysts. The resulting cells are then fused with human cells, and the hybrids are found to retain human chromosome No. 17, which carries the gene for the TK enzyme. The hybrid cells are next injected into mouse blastocysts, which are in turn implanted into mouse foster mothers. The chimeric mice that are born contain tissues derived from both the blastocysts and the hybrid cells [*see illustration at right*]. The question of whether the human TK enzyme is expressed in these mice is currently being investigated.

An interesting experiment for the future will be to produce hybrids by fusing mouse teratoma cells with human cells derived from patients with familial cancers. Such hybrids, having lost most of the human chromosomes but having retained the genetic information responsible for the expression of, say, retinoblastoma or polyposis of the colon, could then be injected into mouse blastocysts, which in turn could be implanted in the uterus of mouse foster mothers. If viable progeny were to develop as a result of the procedure, that would open an entirely new path for exploring the effects of human cancer genes in an experimental animal.



"TOTIPOTENT" CELLS, cells that by definition are capable of developing into the cells of all types of body tissue, can be obtained from a laboratory mouse with a teratoma, a tumor of the gonads. When teratoma cells that had been made deficient in the enzyme TK were fused with human cells deficient in HPRT, and hybrid clones were selected in the HAT medium, the resulting hybrids were found to retain human chromosome No. 17, which carries the gene for the TK enzyme. The hybrid cells were then injected into mouse blastocysts (early embryos), which were in turn implanted into mouse "foster mothers." The chimeric, or multicolored, mice that were then born were found to contain tissues that had been derived from both blastocysts and hybrid cells. It is not yet known whether the human TK enzyme is expressed in these mice.

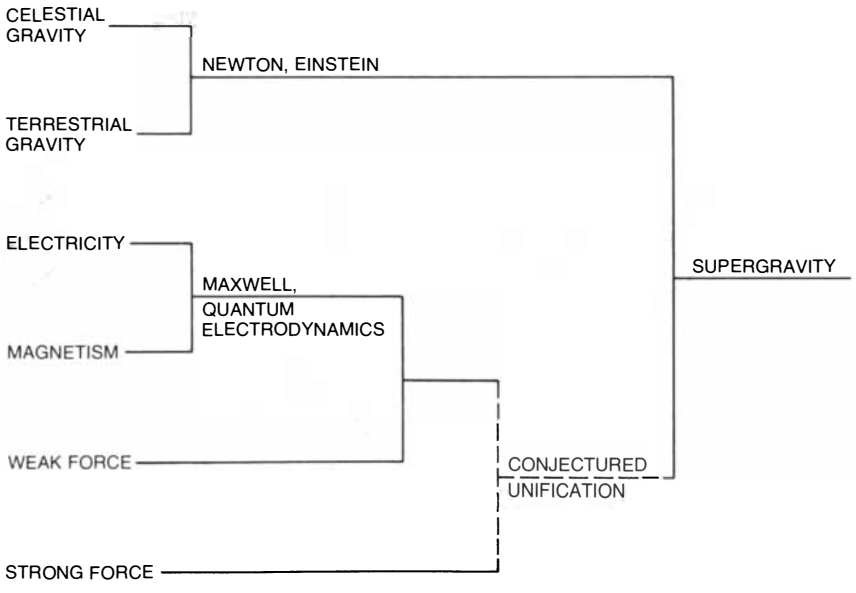
Supergravity and the Unification of the Laws of Physics

In this new theory the gravitational force arises from a symmetry relating particles with vastly different properties. The ultimate result may be a unified theory of all the basic forces in nature

by Daniel Z. Freedman and Peter van Nieuwenhuizen

A catalogue of the most basic constituents of the universe would have to include dozens or even hundreds of particles of matter, which interact with one another through the agency of four kinds of force: strong, electromagnetic, weak and gravitational. There is no obvious reason why nature should be so complicated, and perhaps the most ambitious goal of modern physics is to discover in the diversity of particles and forces a simpler underlying order. In particular, a more satisfying understanding of nature could be achieved if the four forces could somehow be unified. Ideally they would all be shown to have a common origin; they would be viewed as different manifestations of a single more fundamental force.

In the past 50 years remarkable progress has been made in identifying the elementary particles of matter and in understanding the interactions between them. Of course, many problems remain to be solved; two of the most fundamental ones concern gravitation. First, it is not understood how gravitation is related to the other fundamental forces. Second, there is no workable theory of gravitation that is consistent with the principles of quantum mechanics. Recently a new theory of gravitation called supergravity has led to new ideas on both these problems. It may represent a step toward solving them.



HISTORY OF THEORIES in physics suggests a gradual development toward unification. The first great synthesis was achieved by Newton, who showed that the motion of projectiles on the earth and the orbits of the planets could be explained by the same simple law. In a similar way James Clerk Maxwell devised a single theory encompassing both electricity and magnetism. In the 20th century Newton's theory has been superseded by Einstein's general theory of relativity, and Maxwell's theory has been extended to create a quantum field theory, called quantum electrodynamics. Recently the weak force has been combined with electromagnetism. The strong force is also described by a quantum field theory, and ultimately it may be possible to regard all three of these forces (strong, weak and electromagnetic) as manifestations of a single principle. Supergravity is a theory developed in the past two years that describes gravitation in terms of a quantum field theory. It is still untested but it might unify all forces in nature.

Of the fundamental forces in nature gravitation was the first to be recognized and the first for which a mathematically accurate theory was found, namely the theory published by Newton in his *Principia* of 1687. Newton devised the simple law that the gravitational force acts universally between all pairs of particles with a strength directly proportional to the product of their masses and inversely proportional to the square of the distance between them. He could then calculate both the motions of terrestrial projectiles, which agreed with the observations of Galileo, and the orbits of the planets, which agreed with the empirical laws of planetary motion formulated by Kepler. The development of a law of force that correctly described both terrestrial and astronomical motions was an extraordinary synthesis.

A similar unification was accomplished in the treatment of electromagnetism. To the natural philosophers of the 18th century there was no apparent relation between the static electricity generated by combing one's hair, the magnetic force on a compass needle and the light emitted by a candle or the sun. In the 19th century, however, all these phenomena were shown by James Clerk Maxwell to be related by a set of differential equations, which are now known as Maxwell's equations for the electromagnetic field.

Near the end of the 19th century the opinion prevailed that all the complex manifestations of gravitation and electromagnetism could be described by the laws of Newton and Maxwell. All that remained was to work out the consequences of the equations in detail. This

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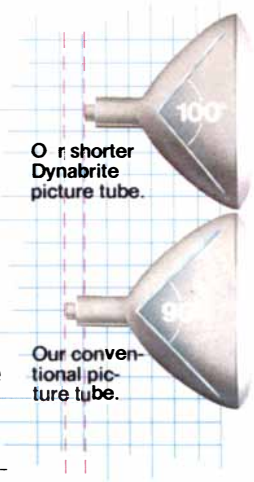

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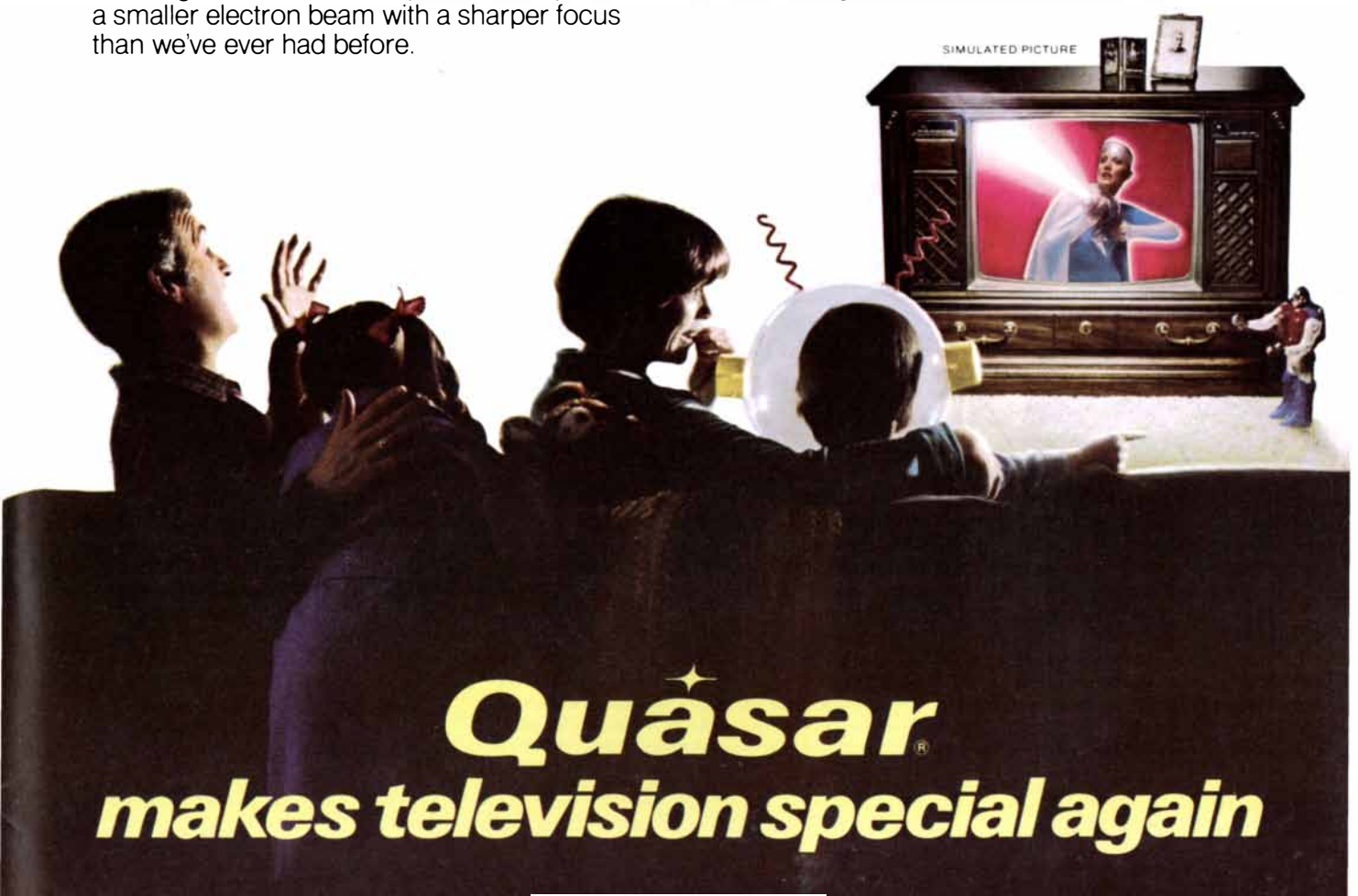

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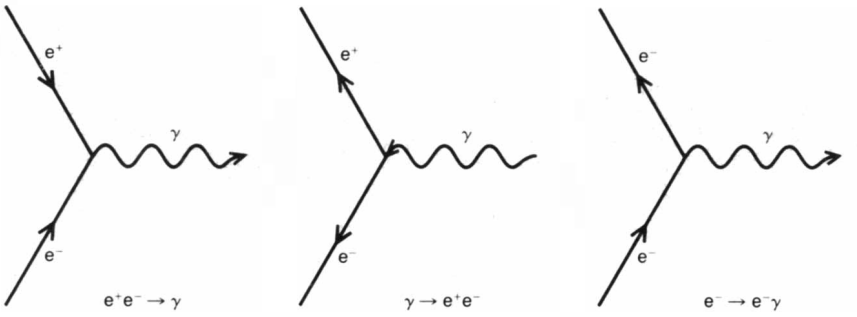
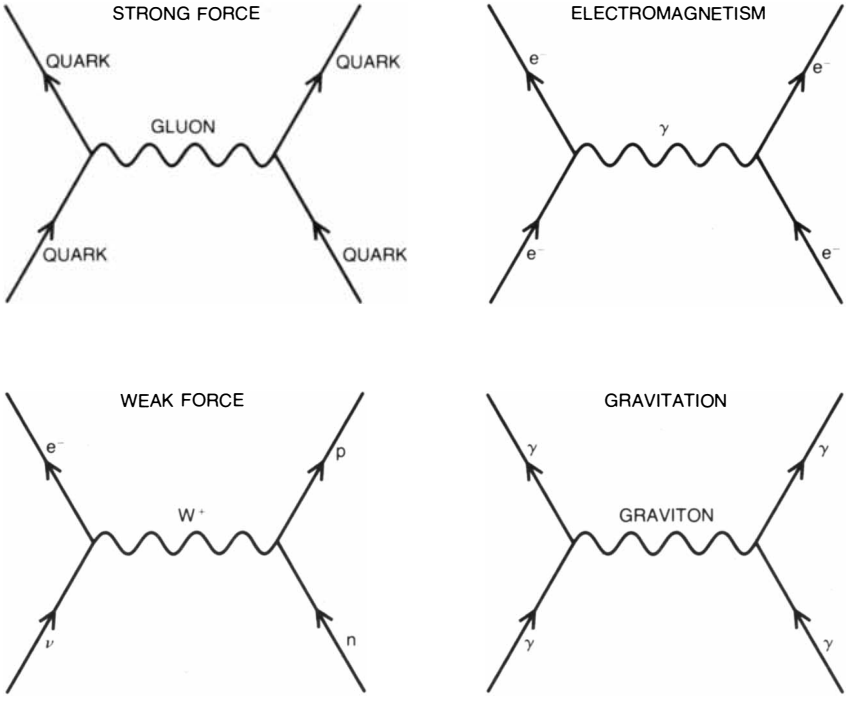
complacent view was shattered by a series of experimental results obtained in the decades immediately before and after the turn of the century. One important conflict between theory and experiment was created by the discovery that the speed of light, unlike the speed of all other waves, does not depend on the motion of the observer. Another difficulty was the interpretation of the discrete lines in the spectra of atoms. It had long been known that atoms emit light only at particular, characteristic frequencies, but this observation could not be reconciled with the discovery that atoms consist of electrons in orbit around a tiny, dense nucleus. Maxwell's theory predicted that a continuous spectrum of light would be emitted as electrons spiral in toward the nucleus.



QUANTUM FIELD THEORIES explain the forces acting on a particle in terms of other particles that can be emitted or absorbed. Such events are represented graphically by vertexes. In the basic vertex of quantum electrodynamics lines representing an electron (e^-) or a positron (e^+) intersect a third line representing a photon (γ). The vertex can be interpreted three ways, depending on the directions in which the various particles are moving. An electron and a positron can annihilate each other to yield a photon (*left*); a photon can decay into an electron and a positron (*middle*), or an electron can decay into a photon and another electron (*right*). The creation and annihilation of particles and antiparticles is the characteristic process that distinguishes quantum field theories from "classical" field theories such as Maxwell's or Einstein's.



INTERACTIONS BETWEEN PARTICLES can be visualized by drawing diagrams in which two vertexes are connected. The force between the two particles is transmitted by the exchange of a third particle, which is said to be virtual because it cannot be detected. Each of the four forces in nature has its own virtual particles, or quanta. The quantum of the electromagnetic force is the photon. Strong interactions between quarks (the supposed constituents of protons and neutrons) are mediated by particles called gluons. The weak force is transmitted by particles (W^+, W^- and Z^0) that are thought to be exactly like the photon except that they have a large mass. The quantum of gravitation is the graviton, a massless particle. Of these exchanged quanta only the photon has been observed, but there is confidence that the others also exist.

These conflicts were resolved with the development of two theories that have become foundation stones of modern physics: the special theory of relativity and quantum mechanics. In order to achieve this resolution it was necessary to abandon the concepts of absolute time and determinism in the motion of particles, concepts that were so deeply ingrained it was difficult to recognize that they were actually hidden assumptions. In special relativity time and space were related, and in quantum mechanics particles and waves were shown to be equivalent. It was then possible to understand why the speed of light is the same for all observers and why the spectral lines of atoms have fixed, discrete frequencies.

In Newton's theory of gravitation space and time do not have the close relation they have in special relativity, and so special relativity made necessary a revised theory of gravitation. Such a theory was proposed by Einstein in 1916 and was called the general theory of relativity. It too became a foundation stone of modern physics.

Early in the 20th century two new fundamental forces of nature were discovered. They are the weak interaction, which is responsible for the beta decay of radioactive elements, and the strong force, which binds together protons and neutrons in atomic nuclei. These forces had not been discovered earlier because they are effective only over the short range of subatomic distances, whereas gravitation and electromagnetism are long-range forces that can be observed macroscopically.

The four forces present a bewildering variety of properties. Differences in range have already been mentioned; there are even greater disparities in effective strength. As might be expected, the strong force is the most powerful of the four (at short range). If the strong interaction between two protons is defined as having a strength of 1, then the electromagnetic force between the same particles has a strength of about 10^{-2} and the weak force has a strength of 10^{-5}. The gravitational force is extraordinarily feeble, with an intrinsic strength of only 10^{-39}. One can visualize how weak that force is by imagining an atom in which the electrons are bound to the nucleus by gravitation instead of electromagnetism; a single hydrogen atom would then be far larger than the estimated size of the universe.

In spite of the disparate properties of the four forces it is natural to search for a deeper theory in which they would have a common origin. Einstein devoted much of the last part of his life to the search for a unified field theory of gravitation and electromagnetism. Other physicists joined the effort, but the results of their work were never convinc-

ing, perhaps because quantum-mechanical ideas were not incorporated in their theories.

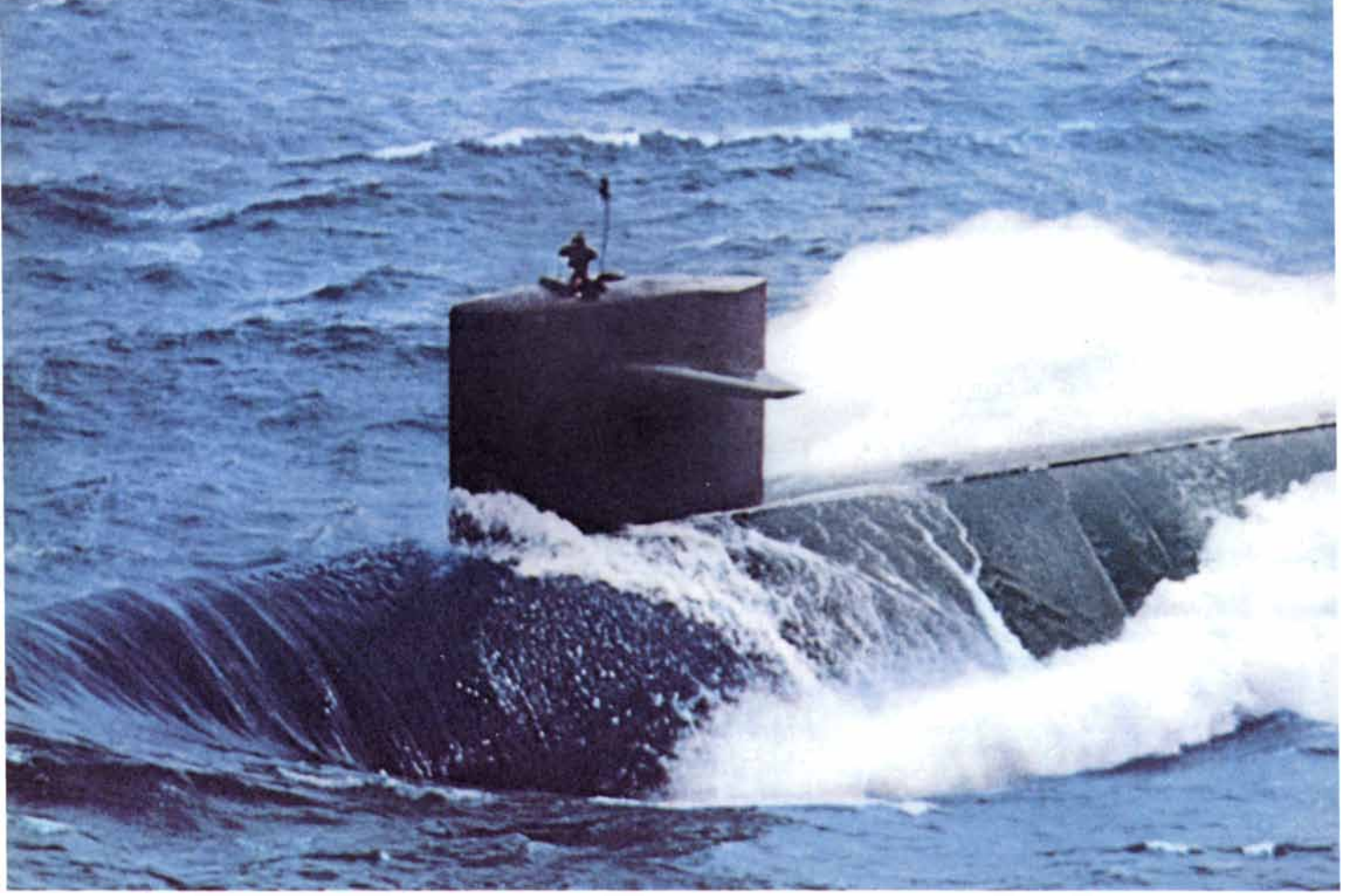
During the past decade the weak and the electromagnetic forces have been unified in the work of Steven Weinberg of Harvard University and later in that of Abdus Salam of the International Centre for Theoretical Physics in Trieste and John Ward of New Zealand. It is thought that a similar approach can also encompass the nuclear force. Ironically, however, this synthesis does not include the force that has been known the longest: gravitation.

The theory of supergravity suggests a new approach to unification. Supergravity is an extension of general relativity, and it makes the same predictions for the classical tests of Einstein's theory, such as the precession of planetary orbits, the bending of starlight passing near the sun, the red shift of stellar spectral lines and the delay of radar signals passing through the solar gravitational field. At the microscopic, or quantum, level, however, supergravity is different from general relativity. When the probability of certain quantum-mechanical effects of gravitation is calculated in general relativity, the probability turns out to be infinite, a result that makes no sense. In supergravity finite answers have been obtained in all calculations that have been done so far.

In constructing new physical theories it is helpful to be guided by principles of symmetry, which allow one law to describe objects or concepts that had seemed unrelated. As will be explained below, a symmetry of a physical theory can hold in either global or local form. Theories with local symmetry, which are also called gauge theories, have proved to be much more powerful. The general theory of relativity and Maxwell's theory of electromagnetism are both based on local symmetries. The recent unified field theories of the weak and the electromagnetic interactions are also gauge theories. It is therefore suspected that any theory unifying the four forces should also have local symmetry.

