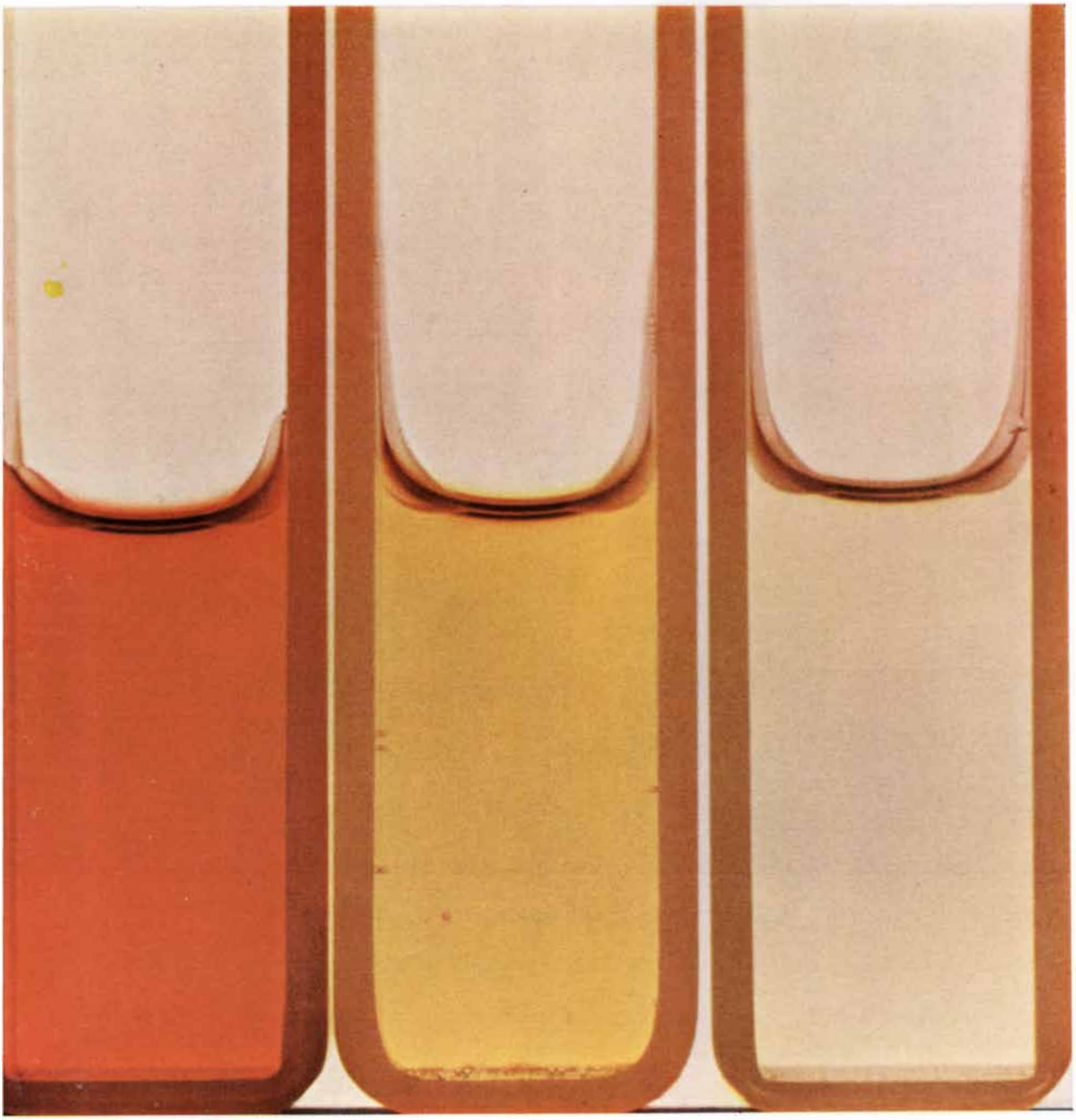
SCIENTIFIC AMERICAN



VISUAL PIGMENT

SIXTY CENTS

October 1966

Rust, rot, fire, decay...old enemies meet new defenses

Today there are new levels of protection for things animal, vegetable, mineral, and man-made, through M&T's work in chemistry and metallurgy. Take the four examples above.

Teeth have always succumbed to decay. Less so now because of M&T* Stannous Fluoride protection.

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One thing this Coronastat 55 won't do is "nickel and dime you to death" with hidden extra charges.

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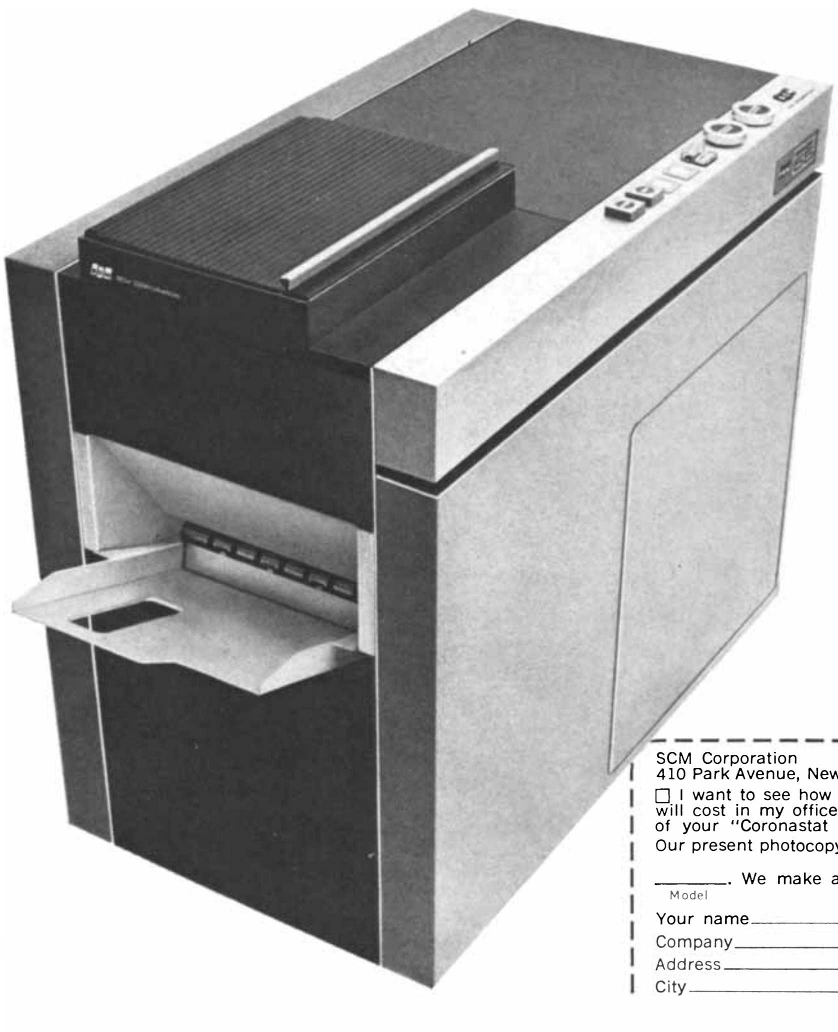

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Brand name
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Model No. of copies
Your name________
Company________Title________
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City________State________Zip________

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When we put the first Sigma 7 together, we found that its cycle time was 850 nanoseconds.

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Because we wanted to wait and be sure. And 1.2 microseconds is impressive enough.

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Sigma 7 was designed from the beginning to do real-time on-line control, conversational time sharing, batch processing, and high-speed input/output all at the same time. With full protection for everybody. And every job done as fast as the user wants it done.

We're delivering both hardware and software a little ahead of schedule. Two Sigma 7's in our plant are busy full time checking out software. When you get your software packages you know they'll run.

So far we're keeping all our promises. Except the one about the cycle time.

Sorry about that.

SDS

Scientific Data Systems,
Santa Monica, California

Established 1845 **SCIENTIFIC AMERICAN** October 1966 Volume 215 Number 4

ARTICLES

DEPARTMENTS

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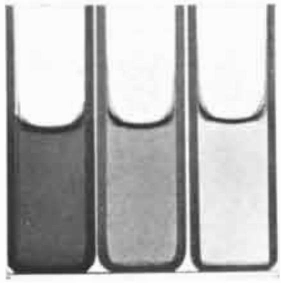

THE COVER

The three vessels in the photograph on the cover contain extracts of the visual pigment rhodopsin in three states. Rhodopsin is the pigment found in the rod cells of the retina, which are responsible for vision in dim light (see "Night Blindness," page 78). It is a complex of the protein opsin and the aldehyde form of vitamin A. When it absorbs light, it initiates excitation of the rod cell and is "bleached" from a purplish red to yellow. In the photograph the vessel at left contains unbleached rhodopsin that has been extracted from the retina of a bullfrog. The vessel in center contains the bleached pigment, which has been dissociated into opsin and vitamin A aldehyde. In the vessel at right the vitamin A aldehyde has been converted into colorless vitamin A. The extracts were prepared by John E. Dowling and Paul K. Brown at the Biological Laboratories of Harvard University.

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Cover photograph by St. Clair and Price

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We cannot blame anyone who swore they would never buy another Renault.

When we first sent our cars into this country we ran into a sad situation.

We had, as we say in France, sold the skin of the bear before having put him on the ground.

Our cars were not fully prepared to meet the demands of America, where sustained high speeds are normal, where a heavy foot with the clutch is normal, and where people are not used to fixing their own cars.

More than a fair share of things went wrong with our cars. Less than a fair share of our dealers were equipped to deal with what went wrong.

Well, that is actually water over the dam, so to speak.

After all, Renault has a reputation to protect as one of the finest and oldest (1898) and largest (7th) manufacturers of automobiles in the world.

So with all our hearts and with all our strength we set out to protect that reputation.

We began by selecting our raw materials more carefully. We used a steel of thicker gauge. And the paint and the rust-proofing and the undercoating we used more thickly.

We improved also the quality of our quality control, and we added another 25% of fine inspectors.

The next step was to improve our dealers. So before we sign on any new dealer, we require that he use only Renault-trained mechanics.

And we make it certain that not one of our cars is sold in this country unless every part for it is available.

And, of course, we developed a fantastic car, the Renault 8. But before we introduced it here we ran it around Europe first. And then very quietly on a small scale we brought it here a few years ago.

And when we were sure the car was perfect, we improved it, and now this is the car we are talking about.

It is the Renault 10.

It is probably as comfortable as any automobile you will ever sit in, "and you can toss in a Bentley Continental or a Rolls if you care to," said one critic, but we don't know if that is not too much for us to say.

It has a five-main-bearing engine that you can drive all day at top speed (84 mph) and not do it injury, so finely is it machined.

It will average an honest 35 mpg.

It has a liquid cooling system that is infinitely quieter than air-cooling, yet it will not boil or freeze.

The Renault 10 is equipped with four doors, four-wheel independent suspension, and disc brakes on all four wheels.

Yet it costs only $1647*.

Now the bear is on the ground.

If you do not at least test drive the Renault 10, you shall have only yourself at whom to swear.