Supergravity is based on a new symmetry so remarkable even at the global level that it has been given the name supersymmetry. Supersymmetry relates the two broad classes of elementary particles, namely the fermions (such as the electron, the proton and the neutron) and the bosons (such as the photon). Fermions and bosons have vastly different properties, and finding a fundamental relation between them was quite unexpected. In supergravity, supersymmetry is extended from the global level to the local level. Remarkably, this extension leads automatically to theories that incorporate the gravitational force and suggest the possibility of unifying gravitation with the other forces.

Supergravity has not been tested by



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experiment. It is still a speculative theory, but the progress that has been made so far is encouraging. By bringing together several of the most fundamental concepts in modern physics, supergravity has already achieved more than any earlier quantum theory of gravity

The present understanding of the fundamental laws of nature arose from three principles: special relativity, general relativity and quantum mechanics. Each of them resolved an experimental or theoretical conflict and each went on to predict new phenomena that were subsequently verified by experiment. Today there can be little doubt about their validity.

Einstein proposed the special theory of relativity in order to reconcile the concept of motion in Newtonian mechanics with the experimental finding that the speed of light is constant for all observers. If light waves behaved in the same way that waves on the surface of water behave, an observer in motion with respect to the waves would measure a wave velocity different from that measured by an observer at rest. Maxwell's equations seemed to predict that the speed of light did not depend on the motion of an observer, and since the prediction was in conflict with common sense it was supposed Maxwell's equations were valid only for observers at rest. In 1888 the experiment of A. A. Michelson and E. W. Morley showed that this supposition was false. It was Einstein's genius to realize that the elegant form of Maxwell's equations was more important than the Newtonian, or commonsense, view of motion. He showed that Maxwell's equations become valid for all observers if the scales of both length and time employed by any two observers depend intrinsically on their relative velocity. He then showed that the laws of Newtonian mechanics could be modified to incorporate these new concepts of space and time. One important prediction is that the speed of light is the maximum velocity allowed for any particle or signal. Another well-known prediction is the relation between the energy and mass of a particle, $E = mc^2$, a formula that determines the energy released in nuclear reactions.

The general theory of relativity was proposed by Einstein in 1916, after nine years of grappling with the problem of formulating a theory of gravitation in agreement with the space-time symmetry of special relativity and with the experimental observation, known since Galileo, that all bodies, regardless of their mass, follow the same trajectory in a gravitational field. In its conceptual content and in the breadth of creative insight required, general relativity is a stunning achievement of the human intellect. Roughly speaking, Einstein first reasoned that if the trajectories of falling bodies are independent of their mass, gravitation must be related to the intrinsic structure of space and time. He then derived equations that express this idea in mathematical form, drawing on the methods of non-Euclidean geometry formulated a century earlier by Carl Friedrich Gauss and Bernhard Riemann. The resulting theory predicted that starlight passing near the limb of the sun would be bent toward the sun twice as much as Newton would have predicted. Einstein suggested that this effect be measured during a total eclipse of the sun. The results of an expedition led by A. S. Eddington were announced on the first anniversary of the armistice of World War I. It was a dramatic and sublime moment in the history of science. Einstein's deep theoretical reasoning had found confirmation in the ultimate laboratory of nature.

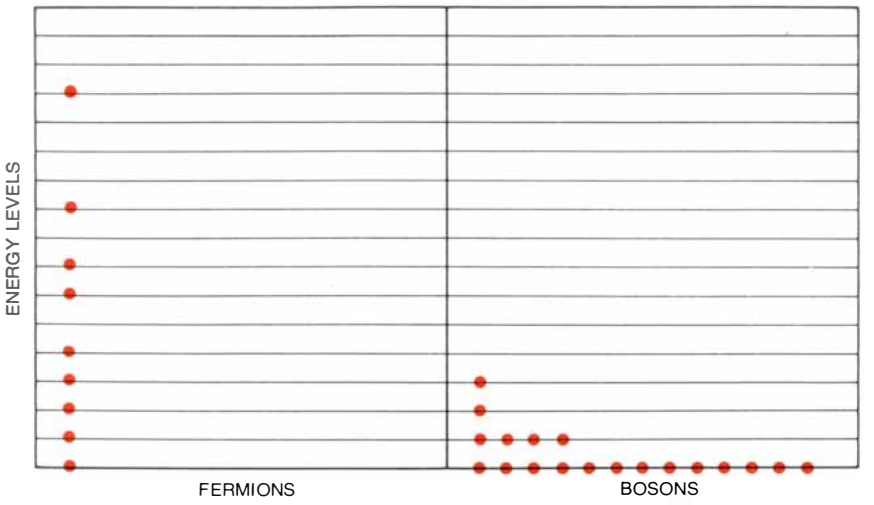
Years after the formulation of general relativity Einstein wrote: "In the light of the knowledge obtained, the happy achievement seems almost a matter of course and any intelligent student can grasp it without too much trouble. But the years of anxious searching in the dark with their intense longing, their alternations of confidence and exhaustion and the final emergence into light—only those who have experienced it can understand that." His words apply equally well to other pathbreaking discoveries in physics.

Quantum mechanics, which was developed in 1926 by Werner Heisenberg, Erwin Schrödinger and others, gave a convincing explanation of the discrete lines in atomic spectra. Quantum mechanics describes the electrons in atoms not as point particles but as superpositions of waves, which can be interpreted as a probability distribution around the nucleus. The energy of each distribution has a definite value, and radiation at discrete frequencies is emitted when an electron jumps from one such quantum state to another. The strict determinism of classical mechanics is abandoned in the quantum theory and is replaced by a probabilistic interpretation of measurements at the microscopic level. For example, an electron in an atom can be anywhere around the nucleus; the probability of finding it at any given point is related to the amplitude of the wave distribution at that point.

If modern theoretical physics was to be built on the foundations of special relativity and quantum mechanics, it was essential to bring the two theories together The first major advance was

FORCE	STRENGTH	RANGE	PARTICLES ACTED ON	PARTICLES EXCHANGED	MASS OF EXCHANGED PARTICLES	SPIN OF EXCHANGED PARTICLES	NATURE OF FORCE BETWEEN IDENTICAL PARTICLES
STRONG	1	SHORT	QUARKS	GLUONS	?	1	REPULSIVE
ELECTRO-MAGNETIC	10^{-2}	LONG	ELECTRICALLY CHARGED PARTICLES	PHOTONS	0	1	REPULSIVE
WEAK	10^{-5}	SHORT	ELECTRONS, NEUTRINOS AND QUARKS	INTERMEDIATE VECTOR BOSONS (W^+, W^-, Z^0)	50-100 GeV	1	REPULSIVE
GRAVITATIONAL	10^{-39}	LONG	ALL PARTICLES	GRAVITONS	0	2	ATTRACTIVE

FOUR FORCES have a character determined largely by the properties of the associated quanta. The mass of the exchanged particle determines the range of the force; only forces transmitted by massless particles can have a long range. Spin angular momentum also has an important influence. Forces transmitted by particles whose spin is an even integer are invariably attractive; quanta with odd-integer spin give rise to repulsive forces between like particles. Although gravitation is exceedingly feeble, it is the only one of the four forces that is both long-range and attractive between all pairs of particles. Gravitation therefore determines the large-scale structure of the universe.



SPIN ANGULAR MOMENTUM affects not only the kinetics of particles but also the statistical behavior of systems made up of two or more identical particles. Those particles whose spin is half an integer (such as the electron and the proton) are called fermions. They obey the exclusion principle formulated by Wolfgang Pauli: No two fermions can occupy the same quantum-mechanical state. Particles with integer spin (such as the photon and the graviton) are called bosons, and they can be brought together in unlimited numbers at one point or in one quantum-mechanical energy state. Hence in any system with a spectrum of energy states fermions distribute themselves one to a state, whereas bosons tend to condense in the lowest state available.

made by P. A. M. Dirac, who formulated a relativistic quantum wave equation for the electron in 1928. A surprising prediction emerged from Dirac's work. His equation was consistent only if there existed a new particle with the same mass as the electron but opposite electric charge. This antiparticle of the electron, called the positron, was discovered in 1932. It is now recognized that there must be an antiparticle for every particle in nature.

A full unification of special relativity and quantum mechanics came with the development of quantum field theory, which began with work by Dirac, Heisenberg and Wolfgang Pauli in the late 1920's. Quantum field theory is a general formalism that in principle can be applied to each of the four forces. In practice, however, difficulties arise from the infinities that appear in the calculation of certain quantum contributions to probabilities. These difficulties were first overcome in quantum electrodynamics, which is the quantum field theory that describes the electromagnetic interactions of electrons, positrons and photons. Success came in the late 1940's, two decades after the formulation of the theory, when Richard P. Feynman, Julian S. Schwinger, and Sin-itiro Tomonaga developed simplified methods of calculation in closer harmony with the underlying symmetries of the theory. It was found that through a method called renormalization the infinities could be removed in an unambiguous way. The finite predictions obtained could then be compared with experiment. The predictions of quantum electrodynamics are confirmed with extraordinary accuracy. For example, the theory predicts that the electron acts as a tiny magnet. The measured value of the electron's magnetic strength, which is $1.0011596524 \pm .0000000002$, agrees with the theoretical prediction to within a few parts in 10 billion.

The renormalization procedure can be applied only in a special class of quantum field theories where the infinities can be compensated for by correction of the basic parameters of the theory, such as the mass and the charge of the electron. The observed electron mass is the sum of the "bare mass" and the "self-energy" resulting from the interaction of the electron with its own electromagnetic field. Only the sum of the two terms is observable. The self-energy can be calculated and turns out to be infinite. Nothing is known about the bare mass, and so it can be assigned a negatively infinite value, with the result that the two infinities cancel and yield the observed finite mass of the electron.

Renormalization works in quantum electrodynamics and in the currently accepted field theories constructed to describe the strong interactions. For many years it seemed there was no convincing renormalizable theory of the weak interactions. That situation was changed in the early 1970's by a theoretical discovery made by Gerard 't Hooft and Martin J. G. Veltman of the University of Utrecht, which was developed further by them and by the late Benjamin W. Lee of the Fermi National Accelerator Laboratory and by J. Zinn-Justin of the Saclay Nuclear Research Center near Paris. They showed that the unified field theories of the weak and the electromagnetic interactions can be renormalized. Quantum theories of the gravitational force still have serious difficulties with infinities; it is here that supergravity offers new hope.

In quantum field theory particles are identified with waves or quanta of the underlying field. An important prediction of quantum field theory is that particles spin about an axis. The rate of spin can take only values that are integer or half-integer multiples of Planck's constant. The short-lived pi meson has a spin of 0, the electron, the proton and the neutron have a spin of 1/2 and the photon has a spin of 1.

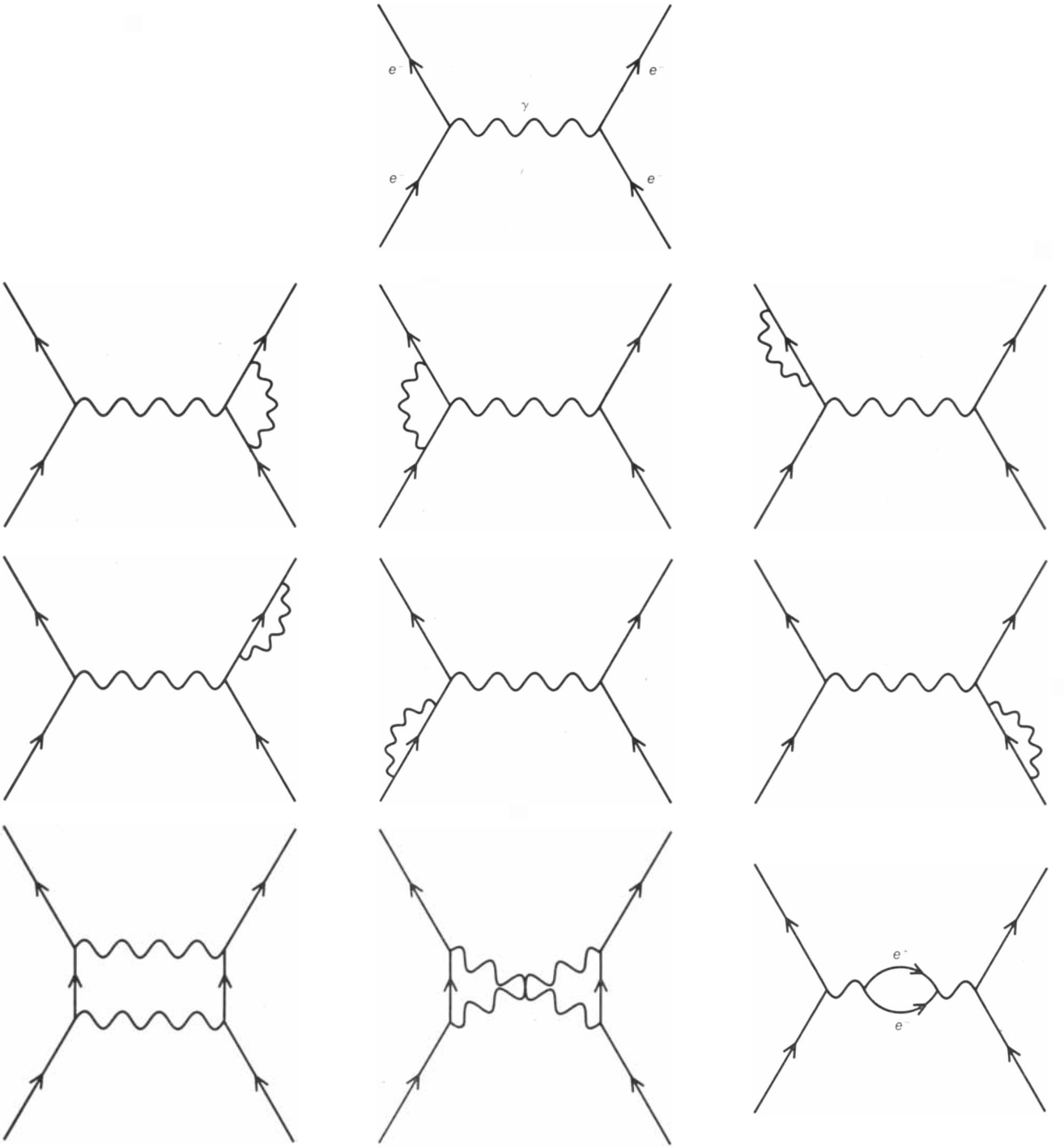
One general prediction of quantum field theory that is strikingly confirmed in nature is the connection between the spin of a particle and its statistics, that is, the behavior of a system made up of two or more identical particles. Particles with half-integer spin (such as 1/2, 3/2, 5/2) are fermions, and they obey the exclusion principle formulated by Pauli, which states that no two identical fermions can occupy the same point in space or, more generally, the same quantum state. It is this property of fermions that explains the elaborate structure of electron shells in atoms and hence the diverse chemical properties of the elements. If it were not for the exclusion principle, all the electrons in an atom would condense in the lowest energy level. In bulk matter at high density the same principle leads to an effective repulsive force between identical fermions. This force explains the stability of white-dwarf stars and neutron stars, which without it would collapse into black holes under the attractive gravitational force.

For particles with integer spin, the bosons, the statistics are entirely different. There is an increased probability for two or more bosons to occupy the same point in space or the same quantum state. Such superpositions of many identical bosons can lead to macroscopically observable effects. For example, laser light is a superposition of many photons with the same energy and direction. Given the disparate properties of bosons and fermions, it is all the more remarkable that a symmetry has been found that can relate them.

In quantum field theory all forces between particles are described by the exchange of "virtual" particles. The repulsive force between two electrons comes about when one electron emits a photon, which is then absorbed by the other electron. The intermediate photon is said to be virtual because it cannot be observed directly in this process; it exists for too short a time. It can be proved in quantum field theory that long-range forces arise from the exchange of massless particles and short-range forces

arise from the exchange of particles with mass. The short-range nuclear force between two protons arises from the exchange of pi mesons, whose mass is 300 times that of an electron. At a more fundamental level the proton, the neutron and the pi meson are thought to be made up of quarks. In this view the strong force arises from the exchange by the quarks of virtual particles called gluons. The weak force is thought to arise from the exchange of intermediate vector bosons, which are very heavy particles of spin 1 predicted by the unified field theories of weak and electromagnetic interactions.

Although a satisfactory theory of quantum gravity is yet to be established, one can anticipate that the Newtonian force will arise from the exchange of a virtual particle. This particle is called the graviton. It must be massless because gravity is a long-range force. Its spin must be an even integer, such as 0, 2



QUANTUM CORRECTIONS to the classical laws of force are represented by diagrams that have closed loops. In the interaction between two electrons the exchange of a single virtual photon (*top*) corresponds to the force predicted by Maxwell's theory of electromagnetism. In quantum electrodynamics more complicated interactions must be considered. For example, a photon can be emitted and then reabsorbed by the same electron, two photons can be exchanged, or the virtual photon can give rise to an electron and a positron, which then annihilate each other to yield another photon. A long-standing problem in quantum field theories is that such loop diagrams predict an infinite probability of interaction. In quantum electrodynamics a procedure called renormalization eliminates the infinities. The difficulty of formulating a quantum theory of gravity is that the renormalization procedure is not effective and some infinities persist.

or 4, because it can be shown that the exchange of bosons whose spin is an odd integer gives rise to forces that are repulsive between like particles. The spin cannot be 0 because in that case light would not bend toward the sun. The next-simplest case, spin 2, satisfies all experimental tests.

The arguments of the preceding paragraph can be reversed, that is, the general theory of relativity can be derived from the assumption that the gravitational force results from the exchange of massless spin-2 particles and that these particles are described by a quantum field theory. All particles are pulled by the virtual gravitons in such a way that they follow the same curved trajectories predicted by Einstein's equations. This new derivation of general relativity does not detract from Einstein's discovery. It simply illuminates it from the new viewpoint of forces in quantum field theory.

The basic difference between classical field theories and quantum field theory is that only in the latter can particles be created and destroyed. The annihilation of an electron and a positron to yield two photons is possible only in quantum field theory. Since the process is frequently observed in the laboratory, there is no doubt that this aspect of quantum field theory is correct. Indeed, the prediction of the probability for this event by quantum electrodynamics is in complete agreement with experiment.

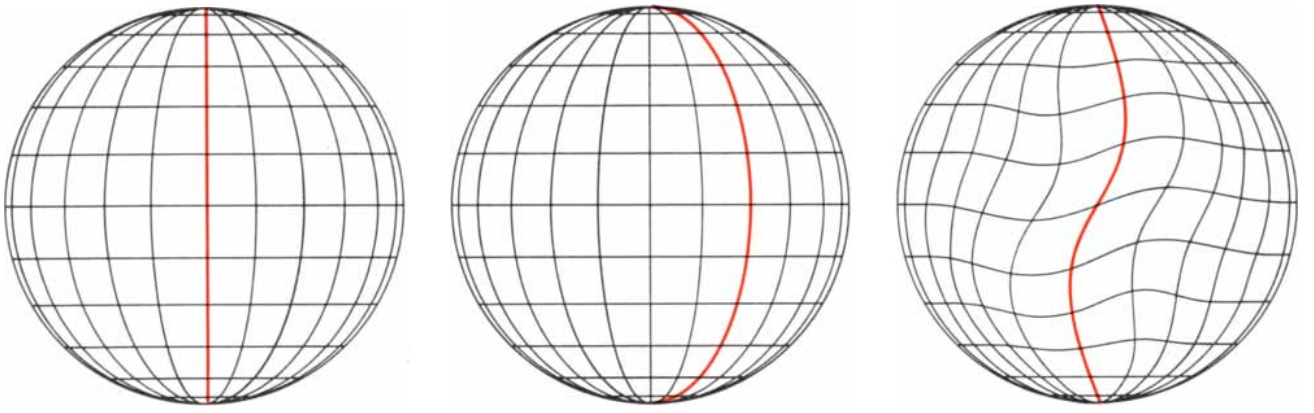
The basic element of a quantum field theory is the "vertex," in which one particle disintegrates to yield two or more other particles. The vertex for quantum electrodynamics is the intersection of two lines that represent electrons or positrons and one line that represents a photon. The vertex can describe the creation of an electron-positron pair by a decaying photon, the annihilation of an electron-positron pair creating a photon or the decay of an electron into a second electron and a photon.

The probability for any process in a quantum field theory is obtained by forming diagrams in which vertexes are connected in all possible ways. For the scattering of one electron by another the simplest diagram shows the exchange of a single photon, which represents the effects of the classical electromagnetic force. Other diagrams have closed loops of virtual particles. The loop diagrams represent the quantum corrections to the classical law of force. For each diagram there is a well-defined but complicated mathematical expression. In successful quantum field theories it is possible to evaluate these expressions and to remove the infinities they often exhibit by renormalization. The probability for the process is then obtained by adding the amplitudes for all the diagrams and squaring the sum. There are an infinite number of diagrams and so it is impossible to obtain an exact result. In quantum electrodynamics the contribution of the diagrams with one loop is smaller than the contribution of the diagrams with no loops by a factor of less than 1 percent. Diagrams with two loops are smaller by an additional factor of 1 percent, and so on. Hence an accurate approximation of the total amplitude can be obtained by considering only a few diagrams.

Throughout history the decorative patterns of many cultures bear witness to the strong appeal symmetry has always had for mankind. A symmetry can be understood as a motion that leaves the form of a pattern or an object invariant. For example, a cube rotated 90 degrees appears to be unchanged, and a sphere is invariant after any rotation around its center. Physical theories can have symmetries of a similar kind, but what is invariant after a transformation is not a pattern or an object but the mathematical laws of the theory itself. Physicists now recognize that symmetries play a vital role in our understanding of nature.

As an example of a fundamental symmetry, consider two astronauts studying electromagnetic phenomena from two spacecraft drifting freely in some interstellar region, where they would have constant relative velocity. Each astronaut defines a coordinate system with the origin at his own position and with different orientation. The two astronauts therefore identify external events by different coordinates, and records of their observations would look quite different. If they reduce their findings to physical laws, however, they both find that Maxwell's equations are valid.

The principle demonstrated by this thought experiment is called Poincaré invariance, after the French mathematician Henri Poincaré. It is the space-time symmetry underlying the special theory of relativity. Comparison of the observations made by the two astronauts would show that their coordinate systems are related in the manner required by special relativity. Poincaré invariance states explicitly the experimentally verified assumption that the laws of nature are the same across town as they are in your backyard. More precisely, it states that all laws of physics take the same form in any two coordinate systems, even if they are shifted and rotated and moving with respect to one another,



SYMMETRIES can be present in laws of nature as well as in patterns and in objects such as crystals. Just as a crystal retains its form after a specified rotation or translation, a symmetrical law of nature remains invariant after some specified transformation. The symmetries in physics are of two types, called global and local; the distinction between them can be illustrated by considering an ideal spherical balloon (*left*), marked with a system of coordinates so that the positions of all points on the surface can be identified. A global symmetry is exhibited if the sphere is rotated about some axis (*middle*). The rotation is a symmetry operation because the form of the sphere remains unchanged; it is a global symmetry because the positions of all the points on the surface are changed by the same angular displacement. Local symmetry requires that the balloon keep its shape even if the points on the surface are moved independently (*right*). It is notable that a local symmetry operation stretches the balloon and therefore introduces forces between points. Each of the four basic forces in nature is thought to arise from a similar requirement that a law of nature be invariant under a local symmetry transformation.

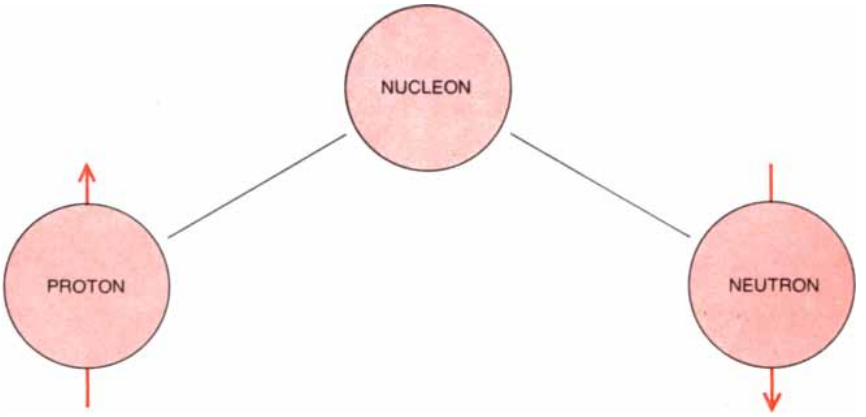
as long as they have a constant relative velocity.

There is a vital distinction between symmetries such as this one, which are said to be global, and local symmetries. Global symmetry may sound like the grander concept, but local symmetries impose more stringent requirements on theories and reveal deeper unities in nature. Indeed, the transition from a global symmetry to a local one describes the origin of the gravitational and the electromagnetic forces, and there is reason to suspect that the other forces also emerge from local symmetries.

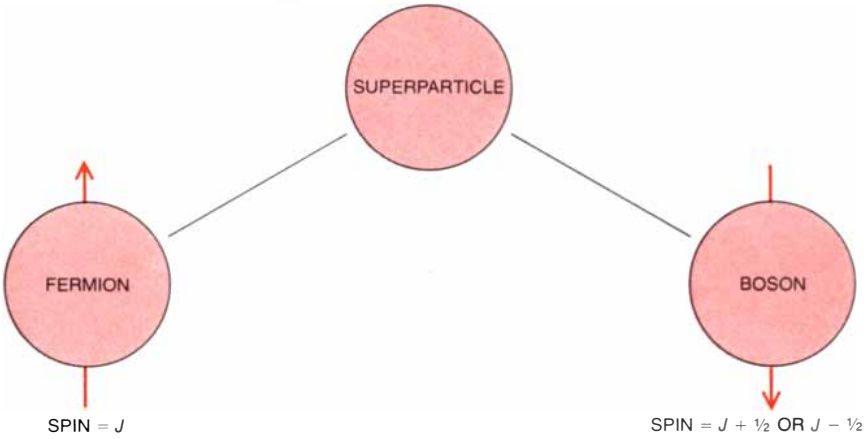
A global symmetry is one in which a transformation is applied uniformly to all points in space; in a local symmetry each point is transformed independently. The distinction can be illustrated by means of a spherical balloon with various points marked on its surface. If an axis through the center of the sphere is chosen, the balloon can be rotated through some angle. Because the balloon keeps its spherical form the rotation is a symmetry operation of the balloon; because all the points on the surface are transformed in the same way (by rotation through the same angle) it is a global symmetry operation.

With an ideal balloon it would also be possible to move each point independently, pushing or pulling the points to new positions on the surface but keeping their distance to the center fixed. Again the sphere retains its form, so that this procedure is also a symmetry operation. Each point is transformed independently of its neighbors and so it is a local symmetry. There is now a significant change: when the points are moved independently, the membrane of the balloon is stretched and elastic forces develop between the displaced points. These forces are not artifacts of an imperfect model; on the contrary, forces appear in the same way when a physical theory has a local symmetry.

The Poincaré invariance discussed above is a global symmetry because a transformation between the two sets of coordinates employed to describe a given point in space-time is the same for all points. The much stronger constraint of local Poincaré invariance is established by requiring the laws of physics to retain the same form when the coordinates of each point are transformed independently. This change is equivalent to allowing the two observers to have accelerated motion with respect to each other. At first it would seem that observers under these circumstances would not derive the same laws of physics because an accelerating observer experiences "fictitious" forces such as the centrifugal force of rotational motion. Einstein recognized that fictitious forces induced by acceleration are closely related to gravitational forces associated with masses. He showed that the laws of physics can be kept invariant if the gravitational field is introduced into the equations. The result is the general theory of relativity.



ISOTOPIC SYMMETRY establishes a relation between particles with the same spin angular momentum, such as the proton and the neutron. Both these particles can be regarded as states of a primitive or undifferentiated particle called the nucleon, which can be imagined to have an arrow associated with it in some fictitious space. If the arrow points up, the nucleon is a proton; if it points down, the nucleon is a neutron. For real particles the arrow is either up or down, since no real particle is half proton and half neutron, but the laws of physics that describe interactions between protons and neutrons remain invariant under arbitrary rotations of the arrow.



SUPERSYMMETRY relates particles with different spins, namely those with the adjacent spins of J and either $J + 1/2$ or $J - 1/2$. Hence any fermion and boson with adjacent spins can be regarded as alternative manifestations of a single "superparticle" with an arrow in an auxiliary space. Such a fundamental symmetry between fermions and bosons was long thought to be impossible. In quantum field theories with local supersymmetry the gravitational force appears naturally. The spin-2 graviton has a fermion partner with a spin of 3/2. The name gravitino has been suggested for this particle. Neither the graviton nor the gravitino has been observed.

The above example illustrates a powerful, general feature of the relation between global and local symmetries. If a set of physical laws is invariant under some global symmetry, the stronger requirement of invariance under local symmetry can be met only by introducing new fields, which give rise to new forces. The fields are called gauge fields, and they are associated with new particles whose exchange gives rise to the corresponding forces. Thus gravitation is the gauge field of local Poincaré invariance, and the gravitational force results from the requirement that Poincaré symmetry be local.

The existence of electromagnetic forces can also be derived from the requirement of local symmetry. In a quantum field theory charged particles are described by fields that have two numbers at every point in space-time: an amplitude and a phase. The amplitude measures the probability of finding a particle at a point and the phase describes the wave properties of the particle. Observable quantities such as the total energy of a set of charged particles do not change when the phase of the field is shifted by an amount that is the same at all points. Thus the field has a global symmetry under a change of phase. Local symmetry would require that observable quantities remain invariant when the phase is allowed to vary independently at each point. To accommodate the local symmetry it is necessary to introduce the electromagnetic

field as a gauge field; the quanta of this field are photons, which give rise to the electromagnetic force. With only a global symmetry there would be no electromagnetic forces between charged particles, no photons and no light.

Local electromagnetic symmetry is called an internal symmetry; unlike Poincaré invariance it does not involve a change in space-time coordinates. Another internal symmetry, called isotopic symmetry, is fundamental to nuclear physics; it establishes a relation between the proton and the neutron.

The proton and the neutron both have a spin of 1/2, and they experience nuclear forces of about the same strength. Isotopic symmetry allows them to be regarded as two alternative states of a single undifferentiated particle, the nucleon. The nucleon can be imagined as a particle with an arrow in some imaginary space. If the arrow points up, say, the particle is a proton; if it points down, it is a neutron. Physical particles always have the arrow pointing either up or down (there are no real particles that are half proton and half neutron), but the equations that describe the nuclear force are invariant under arbitrary rotations of the arrow. In nuclear physics isotopic symmetry is a global symmetry. The arrow must rotate through the same angle at all points if the nuclear forces are to be invariant.

The problem of extending isotopic symmetry from a global symmetry to a local one was solved in 1954 by C. N. Yang and Robert Mills. They found that the transition to a local symmetry required the introduction of three gauge fields, each field associated with a massless particle having a spin of 1. For more than a decade the Yang-Mills field theory was regarded as an elegant mathematical curiosity without physical applications. The three massless particles and the long-range forces they would generate simply do not exist.

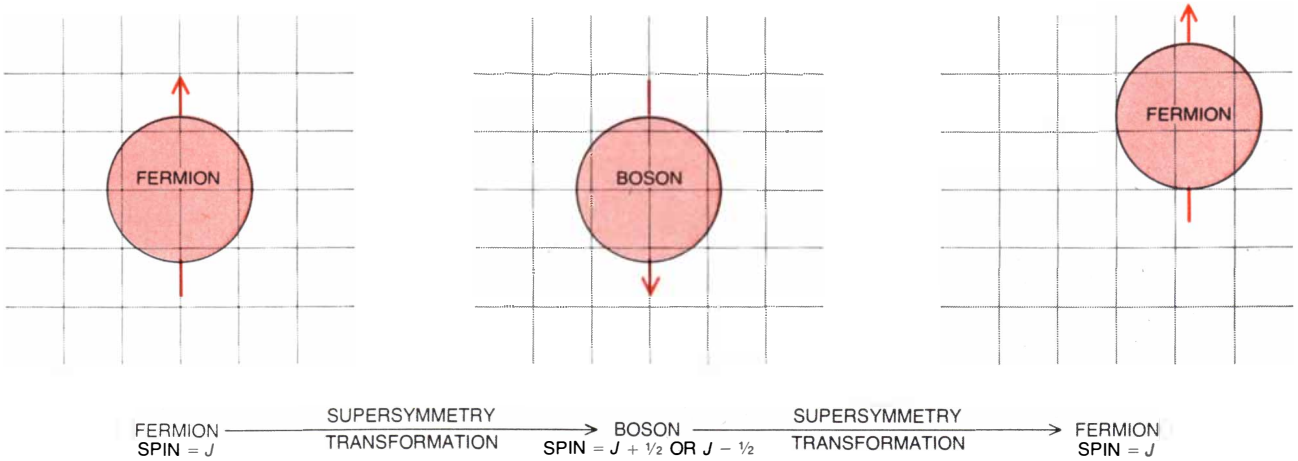
It is now known that the gauge particles of the Yang-Mills field theory can exist, because they are not necessarily massless. They can acquire a mass—a very large mass—through a mechanism called spontaneous symmetry-breaking. It was shown by Jeffrey Goldstone of the University of Cambridge that the physical manifestations of a symmetrical physical theory can sometimes be quite asymmetrical. An analogy to this process is the roulette wheel: the equations of motion for the ball and wheel are symmetrical around the axis of rotation, but the ball invariably comes to rest in an asymmetrical position.

Peter Higgs of the University of Edinburgh subsequently showed that in theories of gauge fields the effect of spontaneous symmetry-breaking is to give a mass to some of the gauge particles whereas others would be massless. Unified theories of the weak and the electromagnetic forces incorporating local isotopic symmetry and spontaneous symmetry-breaking were then constructed. In these theories the carriers of the short-range weak force are the intermediate vector bosons. They are gauge particles of spin 1, which acquire mass through the Higgs mechanism. The photon is a gauge particle that remains massless. Hence the simple requirement of local isotopic invariance led to the unification of two of the basic forces in nature. As will be shown below, the additional requirement of local supersymmetry can further unify these forces with gravitation.

Internal symmetries such as isotopic symmetry relate particles that have the same spin. One of the dreams of theoretical physics has been to find symmetry schemes that would unite particles having different spins. This dream was realized by the invention of supersymmetry. Supersymmetry relates particles that have adjacent spins, such as 1 and 1/2, and thus of necessity it embraces both fermions and bosons. What is equally remarkable, it relates internal symmetries to Poincaré invariance. It is this connection that allows the construction of the new gravitational theory of supergravity.

Supersymmetry was formulated independently by physicists in the U.S.S.R., western Europe and the U.S. It was discussed in 1971 by Y. A. Golfand and E. P. Likhtman of the Lebedev Physical Institute in Moscow. Their work went unnoticed, however, and the subject was rediscovered in 1973 by D. V. Volkov and V. P. Akulov of the Physical-Technical Institute in Kharkov. A symmetry between bosons and fermions was also found in 1971 by Pierre M. Ramond of the California Institute of Technology and by André Neveu of the École Normale Supérieure and John H. Schwarz of Cal Tech. Their work grew out of an approach to particle physics called dual models. In 1973 Julius Wess of the University of Karlsruhe and Bruno Zumino of the European Organization for Nuclear Research (CERN) generalized that work to quantum field theory and gave a systematic procedure for constructing global supersymmetry theories.

In the mid-1960's theorems had been proved that seemed to demonstrate the impossibility of the unification of Poincaré invariance and internal symmetry. It is now apparent that these "no go" theorems are incorrect, but the error was not in the proof. Rather, one of the assumptions implicit in the theorems turned out to be too restrictive and could be relaxed. The assumption seems plausible and unexceptional, namely that the numbers employed in describ-



SUPERSYMMETRY TRANSFORMATIONS result in a change in the position of a particle. Supersymmetry seems to be an internal symmetry that concerns only the properties of a particle and not its position. Remarkably, however, a repeated supersymmetry transformation, such as one from fermion to boson and back to fermion, moves a particle from one point in space to another. In local supersymmetry the displacement can be different at each point in space. The displacement of a particle through a supersymmetry transformation suggests a relation between supersymmetry and the structure of space-time; it is this relation that gives rise to the gravitational force.

ing the symmetry should obey the commutative law for multiplication. It is now known that there is no need for this limitation. Supersymmetry theory incorporates as an essential element numbers that do not have the commutative property.

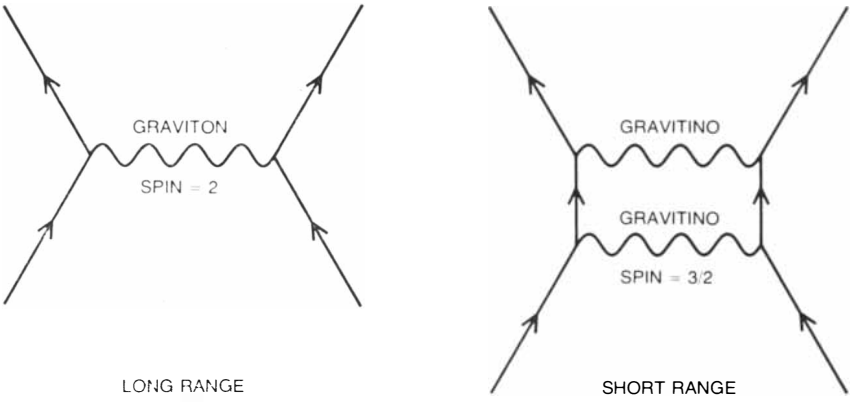
The commutative law for multiplication states that the product of two numbers does not depend on the order in which they are multiplied. Thus if r_1 and r_2 represent any two real numbers, then $(r_1 \times r_2) - (r_2 \times r_1) = 0$. For example, $(6 \times 2) - (2 \times 6) = 0$. For anticommuting numbers the sign in this equation is changed. If ϵ_1 and ϵ_2 are assumed to be two anticommuting numbers, then $(\epsilon_1 \times \epsilon_2) + (\epsilon_2 \times \epsilon_1) = 0$. Of course, one cannot substitute numerical values in this equation, but one can nonetheless imagine that new numbers with this property exist. Such number systems were invented more than a century ago by Hermann Günther Grassmann, who taught mathematics in the German town of Stettin.

Supersymmetry can be described in much the same way that isotopic symmetry is. A hypothetical "superparticle" is endowed with an extra arrow in an imaginary auxiliary space. If the arrow points up, the particle is a fermion; if it points down, it is a boson. The spins of the fermion and the boson are always adjacent. For example, a boson with a spin of 1 can join a fermion whose spin is either 1/2 or 3/2. For physical particles the arrow must always point either up or down, since no real particles are half boson and half fermion, but the equations that describe the forces between elementary particles are invariant under arbitrary rotations of the arrow, just as they are in isotopic symmetry. The supersymmetry is global if the angle of rotation is the same at all points of space-time and local if the rotation is different at each point.

Let us explain how a supersymmetry transformation works. Denoting the boson and fermion fields b and f, a transformation connects them with new fields b' and f', where $f' = f + b\epsilon$ and $b' = b + f\epsilon$. The factor ϵ is a measure of the angle of rotation of the superparticle arrow. Although b is an ordinary number, f and ϵ are anticommuting numbers.

The necessity of anticommuting numbers in supersymmetry theories is related to the Pauli exclusion principle, the rule that forbids two fermions from occupying the same point. The probability of finding one fermion at a point is given by the value of the field f and the probability of finding two fermions is given by $f \times f$. The Pauli exclusion principle requires that $f \times f = 0$, and anticommuting numbers have precisely this property. The probability of finding two bosons at a point, which is $b \times b$, need not vanish, so that b can be an ordinary number. Compliance with the Pauli principle must also be incorporated in the supersymmetry rotation law. Two bosons can occupy the same point, but if they are both transformed into fermions by a supersymmetry rotation, the probability of finding them at the same point must vanish. The probability is given by $(f + b\epsilon) \times (f + b\epsilon)$, and it must be equal to zero. This requirement implies that $(f \times \epsilon) + (\epsilon \times f)$ is zero and that $\epsilon \times \epsilon$ equals zero.

The most surprising property of supersymmetry is that repeated application of the fermion-boson transformation moves a particle from one point to another in space-time. Thus a Poincaré transformation (of position) is obtained by repeating a supersymmetry transformation. Since local Poincaré invariance is the symmetry that gives rise to general relativity, a connection between supersymmetry and gravitation can also be expected.



SUPERGRAVITY provides corrections to the general theory of relativity at the quantum level. In general relativity the gravitational force arises entirely from the exchange of gravitons; in supergravity there is an additional contribution from the exchange of spin-3/2 gravitinos. Because the gravitinos are fermions they are exchanged only in pairs, a process with negligible probability except at short range. The predictions of general relativity for long-range interactions are unchanged in supergravity; new effects are predicted only at microscopic scale.

It was argued above that the transition from a global to a local symmetry always introduces new gauge fields, which in turn give rise to new forces. An obvious question, then, is whether global supersymmetry can be promoted to a local invariance and, if so, what the nature of the new gauge fields will be. Local supersymmetry is indeed possible if two new fields are introduced; they are the field of the spin-2 graviton and a new spin-3/2 field.

The construction of a gauge theory of supersymmetry begins with the observation that a repeated supersymmetry transformation yields a physical translation of a particle. This relation is embodied in an equation that in effect states that the product of two supersymmetry rotations is a shift in space-time. To obtain a local supersymmetry theory a gauge field must be introduced for each of the symmetries present in the equation. The shift in space-time is a Poincaré transformation for which the spin-2 graviton is the appropriate gauge particle. Hence gravitation appears naturally in the theory, and it is for this reason that local supersymmetry is usually called supergravity. The gauge field for supersymmetry transformations is less readily determined, but since supersymmetry relates only particles of adjacent spin, it must be a fermion with a spin of $2 + 1/2$ or $2 - 1/2$, that is, $5/2$ or $3/2$. Simplicity argues that the spin should be $3/2$, and more technical considerations support the same choice.

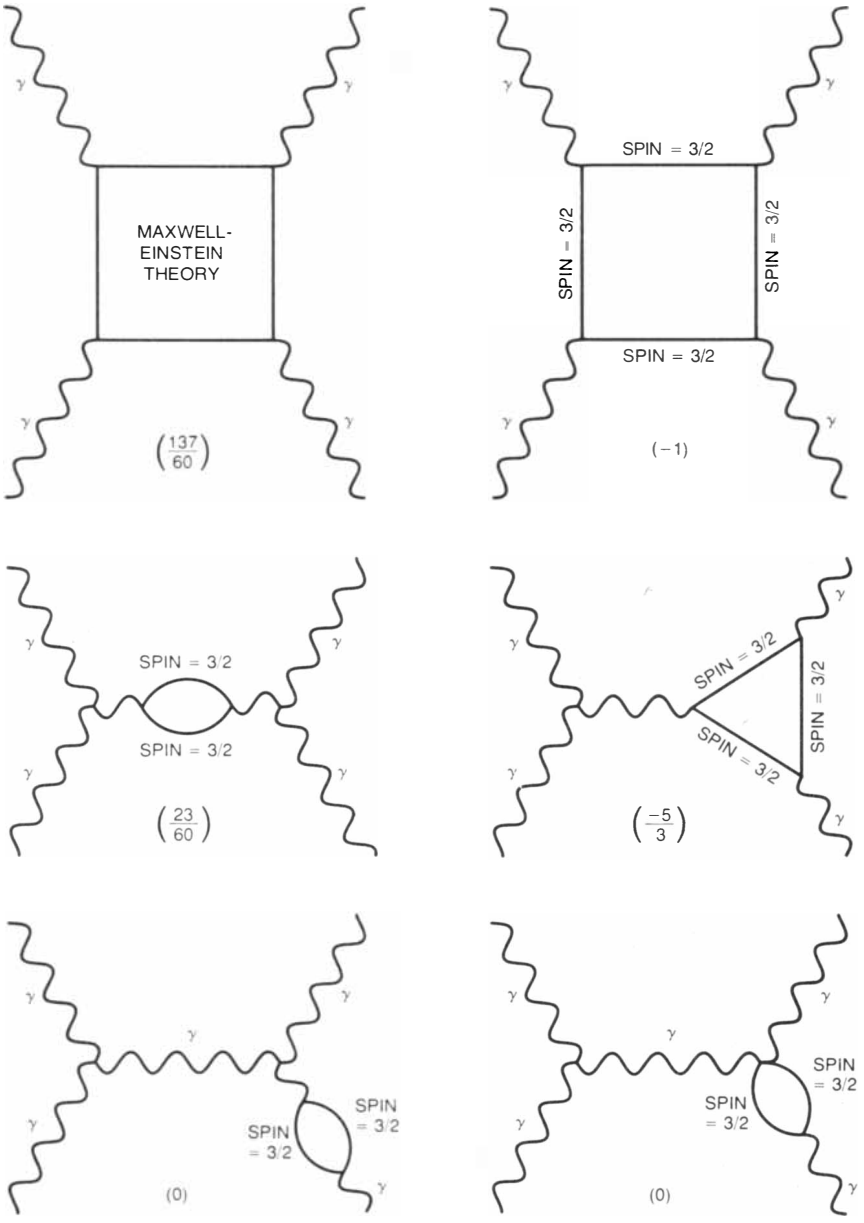
In 1976 the most elementary example of a supergravity theory was constructed by us in collaboration with Sergio Ferrara of the Frascati Laboratories near Rome. Shortly afterward Stanley Deser of Brandeis University and Zumino showed how to formulate the theory in a simpler way. In our derivation we started with the assumption that the theory should include a spin-2 graviton and a spin-3/2 particle and that it should possess local Poincaré invariance and local supersymmetry. After a great deal of mathematical work we found a theory that meets these requirements.