RENAULT

The Renault 10

*East and Gulf Coast, P.O.E. Slightly higher on West Coast. *Whitewalls, Automatic Transmision optional.
For Renault dealer nearest you or information on money saving overseas delivery, write Renault, Inc., 750 Third Ave., N.Y., N.Y. 10017

LETTERS

Sir:

The article by Lawrence Badash on the remarkably quick acceptance of the Rutherford-Soddy theory of the transmutation of the chemical elements [SCIENTIFIC AMERICAN, August] is most interesting. It points out that the conservative outlook of serious investigators of nature in the 19th century had changed so as to facilitate the acceptance of radically new viewpoints. As examples mostly physical discoveries are cited. Badash also mentions that the idea of transmutation seemed to be already in the air in 1902, as evidenced by Sir Norman Lockyer's "inorganic evolution." He fails to stress, however, that the long battle for acceptance of the principle of organic evolution, waged since 1859 by Charles Darwin and his adherents, had made this idea much more acceptable, not just to biologists but to the intellectual community as a whole.

I suggest that once the immutability-of-the-species concept had been breached it was easier to accept mutability in other fields of natural philosophy. The concept of mutation is not the only one in which biology had spearheaded the thinking of physicists and chemists. A good case can be made for the leading role biologists played in the development of ideas such as the conservation of energy, osmosis and causality. This points up the essential unity of science and of human thinking in general. Is it pure chance that one of the milestones in biological theory, the publication of Hugo De Vries's *Mutation Theory*, is dated 1901?

F. W. WENT

Desert Research Institute
University of Nevada
Reno, Nev.

Sirs:

Louis Z. Cooper's account of German measles [SCIENTIFIC AMERICAN, July] failed to mention the origin of the disease's curious English name. The story is little known and might interest your readers. It was related to me in the 1920's by Ulrich Friedemann of the Robert Koch Institute in Berlin. Dr. Friedemann, who had been an assistant to Paul Ehrlich, together with A. Paul Wassermann, has vouched for its authenticity.

The story goes back to a time in the 19th century when an international congress on infectious diseases was meeting in London. One of the subjects under discussion was the acute febrile rash (acute exanthema) of childhood. A dispute to be settled related to the classification of the various rashes and to their nomenclature.

The English school called all measles-like rashes measles. The German school objected vigorously and maintained that there were two separate measles-like diseases, which they recognized as "morbilli" and "rubeola" (in German *Masern* and *Röteln*). Neither faction would yield, and the heated debate did not end until a wise Englishman rose and addressed the assembly:

"In honor of our German guests let us all recognize that perhaps there *is* a separate clinical entity, not a mere variant, which is to be distinguished from ordinary measles, and which the Germans have identified as *Röteln*. I propose a new name. It will be *German* measles. ... For the benefit of my esteemed British colleagues it is a separate name, but still measles."

E. F. SCHMERL, M.D.

Chief, Geriatric Service
Alameda County Medical Institutions
San Leandro, Calif.

ERRATUM

In "A Solid-State Source of Microwaves" (SCIENTIFIC AMERICAN, August) the table on page 31 gives the power of the Read diode as 5 watts. A decimal point was inadvertently removed from the number; it should be .5 watt.

Sirs:

In the interests of bear-shooting I wish to submit another infinite set of answers to the problem posed in the "Mathematical Games" department of your magazine for May. My solution alleviates the frustrations attendant on this form of hunting in antarctic regions due to the scarcity of the genus *Ursus* at these latitudes. My proposal is such that, although the bear must be in the Southern Hemisphere, the explorer can position himself anywhere on the earth's surface at a similar longitude to the long-suffering beast and shoot it at any range whatever to the south.

The method is based on the fact that an easterly component of velocity is imparted to a bullet fired from a gun pointed in a southerly direction, owing to the earth's spin. This component is equal to the peripheral speed of the earth at the Equator times the sine of the latitude of the explorer. Providing that the bear is at a greater angle of latitude (south) than the explorer (north or south) and the latter's weapon is of sufficiently long range and/or low muzzle velocity, the bear will be shot. As an example, if the explorer is at latitude 89 degrees south and the bear at 89 degrees 10 minutes south (that is, about 11½ miles distant), a bullet fired due south at about 600 miles per hour will still hit the bear after it has moved 100 yards to the east. Smaller ranges and/or latitudes at which the encounter between explorer and bear takes place will necessitate a weapon of lower muzzle velocity and vice versa.

It is of interest in this connection that during World War I the Germans had to make allowance for the difference in latitude between their long-range "Paris guns" and the target, aiming off to the east in order to counteract this effect of the earth's rotation.

R. S. BURTON

Shepperton
Middlesex
England

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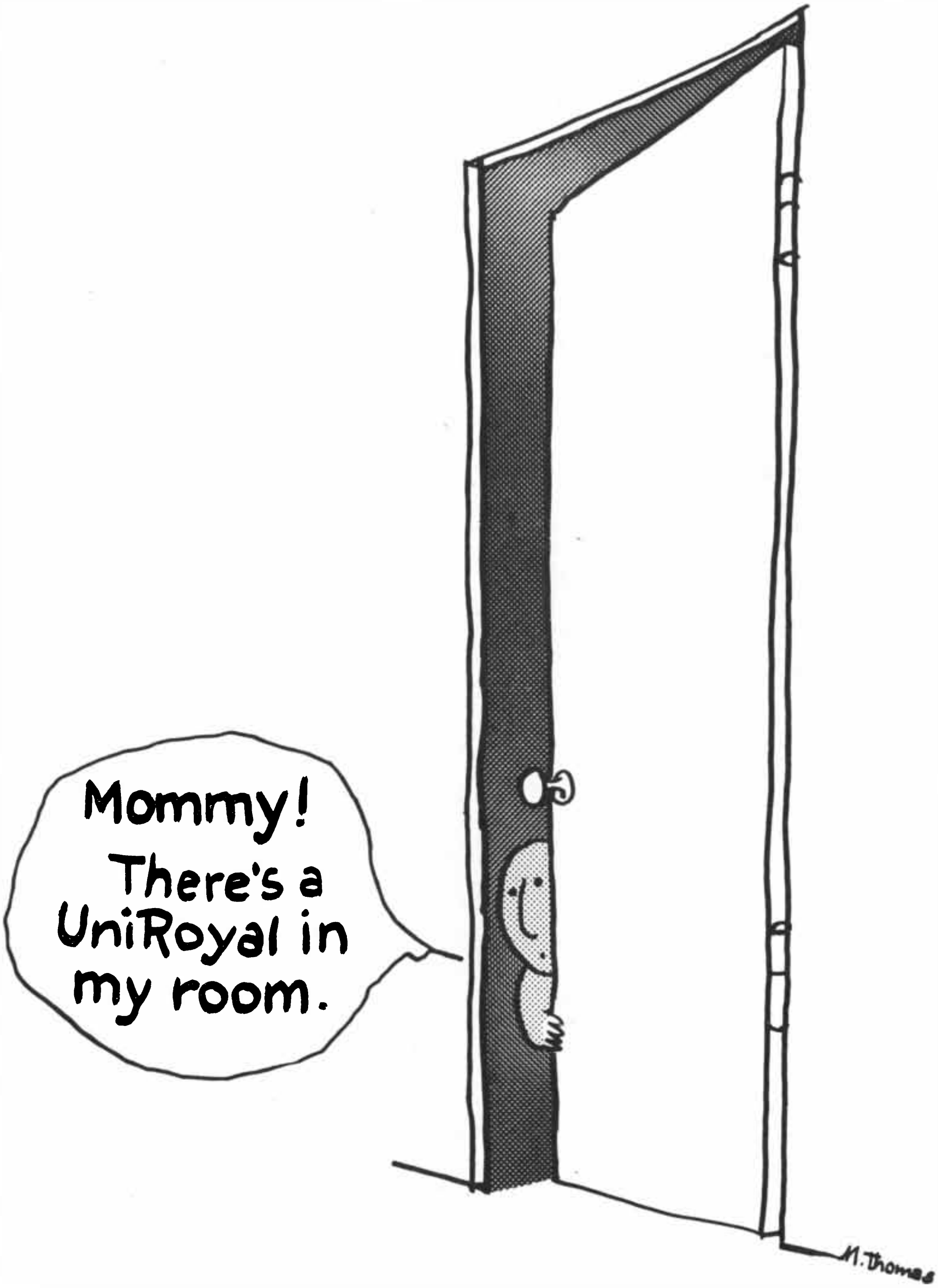
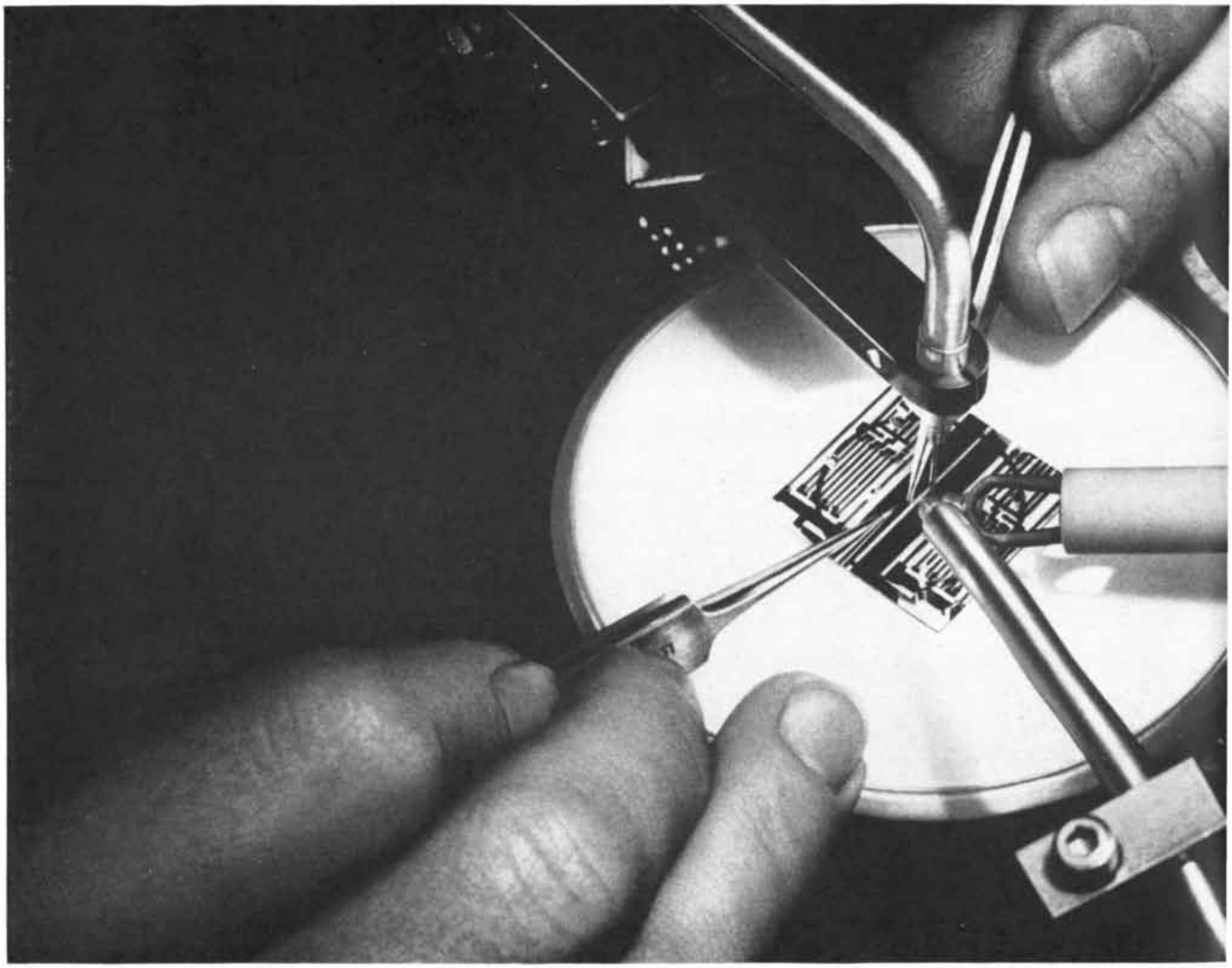

Mommy!
There's a UniRoyal in my room.
M. Thomas

Can human beings work without error?