Work with fields that describe particles of high spin is notoriously difficult. A theory for noninteracting spin-3/2 fields was published in 1941 by Schwinger and William R. Rarita of the Lawrence Berkeley Laboratory of the University of California, but all attempts to introduce forces between the spin-3/2 particles and other particles led to inconsistencies. For example, in some of the proposed theories signals would travel faster than light, with the result that the laws of causality would be violated. We now know that these attempts failed because spin-3/2 particles can be coupled to other particles only when the forces are supersymmetric.

The existence of a fundamental particle with a spin of 3/2 is inescapable in

supergravity. The particle is a companion to the graviton, and the name gravitino has been suggested for it. It is not yet clear what properties the gravitino should be expected to have. In the simplest supergravity theories it is massless and is coupled to other particles only by the feeble force of microscopic gravitation. Such particles have not been observed, but they would be exceedingly difficult to detect. Even gravitons have not yet been observed experimentally. In more complex supergravity theories, however, the gravitino can acquire a mass through spontaneous symmetry-breaking, and stronger forces can arise between the gravitino and other particles. In these theories the gravitino would be much easier to detect. The discovery of such spin-3/2 particles would be strong experimental evidence for supergravity.

Part of the difficulty of uniting gravitation with the other three forces is not that the respective theories are in conflict but that they simply have too little in common. In general relativity forces are derived from the geometric properties of space and time, and in quantum field theory they are derived from the exchange of quanta. Supergravity describes general relativity in the language of quantum field theory, but there is no apparent reason supergravity could not also be formulated in geometric terms. Such a geometric derivation seems to be possible in an extended space-time in which every point has not only the four usual space and time coordinates but also an additional set of coordinates identified by anticommuting numbers. A "superspace" of this kind was introduced by Akulov and Volkov and was investigated further by Salam and John Strathdee of the International Centre for Theoretical Physics. This approach led to the construction of other supergravity theories, which actually preceded the one discussed here. One such theory was developed by Richard L. Arnowitt and Pran Nath of Northeastern University, who followed the same steps as Einstein but in superspace rather than ordinary space. The superspace theories are elegant but technically complicated. It is not yet known what particles they describe or whether they are physically consistent.



FINITE PROBABILITY for loop diagrams in a quantum theory of gravity is obtained by including gravitinos in the interaction. The diagrams shown here are those for the interaction between two photons. The first diagram, labeled Maxwell-Einstein Theory, consolidates all the one-loop diagrams that involve only gravitons and photons; the contribution from these diagrams is equal to an infinite quantity multiplied by the coefficient 137/60. Five one-loop diagrams involving gravitinos can be constructed; each of them is proportional to the same infinite term multiplied by the coefficients shown in brackets. Only the sum of the diagrams is observable, and adding the coefficients shows that the sum is zero. Hence the infinite contributions of the gravitinos cancel those of the gravitons and the diagrams have a finite probability.

The simplest supergravity theory describes a world consisting of gravitons and gravitinos only. That is clearly unrealistic since a unified field theory must have a place for all elementary particles. The number of such particles is not precisely known. It now appears that the quarks, which are the building blocks of protons and neutrons, are elementary. Other particles that must be included are the electron and three related particles: the muon and two kinds of neutrino. The various gauge particles must also be counted: the photon, the intermediate vector bosons of the weak interaction and the graviton. If supergravity is correct, the gravitino must be added to the list.

To accommodate these particles local supersymmetry must be extended to include states with a spin of less than 3/2. In principle this extension is easily achieved, since supersymmetry can connect any fermion-boson pair with adjacent spins. What is required, then, is that more particles be added to the theory in adjacent-spin doublets. Techniques have been developed for describing the interactions of these doublets with the basic spin-2 and spin-3/2 doublet of the supergravity gauge fields. In the past year many such theories have been devised.

In one category of theories an arbitrary number of particles can be added in doublets of spin-1 and spin-1/2 or of spin-1/2 and spin-0. The advantage of these theories is that the number of particles can be adjusted almost at will to suit the elementary particles observed. A price must be paid, however, for this flexibility. Such theories have the unde-

sirable characteristic that infinities in the one-loop diagrams cannot be eliminated. The reason is the lack of full unification. In these theories there are no symmetry transformations that connect the graviton and the gravitino to the lower-spin particles. Nevertheless, these theories may play an important role in the description of nature.

Another set of theories, known as extended supergravity theories, is much more restrictive and completely unified. There are just eight of these theories and each of them has a characteristic number of distinct boson-fermion transformations; this number is designated n, and it can assume values from 1 through 8. In each theory there is one spin-2 graviton and there are n spin-3/2 gravitinos. The number of particles with lower spins is also completely determined. If n is equal to 1, the theory is simply supergravity in its original form, with one graviton and one gravitino. If n is 2, the theory includes one graviton, two gravitinos and one spin-1 particle. Perhaps the most realistic model of this kind is given when n is 8. The complement of elementary particles then consists of one graviton, eight gravitinos, 28 spin-1 particles, 56 spin-1/2 particles and 70 spin-0 particles.

An intriguing property of the eight extended supergravity theories is their extreme degree of symmetry. Each particle is related to particles with adjacent values of spin by supersymmetry transformations, and these supersymmetries are of local form. Thus a graviton can be transformed into a gravitino and a gravitino into a spin-1 particle. Within each family of particles that have the same spin all the particles are related by a global internal symmetry, much like the isotopic symmetry that relates proton and neutron. Hence any gravitino can be transformed into any other gravitino by an internal symmetry operation. By combining the supersymmetry and the internal symmetry the entire group of particles is unified. One could start with the graviton and by a series of supersymmetry operations and internal-symmetry operations transform it into any other elementary particle that is included in the theory.

Like other physical symmetries, extended supergravity can also be viewed in terms of a "superparticle" with an arrow in an auxiliary space of many dimensions. As the arrow rotates, the particle becomes in turn a graviton, a gravitino, a photon, a quark and so on. The quanta of all the forces are present in the theory, and they are unified, or derived from a common source. This degree of unification has never before been achieved in a quantum field theory.

One remaining requirement for unification is to make the internal symmetries, which relate particles that have the same spin, local rather than global. Local internal symmetry is necessary so

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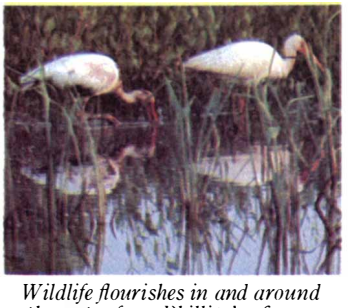
Before waste water leaves our refinery, the people of Phillips Petroleum put it through a 40-day purification process to insure it is clean.



Wildlife flourishes in and around the water from Phillips' refinery.

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that forces such as electromagnetism can be incorporated. The requirement of local invariance can in fact be satisfied, as was demonstrated by one of us (Freedman) and Ashok Das of City College of the City University of New York and by E. S. Fradkin and M. A. Vasiliev of the Lebedev Institute. The resulting theories potentially unify gravitation with the strong, the weak and the electromagnetic forces.

In the extended supergravity theories the strength of the gravitational force is determined by one parameter and the strengths of all the other forces are determined by another parameter. Ideally in a unified theory all the forces would be governed by a single universal constant. There does exist a third class of supergravity theories that have this feature. The simplest of them was found by, among others, Michio Kaku of City College and Paul Townsend of the State University of New York at Stony Brook. These theories are not based on Einstein's general theory of relativity but are supersymmetric generalizations of another theory of gravitation, discovered by Hermann Weyl in 1923. As in Einstein's theory, gravitation is described by the curvature of space-time, but there is an additional local symmetry that allows the scale by which length and time are measured to be chosen arbitrarily at each space-time point. The corresponding supersymmetric Weyl theories achieve a complete fusion of gravity with all the other forces, but for now the other two types of supergravity theories are likely to be more successful in applications to the real world.

The principle of local supersymmetry leads to an elegant unification of the basic forces, but elegance is not enough. The theories must pass a test that has been failed by all earlier theories of quantum gravity: the infinities that appear in calculations of interaction probabilities must be eliminated.

In all quantum field theories the diagrams in which virtual particles form closed loops describe the genuine quantum effects. The computation of the probabilities associated with any such diagram requires the summation of the virtual particles over all possible energies. These sums usually lead to infinities in the mathematical expressions for the diagrams. In some cases, such as quantum electrodynamics, the infinities are of a relatively harmless nature and can be removed by the renormalization procedure. In quantum gravity, however, the infinities are much worse and cannot be removed by renormalization. One hope remains for eliminating them. In some diagrams the infinity is positive and in others it is negative. It is only the sum of the diagrams that gives a physically observable probability, and it is possible that the infinities might miraculously cancel one another in the sum.

A simple argument explains why the infinities in quantum gravitation are worse than those in quantum electrodynamics. The electric force between charged particles is independent of the masses or energies of the particles and depends only on their charge, whereas the gravitational force is proportional to the masses. Since in special relativity mass and energy are related by $E = mc^2$, it follows that the strength of the gravitational force increases when the energies of the virtual particles increase. Thus in the sum of the probabilities contributed by all possible energies of the virtual particles the higher energies give a larger contribution in the case of gravitation and lead to more serious infinities. Roughly speaking the infinities are of the form of the mathematical series $1 + 2 + 3 + \ldots$ in gravitation and of the milder form $1 + 1 + 1 + \ldots$ in electromagnetism.

Before the development of supergravity a careful analysis of the one-loop diagrams was undertaken in the quantized form of general relativity. The desired cancellation was found in diagrams that contain gravitons but no other particles. This result was obtained by Bryce S. DeWitt of the University of Texas and by 't Hooft and Veltman. The infinities cancel because of a special property of four-dimensional space-time; they would not cancel if our world had some other dimensionality.

Since the world is not made of gravitons alone, this finding would seem to be of limited practicality. All attempts to retain the finite result in theories with both gravitons and other kinds of particles have failed; when the lower-spin particles are introduced, the infinities spring up again.

It was therefore a dramatic moment when an explicit calculation of a physical process, a process known to be plagued by infinities in Einstein's theory, turned out to be finite in supergravity. Ensuing theoretical work and other explicit calculations have shown that in each of the eight theories of extended supergravity the sum of all diagrams with one loop is finite for all physical processes. This amelioration of the problem of infinities in quantum gravity is a most encouraging feature of supergravity.

The exact cancellation of some dozens of infinite terms seems too extraordinary to be entirely fortuitous, and it has a simple explanation. Consider first the subset of loop diagrams in which all the incoming and outgoing particles are gravitons; other particles can appear in these diagrams only as virtual particles. The sum of all the diagrams in this set can be shown to be finite by an extension of the similar result obtained in general relativity.

In the eight theories of extended supergravity finite results can also be obtained in diagrams with incoming and outgoing particles of lower spin. The infinities cancel in these diagrams because of the full unification of the theories. Diagrams with incoming photons or outgoing electrons, for example, can be related to diagrams that have only gravitons by applying the symmetry transformations available in these theories. In effect all the diagrams can be reduced to those that have only gravitons, and diagrams containing only gravitons are already known to have a finite sum.

The infinities cancel only in extended supergravity theories because only in those theories can all particles be transformed into gravitons. Other supergravity theories that include an arbitrary

THEORY	PARTICLE CONTENT				
	SPIN = 0	SPIN = 1/2	SPIN = 1	SPIN = 3/2	SPIN = 2
$N = 1$				1	1
$N = 2$			1	2	1
$N = 3$		1	3	3	1
$N = 4$	2	4	6	4	1
$N = 5$	10	11	10	5	1
$N = 6$	30	26	16	6	1
$N = 7$	70	56	28	7	1
$N = 8$	70	56	28	8	1

EXTENDED SUPERGRAVITY THEORIES incorporate not only gravitons and gravitinos but also elementary particles of lower spin, some of which might correspond to known particles such as the photon and the electron. There are eight such extended theories, each designated by a number, *n*, equal to the number of spin-3/2 gravitinos included in the theory. If any of these theories is a valid description of nature, the ensemble of particles it predicts must include all the elementary particles in the universe. In this way all the elementary states of matter would be unified, but a disturbing problem remains: even the largest of the extended theories does not seem to have room enough for all the known spin-1/2 and spin-1 particles.

number of spin-0, spin-1/2 and spin-1 particles lack a crucial symmetry between the spin-1 particles and the spin-3/2 gravitinos. In the theories based on Weyl's theory of gravitation infinities present no problem in diagrams with any number of loops. On the other hand, in these theories it is not known whether probabilities always have positive values, which is a necessary criterion for any sensible physical theory.

The process in which the cancellation of infinities was first discovered by explicit calculation was the scattering of one photon by another photon. In general relativity each of the one-loop diagrams for this process has an associated probability amplitude that consists of an infinite quantity multiplied by a coefficient, which is generally a fraction. The sum of the coefficients is greater than zero and so the probability amplitude for the scattering is infinite. In supergravity additional diagrams that contain gravitinos must be added to the calculation. Each of these diagrams is also infinite, but the sum of the coefficients for all the diagrams is now zero.

Explicit calculations for other processes in supergravity have now been completed. Further theoretical arguments have been found indicating that in the eight extended supergravity theories the infinities also cancel in the sum of all two-loop diagrams. The finite results were first obtained by one of us (van Nieuwenhuizen) with Marcus T. Grisaru of Brandeis and J. A. M. Vermaseren of Purdue University.

Supergravity is a significant theoretical development because it offers hope of solving important, long-standing problems in physics: the unification of the fundamental forces and the elimination of infinities in quantum gravity. In the unification of fermions and bosons and in the derivation of all forces from the common requirement of local symmetry one can glimpse a deeply satisfying order in the theory. It remains to be determined, however, whether that order exists in nature. Several difficulties in the interpretation of the theory remain to be overcome.

One problem arises from the requirement that the internal symmetry in extended supergravity be a local one. In going from a global to a local symmetry an unexpected term is introduced into the equations; it is called the cosmological term, and it was first discussed by Einstein in early applications of general relativity to cosmology. The effect of the cosmological term is to assign a finite size to the universe. The emergence of the term in this context is puzzling: the internal symmetry has to do with the strength of electromagnetic and nuclear forces, and it seems curious that they should affect the size of the universe. What is worse, the value of the cosmological term predicted by the theory ex-

ceeds the upper limit derived from observational evidence.

Another conflict with observation is even more conspicuous. All particles in the extended supergravity theories are massless, but there is no question that many real particles, such as the electron, have a nonzero mass. A promising approach to the problem is to assume that some of the particles in extended supergravity acquire a mass through the mechanism of spontaneous symmetry-breaking. This might explain why the fundamental gravitinos predicted by extended supergravity have not been observed. Their mass might be so large that the accelerators available today have too little energy to create them. It is intriguing to note that spontaneous symmetry-breaking also changes the cosmological term in a quantum field theory. The question of whether it could reduce the term in extended supergravity is currently under study.

An important requirement if supergravity is to be considered a realistic theory is a definitive proof that the infinities cancel in the sum of all loop diagrams. So far cancellation has been demonstrated only for diagrams with one loop or two loops. Diagrams with three or more loops are no less important. Demonstrating that they are finite will probably require qualitatively different mathematical techniques. Most desirable would be a general proof that the sum of all possible diagrams is finite.

The specificity of extended supergravity must be counted among its virtues rather than its failings: the eight theories have few free or adjustable parameters and so they make well-defined predictions. Indeed, each of the theories provides a complete list of all the elementary particles in nature. The predictions, however, do not entirely correspond to the list of elementary particles known today. The most promising theory results when n is equal to 8. This theory is the largest one possible in extended supergravity, and some of its families of particles bear a tantalizing resemblance to groups recognized in nature. For example, Murray Gell-Mann of Cal Tech has recently shown that after spontaneous symmetry-breaking the theory correctly predicts certain properties of quarks, such as their electric charge. The prediction is all the more remarkable in that quarks, among all elementary particles, are assigned fractional electric charges. On the other hand, the same theory has a serious shortcoming. There are not enough places for other known particles such as the muon and the intermediate vector bosons.

These problems must ultimately be resolved by further study of supergravity theories and perhaps by their revision. It may develop instead, however, that what is in need of revision is current opinion as to which particles in nature are elementary.

Passive Cooling Systems in Iranian Architecture

They have no energy sources other than the sun and wind, and yet they circulate cool air through buildings and traditionally provided cold water and ice for the hot summer of the country's arid regions

by Mehdi N. Bahadori

The internal environment of a modern building can be a comfortable one no matter how uncomfortable the external environment is. In general the reason is that energy is freely spent to heat or cool the building. In earlier times, however, when energy was not so readily available and machines such as air conditioners did not exist, the designers of buildings had to rely on other stratagems to maximize the comfort of the internal environment. For example, the traditional architecture of many cultures in climates where the temperatures are uncomfortably hot during the day and uncomfortably cool at night features buildings with thick walls of brick or stone. Such walls are both insulators and reservoirs of heat, so that during the hotter hours of the day the flow of heat from the external environment to the internal one is retarded and during the cooler hours part of the heat stored in the walls warms the internal environment and the rest is lost to the external one. The net result is a flattening of the temperature-variation curve inside the building. In a period when the energy costs of buildings are being intensively reevaluated such stratagems clearly merit close consideration.

In Iran certain traditional building designs achieve more than a flattening of the temperature curve; they circulate cool air through the building and can even keep water cold and ice frozen from the winter until the height of the long, hot summer of the country's arid central and eastern plains. They do so without any input of energy other than that of the natural environment; hence they can be characterized as passive cooling systems. Some of these systems, for example curved-roof systems, were incorporated in buildings as early as 3000 B.C.; others, for example wind-tower systems, the cistern and the ice maker, may not have appeared until about 900 A.D. Many of the passive cooling systems are still in use at present.

The passive cooling systems take many forms. For example, in the arid regions of Iran buildings are traditionally constructed in clusters, attached to one another by common walls. Summer days in that climate are obviously characterized by large inputs of solar radiation. Clustering the buildings reduces their total exposed surface area, thereby reducing the solar-heat gain. (Clustered buildings were also easier to defend.) Heat transfer from the outside air is further reduced by limiting the number of doors and windows. The Iranian summer is windy and dusty, so that this feature also serves to reduce the amount of dust entering the buildings.

Although the summer days in the arid regions are extremely hot, the summer nights are cool. Several features of traditional Iranian architecture are designed to take advantage of this wide daily temperature range. The walls of the buildings are constructed of adobe brick, and like the walls in lands with a similar climate they are particularly thick, so that they have a high heat capacity. Therefore they can absorb the daily solar heat load rather than immediately transmitting it to the interior of the building. The heat is stored in the walls and later released to the interior of the building and to the cool night air.

Another way Iranian architecture has exploited the cool night air is courtyards planted with trees and shrubs. The plantings shield the walls of the rooms that open onto the courtyard so that the solar heat load on the walls is reduced. Both the walls and the plantings remain cool for several hours in the morning.