To err is human. Or is it? In an attempt to reduce errors, our Martin division conceived a program called Zero Defects, which aims at a theoretical goal of perfection. The program has produced valuable results. Since Martin introduced it four years ago, it has been adopted by more than a thousand companies.

Industry in general has come to tolerate a certain level of human error in its operations. After all, nobody is perfect, the reasoning goes.

In space and defense work, however, there can be no such thing as a "tolerable" level of error. Men's lives may literally depend on a product being completely reliable.

In July of 1962, Martin, which produces missile systems, spacecraft and other technologically advanced products, formalized a program called Zero Defects.

The program aimed deliberately high—at perfection in every aspect of the company's operations. It has been a potent stimulus to high-quality work at Martin.

The basic value of a Zero Defects program lies not in achieving perfection, but in reducing errors through a strong, sustained drive toward this ideal goal.

The program owes its overall success to thousands of individual achievements.

Some examples:

- A man made 18,000 entries in a production logbook without error.
- Two men welded 36,000 inches of seams without a defect.
- A woman processed over 30,000 cost-and-payroll records without a mistake.
- A woman soldered 336,000 circuit board connections without a defect.

As a measure of overall results, in one plant the reject rate of components—already low at Martin plants—was cut by more than a third in a single year.

This has helped Martin keep costs down, yet deliver products which are as reliable as human ingenuity and purpose can make them.

Since its introduction at Martin in '62, a Zero Defects program has been formally adopted by the Department of Defense and by more than a thousand American companies. Rolls-Royce is introducing it in Britain.

The authoritative book on the subject, written by Martin's J. F. Halpin, is *Zero Defects, New Dimension in Quality Assurance.* If your bookstore can't supply you, write McGraw-Hill Books, New York, N.Y. 10036.

The several divisions of Martin Marietta produce a broadly diversified range of products, including missile systems, space launchers, nuclear power systems, spacecraft, electronic systems, chemicals and construction materials. Martin Marietta Corporation, 277 Park Avenue, New York, N.Y.

MARTIN MARIETTA

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1916: "The most novel, if not the most spectacular, feature of the recent successful offensive by the French and British armies on the Somme was the presence of several armed and armored tractors of the caterpillar type, which, if we may judge from the press reports, proved wonderfully effective in following up the heavy gun attack, riding down or cleaning out machine-gun emplacements, enfilading trenches and otherwise preparing the way for the rush of infantry attack. What part these machines are destined to play in the later stages of the war is a matter of pure speculation. The British speak of them as a great success; Berlin naturally describes them as being a complete failure—unwieldy, slow and liable to break down. If they are successful, Germany is certain to come back with something of the same kind; and if so, we may see squadrons of these mechanical armadillos maneuvering against each other in the open field."

"A movement on behalf of the systematic investigation of atmospheric pollution in Britain began with a conference of delegates of municipal authorities and others held in connection with the Smoke Abatement Exhibition in 1912. A committee was appointed at that time to undertake regular observations. The first report of the committee, published as a supplement to the *Lancet*, contains detailed statistics for 39 stations for various periods of time and town maps showing the location of all the pollution gauges. Of total solids found in rainfall the greatest amount was deposited at Oldham: 35 tons per square kilometer per month. Ancoats Hospital, Manchester, came next with 27 tons. The smallest deposit was at Malvern: two tons per square kilometer per month. If the records of these 39 stations represent the average condition of the air as breathed by the British population, it may be stated that the average atmosphere deposits upon a square kilometer in any one winter month 15 tons of solid matter, made up of .15 ton of tarry matter, three tons of other carbonaceous substances, six tons of insoluble inorganic dust, besides soluble salts, which include three tons of sulphuric acid, a ton of chlorine and .3 ton of ammonia."

"The great war has certainly not been lacking in the element of the dramatic, and the latest evidence of this has come in the form of a sudden and most spectacular raid by German submarines, right under the very eyes of our Atlantic fleet and almost within vision of visitors to that quaint and peaceful summer resort—Nantucket Island. That so many ships should have been sunk so quickly is not surprising. The bulk of the transatlantic shipping passes close to the Nantucket lightship, and a U-boat that lay in wait in that busy thoroughfare would make a big bag as surely as a concealed hunter in the duck-hunting season. The raid serves to show, in a very dramatic fashion, how valuable an asset in submarine warfare is the element of surprise. In conclusion we draw attention to the very grave possibilities of a break with Germany to which she exposes herself by boldly opening an indiscriminate submarine warfare in crowded American waters. The wholesale *Lusitania* murder included the killing with deliberation of over 100 American citizens. The memory of that crime is as fresh to-day as a year ago—and atonement by Germany has yet to be made. If the loss of so much as one American life should occur almost within sight of our shores, it is doubtful if the wave of indignation which would sweep the country could any longer be controlled within the limits of diplomatic correspondence."

Scientific American.

OCTOBER, 1866: "The complete success of the Atlantic cable has occasioned the formation of several rival companies, designed to break up this monopoly, as it is even now characterized by many. In addition to the projected line over Behring's Straits and another from Spain to Florida via the West Indies, both of which are owned by Americans exclusively, there is the new English enterprise of completing telegraphic communication by means of several short lengths of cable between Scotland, the Faroe Islands, Iceland, Greenland and Labrador. The entire route has been thoroughly and efficiently surveyed, and a contract has been made for duplicate cables for the whole distance of nearly 4,000 miles."

"In the diplomatic relations between this country and the nations of Europe the telegraph is destined, we think, to play an important part. With it mistakes can be rectified, misunderstandings corrected and unpleasant complications avoided. Occurrences trifling and unimportant in themselves are often made by journalists the means of exciting the passions and arousing the prejudices of the people. The European mails bring us accounts of speeches and of the action of Parliament, the opinions of influential men and the intentions of those in authority, which are sometimes misleading and erroneous, the error being strengthened by editorial remarks in prominent journals. Before the next mail arrival the subject has been debated and discussed in the journals all over the country, passions inflamed, antipathies renewed and the public mind put into a ferment. The telegraph, in such a case, will prove a ready means of correcting false impressions before they have taken root in the popular mind."

"In a little more than a year the Suez Canal, the great work projected but never begun by Napoleon the Great, will be completed. The Cape of Good Hope, at the southern extremity of Africa, will become to European commerce what the Isthmus railway has made Cape Horn to our Atlantic and Pacific trade. Africa will no longer block the highway between Europe and the East. While we are endeavoring to reach the Indies by a railroad across this continent, Louis Napoleon is connecting the Mediterranean with the Red Sea and the Arabian Gulf. It will undoubtedly be a success and become one more link to bind the nations together in the bonds of commerce."

"The project of Mr. Hawkshaw for tunneling the English Channel—which plan, by the way, is nothing new, but has been regularly proposed at intervals for many years past—meets with a counter project in a proposed international railway bridge, composed of pontoons, reaching from Calais to Dover, a distance of 22 miles. The bridge is to have several draws to allow the passage of vessels, is to be 214 feet in width and to be constructed at a cost not exceeding 16 millions of pounds sterling."

Report from

BELL LABORATORIES

Found: A rapid route to the shortest path

What is the shortest path through a number of points, touching each just once and ending at the starting point? This "traveling salesman problem" is important in many areas of modern business and technology, where "shortest path" may really mean the least hook-up wire, travel time, or transmission power.

It might seem that the problem could be solved by measuring all paths and taking the shortest but, even with a computer, this is a colossal task. At a million paths per second, for instance, it would take several billion years to compute and compare all paths in a 25-point problem! Shortcut methods have been devised, but they are still too slow when, say, 60 points are involved. In practice, approximate solutions (almost-shortest paths) are found largely through the educated judgments of engineers looking at graphs or maps . . . or for certain limited problems, through special computer programs.

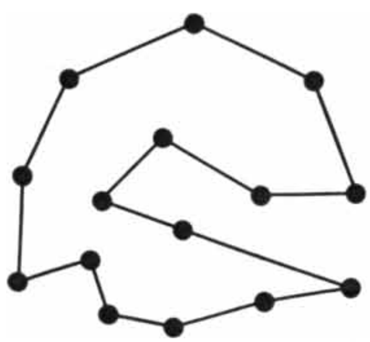
Now, mathematician Shen Lin of Bell Telephone Laboratories has developed a new way of getting good approximate solutions to problems of up to 145 points. Because his method is fast, it is possible to find many such approximations. It is then easy to pick the shortest of these. Often (see left), this is the absolute minimum. If not, it is at least short enough for most engineering purposes.

The critical feature of Shen Lin's method is its speed; it makes many good approximations in a reasonable time and selects the best.

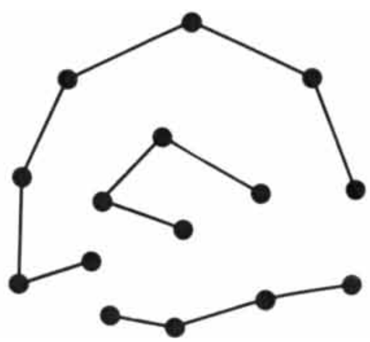
To make one approximation, the computer chooses a "starting path" at random. It removes three links of this path (thus breaking it into three sections – see figures) and connects the sections differently to see if a shorter path results. If not, it systematically removes other combinations of three links in the original random path, until all combinations have been tried. But, whenever such a reconnection *does* produce a shorter path, it takes this as a *new* starting path, and begins the series of breaks again. One "approximation" is completed when no further improvement results from such breaking and reconnection.

In the same way – beginning each time with a new and different "starting path" – many additional approximations are found. They usually have some path sections in common; it simplifies the problem to assume that these are part of the absolute minimum path. So, they are routinely incorporated into every new starting path and no longer broken. This speeds computation and the time that's saved is used to find even more approximations.

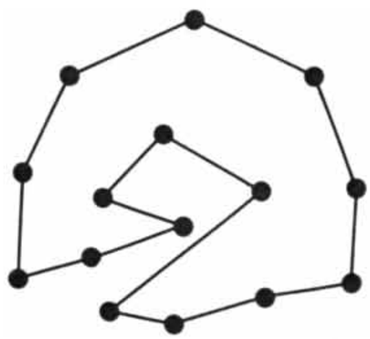
In general, using a high-speed digital computer, 100 approximations take about $0.75n^3$ milliseconds (n = number of points). For a typical 40-point problem, experiments indicate that about one out of 16 approximations will be the actual minimum solution; for 60 points, about one out of 64. So, if we find 300 approximations in a 60-point problem (roughly eight minutes on a computer) there is a high probability that one of these is the shortest possible.



Start with a random path . . .



Break it into three sections . . .



Reconnect them differently.

Bell Telephone Laboratories

Research and Development Unit of the Bell System


Arabic
再接再勵
Chinese
En tand bedre.
Danish
Wij doen nòg meer ons best.
Dutch
Wij proberen steeds meer.
Flemish
Nous faisons plus pour vous satisfaire.
French
Táimid Aᵹ Ḋéanaṁ An-Iarraċt
Gaelic
Wir geben uns mehr Mühe.
German
ΜΕΓΑΛΥΤΕΡΗ ΠΡΟΣΠΑΘΕΙΑ ΓΙΑ ΤΟ ΚΑΛΛΙΤΕΡΟ
Greek
Hooikaika oi aku makou.
Hawaiian
אנו משתדלים יותר
Hebrew
Faremo più e meglio.
Italian
私たちはもっと
頑張ります
Japanese
Vi anstrenger oss ytterligere
Norwegian
Tentamos sempre fazer melhor ainda.
Portuguese
Nosotros nos esforzamos más.
Spanish
Vi gör vårt bästa.
Swedish
Te tutava nei matou.
Tahitian
Rao payayam prap prŏong yu samur.
Thai
Ymdrechwn yn galetach.
Welsh

THE AUTHORS

OSCAR LEWIS ("The Culture of Poverty") is professor of anthropology at the University of Illinois. Although he was born in New York City, he grew up on a small farm in upstate New York. He was graduated from the City College of the City of New York in 1936 and received a Ph.D. in anthropology from Columbia University in 1940. Before going to the University of Illinois in 1948 he taught at Brooklyn College and Washington University. Lewis has spent 25 years in the study of other cultures, including the Blackfoot Indians of Canada, Mexican peasants and city dwellers and low-income Puerto Ricans in San Juan and New York. Among his extensive writings are several books, including *Five Families* and *The Children of Sánchez.*

S. K. RUNCORN ("Corals as Paleontological Clocks") is professor of physics and director of the school of physics at the University of Newcastle upon Tyne. He did his undergraduate work at the University of Cambridge and obtained a Ph.D. at the University of Manchester. There he began work in geomagnetism. Returning to Cambridge in 1950, he spent six years as assistant director of research in geophysics before assuming his present responsibilities. This past summer he was visiting professor at the Institute of Marine Science of the University of Miami. Runcorn's interests include paleomagnetism and the effect of convection currents in the earth's mantle on continental drift. Last year Runcorn was elected a Fellow of the Royal Society.

GEORGE A. HOFFMAN ("The Electric Automobile") is a research engineer at the Institute of Government and Public Affairs of the University of California at Los Angeles. A native of Italy, now a U.S. citizen, Hoffman was graduated from the Case Institute of Technology in 1944 and received a doctorate from Harvard University in 1950. From then until last year, when he took up his present work, he was associated with the aerospace industry as a designer and analyst of unconventional structures, materials and vehicles. His work at the Institute of Government and Public Affairs involves a program of improving the quality of the physical environment. Hoffman writes that his inspiration for studying electric automobiles came from his two sons, "who toyed with battery-operated cars way before me."

F. H. C. CRICK ("The Genetic Code: III") is a molecular biologist who works for the British Medical Research Council's Laboratory of Molecular Biology at the University Postgraduate Medical School in Cambridge. He was originally a physicist but turned to basic research on the structure of viruses, collagen and the nucleic acids. He is best known for putting forward (with James D. Watson) the idea that the molecule of the genetic material deoxyribonucleic acid (DNA) is a double helix; for work on the structure of DNA, Crick, Watson and M. H. F. Wilkins jointly received the Nobel prize for physiology and medicine in 1962.

GERALD L. POLLACK ("Solid Noble Gases") is associate professor of physics at Michigan State University. After graduation from Brooklyn College in 1954 he spent a year at the University of Göttingen as a Fulbright scholar and then went to the California Institute of Technology, where he received a Ph.D. in physics in 1962. From 1961 to 1965 he was a solid-state physicist at the National Bureau of Standards, going to his present position in the fall of 1965. Pollack writes that in addition to the work described in his article he is "particularly interested in the properties of superfluid helium films" and has "a peripheral interest in biophysics, mostly in questions of growth and form in living systems." He adds: "Currently the only thing I do about this interest is to encourage my wife's expert gardening so that I can put the flowers on my desk. For nonprofessional activities I like to play with my children, read old novels and swim."

JOHN E. DOWLING ("Night Blindness") is associate professor of biology at the Wilmer Ophthalmological Institute of the Johns Hopkins University School of Medicine. After graduation from Harvard College in 1957 he spent two years at the Harvard Medical School; he then switched to biology and obtained a Ph.D. from Harvard in 1961. He taught in the Harvard department of biology until 1964, when he went to Johns Hopkins. Dowling writes: "A major goal of our group at Hopkins is to correlate structure and function in the vertebrate retina. In particular I have worked extensively on problems of visual adaptation, and most recently on the synaptic organization of the retina as revealed by electron microscopy."

JEROME R. RAVETZ ("The Origins of the Copernican Revolution") is senior lecturer in the history and philosophy of science at the University of Leeds. Born in Philadelphia, he was graduated from Swarthmore College and then went to the University of Cambridge as a Fulbright scholar. After receiving a doctorate in mathematics at Cambridge he taught mathematics at the University of Durham until he went to Leeds to work in the history and philosophy of science. Ravetz is interested in the history of the mathematical sciences; he is also concerned with the social problems of contemporary science. His writings include papers on nuclear strategy and the Mohole project. Ravetz is now a British citizen.

JOHN T. EMLEN and RICHARD L. PENNEY ("The Navigation of Penguins") are respectively professor of zoology at the University of Wisconsin and an investigator at the Institute for Research in Animal Behavior, which is sponsored jointly by Rockefeller University and the New York Zoological Society. Emlen was graduated from Haverford College in 1931 and obtained a Ph.D. in ornithology from Cornell University in 1934. He spent some years as a biologist with the U.S. Department of Agriculture and as a research associate at Johns Hopkins University before going to the University of Wisconsin in 1946. In addition to his work with penguins he has studied social and population control in gulls, swallows, blackbirds, mice, squirrels and bats and made special studies of gorillas, bison and porpoises. Penney took a bachelor's degree at St. Olaf College in 1957 and a doctorate in zoology at the University of Wisconsin in 1963. He was a postdoctoral fellow and assistant professor at Johns Hopkins before going to his present position in May. Penney says he is a "hobbyist carpenter, gun collector and outdoorsman."

ANATOL RAPOPORT, who in this issue reviews *The Strategy of World Order: Volume I, Toward a Theory of War Prevention; Volume II, International Law; Volume III, The United Nations; Volume IV, Disarmament and Economic Development,* edited by Richard A. Falk and Saul H. Mendlovitz, is professor of mathematical biology at the University of Michigan.

Getting Boron Atoms Together...Alone, in Amorphous Form, and in Useful Quantities

The "corncob" shown is a section of 4-mil diameter boron filament, magnified 500 times. It shares with the potential of carbon filaments the distinction of being about the highest-performance material known to man. It approaches the strength of glass filaments and is six times as stiff.

These boron filaments are being used as reinforcements in plastics and metals to produce some remarkable improvements in strength and stiffness. For example, the strength and stiffness of aluminum have been increased by a factor of five above the pure metal by inclusion of these filaments. Imagine how much lighter a boron composite might make a future reentry vehicle or aircraft.

From Ounces to Pounds

Wonderful! But how far can one go with a material whose total annual production a few years ago was only a few ounces at a price of thousands of dollars? The problem of producing useful quantities of high-strength boron filaments comes in two parts: understanding the techniques by which these filaments can be made, and then transforming these techniques from laboratory operations into an economical mass-production process.

The most successful technique that will create high-strength boron filaments consists of bringing boron-containing gas in contact with an electrically-heated wire where the boron is vapor deposited onto the wire substrate with the characteristic "corncob" surface. Avco, under Air Force sponsorship, has taken this laboratory process and developed it into a continuous, well-automated process which has been set up in a pilot plant. This type of processing equipment is capable of producing hundreds of pounds per year of this exotic material and is being used to provide information for scale-up to a larger facility.

How it works

In this pilot plant, a series of ½-mil tungsten wire substrates are unwound from reels and fed through long glass reactor tubes in which flow boron trichloride (BCl_3) and hydrogen. The filament emerges at the other end of the reactor tube and is rewound as 4-mil boron filament. The 1¾-mil thick sheath of boron "corncob" is gradually built up on the substrate by vapor deposition as it moves through the glass tubing.

The tungsten substrate throughout the reactor tube is heated to a cherry-red 1000-1100°C temperature by an electric current introduced into the substrate by mercury-filled standpipes spaced at intervals along the reactor. The current levels in the substrate are not unlike those in the filament of the common incandescent lamp; the voltage levels are much higher.

The boron trichloride and hydrogen gas is automatically passed through the tubes and the unreacted boron trichloride is recovered for recycle while the unreacted hydrogen is vented through a flare.

The "Composites Age"?

With the filament being automatically reeled along at tens of feet per minute, and the numerous deposition units in the pilot plant working around the clock, Avco has become one of the nation's major producers of high-strength, high-modulus boron filament. Avco's future success in turning what is being learned in this pilot plant into a large-scale production facility could play a vital part in determining whether the "steel age" will ever be followed by the "composites age."

Avco has openings in many project and research areas, such as boron, high average-power lasers, artificial circulatory aids for medicine, advanced ballistic missile decoy systems, scientific satellites, higher-performance gas turbines. If you'd like to be out in this advance guard, write: The Avco Corporation, 750 Third Ave., N. Y. 10017.
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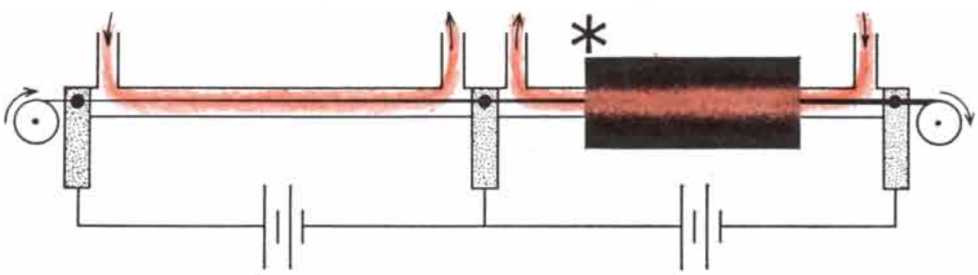

Sylvania ECG finds the way to make decisions in $\frac{6}{1{,}000{,}000{,}000}$ / second, reliably

Developing high-speed saturated digital logic which would contribute to, rather than compromise, overall system performance has been a universal problem of integrated circuit technology. Until now.

The Sylvania Electronic Components Group solved it.

Sylvania's solution, a bold approach to integrated circuit technology, incorporates Transistor-Transistor-Logic in a whole new generation of monolithic integrated circuits. They're capable of performing as many as 160 million switching functions every second. A switching rate about twice that of conventional saturated logic circuits.