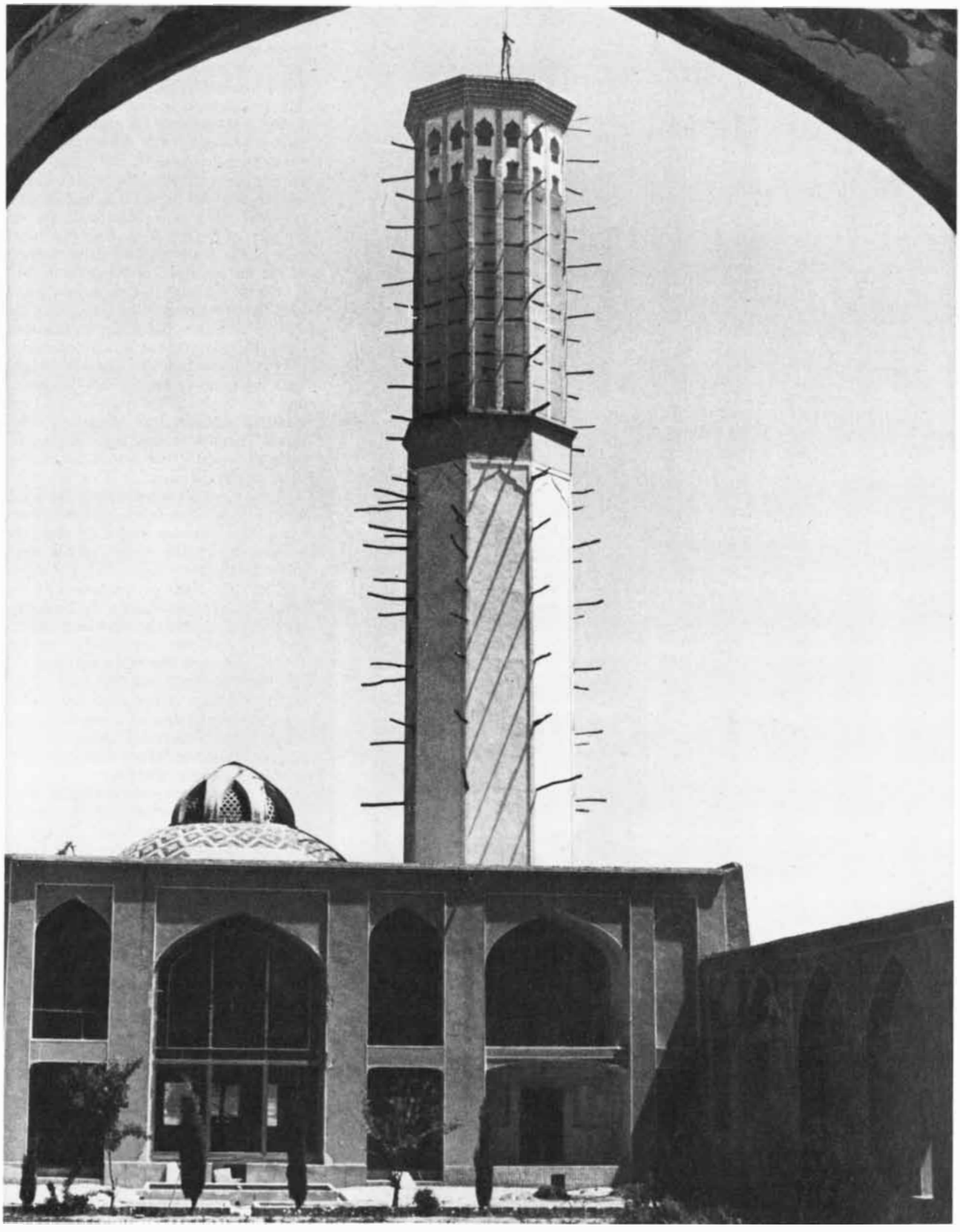
In earlier times the people who lived in the buildings of the arid regions of Iran also had behavioral ways of maximizing their comfort. For example, many people lived in basements, particularly during the hot summer afternoons, because the relatively low ground temperature kept the basement rooms cool. During the cool summer nights many people slept on the roof; the roofs had high parapets to ensure privacy, and the parapets also shielded the roofs from the dusty summer winds. Moreover, the streets were narrow, so that the parapets shaded the neighboring buildings (and pedestrians), reducing the solar heat load.

These approaches provided much relief from the severe climate, but four ingenious passive cooling systems achieve even more. They are the wind tower, the air vent, the cistern and the ice maker. I shall briefly describe each of the systems in turn.

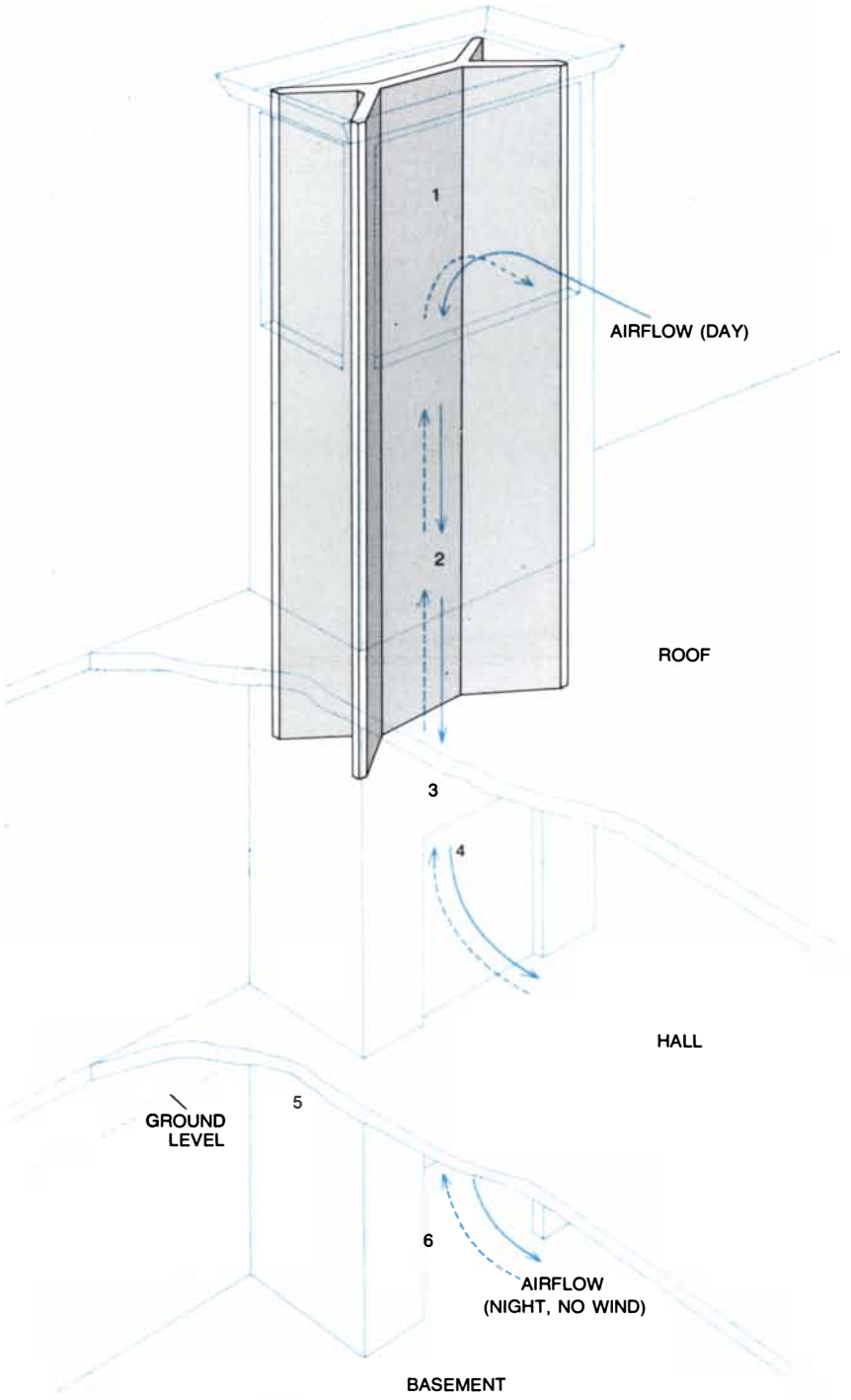
The arid regions of Iran have fairly fixed seasonal and daily patterns of wind. The "wind catcher," or wind tower, harnesses the prevailing summer winds to cool the air and circulate it through a building. A typical wind tower resembles a chimney, with one end in the basement of the building and the other end rising from the roof. The upper part of the tower is divided into several vertical air passages that terminate in openings in the sides of the tower. Tower designs differ in the height of the tower, the cross section of the air passages, the placement and number of the openings and the placement of the tower with respect to the structure it cools.

The wind tower operates by changing the temperature and thus the density of the air in and around the tower. The difference in density creates a draft, pulling air either up or down through the tower. Doors in the lower part of the tower open into the basement and the central hall of the main floor of the building. The flow of air through different parts of the building can be controlled by opening or closing the doors from the tower and the doors of the rooms off the central hall.

The operation of the tower depends



THREE PASSIVE SYSTEMS cool this building in the Iranian city of Yazd: a wind tower, a domed roof and an air vent. The wind tower acts to cool the ambient air and circulate it through the building. (Projecting from the tower are the ends of wood beams that reinforce it; the ends are left in place to provide support for scaffolds for maintenance of the exterior of the tower.) The domed roof to the left of the tower acts to keep the room under the roof cool. The small structure on top of the domed roof covers the air vent, which also acts to cool the room below and maintain a circulation of air through it. The three systems keep the building comfortable during the summer months.



A WIND TOWER OPERATES in various ways according to the time of day and the presence or absence of wind. The walls and airflow passages of the tower (*2*) absorb heat during the day and release it to the cool air at night. The next day the walls are cool. When there is no wind, hot ambient air (*solid arrows*) enters the tower through the openings in the sides (*1*) and is cooled when it comes in contact with the tower. Since the cooler air is denser than the warmer air, it sinks down through the tower, creating a downdraft (*2, 3, 5*). When there is a wind, the air is cooled more effectively and flows faster. Doors in the lower part of the tower (*4, 6*) open into the central hall and basement of the building. When these doors are open, the cooled air from the tower is pushed through the building and out the windows and other doors, entraining room air with it. The cooled air's path of circulation depends on the arrangement of doors in the tower and the building. (Some of the air flowing down the windward passages of the tower is forced back up through the opposite air passages and out through the leeward openings.) When there is no wind at night (*broken arrows*), the tower operates like a chimney. Heat that has been stored in walls during the day warms the cool night air in the tower. Since the warmer air is less dense than the cooler air, the pressure at the top of the tower is reduced, creating an updraft. Air in building is entrained up through the tower and cool night air is pulled into building through the doors and windows. When there is wind at night, air flows down tower and through building. Since tower walls warm night air before it enters building, rate of cooling can be lower.

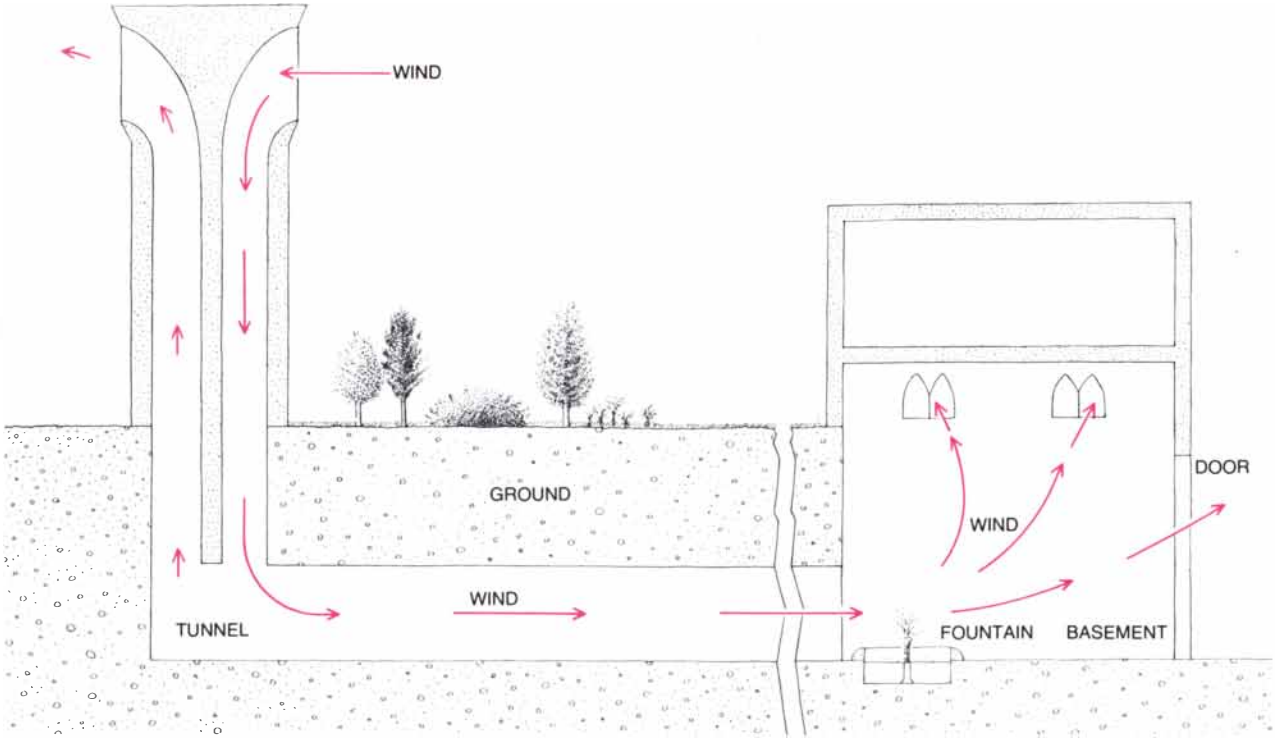
on wind conditions and the time of day. When there is no wind at night, the tower operates like a chimney, circulating air by pulling it upward and out through the tower openings. It works as follows. The tower walls (including the internal walls that separate the air passages) have absorbed heat during the day. Since heat flows in the direction of decreasing temperature, the walls transfer heat to the cool night air in and around the tower. The configuration of the upper part of the tower, namely the thickness of the walls and the cross section of the air passages, is designed to provide sufficient heat-storage capacity and heat-transfer area for the task. Since the warmer air is less dense, the air pressure at the top of the tower is reduced, creating an upward draft. The air in the building is drawn up through the tower, and cool ambient air is pulled into the building through the doors and windows. The process continues during the night, so that cool air is kept circulating through the building.

When there is a wind at night, the air is forced to circulate in the opposite direction; the rooms are cooled by night air coming down the tower rather than through the doors and windows. Here, although the night air is warmed by the tower walls before it enters the building, the cooling can still be sufficiently effective to bring the temperature in the building close to that of the ambient air. The external walls and the roof of the building radiate stored solar heat to the night sky, which further cools the building. Since the desert sky tends to be very clear at night, the radiative heat transfer to it is extremely effective.

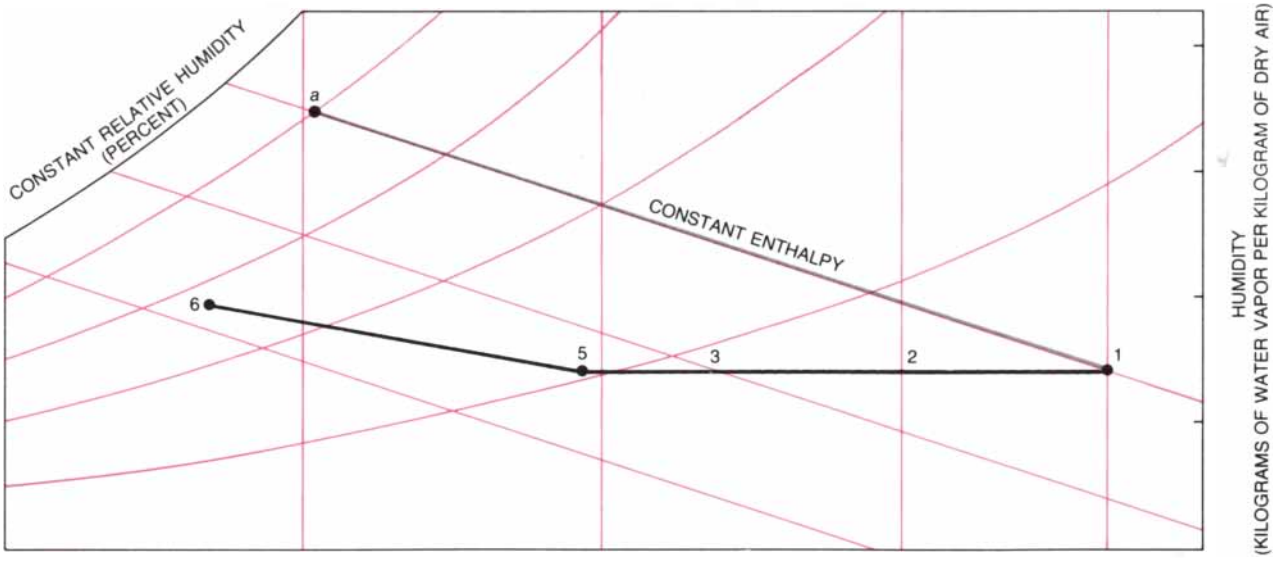
When there is no wind during the day, the operation of the tower is the reverse of a chimney. The walls of the upper part of the tower have been cooled during the previous night. Hot ambient air comes in contact with them and is cooled. Being denser than the hot air, the cooled air sinks down through the tower, creating a downdraft. The cooled air is pushed through the building and eventually out through the doors and windows, entraining room air with it.

When there is a wind during the day, the rate of circulation is increased. The cool air can be circulated through any room in the building by the appropriate arrangement of doors in the tower and the rooms. If there is no wind during the day, when the temperature of the tower reaches that of the ambient air, the circulation of air down through the tower and into the building ceases and the tower begins to operate like a chimney. (Of course, the operation of the tower is not constant throughout the day and night; the cooling effect and the duration of each phase of tower operation change according to fluctuations in the air temperature, the intensity of solar radiation, the wind velocity and so on.)

The openings in the upper part of



TWO KINDS OF COOLING operate in the passive system shown in this section. In sensible cooling heat loss from the air results in a decreased air temperature but no change in the water-vapor content of the air. Air in the upper part of a wind tower is sensibly cooled. When water is introduced into a system, evaporative cooling occurs. Such cooling involves a change in both the water-vapor content and the temperature of the air. When unsaturated air comes in contact with water, some of the water is evaporated. This process is driven by heat from the air, so that the temperature of the air is decreased as its water-vapor content is increased. A wind-tower system that cools air evaporatively as well as sensibly is particularly effective. In most wind towers water in the ground seeps through to the inside of the basement wall of the tower, so that air passing over the wall is evaporatively cooled. Evaporative cooling plays an even larger part in the system shown here. The wind tower is placed some 50 meters from the building and is connected to it by a tunnel. When the trees, shrubs and grass in the ground over the tunnel are watered, water seeps through the soil and keeps the inside surfaces of the tunnel walls damp. Thus air from the tower is evaporatively cooled as it passes through the tunnel. Pool and fountain in the basement of the building further cool the air.



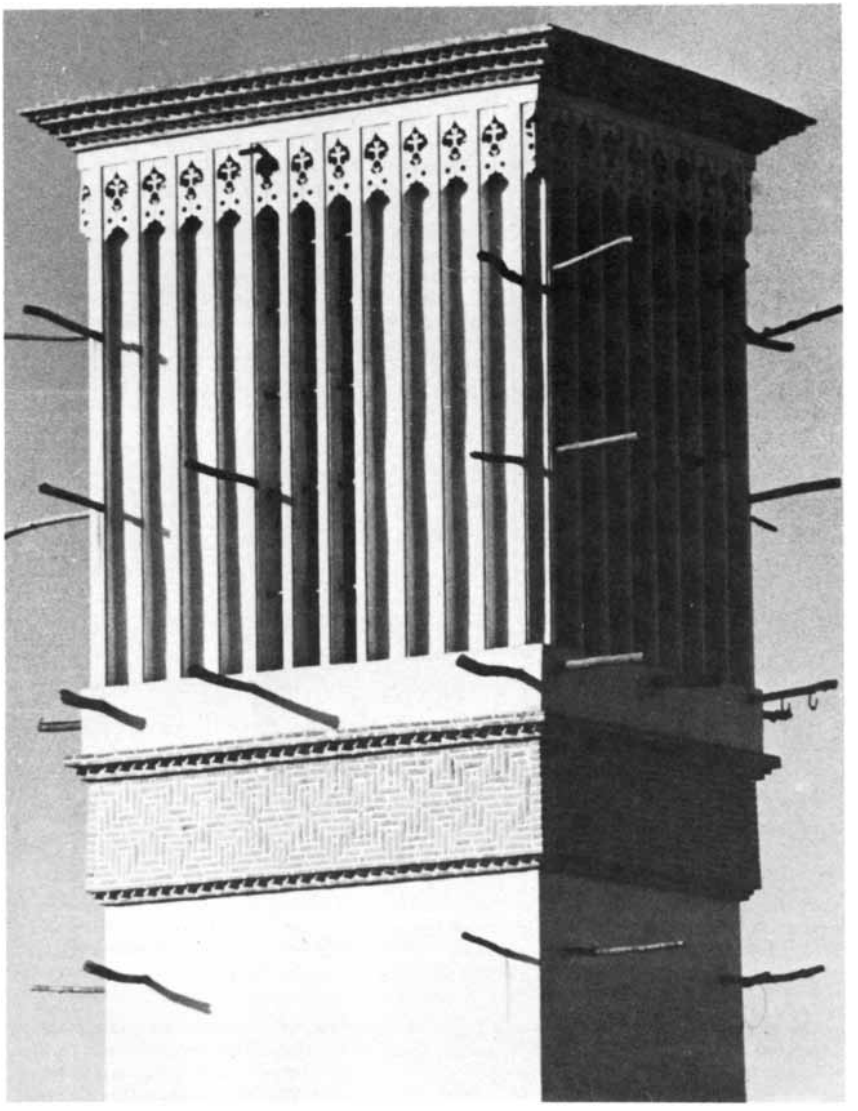
PSYCHROMETRIC CHART shows the conditioning of air during the daytime as it flows through the wind tower that appears in the illustration on the opposite page. Air flowing down the tower is sensibly cooled (*1, 2, 3, 5*), so that the temperature of the air decreases but the water-vapor content remains the same. Since cooler air can hold less water than warmer air, however, the relative humidity (the ratio of the actual vapor pressure to the maximum vapor pressure at the same temperature) increases. When air flows over the damp basement wall of the tower, it is also cooled evaporatively and water vapor is added to it (*5, 6*). Hence the temperature of the cooled air decreases further, and its water-vapor content and relative humidity increase before it enters the basement of the building. The line *1–a* shows the air conditioning that occurs when only evaporative cooling is operating. It is a line of constant enthalpy because no heat is entering or leaving the system of air and water vapor. The numbers that are shown on the chart are the same as those in the illustration on the opposite page.

the tower are placed in pairs so that for every windward opening there is a leeward one. When the doors in the lower part of the tower are closed, wind flowing down the tower is forced back up through the opposite air passages and out through the leeward openings. In fact, even when the tower doors are open, some of the air flowing down the tower leaves by those openings. The upward draft created in the opposite passages entrains room air and pulls it up the tower. In other words, in the normal operation of a wind tower there is always some entrainment of room air through the leeward openings. In this way the tower provides a continuous circulation of air through the building.