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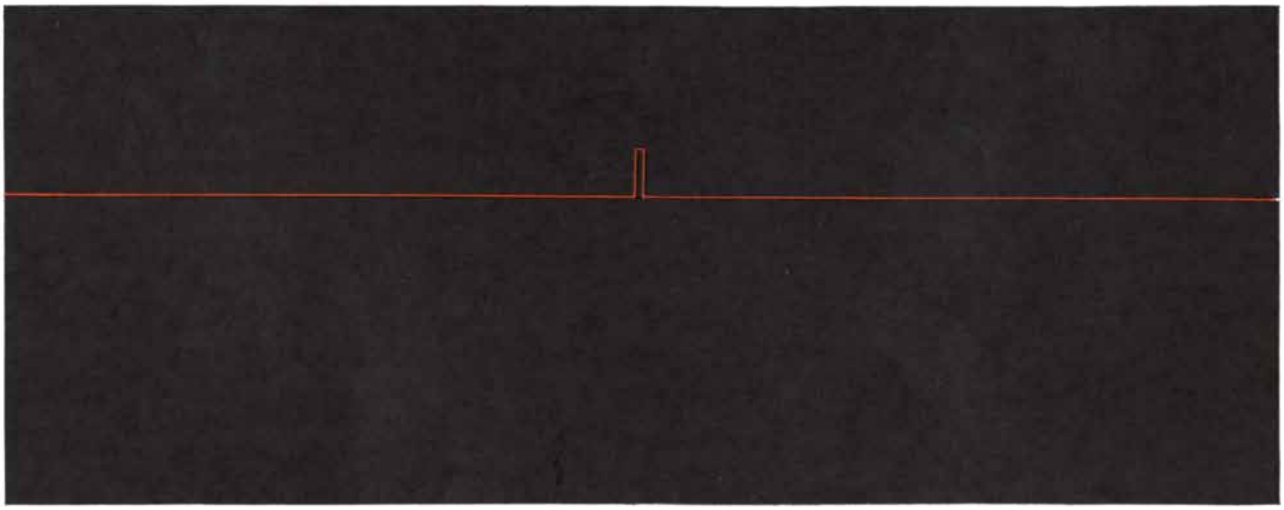
Sylvania Electronic Components Group, Sylvania Electric Products Inc., Seneca Falls, N.Y. 13148.



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The Culture of Poverty

Does membership in a group that has been poor for generations constitute belonging to a separate culture? A study of Puerto Ricans in both Puerto Rico and New York indicates that it does

by Oscar Lewis

Poverty and the so-called war against it provide a principal theme for the domestic program of the present Administration. In the midst of a population that enjoys unexampled material well-being—with the average annual family income exceeding $7,000—it is officially acknowledged that some 18 million families, numbering more than 50 million individuals, live below the $3,000 "poverty line." Toward the improvement of the lot of these people some $1,600 million of Federal funds are directly allocated through the Office of Economic Opportunity, and many hundreds of millions of additional dollars flow indirectly through expanded Federal expenditures in the fields of health, education, welfare and urban affairs.

Along with the increase in activity on behalf of the poor indicated by these figures there has come a parallel expansion of publication in the social sciences on the subject of poverty. The new writings advance the same two opposed evaluations of the poor that are to be found in literature, in proverbs and in popular sayings throughout recorded history. Just as the poor have been pronounced blessed, virtuous, upright, serene, independent, honest, kind and happy, so contemporary students stress their great and neglected capacity for self-help, leadership and community organization. Conversely, as the poor have been characterized as shiftless, mean, sordid, violent, evil and criminal, so other students point to the irreversibly destructive effects of poverty on individual character and emphasize the corresponding need to keep guidance and control of poverty projects in the hands of duly constituted authorities. This clash of viewpoints reflects in part the infighting for political control of the program between Federal and local officials. The confusion results also from the tendency to focus study and attention on the personality of the individual victim of poverty rather than on the slum community and family and from the consequent failure to distinguish between poverty and what I have called the culture of poverty.

The phrase is a catchy one and is used and misused with some frequency in the current literature. In my writings it is the label for a specific conceptual model that describes in positive terms a subculture of Western society with its own structure and rationale, a way of life handed on from generation to generation along family lines. The culture of poverty is not just a matter of deprivation or disorganization, a term signifying the absence of something. It is a culture in the traditional anthropological sense in that it provides human beings with a design for living, with a ready-made set of solutions for human problems, and so serves a significant adaptive function. This style of life transcends national boundaries and regional and rural-urban differences within nations. Wherever it occurs, its practitioners exhibit remarkable similarity in the structure of their families, in interpersonal relations, in spending habits, in their value systems and in their orientation in time.

Not nearly enough is known about this important complex of human behavior. My own concept of it has evolved as my work has progressed and remains subject to amendment by my own further work and that of others. The scarcity of literature on the culture of poverty is a measure of the gap in communication that exists between the very poor and the middle-class personnel—social scientists, social workers, teachers, physicians, priests and others—who bear the major responsibility for carrying out the antipoverty programs. Much of the behavior accepted in the culture of poverty goes counter to cherished ideals of the larger society. In writing about "multiproblem" families social scientists thus often stress their instability, their lack of order, direction and organization. Yet, as I have observed them, their behavior seems clearly patterned and reasonably predictable. I am more often struck by the inexorable repetitiousness and the iron entrenchment of their lifeways.

The concept of the culture of poverty may help to correct misapprehensions that have ascribed some behavior patterns of ethnic, national or regional groups as distinctive characteristics. For example, a high incidence of common-law marriage and of households headed by women has been thought to be distinctive of Negro family life in this country and has been attributed to the Negro's historical experience of slavery. In actuality it turns out that such households express essential traits of the culture of poverty and are found among diverse peoples in many parts of the world and among peoples that have had no history of slavery. Although it is now possible to assert such generalizations, there is still much to be learned about this difficult and affecting subject. The absence of intensive anthropological studies of poor families in a wide variety of national contexts—particularly the lack of such studies in socialist countries—remains a serious handicap to the formulation of dependable cross-cultural constants of the culture of poverty.

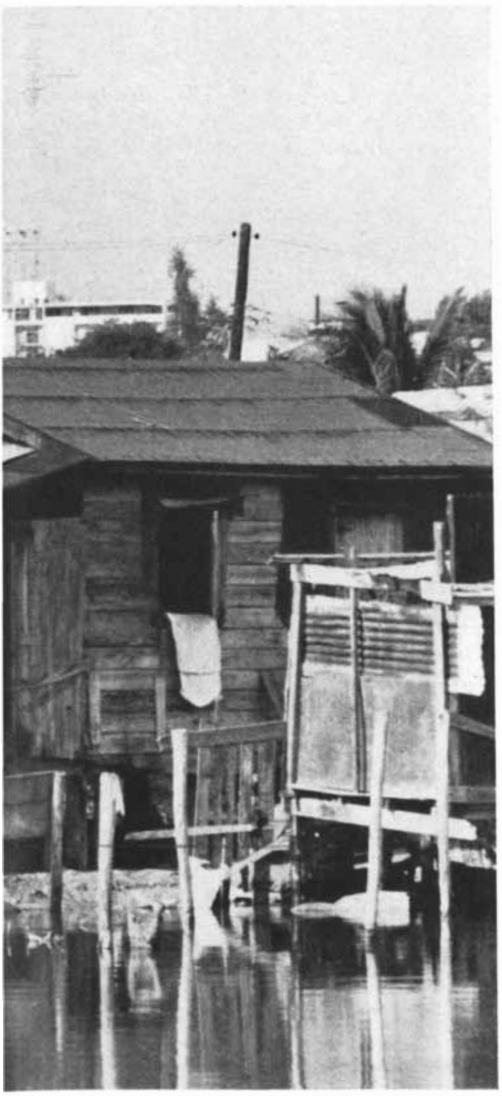
My studies of poverty and family life have centered largely in Mexico. On occasion some of my Mexican friends have suggested delicately that I turn to a study of poverty in my own country. As a first step in this direction I am currently engaged in a study of Puerto Rican families. Over the past three years my staff and I have been assembling data on 100 representative families in four slums of Greater San Juan and some 50 families of their relatives in New York City.

Our methods combine the traditional techniques of sociology, anthropology and psychology. This includes a battery of 19 questionnaires, the administration of which requires 12 hours per informant. They cover the residence and employment history of each adult; family relations; income and expenditure; complete inventory of household and personal possessions; friendship patterns, particularly the *compadrazgo*, or godparent, relationship that serves as a kind of informal social security for the children of these families and establishes special obligations among the adults; recreational patterns; health and medical history; politics; religion; world view and "cosmopolitanism." Open-end interviews and psychological tests (such as the thematic apperception test, the Rorschach test and the sentence-completion test) are administered to a sampling of this population.

All this work serves to establish the context for close-range study of a selected few families. Because the family is a small social system, it lends itself to

WATERFRONT SHACKS of a Puerto Rican slum provide a sharp contrast to the modern construction that characterizes the prosperous parts of San Juan's Santurce district (*rear*). The author has found that residents in clearly delineated slum neighborhoods such as this one often have a community sense similar to that characteristic of villagers in rural areas. Such *esprit de corps* is the holistic approach of anthropology. Whole-family studies bridge the gap between the conceptual extremes of the culture at one pole and of the individual at the other, making possible observation of both culture and personality as they are interrelated in real life. In a large metropolis such as San Juan or New York the family is the natural unit of study.

Ideally our objective is the naturalistic observation of the life of "our" families, with a minimum of intervention. Such intensive study, however, necessarily involves the establishment of deep personal ties. My assistants include two Mexicans whose families I had studied; their "Mexican's-eye view" of the Puerto Rican slum has helped to point up the similarities and differences between the Mexican and Puerto Rican subcultures. We have spent many hours attending family parties, wakes and baptisms, responding to emergency calls, taking people to the hospital, getting them out of jail, filling out applications for them, hunting apartments with them, helping them to get jobs or to get on relief. With each member of these families we conduct tape-recorded interviews, taking down their life stories and their answers to questions on a wide variety of topics. For the ordering of our material we undertake to reconstruct, by close interrogation, the history of a week or more of consecutive days in the lives of each family, and we observe and record complete days as they unfold. The first volume to issue from this study is to be published next month under the title of *La Vida, a Puerto Rican Family in the Culture of Poverty—San Juan and New York* (Random House).



uncommon among participants in the culture of poverty; although gregarious, they seldom manage to become well organized.

There are many poor people in the world. Indeed, the poverty of the two-thirds of the world's population who live in the underdeveloped countries has been rightly called "the problem of problems." But not all of them by any means live in the culture of poverty. For this way of life to come into being and flourish it seems clear that certain preconditions must be met.

The setting is a cash economy, with wage labor and production for profit and with a persistently high rate of unemployment and underemployment, at low wages, for unskilled labor. The society fails to provide social, political and economic organization, on either a voluntary basis or by government imposition, for the low-income population. There is a bilateral kinship system centered on the nuclear progenitive family, as distinguished from the unilateral extended kinship system of lineage and clan. The dominant class asserts a set of values that prizes thrift and the accumulation of wealth and property, stresses the possibility of upward mobility and explains low economic status as the result of individual personal inadequacy and inferiority.

Where these conditions prevail the way of life that develops among some of the poor is the culture of poverty. That is why I have described it as a subculture of the Western social order. It is both an adaptation and a reaction of the poor to their marginal position in a class-stratified, highly individuated, capitalistic society. It represents an effort to cope with feelings of hopelessness and despair that arise from the realization by the members of the marginal communities in these societies of the improbability of their achieving success in terms of the prevailing values and goals. Many of the traits of the culture of poverty can be viewed as local, spontaneous attempts to meet needs not served in the case of the poor by the institutions and agencies of the larger society because the poor are not eligible for such service, cannot afford it or are ignorant and suspicious.

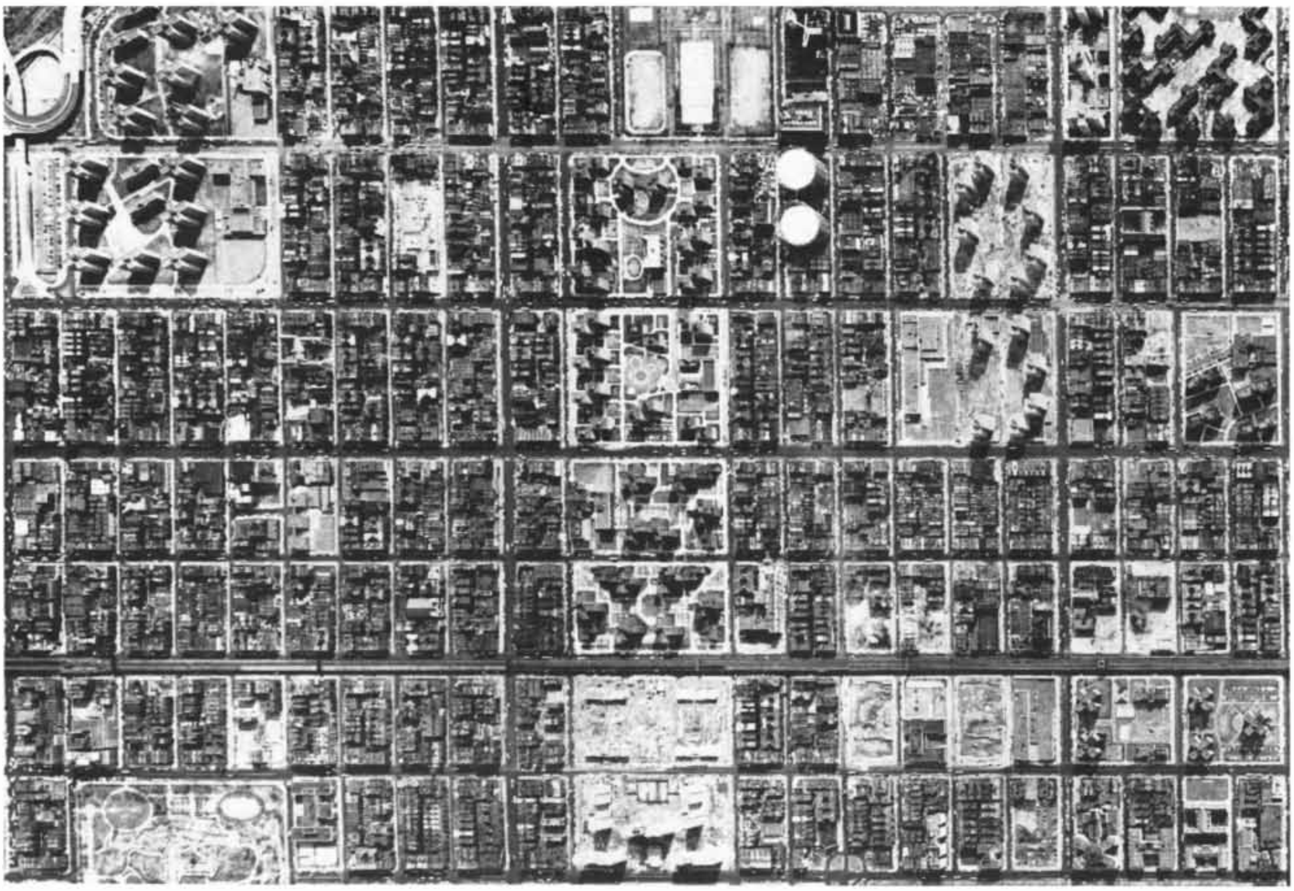
Once the culture of poverty has come into existence it tends to perpetuate itself. By the time slum children are six or seven they have usually absorbed the basic attitudes and values of their subculture. Thereafter they are psychologically unready to take full advantage of changing conditions or improving opportunities that may develop in their lifetime.

My studies have identified some 70 traits that characterize the culture of poverty. The principal ones may be described in four dimensions of the system: the relationship between the subculture and the larger society; the nature of the slum community; the nature of the family, and the attitudes, values and character structure of the individual.

The disengagement, the nonintegration, of the poor with respect to the major institutions of society is a crucial element in the culture of poverty. It reflects the combined effect of a variety of factors including poverty, to begin with, but also segregation and discrimination, fear, suspicion and apathy and the development of alternative institutions and procedures in the slum community. The people do not belong to labor unions or political parties and make little use of banks, hospitals, department stores or museums. Such involvement as there is in the institutions of the larger society—in the jails, the army and the public welfare system—does little to suppress the traits of the culture of poverty. A relief system that barely keeps people alive perpetuates rather than eliminates poverty and the pervading sense of hopelessness.

People in a culture of poverty produce little wealth and receive little in return. Chronic unemployment and underemployment, low wages, lack of property, lack of savings, absence of food reserves in the home and chronic shortage of cash imprison the family and the individual in a vicious circle. Thus for lack of cash the slum householder makes frequent purchases of

SAN JUAN SLUM AREA in the Santurce district sprawls along the edge of the tidal inlet (*top*) that connects the city's harbor with San José Lake. Rickety buildings have been erected on stilts beyond the high-water line and narrow alleyways crisscross the district. Compared to this area, many of New York's worst slum areas, such as the ones that appear below, are nearly middle-class.



EL BARRIO, the original nuclear Latin-American slum area of Manhattan, occupies the greater part of this aerial photograph. Lying roughly between Central Park and the East River north of 99th Street and south of 125th Street in Manhattan, this is the area that received the pioneer Puerto Rican immigrants to New York in the early years of this century. Photograph was made in 1961.

small quantities of food at higher prices. The slum economy turns inward; it shows a high incidence of pawning of personal goods, borrowing at usurious rates of interest, informal credit arrangements among neighbors, use of secondhand clothing and furniture.

There is awareness of middle-class values. People talk about them and even claim some of them as their own. On the whole, however, they do not live by them. They will declare that marriage by law, by the church or by both is the ideal form of marriage, but few will marry. For men who have no steady jobs, no property and no prospect of wealth to pass on to their children, who live in the present without expectations of the future, who want to avoid the expense and legal difficulties involved in marriage and divorce, a free union or consensual marriage makes good sense. The women, for their part, will turn down offers of marriage from men who are likely to be immature, punishing and generally unreliable. They feel that a consensual union gives them some of the freedom and flexibility men have. By not giving the fathers of their children legal status as husbands, the women have a stronger claim on the children. They also maintain exclusive rights to their own property.

Along with disengagement from the larger society, there is a hostility to the basic institutions of what are regarded as the dominant classes. There is hatred of the police, mistrust of government and of those in high positions and a cynicism that extends to the church. The culture of poverty thus holds a certain potential for protest and for entrainment in political movements aimed against the existing order.

With its poor housing and overcrowding, the community of the culture of poverty is high in gregariousness, but it has a minimum of organization beyond the nuclear and extended family. Occasionally slum dwellers come together in temporary informal groupings; neighborhood gangs that cut across slum settlements represent a considerable advance beyond the zero point of the continuum I have in mind. It is the low level of organization that gives the culture of poverty its marginal and anomalous quality in our highly organized society. Most primitive peoples have achieved a higher degree of sociocultural organization than contemporary urban slum dwellers. This is not to say that there may not be a sense of community and *esprit de corps* in a slum neighborhood. In fact, where slums are isolated from their surroundings by enclosing walls or other physical barriers, where rents are low and residence is stable and where the population constitutes a distinct ethnic, racial or language group, the sense of community may approach that of a village. In Mexico City and San Juan such territoriality is engendered by the scarcity of low-cost housing outside of established slum areas. In South Africa it is actively enforced by the *apartheid* that confines rural migrants to prescribed locations.

The family in the culture of poverty does not cherish childhood as a specially prolonged and protected stage in the life cycle. Initiation into sex comes early. With the instability of consensual marriage the family tends to be mother-centered and tied more closely to the mother's extended family. The female head of the house is given to authoritarian rule. In spite of much verbal emphasis on family solidarity, sibling rivalry for the limited supply of goods and maternal affection is intense. There is little privacy.

The individual who grows up in this culture has a strong feeling of fatalism, helplessness, dependence and inferiority. These traits, so often remarked in the current literature as characteristic of the American Negro, I found equally strong in slum dwellers of Mexico City and San Juan, who are not segregated or discriminated against as a distinct ethnic or racial group. Other traits include a high incidence of weak ego structure, orality and confusion of sexual identification, all reflecting maternal deprivation; a strong present-time orientation with relatively little disposition to defer gratification and plan for the future, and a high tolerance for psychological pathology of all kinds. There is widespread belief in male superiority and among the men a strong preoccupation with *machismo,* their masculinity.

Provincial and local in outlook, with little sense of history, these people know only their own neighborhood and their own way of life. Usually they do not have the knowledge, the vision or the ideology to see the similarities between their troubles and those of their counterparts elsewhere in the world. They are not class-conscious, although they are sensitive indeed to symbols of status.

The distinction between poverty and the culture of poverty is basic to the model described here. There are numerous examples of poor people whose way of life I would not characterize as belonging to this subculture. Many primitive and preliterate peoples that have been studied by anthropologists suffer dire poverty attributable to low technology or thin resources or both. Yet even the simplest of these peoples have a high degree of social organization and a relatively integrated, satisfying and self-sufficient culture.

In India the destitute lower-caste peoples—such as the Chamars, the leatherworkers, and the Bhangis, the sweepers—remain integrated in the larger society and have their own panchayat institutions of self-government. Their panchayats and their extended unilateral kinship systems, or clans, cut across village lines, giving them a strong sense of identity and continuity. In my studies of these peoples I found no culture of poverty to go with their poverty.

The Jews of eastern Europe were a poor urban people, often confined to ghettos. Yet they did not have many traits of the culture of poverty. They had a tradition of literacy that placed great value on learning; they formed many voluntary associations and adhered with devotion to the central community organization around the rabbi, and they had a religion that taught them they were the chosen people.

I would cite also a fourth, somewhat speculative example of poverty dissociated from the culture of poverty. On the basis of limited direct observation in one country—Cuba—and from indirect evidence, I am inclined to believe the culture of poverty does not exist in socialist countries. In 1947 I undertook a study of a slum in Havana. Recently I had an opportunity to revisit the same slum and some of the same families. The physical aspect of the place had changed little, except for a beautiful new nursery school. The people were as poor as before, but I was impressed to find much less of the feelings of despair and apathy, so symptomatic of the culture of poverty in the urban slums of the U.S. The slum was now highly organized, with block committees, educational committees, party committees. The people had found a new sense of power and importance in a doctrine that glorified the lower class as the hope of humanity, and they were armed. I was told by one Cuban official that the Castro government had practically eliminated delinquency by giving arms to the delinquents!