So far I have discussed only those temperature changes in wind towers that are due to what is known as sensible cooling. Sensible cooling occurs when there is a change in the temperature of air without a change in its humidity, or water-vapor content. Evaporative cooling occurs when there is a change in the temperature and the humidity, and it can play an important role in the operation of wind towers. For example, when the basement wall of a tower is damp, as is often the case, the air coming down the tower is cooled both sensibly and evaporatively. In other words, water on the wall absorbs enough heat to be vaporized. Since vaporization requires relatively large amounts of heat, wind towers that incorporate evaporative processes can cool the air quite effectively. In fact, before refrigerators came into wide use in Iran, the damp basements of wind towers served as cold-storage areas. Moreover, the humidifying of the air that accompanies evaporative processes is an important contribution to comfort at lower temperatures.

Another way of exploiting evaporative cooling is to place a small pool with a fountain at the bottom of the wind tower. Wind can be sensibly and evaporatively cooled coming down the tower and then evaporatively cooled by the pool and the fountain before it enters the rooms of the building. There are many buildings with towers of this type in the Iranian city of Yazd.

A wind tower in the city of Bam is employed in a different way. The tower is placed about 50 meters from the building it serves, and an underground tunnel runs from the bottom of the tower to the basement of the building. The ground over the tunnel is planted with trees, shrubs and grass. When the ground is watered, the water diffuses through the soil so that the tunnel walls are kept damp, and air coming down the tower and through the tunnel is sensibly and evaporatively cooled. A pool and fountain where the cooled air enters the basement furnish further cooling.

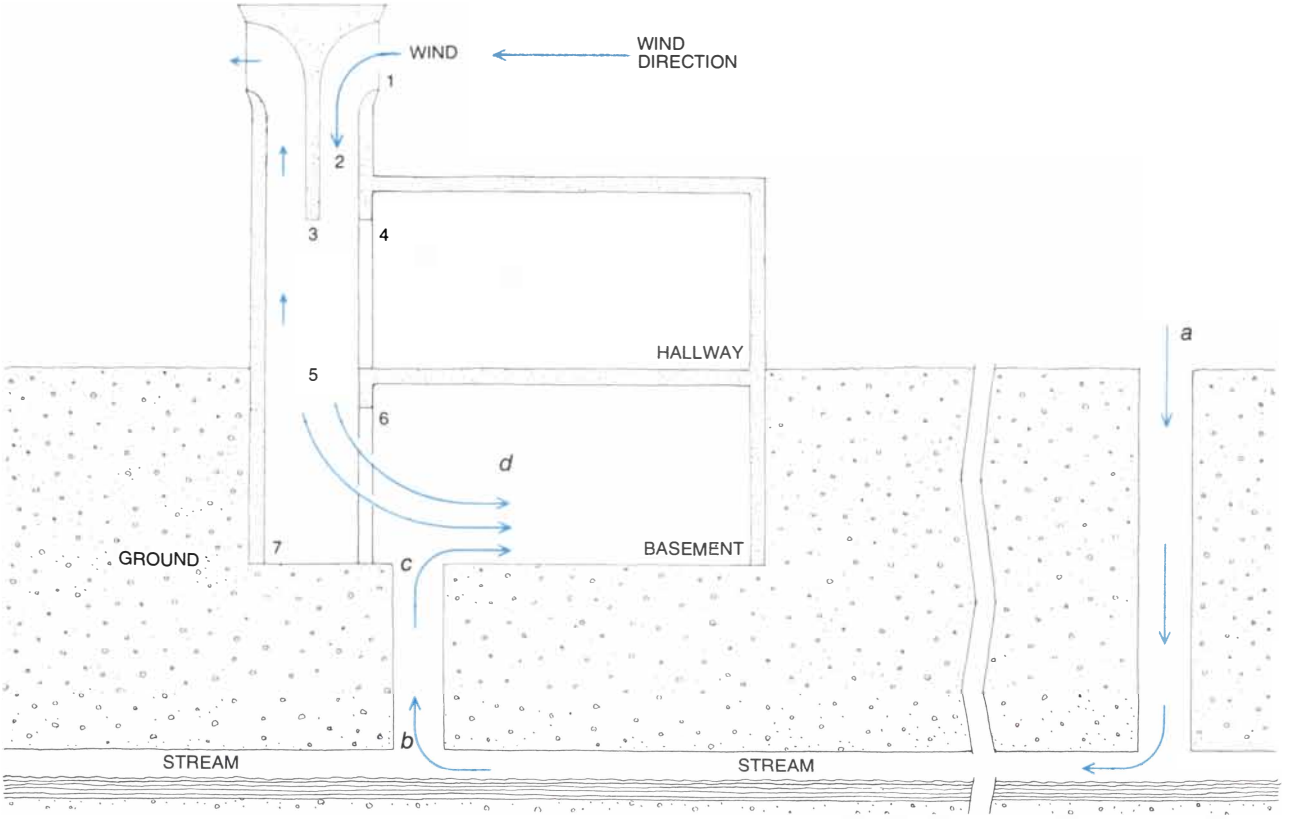


CLOSEUP VIEW OF THE TOP OF A WIND TOWER in Yazd shows the ends of its reinforcing beams. The tower is about 13 meters high and its openings are about three meters high. The tower in illustration on page 145 is about 34 meters high; its openings are about 11 meters high.

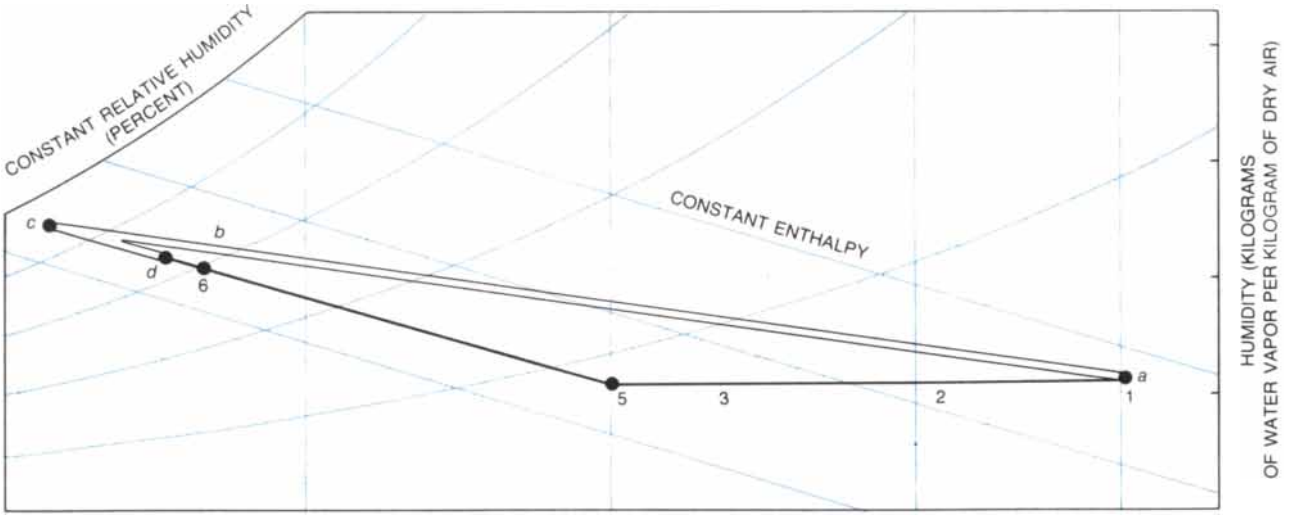
Another variation of the wind tower operates in conjunction with an underground stream. A vertical shaft runs from the stream to the basement of the building, and the tower is placed so that wind coming through the basement door of the tower goes over the top of the shaft. When air flowing through a large passage enters a smaller one, its velocity increases and its pressure decreases. The cross-sectional area of the tower is larger than that of the door, and so the pressure of the air from the tower is still decreased as it passes over the top of the shaft. When air from the tower flows at a high velocity across the top of the shaft, a point of entrainment is created there. The result is that air from the shaft is drawn into the flow of tower air.

Air enters the passageway of the underground stream through other shafts that connect the passageway to the surface. Since underground water is usually cold, air passing over it is effectively cooled, and so the cooling rate of wind-tower systems operating in conjunction with underground streams is quite high. Here again the air at the point of entrainment is so cool that food was often stored near the opening of the shaft. The cooling is effective even on windless nights, when the tower operates like a chimney; the outside air flows over the underground stream, where it is evaporatively and sensibly cooled, and then up through the shaft into the building. It mixes with the basement air and is finally vented from the top of the tower.

One problem with wind towers is that they admit dust, insects and birds to a building. Newer towers are equipped with screens to keep out at least the insects and birds. Taller towers bring in less dust, but they are expensive to build and maintain. Another way of keeping the dust out of a building is to construct a tower with a base that is wider than the rest of the tower. Increasing the cross-



UNDERGROUND STREAM and a wind tower are an effective cooling combination. In the system shown here a shaft connects the stream to the surface and another shaft connects the stream to the basement of the building to be cooled. Hot, dry ambient air enters the passageway of the stream through a shaft outside the building (*a*) and is both sensibly and evaporatively cooled as it flows along the water (*b*). Since underground water is usually cold, the rate of cooling is quite high. The wind tower is placed so that wind flowing through the basement door of the tower passes over the top of the shaft from the stream. When the air flows from a large passage (the tunnel) through a smaller one (the door), its pressure decreases. The pressure of the air from the tower is still diminished when it passes over the top of the shaft, so that cold, moist air from the shaft is entrained by the flow of cooled air from the tower (*c*). The mixture of air from the shaft and air from the tower (*d*) circulates through the basement. Single underground stream can serve several wind-tower systems of this type.



CONDITIONING OF AIR by a wind-tower system with an underground stream is shown in this psychrometric chart. Warm, dry outside air enters the system at two different points (*1, a*). The air entering the wind tower (*black line*) is sensibly cooled as it flows down the tower; the temperature of the air decreases and its relative humidity increases (*1, 2, 3, 5*). The air is also evaporatively cooled as it flows over the damp basement wall of the tower; the temperature decreases, and both the water-vapor content and the relative humidity increase (*5, 6*). The warm, dry air that enters the passageway of the underground stream (*double line*) is sensibly and evaporatively cooled as it flows over the cold water. Thus there is a large drop in the temperature of the air and a large increase in its water-vapor content and relative humidity before it flows up through the shaft to the basement of the building (*a, b, c*). In the basement the cold, moist air from the passageway of the underground stream (*c*) mixes with the warmer, drier air from the wind tower (*6*). The final mixture (*d*) is the air that circulates through the basement. The numbers and letters that are shown on the chart are the same as those in the illustration above.

sectional area of the airflow reduces the wind velocity at the bottom of the tower, which allows the dust to settle on shelves called dust pockets. The placement of the openings at the top of the tower can also control the infiltration of dust; in areas where dusty winds blow in one direction and dust-free winds blow in the other the openings are placed accordingly. Similarly, in areas where there are prevailing winds the openings are placed to take advantage of them.

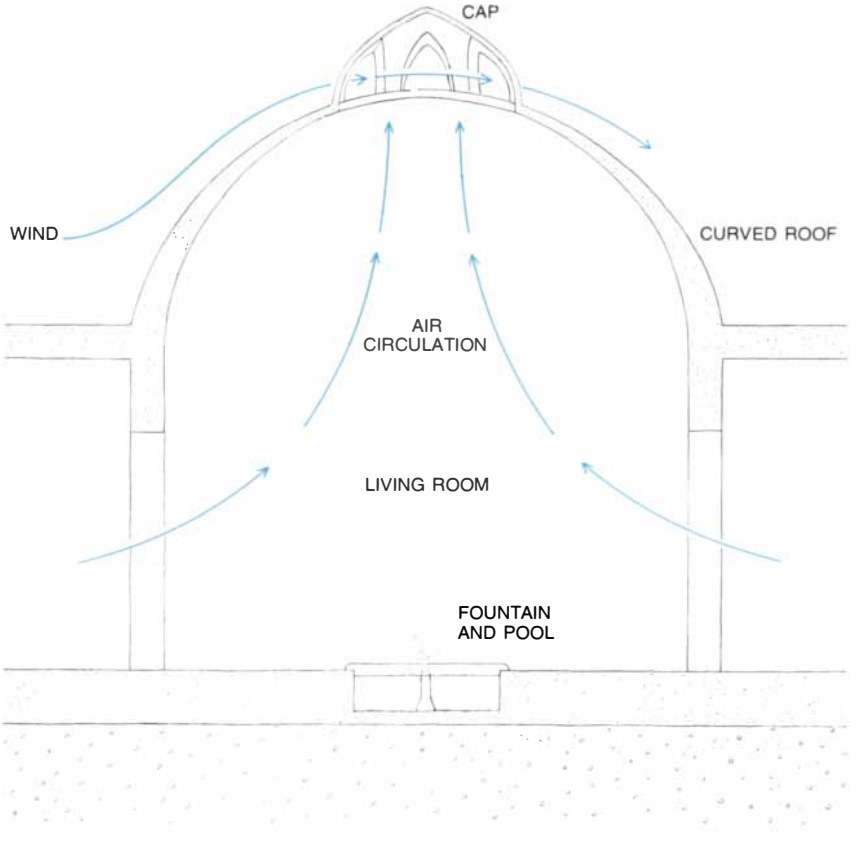
Wind towers are still in service in Iran and are even included in some new buildings. They are of course intended only for summer use and must be properly closed in winter. For example, in Bam the towers are sealed off by thin walls. If the towers are not closed in winter, they greatly increase infiltration heat losses, that is, losses to the cold ambient air that has leaked into the building.

Wind towers can be employed in conjunction with curved roofs, which are another source of comfort in Iran's hot summer climate. Curved (domed or cylindrical) roofs offer many advantages over flat ones. They are inherently stronger; therefore they can be made lighter and do not require the support of wood beams, which are scarce in the desert areas. Furthermore, the hot air that gathers under a curved roof is well above the living area of the room the roof covers. In this way the room is kept more comfortable, and heat transfer from the roof to the room is limited because a high temperature is maintained next to the roof.

Any roof absorbs solar heat directly by radiation, and flat and curved roofs of the same base area absorb about the same amount of solar radiation. A roof loses most of its heat, however, not by radiation but by convection; that is, the principal heat loss depends on the movement of air across the roof. A curved roof has a larger convection heat-transfer area and transfers heat more efficiently than a flat roof. Therefore a curved roof is more easily cooled.

A curved roof is most effective when it incorporates an air vent. The operation of an air vent depends on the fact that when air flows over a cylindrical or spherical object, the velocity at the apex of the object increases; consequently the pressure at the apex decreases. If there is a hole at the apex of a domed or cylindrical roof, the difference in pressure induces the hot air under the roof to flow out through the vent.

An air vent is usually protected by a small cap in which there are openings that direct the wind across the vent. Since the functioning of the vent depends on air flowing over a curved surface, roofs with vents are oriented to present the maximum curve to the wind. In areas where the wind is a prevailing one cylindrical roofs are built with the axis of the cylinder perpendicular to the wind direction; in areas where the winds blow in all directions domed roofs are employed. Air vents are usually placed over the living rooms of buildings.



AIR VENTS are employed in areas where dusty winds make wind towers impractical. Such a vent is a hole cut in the apex of a domed or cylindrical roof. Openings in the protective cap over the vent direct wind across it. When air flows over a curved surface, its velocity increases and its pressure decreases at the apex of the surface. The decrease in pressure at the apex of a curved roof induces the hot air under the roof to flow out through the vent. In this way air is kept circulating through the room under the roof. Air vents are usually placed over living rooms, often with a pool of water directly under vent to cool air moving through the room.

A passive cooling system of the cistern type incorporates several other passive systems. The cistern is a reservoir 10 to 20 meters deep, sunk into the ground, covered by a domed roof and surrounded by several wind towers. In some areas on the arid plains of Iran water is brought from the highlands by the system of underground aqueducts called qanats. The purpose of the cisterns is to hold the water at a reasonably low temperature during the hot summer months. The design of the cistern takes advantage of the seasonal temperature changes in the desert and the insulating properties of the ground.

In the arid zones of Iran the winter nights are very cold. In winter cold water is admitted to the cisterns, partly filling them. In summer the domed roof of the cistern is warmed, and so is the air and the top layer of water in the cistern. Before the deeper layers of the water are warmed, however, the water in the top layer evaporates and the water vapor is carried away by a draft across the surface, maintained by the wind towers. In this way the water is kept cold.

A cistern cooling system operates in one of two ways. If it has a domed roof with an air vent in it, the air flows down the wind tower, across the water and up through the vent. This airflow entrains the mixture of air and water vapor under the roof. If the cistern has an air vent, however, dust, insects and other matter can fall into it and foul the water, and so some cisterns are constructed without vents. In these cisterns the flow of air from the tower is short-circuited: the air flows down through the passages on one side of the tower and back up through the passages on the other side, entraining the mixture of air and water vapor in the cistern and inducing it to flow out through the openings on the leeward side of the tower. Cisterns of either type are not much used at present because although the water they supply is cold, it is also stagnant and therefore

SCIENCE/SCOPE

For the first time in the history of space technology, a single electronics system will perform both radar and communications functions aboard NASA's Space Shuttle Orbiter. Meshing the "eyes, ears and voice" functions into a 260-pound hardware package, results in a significant reduction in weight and space. Major components such as the transmitter, receiver, antenna and servo mechanisms perform dual roles.

As a radar, the unit searches for, acquires, tracks and delivers spatial data needed for Orbiter to effect a quick, efficient rendezvous with other space vehicles. As a communications system, it provides high-quality transmission and reception with ground stations via two relay satellites. The Ku-band subsystem will be built by Hughes for prime Space Shuttle contractor Rockwell International.

Printed repair manuals may soon be replaced by an electronic display, part of the Technician's Maintenance Information System (TMIS) developed by Hughes. It can direct the repair of equipment as complex as a radar unit simply by asking the repairman to describe his problem. The system comes in two portable packages: a video display with an electronic keyboard; and a mass memory device that uses floppy disks, plus a microprocessor. A few disks can store all the troubleshooting data normally contained in a large stack of manuals.

A technician simply selects the appropriate disk, loads it into the system and types in the problem. In less than two seconds, the display screen provides a series of pertinent questions. After he provides the answers, the system pinpoints the failure, the part needing replacement, shows its location, and tells how to replace it. It also explains what tools and test equipment are needed, and how to use them. With this method, many repairmen will no longer require extensive technical training or cumbersome stacks of data. By cutting troubleshooting and repair time to a small fraction of present requirements, costs can be reduced drastically.

The Communications and Radar Division of Ground Systems Group is engaged in the design, development, test and production of several modern phased array radar systems, synchronous time ordered Spread Spectrum Communications systems and advanced electronic warfare systems. These systems feature automatic operation under computer control, low vulnerability to countermeasures, high reliability, and automatic built-in test equipment for ease of maintenance. Electronic Engineers experienced in any of these areas are invited to send resume to: Ground Systems Group, Professional Employment, J.E. Tenney, Department-14, 1901 West Malvern, Fullerton, CA. 92634.

Plant engineers now can see an instant picture of energy losses during plant operations. Using a handheld infrared viewing device, they can pinpoint a wide range of energy-wasting situations -- among them: steam leaks, product-flow problems, electrical overloads, components failures, machinery hotspots, cable shorts, heating/airconditioning system losses, insulation defects, chemical/thermal pollution.

The device is an industrial version of the Probeye^{R} Infrared Viewer, originally developed and marketed by Hughes for use in law enforcement, fire detection and search-and-rescue. It senses infrared rays radiated by objects within its viewing field and converts the radiation to a red image viewable through its eyepiece. Temperature differences as small as 0.1^{o}C. are detected and portrayed by the 7.2-lb. self-contained unit.

Creating a new world with electronics

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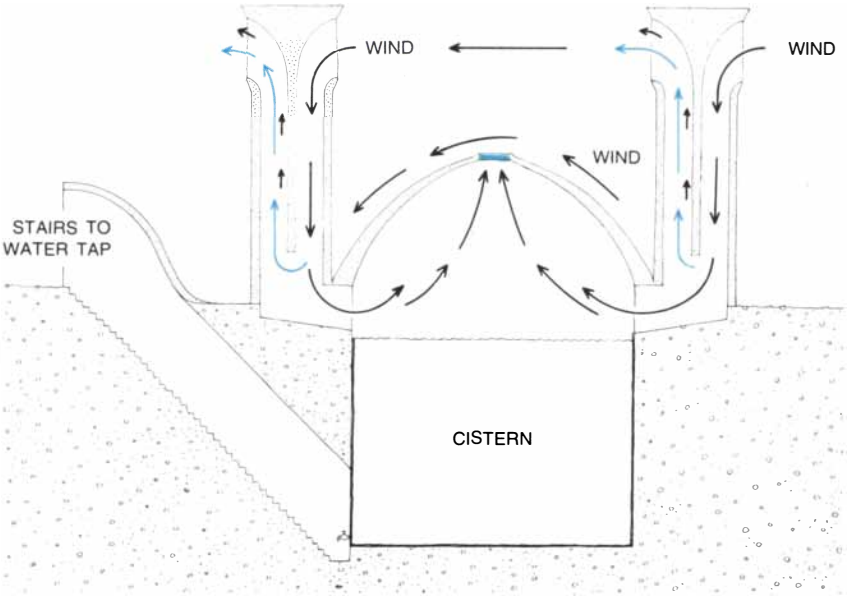
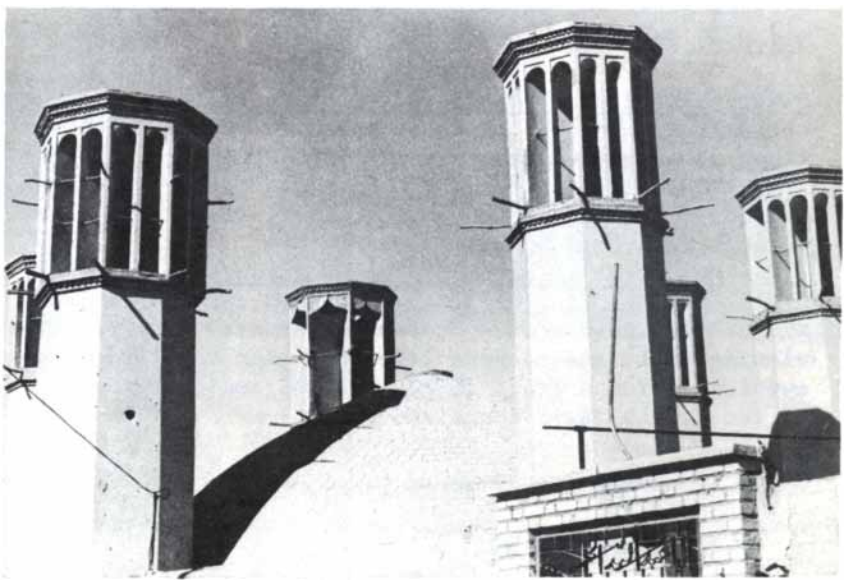


CISTERN is filled with cold water during winter nights, when the temperature in the arid regions of Iran is usually only a few degrees above freezing. The wind towers that surround the cistern keep the water cold for use during the hot summer months. When the domed roof of the cistern is heated by the sun, it warms the air over the water in the cistern and increases the rate at which it evaporates. The towers maintain a draft across the surface of the water, so that the water vapor is removed, saturation is prevented and evaporation can continue. The deeper layers of the water are little warmed because the heat from the air is almost entirely spent in evaporating the water at the surface. When there is an air vent in the roof of the cistern, wind flows down the towers, across the water and up through the vent (*black arrows*), entraining vapor-laden air from the cistern out through the vent. When there is no air vent, wind flows down the towers and is forced back up through the air passages on the leeward side of the towers (*colored arrows*). The updraft created in the leeward passages entrains cistern air out through the leeward tower openings. Cistern is partly buried to take advantage of the insulating properties of ground. Domed roof is more easily cooled than a flat one and transmits less heat into cistern.

not safe for direct human consumption.