Evidently the Castro regime—revising Marx and Engels—did not write off the so-called *lumpenproletariat* as an inherently reactionary and antirevolutionary

PUERTO RICAN BOYS in a Manhattan upper East Side neighborhood use the fenced-off yard of a deserted school as an impromptu playground. The culture of poverty does not cherish childhood as a protected and especially prolonged part of the life cycle. Sexual maturity is early, the male is accepted as a superior and men are strongly preoccupied with *machismo*, or masculinity.

force but rather found in them a revolutionary potential and utilized it. Frantz Fanon, in his book *The Wretched of the Earth,* makes a similar evaluation of their role in the Algerian revolution: "It is within this mass of humanity, this people of the shantytowns, at the core of the *lumpenproletariat,* that the rebellion will find its urban spearhead. For the *lumpenproletariat,* that horde of starving men, uprooted from their tribe and from their clan, constitutes one of the most spontaneous and most radically revolutionary forces of a colonized people."

It is true that I have found little revolutionary spirit or radical ideology among low-income Puerto Ricans. Most of the families I studied were politically conservative, about half of them favoring the Statehood Republican Party, which provides opposition on the right to the Popular Democratic Party that dominates the politics of the commonwealth. It seems to me, therefore, that disposition for protest among people living in the culture of poverty will vary considerably according to the national context and historical circumstances. In contrast to Algeria, the independence movement in Puerto Rico has found little popular support. In Mexico, where the cause of independence carried long ago, there is no longer any such movement to stir the dwellers in the new and old slums of the capital city.

Yet it would seem that any movement—be it religious, pacifist or revolutionary—that organizes and gives hope to the poor and effectively promotes a sense of solidarity with larger groups must effectively destroy the psychological and social core of the culture of poverty. In this connection, I suspect that the civil rights movement among American Negroes has of itself done more to improve their self-image and self-respect than such economic gains as it has won although, without doubt, the two kinds of progress are mutually reinforcing. In the culture of poverty of the American Negro the additional disadvantage of racial discrimination has generated a potential for revolutionary protest and organization that is absent in the slums of San Juan and Mexico City and, for that matter, among the poor whites in the South.

If it is true, as I suspect, that the culture of poverty flourishes and is endemic to the free-enterprise, pre-welfare-state stage of capitalism, then it is also endemic in colonial societies. The most likely candidates for the culture of poverty would be the people who come from the lower strata of a rapidly changing society and who are already partially alienated from it. Accordingly the subculture is likely to be found where imperial conquest has smashed the native social and economic structure and held the natives, perhaps for generations, in servile status, or where feudalism is yielding to capitalism in the later evolution of a colonial economy. Landless rural workers who migrate to the cities, as in Latin America, can be expected to fall into this way of life more readily than migrants from stable peasant villages with a well-organized traditional culture, as in India. It remains to be seen, however, whether the culture of poverty has not already begun to develop in the slums of Bombay and Calcutta. Compared with Latin America also, the strong corporate nature of many African tribal societies may tend to inhibit or delay the formation of a full-blown culture of poverty in the new towns and cities of that continent. In South Africa the institutionalization of repression and discrimination under *apartheid* may also have begun to promote an immunizing sense of identity and group consciousness among the African Negroes.

One must therefore keep the dynamic aspects of human institutions forward in observing and assessing the evidence for the presence, the waxing or the waning of this subculture. Measured on the dimension of relationship to the larger society, some slum dwellers may have a warmer identification with their national tradition even though they suffer deeper poverty than members of a similar community in another country. In Mexico City a high percentage of our respondents, including those with little or no formal schooling, knew of Cuauhtémoc,

MOTHER AND DAUGHTER stand together by the door of a run-down apartment building on upper Park Avenue. Because common-law marriage offers the female participant in the culture of poverty more protection of her property rights and surer custody of her children than formal marriage does, the mother is usually the head of the household and family ties are to her kin and not the father's.

Hidalgo, Father Morelos, Juárez, Díaz, Zapata, Carranza and Cárdenas. In San Juan the names of Rámon Power, José de Diego, Baldorioty de Castro, Rámon Betances, Nemesio Canales, Lloréns Torres rang no bell; a few could tell about the late Albizu Campos. For the lower-income Puerto Rican, however, history begins with Muñoz Rivera and ends with his son Muñoz Marín.

The national context can make a big difference in the play of the crucial traits of fatalism and hopelessness. Given the advanced technology, the high level of literacy, the all-pervasive reach of the media of mass communications and the relatively high aspirations of all sectors of the population, even the poorest and most marginal communities of the U.S. must aspire to a larger future than the slum dwellers of Ecuador and Peru, where the actual possibilities are more limited and where an authoritarian social order persists in city and country. Among the 50 million U.S. citizens now more or less officially certified as poor, I would guess that about 20 percent live in a culture of poverty. The largest numbers in this group are made up of Negroes, Puerto Ricans, Mexicans, American Indians and Southern poor whites. In these figures there is some reassurance for those concerned, because it is much more difficult to undo the culture of poverty than to cure poverty itself.

Middle-class people—this would certainly include most social scientists—tend to concentrate on the negative aspects of the culture of poverty. They attach a minus sign to such traits as present-time orientation and readiness to indulge impulses. I do not intend to idealize or romanticize the culture of poverty—"it is easier to praise poverty than to live in it." Yet the positive aspects of these traits must not be overlooked. Living in the present may develop a capacity for spontaneity, for the enjoyment of the sensual, which is often blunted in the middle-class, future-oriented man. Indeed, I am often struck by the analogies that can be drawn between the mores of the very rich—of the "jet set" and "café society"—and the culture of the very poor. Yet it is, on the whole, a comparatively superficial culture. There is in it much pathos, suffering and emptiness. It does not provide much support or satisfaction; its pervading mistrust magnifies individual helplessness and isolation. Indeed, poverty of culture is one of the crucial traits of the culture of poverty.

The concept of the culture of poverty provides a generalization that may help to unify and explain a number of phenomena hitherto viewed as peculiar to certain racial, national or regional groups. Problems we think of as being distinctively our own or distinctively Negro (or as typifying any other ethnic group) prove to be endemic in countries where there are no segregated ethnic minority groups. If it follows that the elimination of physical poverty may not by itself eliminate the culture of poverty, then an understanding of the subculture may contribute to the design of measures specific to that purpose.

What is the future of the culture of poverty? In considering this question one must distinguish between those countries in which it represents a relatively small segment of the population and those in which it constitutes a large one. In the U.S. the major solution proposed by social workers dealing with the "hard core" poor has been slowly to raise their level of living and incorporate them in the middle class. Wherever possible psychiatric treatment is prescribed.

In underdeveloped countries where great masses of people live in the culture of poverty, such a social-work solution does not seem feasible. The local psychiatrists have all they can do to care for their own growing middle class. In those countries the people with a culture of poverty may seek a more revolutionary solution. By creating basic structural changes in society, by redistributing wealth, by organizing the poor and giving them a sense of belonging, of power and of leadership, revolutions frequently succeed in abolishing some of the basic characteristics of the culture of poverty even when they do not succeed in curing poverty itself.

Corals as Paleontological Clocks

Banding on certain corals evidently represents annual, monthly and daily growth. Ancient corals thus provide clues to the length of the year in past eras and to changes in the earth's rotation

by S. K. Runcorn

The astronomers, geophysicists and other investigators whose concern is the origin and evolution of the earth are handicapped by a shortage of evidence. The events of interest to these workers occurred in times so distant that even geological records are seldom available. As a result the theories that have been advanced about such matters as the origin of the continents are largely conjectural. Moreover, as might be expected in the circumstances, the theories differ considerably and therefore are highly controversial.

An example of the kind of information that would help to overcome the handicap is a reliable measurement of the length of the day, that is, the speed of the earth's rotation on its axis. It is clear that the length of the day has increased slowly throughout geologic time; the earth's rotation has been slowed by the friction of the tides and may also have been changed slightly by internal processes. Hence the number of days in the year has decreased. Calculations on the basis of tidal friction alone indicate that the year had about 428 days at the beginning of the Cambrian period some 570 million years ago and about 400 days in the middle of the Devonian period some 370 million years ago [*see illustration on page 30*]. If a "clock" could be found that had recorded the days of ancient geological periods, it would be possible to arrive at a more precise measurement of the number of days in the year and so to obtain evidence about the earth's rotation and the factors affecting it.

Such a fossil clock may be at hand in certain corals. These organisms have long been known to have distinct bands that represent annual growth. The bands are themselves made up of narrower bands that seem to represent monthly growth and are probably related to the tides and the monthly cycle of the moon. The intriguing possibility now under investigation is that the still finer ridges or bands found in some of the corals represent daily growth. If this is the case, a coral that could be accurately assigned to a particular geological period (by radioactive dating or the evidence of stratigraphy) would provide a measurement of the number of days in the year at that time. Corals thus hold the promise of being a powerful geophysical tool.

The corals that are of interest in this connection are those broadly known as stony because their skeleton consists of hard calcium carbonate. The portion of the coral on which the investigation focuses is the epitheca, which is the external layer on the lower part of the conical skeleton [*see illustration on page 28*]. Geologically the corals under study fall into three groups. Two are from the Paleozoic era and are known as rugose (wrinkled) and tabulate (having tabulae, or horizontal partitions). The third, which is a successor of the others, has existed from Mesozoic time to the present; it is called scleractinian, a name from the Greek word meaning "hard."

Whenever the epitheca is present, it shows fine banding, provided that the surface has not been abraded by wear or accident. There are between 20 and 60 bands per millimeter. Numerous observers have noted these bands and have regarded them as growth increments representing the periodic deposition of calcium carbonate by the coral. The first to suggest that the bands were daily growth increments was John W. Wells of Cornell University.

Wells reported in 1963 that his count of the fine bands within the annual bands in several corals dating from the middle of the Devonian period ranged between 385 and 410 and averaged nearly 400. The average agreed closely with the number of days in the Devonian year as obtained from calculations of the effect of tidal friction. Similarly, the average of 380 bands obtained by Wells with corals from the more recent Carboniferous period showed a close correlation with the number of days in the year as calculated for that time. Wells also reported that he had counted bands on some contemporary corals, for which the annual rate of growth is fairly well known, and had found that "the number of ridges on the epitheca of the living West Indian scleractinian *Manicina areolata* hovers around 360 in the space of a year's growth."

Wells's suggestion that the ridges making up the fine banding represent daily growth gains support from some work with modern corals by Thomas F. Goreau of the University of the West Indies. Goreau showed that in these living corals the secretion of calcium carbonate varies between night and day. Curiously there has been little other work on the growth of corals. It is a field waiting to be explored.

Soon after Wells put forward his suggestion about daily growth, Colin T. Scrutton of the British Museum (Natural History) made the equally important suggestion that some corals have monthly bands. He reported that he had found what appeared to be such bands on some Middle Devonian corals from North America. Counting the number of fine bands in these larger groupings, Scrutton obtained an average of 30.6. That would represent the length of the Devonian month if the closely spaced

FOSSIL CORAL found in central New York by John W. Wells of Cornell University dates from the Middle Devonian period some 370 million years ago. The region in which the coral was found was then shallow ocean. The prominent bands visible on this coral, which is still in the matrix of other material in which it was found, represent annual growth. On closer view, such as that in the illustration below, closely spaced ridges or bands can be seen. Each such ridge is believed to represent one day of growth.