A cistern system effectively operates by storing energy from one season to another. Many passive cooling and heating systems operate on this principle. Another example is the traditional ice-making system of Iran. (Like the cistern, the ice maker has been abandoned for health reasons.) In Iran's arid regions the nighttime temperature of the air in winter is usually only a few degrees above freezing. With an ice maker, ice can be produced in winter and stored for the summer. The system depends on ra-



DOMED ROOF AND WIND TOWERS of a cistern in Yazd appear here. Towers are about 12 meters high; cistern is about 12 meters deep and can hold some 1,000 cubic meters of water.

W. H. Freeman and Company
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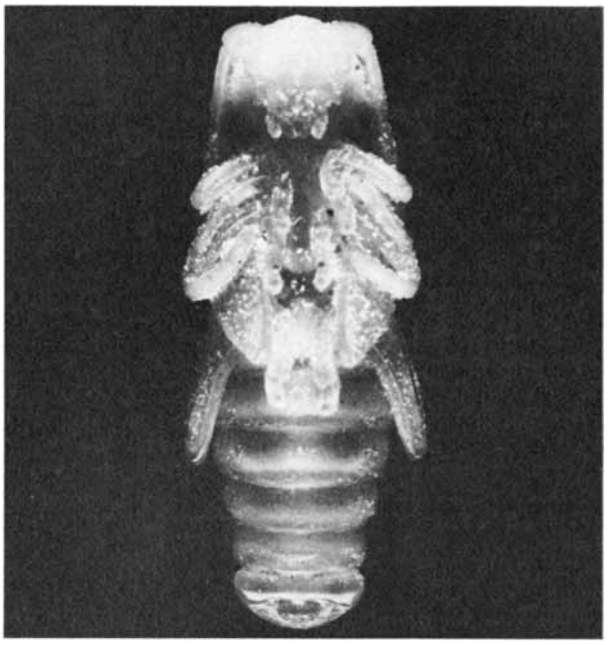

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1976, 451 pages, 156 illustrations (18 in full color), 48-page Field Supplement, cloth $19.95

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1977, 304 pages, 138 illustrations (16 in full color), cloth $22.50

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diation losses to the sky on clear, cold winter nights.

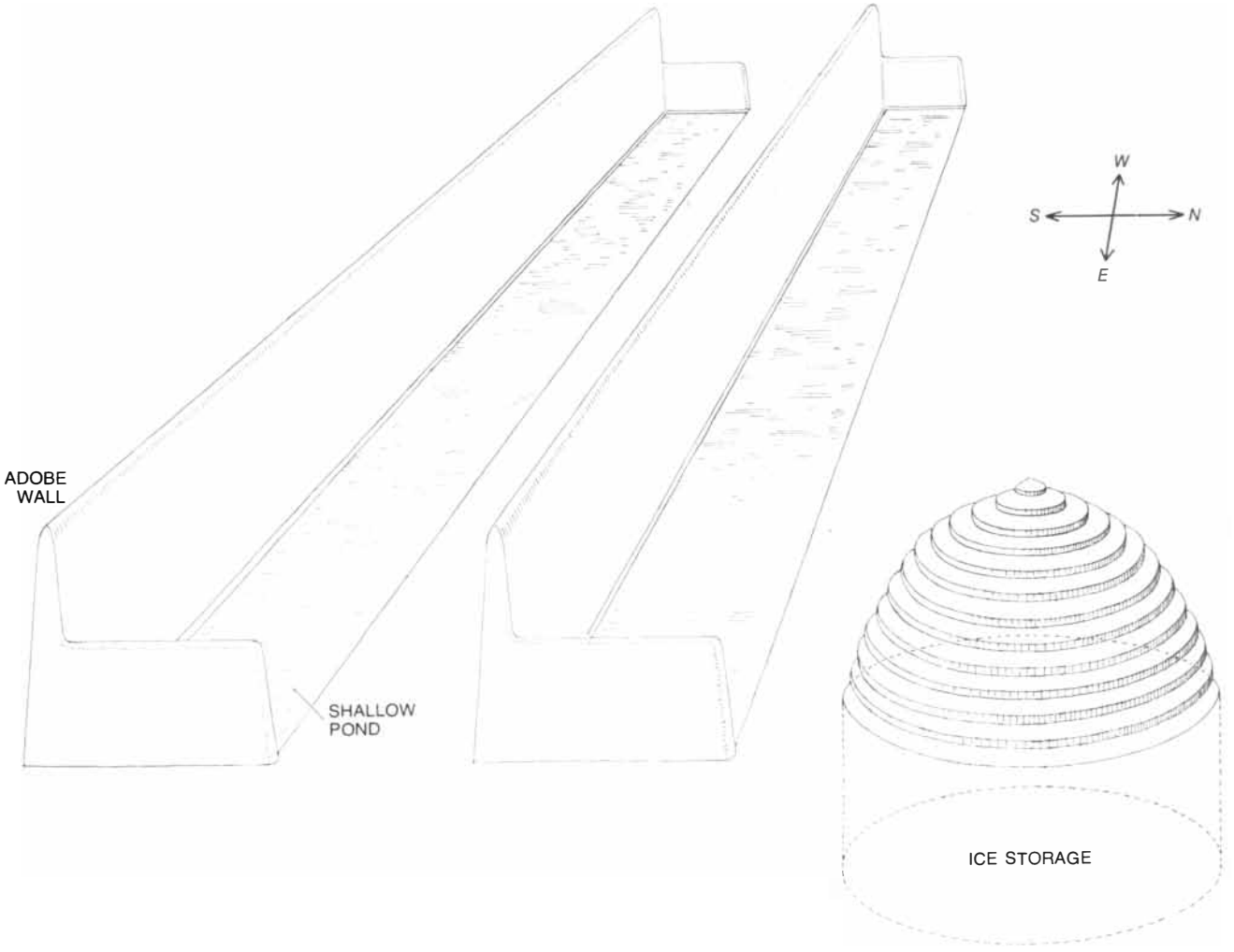
The ice maker consists of a large storage pit 10 to 15 meters deep and one or more shallow rectangular ponds, 10 to 20 meters wide on a north-south axis and several hundred meters long on an east-west axis. An adobe wall is built on the south side of each pond, high enough to shade the entire width of the pond during the ice-making season. Lower walls at the east and west ends of the pond shield it from early-morning and late-afternoon solar radiation.

On cloudless winter nights each pond is filled with water. Water in such a pond loses heat to the sky by radiation and receives heat from the air by convection and from the ground by conduction. The walls along the pond, however, shield the pond from the wind and thus reduce the heat gain by convection. (When there are several ponds, their parallel walls contribute to the overall shielding effect.) Under these circumstances the heat loss by radiation to the night sky is sufficient to freeze the water in the pond.

The weather conditions dictate to what depth the water can be made to freeze. Sometimes the pond is filled a few centimeters at a time during the night, which increases the rate of ice formation. On the following day the ice is cut up and placed in the storage pit. While that is being done the walls of the pond help to keep the ice from melting in the heat of the daytime sun. On the other hand, conduction from the ground tends to melt the bottom of the ice, so that it can be more easily removed.

A passive cooling system exploits the very features of the climate it seeks to overcome. For this reason the passive cooling and ventilating systems of Iran cannot be applied at random in other areas of the world. These systems could work well, however, in climates similar to the climate of Iran. For example, although the cistern and ice-making systems have been abandoned for public-health reasons in Iran, they could be employed in Iran and elsewhere to supply cold water and ice for purposes other than direct human consumption.

In climates where the passive cooling systems of Iran cannot be applied they should still be of interest. They demonstrate the possibilities of working with rather than against the external environment. In the future architects and engineers will need to take more account of climate and might well examine the possibilities it affords for passive heating, cooling and ventilating systems. With this information they should be able to design buildings that have modern amenities and yet consume minimal amounts of energy.



ICE MAKER is a passive cooling system that takes advantage of the near-freezing temperatures of winter nights in the desert. Several shallow ponds, 10 to 20 meters wide on a north-south axis and several hundred meters long, are filled with cold water on winter nights. A tall adobe wall on the south side of each pond and lower walls at the east and west ends shield the pond from the wind. At night the water in the pond loses heat to the sky by radiation and gains heat from the ground by conduction and from the air by convection (that is, by the movement of air across the water surface). Shielding the pond from the wind reduces the heat gain by convection, so that on cloudless nights the heat loss to the sky by radiation is sufficient to freeze the water. On the following day the ice is cut up and placed in a covered storage pit 10 to 15 meters deep. The walls shade the pond during the day so that the ice does not melt before it can be cut up and stored.

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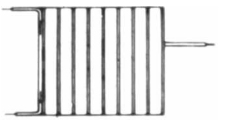

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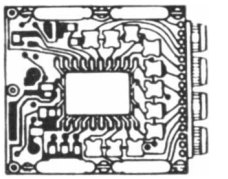

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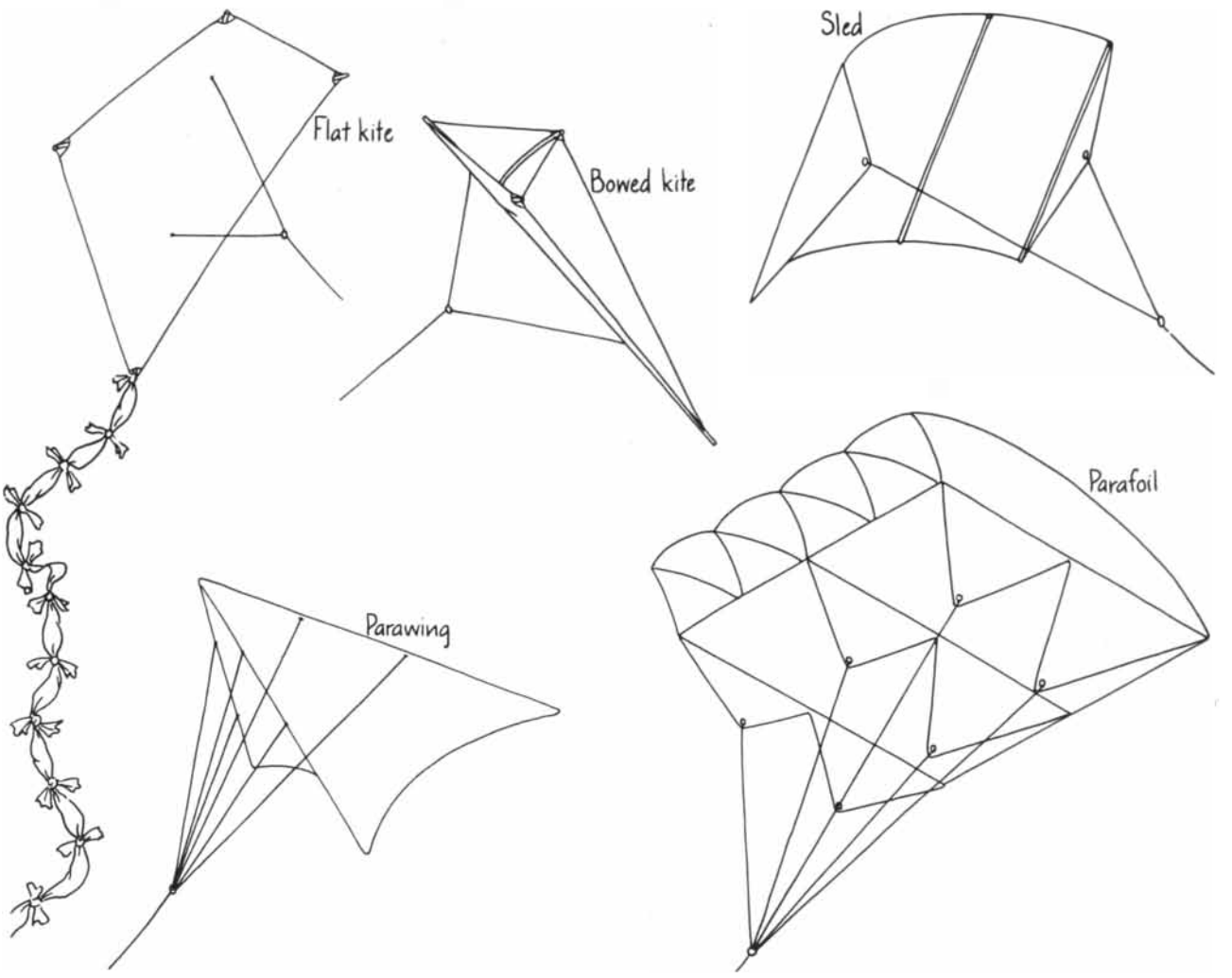
THE AMATEUR SCIENTIST

Introducing the Musha, the double lozenge and a number of other kites to build and fly

by Jearl Walker

Spring is coming, and with it will come the moderate winds that are good for flying kites. Kite making has recently undergone a small revolution, at least from the amateur's viewpoint, through the introduction of new materials and tools that facilitate the construction of durable kites. Nevertheless, the making and flying of kites are still highly experimental activities. There are no simple definitive equations by which one can predetermine the lift and stability of a kite; the fluid dynamics of an airstream passing a kite is just too complicated for solution unless one gets into fairly sophisticated aerodynamics. And one cannot treat a kite like an airplane, fabricating a small mock-up for a wind-tunnel test and then determining whether the kite will lift and remain stable. About the only wind tunnel the amateur has is the natural wind itself. Thus regardless of whether you are building a basic design or inventing your own there is only one way to tell if the kite is satisfactory: fly it.

The late C. L. Stong wrote an excellent introduction to kites for this department in April, 1969. Recently several good kite books have been published describing not only kite designs but also the new kiting materials. Here I shall discuss the aerodynamics, design and flying of kites and describe a few good designs that are not difficult to build. For much valuable information I am indebted to Peter Pruden of Cleveland and to Judy Neuger, who owns the Kite Kompany, Inc. (33 West Orange Street, Chagrin Falls, Ohio 44022). Kites and kite materials can be bought from that store and many others. A list can be made from the advertisements in *Kite*



Five types of kite

Lines, the quarterly magazine of the American Kitefliers Association, to which one can subscribe for $6 per year (7106 Campfield Road, Baltimore, Md. 21207). It is great for both beginners and experienced kite makers and fliers.

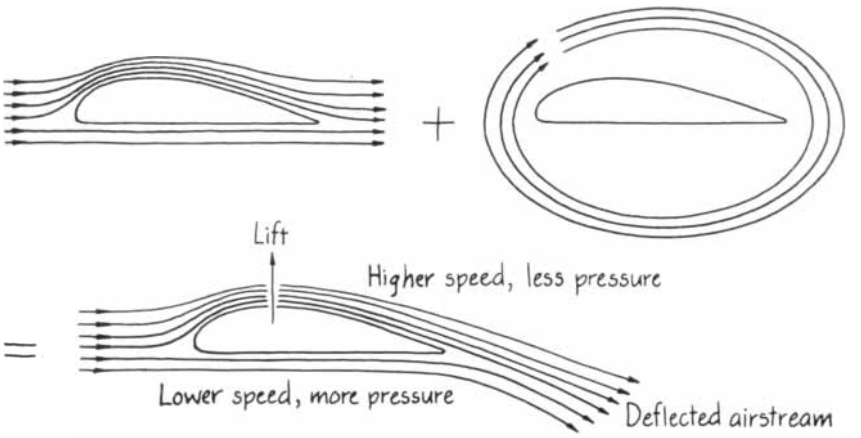
Kites are no fun unless you can get them up in the air and then keep them stable or at least controllable. Lift comes from two features of the passing airstream. One feature, the impact and deflection of the airstream on a flat surface flying at an angle to the horizontal, pushes the kite upward. The magnitude of the pushing depends on the wind speed and the cross-sectional area the kite presents to the wind. Increasing either of them increases the lift. With too much wind deflected, however, the kite becomes difficult to handle and may even break up. The greater the wind speed is, the smaller the angle between the kite face and the horizontal should be. Part of the kite's adjustment is automatic, and part must come from proper adjustment of the bridle attaching the kite to the kite string.

Another component of the kite's lift is similar to the lift on a classic airfoil. The airflow around an airfoil can be considered as having two parts, one circulating around the airfoil and the other nonrotational. The actual airflow, at least in a simple model, is a superposition of the two, with the result that the airspeed is greater above the airfoil than below it. Because the air pressure is less the greater the airspeed is, there is more pressure below the foil than above it. This difference in air pressure lifts the foil. A kite gains lift in much the same way, although the application of the simple airflow models may not be very straightforward.

The instability of a kite is divided into three types: roll, pitch and yaw. Roll is a longitudinal rotation, pitch is a lateral rotation and yaw is a rotation around an axis perpendicular to the kite face. Several features can be built into a kite's design to stabilize its flight. They include proper bridling and frame balancing, tails, a bowed or boxed shape, fins on either the face or the back and vents.

The frame of the kite must be carefully balanced to have a symmetrical distribution of weight from left to right as the kite faces the airstream. If one side is heavier than the other, the kite almost certainly will fly erratically.

The bridle is the combination of lines running from the kite to the kite string. Sometimes (but rarely) it is a single string (the kite string itself), in which case the definition is academic. Usually a bridle consists of two or more strings attached to strategic points on the kite and tied in a common knot or to a small ring on the kite line. The tasks of the bridle are to distribute the stress of the air pressure as much as possible, to provide stability and (under some circumstances) to enable the kite flier to maneuver the kite.



A simple model of airflow for an airfoil

The combined pull of the bridle lines provides a force that counters the combination of the other two forces on the kite: its own weight, which acts downward, and the force due to the passage of air, which acts upward and to the rear for a nicely riding kite. Another function of the bridle is to keep the kite at a proper angle of attack: the angle between the kite face and the wind direction. Once you get your kite into the upper winds you may find that its angle of attack is wrong. The only solution is to bring the kite back to the ground in order to adjust the bridle. Some bridles have a spring or a strong rubber band on the lower line so that as the wind speed increases, the angle of attack is automatically adjusted because the wind pressure stretches the spring or the rubber band.

The tail provides lateral stability and is needed on most flat kites. It should not be too long or too short; the correct length can be determined only by experiment. By adding extra drag (as essentially an extension of the kite's spine) the tail should respond to the lateral motion of the kite by pulling in the opposite direction and thereby damping out the lateral oscillations. The tail can be made of a strip of cloth, a length of paper or plastic or a cup or several cups designed to catch and funnel the wind.

Stong's article in this department described the use of cups, called drogues, that were first employed in the 19th century to stabilize kites. If the cup is tapered, with the narrow neck to the rear, it funnels the wind down through a narrower opening and so forces the wind to speed up. The outgoing airstream, moving faster than the surrounding one, helps to maintain the orientation of the drogue. Some kites have side tassels or two tails on outriggers instead of a single tail to provide longitudinal stability.

A great deal of stability can be built into the shape of the kite. Some kites present to the wind a face that has either a sharp angle or a blunt one; it is termed the dihedral angle. The Eddy bowed kite, first introduced by William A. Eddy in 1897, is a classic example of an otherwise flat kite that has been bowed backward to present a curved face to the wind. Stability against gusts is provided by the bowing. When the kite is turned by a sudden gust on one side, the other side rotates to present more surface area to the wind and thereby experiences a greater force, which prevents the kite from turning further. The Eddy kite is so stable against gusts that it needs no tail. The extent of the bowing is usually adjustable, so that more bowing can be created for greater wind speeds.

Other kite designs employ fins on the face or the back to keep the kite stable against gusts. Still others have vents to allow air to stream through unimpeded. Such vents have several functions. They reduce drag on the kite and therefore the force on your end of the kite line. They can also help to eliminate vortexes shed by air passing the sides of the kite.

You may have noticed the seemingly paradoxical venting of most parachutes. Aircraft parachutes have a single hole in the center. Parachutes for slowing down race cars, dragsters and landing aircraft sometimes have so much venting area that the parachute resembles two crossed strips of bandage. With an unvented parachute vortexes are shed alternately on opposite sides of the parachute as the air passes the edges. The air pressure in the vortexes is lower than the ambient air pressure, so that the parachute finds itself with different and periodically changing air pressures on opposite sides. The parachute begins to swing. The swinging builds in amplitude just as the amplitude of swinging for a child is built up by periodic pushes on the swing.

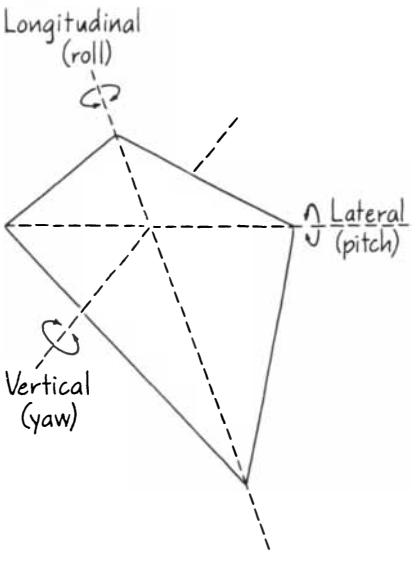
The swinging could be disastrous for the load at the other end of the parachute. Air is vented through the parachute to break up the vortexes and thus

reduce the swinging. Venting on some kites serves the same purpose. The vent for a kite can be a simple rectangle or circle or it can be subtler, as in the venting achieved through the cellular structure of a box kite.

You should be somewhat careful about choosing a site for flying your kite. An upward deflection of the wind on the windward side of a hill would be helpful, but the turbulence on the other side would not. Hence it is better to stand at the foot of a hill on the windward side rather than at the top of the hill. Relatively warm ground, as in a parking lot, may provide rising thermals of warm air to contribute lift to your kite. Once the kite is airborne it can ride the stronger winds higher up.

Never fly a kite near a crowd or over motorists, who may be distracted by the sight. Flying a kite in the air lanes near airports is illegal. Never fly a kite with wire as the kite line; even with a string never fly a kite near power lines or during a thunderstorm. (Contrary to the impression many people have, Benjamin Franklin conducted his famous experiment not during a thunderstorm but as a thunderstorm was approaching. Even so, he was lucky not to have been electrocuted.) In anything but gentle breezes wear heavy-duty gloves so that you can grab the line without risking a bad string burn. Finally, be wary of kite-eating trees; they have been known to gobble up hours of work in a minute.

To launch a kite hold it about 20 degrees forward of the vertical and in approximately the correct flying attitude, release it as a gust of wind passes and slowly reel out line. Keep the line taut to maintain lift. If the breeze is light, have a friend stand with the kite about 150 feet away from you while you hold the line taut. When a gust comes, your friend releases the kite upward and you pull the line hand over hand. By tugging and bringing the kite forward into the light breeze you give the kite lift.



Three instabilities

If the kite flaps and fails to rise, the bridle point is probably too high and should be lowered. If the kite goes crazy and continuously loops, the bridle point is too low and should be raised. When a flat or a bowed kite climbs to the zenith, it no longer presents any cross section to the wind and therefore loses its lift. As it falls (partly upside down) it presents a negative angle of attack, but it can correct itself after it has fallen a sufficient distance. If the kite is high in the air, this type of looping may be fun to watch; if the kite is low, it may crash at the bottom of the loop.

To bring the kite down you probably will reel in the kite line, but with a stronger breeze reeling in may be hard work or impossible. An alternative is to walk down the kite. Secure the end of the line to a stationary object or have a friend hold it as you walk toward the kite and pull the line down hand over hand. Once the kite is lowered into the lighter breezes near the ground reeling is easier.

To build a kite you first must decide on the materials for the two basic parts of the kite, the framework and the covering. In the Orient split bamboo rods traditionally formed the framework. They were light and strong and could be bent without too much trouble. In the U.S. pine sticks are usually employed. Recently fiberglass rods and hollow tubes of aluminum have been offered for the purpose. They are much stronger but are not as easy to work with and are expensive. (Cutting fiberglass might even require wearing a mask, since breathing the glass particles is dangerous.) The fiberglass and aluminum rods must be connected with some type of slightly larger plastic tubing. Unless you are already an experienced kite maker, I suggest you build with ordinary round wood dowels 36 or 48 inches long and 3/16 or 1/4 inch in diameter. Rectangular cross-sectional strips with dimensions of about 1/8 by 3/8 inch will also serve. Spruce appears to be the best type of wood, although most other kinds of wood will do. Dowels can be bought inexpensively in any hardware or lumber store. Before buying a dowel carefully inspect it for straightness and straight grain.

The traditional material for covering kites has been either cloth or strong lightweight paper. Cloth is strong and durable but has to be stitched. Paper tears more easily but has the advantage of requiring only common white glue or rubber cement to be fastened around the kite's framework. Recently the thin plastic film Mylar has become popular. It is strong, relatively cheap, light in weight and can be attached with adhesive tape or reinforced tape. You can buy Mylar from kite stores and some hardware stores. Other modern materials are Zephyrlite and Stabilkote, which can either be sewn or taped in place. Both are light and strong and have good resistance to tearing.

To me the best material available is Tyvek, a Du Pont synthetic fabric. Depending on what grade of weight you buy, it feels like either cloth or paper, but it is almost impossible to tear by hand. It has all the advantages of paper in that it is fairly cheap, can be fastened in a few minutes with rubber cement and can be colored with common paints and markers, and its high tear strength makes it superior to paper. Du Pont is selling Tyvek only in large lots, but a smaller amount (27 feet by three feet) can be bought from the L. G. Striegel Mfg. Co. (1223 Arcade Avenue, Louisville, Ky. 40215). Other covering materials include sailcloth (you may be able to obtain remnants from local sailmakers) and nylon rip-stop. Some household materials are also suitable: wrapping paper, brown paper bags and plastic trash bags (the kind used to line the inside of garbage cans).

The kite line can be ordinary cotton string, but nylon string is lighter and stronger. One limitation on the maximum height a kite can reach is the weight of the string it must support, and so a string with a high ratio of strength to weight is best. The breaking point of the string should be high enough to spare you from losing the kite the first time out. Wyatt Brummitt, writing in *Kite Lines,* has a rule of thumb on what strength you should buy: the breaking point (expressed in pounds) should be at least three times the total front cross-sectional area of the kite (expressed in square feet). The spool on which the kite line is wrapped can be anything from a wood rod, which is what I use, to more convenient spools such as fishing reels. Some kiters fly their kites from the end of a fishing rod, which presents a rather curious sight to passers-by.

Other equipment can make kite building much easier. If your kites are made with wood dowels, the dowels can be glued together after they have been lashed with string. White glue has been favored, but recently kiters have been buying hot-glue guns (about $6 in most department and hardware stores). White glue can take up to an hour to dry, whereas glue from the gun requires only about two minutes. The guns therefore speed up the construction and make it possible to do quick repair work on broken frames. If you use a glue gun, however, you had better keep a bowl of water nearby because eventually you will get hot glue on your skin. Quickly submerging the skin in water is the only way to avoid a bad burn. Two other convenient pieces of equipment are a razor

saw (from a hardware or hobby store) for cutting wood dowels and an eyeleteer and eyelets (from a hardware or sewing-supply store) for making reinforced holes in materials.

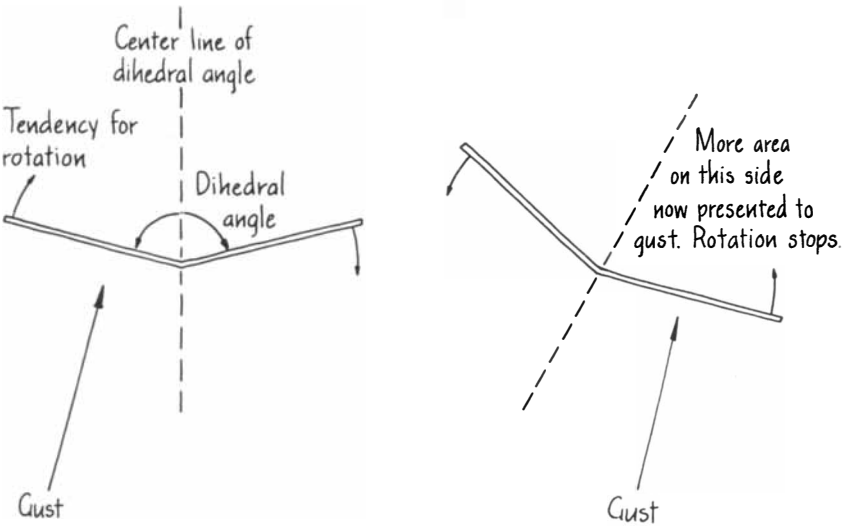
The bridle can end in a small loop to which the kite line is fastened, but if your kite rotates in midair, the bridle will become twisted. To avoid the problem fasten the bridle to a small metal or plastic ring with a lark's-head knot and then attach a swivel clip (of the type used on fishing lines) between the ring and the kite line. Such a clip can be bought in a sporting-goods store.

Now let us build a kite or two. Here I shall describe several basic kite designs. There are certainly many more that would be interesting to build because of their different aerodynamics. Perhaps I shall return to some of the other designs in a future article in this space.

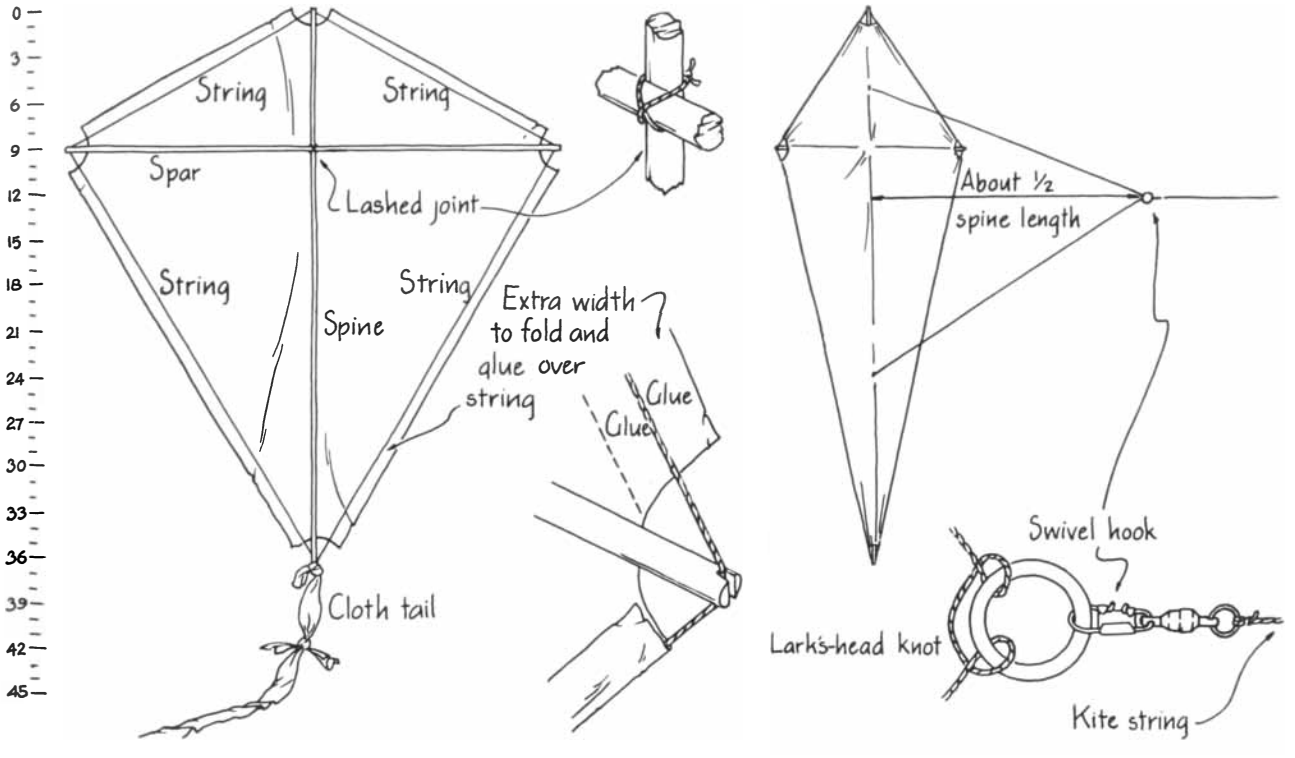
All the illustrations of the designs I shall discuss are drawn to the same scale in inches; the scale appears on the left side of the illustration below. To measure the length of any one stick or the side of a kite, mark the length in the illustration off on the side of a sheet of paper and then lay the edge of the paper down on the scale. If you want to make a kite that is larger or smaller than my plan, first measure the dimensions of my kite and then scale all of them up or down uniformly. Bear in mind a hazard in making large kites: you have to be able to get the kite through the door.

The first design is a flat diamond kite with a single spar (horizontal stick) lying perpendicular to a single spine (vertical stick) about a quarter of the spine's length from the top of the spine. Cut the wood dowels to size with a razor saw, keeping the cut edges smooth. Mark the intersection points for the crossing of the two sticks, taking care that the point is exactly halfway along the spar. With a touch from a hot-glue gun fasten the two sticks together. After a few minutes you can lash them in place with strong string (fishing line, for example), applying more glue if you like. Alternatively you can first apply glue and then cover the joint with masking tape for added support. Be careful about keeping the sticks accurately perpendicular to each other.

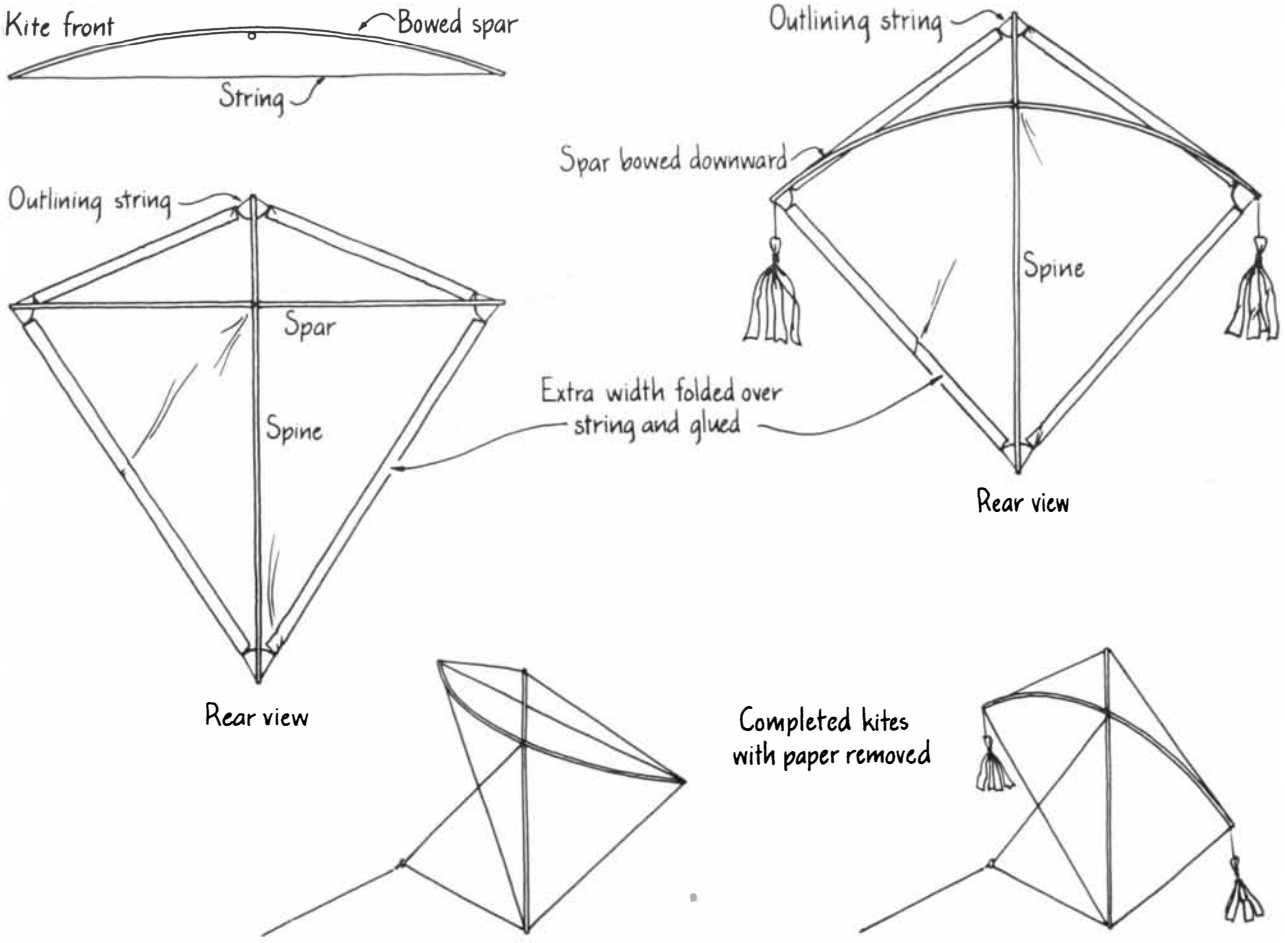
Before assembling the sticks cut narrow notches in the ends with a hacksaw blade. At one end tie the end of a string and run the string through the notch and then around through the other notches in turn until the string outlines the basic diamond of the kite. Tie off the other



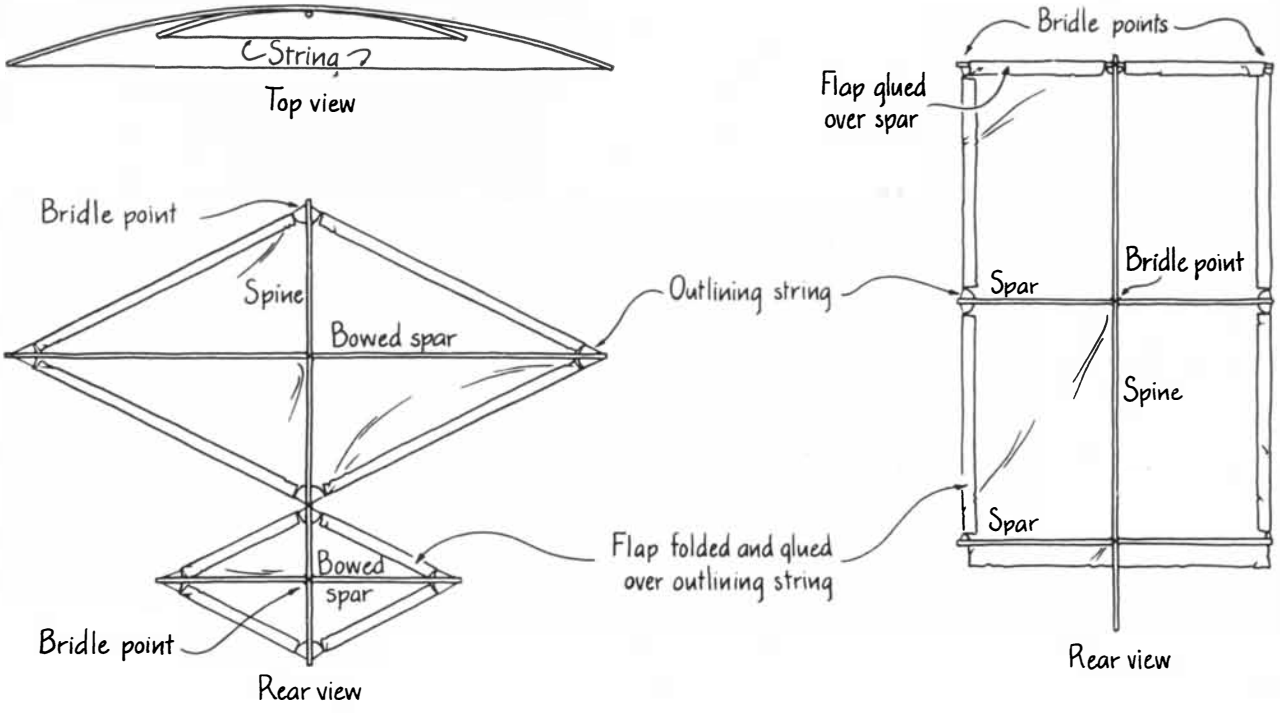
A view of the dihedral angle from above



Steps in making a basic diamond kite



The Eddy bowed kite **(left)** *and the Nagasaki Hata* **(right)**



The double lozenge **(left)** *and the Musha* **(right)**

end of the string. Check the kite for balance by visual inspection and by inserting a needle through the spar-spine joint and seeing if the frame of the kite hangs straight from the needle. If it is obviously unbalanced, you will have to adjust the sticks and the string.

Lay the frame down on whatever material you plan to use for a kite covering. Cut the material in the shape of the kite, leaving extra width on the sides that can be folded over the outlining string to lie on the material inside the diamond. If the material is paper or Tyvek, fasten the flap down with rubber cement. If you are using cloth, stitch the flap down. With Mylar, tape it down. Run a two-legged bridle to the spine. Make a tail of six-inch lengths of cloth tied to a narrow piece of cloth that is about five times longer than the spine.

An Eddy kite is made in much the same way, with the exceptions that no tail is needed and that the spar is bowed backward after the covering is put on the frame. Place one end of the spar on the floor and bend it so that the covering is on the outside of the curve. Run a line from one end of the spar to the other to keep the spar bowed. The bridle lines are run through small holes pierced in the covering and are attached to the spine at the points indicated in the left-hand part of the top illustration on the opposite page. The bowed shape provides the dihedral angle needed for the kite's stability. This kite performs well in light to moderate winds.

The first step in making a third kind of kite, the Nagasaki Hata, is to connect the spar and spine at right angles after making certain of their balance. Lash the joint well. Bow the spar downward and fasten it in place by attaching it to the covering. Attach the kite covering to the spine and add tassels on the spar ends. The tassels can be ribbon of the kind used for a Christmas package. Be sure to balance the kite by appropriately trimming the tassels. Properly balanced, they aid in stabilizing the kite as a tail does. The bowed spar is pushed backward by the wind, producing a curved face similar to that of the Eddy kite, except that with this design the extent of the bowing is determined by the strength of the wind.

A fourth kind of kite, the double-lozenge kite, is similar to the Eddy kite except that a smaller diamond is below the main one. Both diamonds are built on the same spine and are bowed backward. The smaller diamond acts as a rudder to stabilize the kite, which is flown in light to moderate winds.

Many of the Oriental kites are rectangular. The Musha kite is easy to build and has an interesting aerodynamic feature: the trailing edge (below the lower spar) helps to stabilize the kite much as a tail does. This kite can be flown in light to gentle winds.

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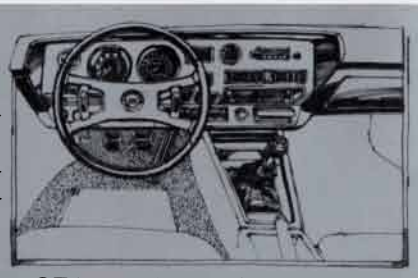

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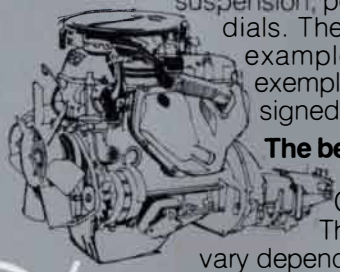

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