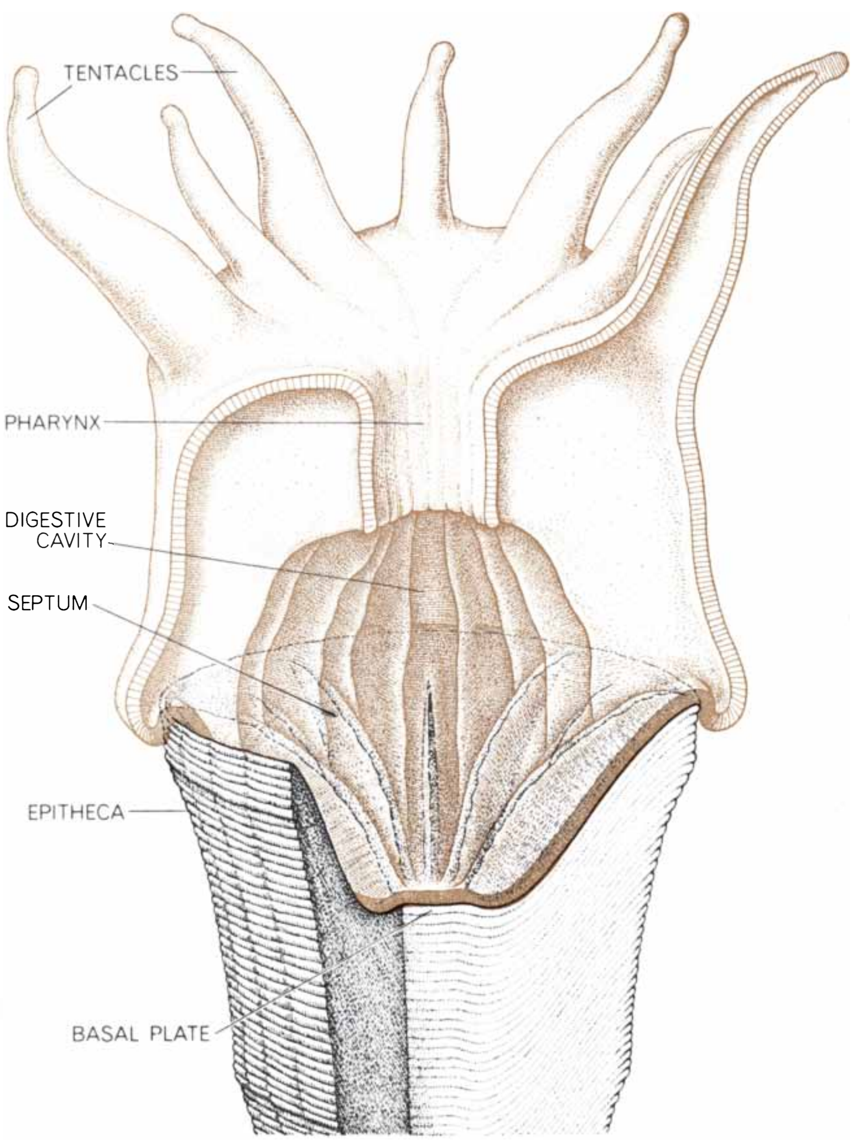
ANCIENT CORAL shows the closely spaced horizontal ridges that are thought to represent daily depositions of calcium carbonate by the organism when it was alive. This specimen of *Eridophyllum archiaci* was found by Wells in central New York; it is of Middle Devonian age. Band counts on several Devonian corals gave 400 days as length of Devonian year; other methods give same figure.

bands were indeed indicative of daily growth. Dividing 30.6 into 399 (the number of days in the Devonian year according to computations of the effect of tidal friction), Scrutton obtained 13.04 as the evident number of lunar months in the year of Devonian time.

The lunar month is known to influence marine life, but the ways in which it does so are still poorly understood. There are nonetheless a few clues. For example, zooplankton rise closer to the surface of the ocean on dark nights than on moonlit nights. The lunar month that Scrutton found—the one that influences marine life—is called the synodical month: the interval between successive new moons. It is roughly two days longer than the sidereal month, in which the moon returns to the same position among the stars.

A variety of difficulties confront the investigator who hopes to use corals as paleontological clocks. For one thing, it is no easy matter to count the number of "daily" ridges in a "monthly" or "annual" band. The bands vary in distinctness, and it is often difficult to see where one band ends and another begins.

Furthermore, at present a worker in this field knows approximately how many days he should find in the Devonian month or year (or the month or year of other geological periods), and so the likelihood that this knowledge will subconsciously influence his count of bands is considerable. To meet this difficulty my colleagues and I at the University of Newcastle upon Tyne have been experimenting with a method that removes the personal factor by automating the process of counting the ridges in the bands. The technique resembles one used in X-ray crystallography. The epitheca and its hierarchy of growth bands are photographed; the negative is used as a diffraction grating to obtain spectra of the band frequencies. My colleague K. M. Creer at the university is attempting to count the bands with an analyzer that detects slight chemical variations between one band and the next.



LIVING CORAL shows the relation of the epitheca, which is the outer portion of the coral's hard skeleton, to the growing organism. The living part of the coral is in color. The growth of the skeleton apparently occurs through daily depositions of calcium carbonate by the organism; the process produces bands on the epitheca at a spacing of 20 to 60 per millimeter.

Another major problem is the lack of certainty that the corals preserved in the geological record responded to the same environmental forces that modern corals do. Fortunately at this point the geophysicist can help to test the self-consistency of the numbers obtained by Wells and Scrutton. First Scrutton's number must be changed to the number of days in the sidereal month, so that both the Wells and the Scrutton numbers will be expressed in sidereal terms. The change gives a value of 28.4 days for the length of the sidereal month in Middle Devonian time.

Now, the laws of planetary motion or gravitational theory can be applied to the earth-moon system. By applying Kepler's first and second laws a formula can be derived giving the orbital angular momentum of the moon at any time in the past in terms of its present value. The formula, which makes use of the Wells and Scrutton numbers, shows that if the present orbital angular momentum of the moon is assigned a value of 101.6, the value in Devonian time was 100.

The tides cause the earth to lose angular momentum. Under the laws of planetary motion a loss of angular momentum by the earth can only be transferred to the orbital angular momentum of the moon. The formula using the Wells and Scrutton numbers indeed shows that the moon has picked up 1.6 percent of its orbital angular momentum since Middle Devonian time.

The formula is remarkably interesting because it relates an astronomical quantity—the orbital angular momentum of the moon—to a ratio of counts on corals as reflected in the Wells and Scrutton numbers. Moreover, by means of the ratio obtained from the formula it is possible to calculate the rate of loss of angular momentum by the earth due to the tides. The figure obtained (3.9×10^{23} dyne per centimeter) is exactly in agreement with the figure obtained for the rate by modern astronomical calculations based on measurements of the longitude of the sun and moon over the past three centuries. This agreement between the geophysical and the astronomical calculations could be a lucky accident. That it is unlikely to be, however, is shown by the following argument.

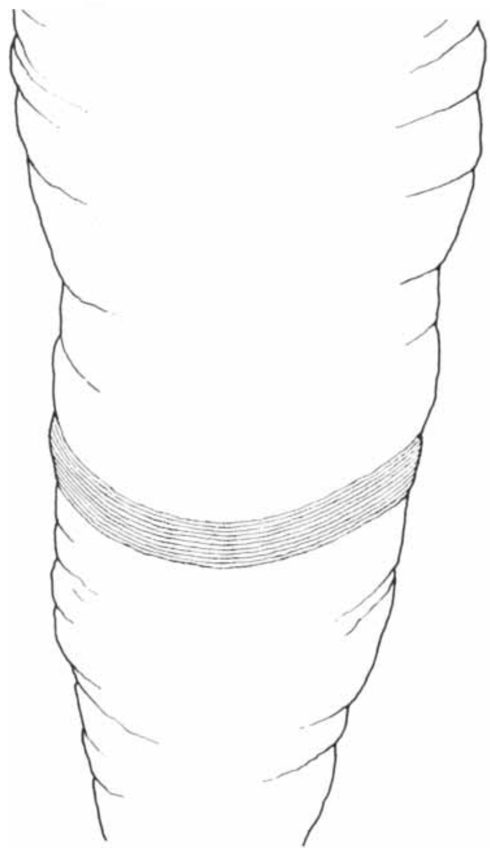
Kepler's laws state that as the moon's angular momentum increases, the month lengthens and the moon moves farther away from the earth. The only factor other than tidal friction that could be affecting the number of days in the month (by changing the length of the day) is the earth's moment of inertia, a figure summing up the relations between the shape and size of the earth and the distribution of its internal substance. The earth's moment of inertia could have been altered by expansion or contraction of the earth or by changes in the distribution of mass in its core. Any such change would affect the length of the day. If the moment of inertia of the earth does not change, there will be a fixed relation between the month and the day.

Since the figure obtained by Wells measures the length of the day and that obtained by Scrutton the number of days in the month, we can test if the earth's moment of inertia has changed. Using the paleontologist's counts of the bands on corals, one finds that the moment of inertia in Devonian time was very close to the modern value—it was less by about .5 percent. Thus it is evident that tidal friction has been the principal factor affecting the earth's rotation.

Although one should not assume a priori that the magnitude of the tidal slowing down remains the same over long periods, the double agreement between the geophysical and the astronomical findings about the effect of tidal friction strongly suggests that Wells and Scrutton were correct in identifying the coral bands with the day, the month and the year. The counts made by Wells and Scrutton were quite independent, and both men were unaware of the calculations I have put forward about the comparative effects of tidal friction and the moment of inertia on the earth's rotation. Had the bands on the corals been caused by environmental forces other than the day and the lunar month, it would be quite difficult to imagine that such closely comparable findings would result from the counts.

Concluding, therefore, that certain corals are clocks of extraordinary value, it is pertinent to inquire what kind of geophysical questions the study of corals might answer. The questions fall into two broad categories. One concerns the evolution of the earth, the other the evolution of the moon.

It was once taken for granted that the earth originated as a molten object and has gradually cooled. Mountains were thought to have formed through the consequent contraction of its interior, just as the skin of an old apple wrinkles. The heat of the interior, which is revealed by volcanoes and by the rise in temperature as one penetrates the crust in mines and boreholes, was held to be original heat that had not been able to escape because of the earth's size. From the fundamental principle of the conservation of angular momentum an interesting consequence follows. Just as



FINE GROWTH BANDS can be seen in this enlarged view of a specimen of *Holophragma calceoloides*, which dates from Middle Silurian time. The actual specimen is less than an inch long; the enlargement therefore indicates how difficult the counting of "daily" bands can be. At right a segment of 11 such bands is reproduced to show their configuration and the regularity of their spacing.

a ballet dancer spins faster as she draws in her arms, so the length of the day will shorten as the earth contracts and its mass moves toward its axis.

Since the discovery that rocks likely to be those making up the earth's interior contain radioactive elements, it has been possible to assume that the earth's heat has been generated by radioactive decay and that the earth was originally cold. Such a theory supposes that the earth originated in the accumulation of small solid fragments. This theory fits in with modern ideas on the origin of the solar system, which is thought to have started as a diffuse cloud of gas and dust that was flattened by rotation into a disk, in which the planets grew by accretion.

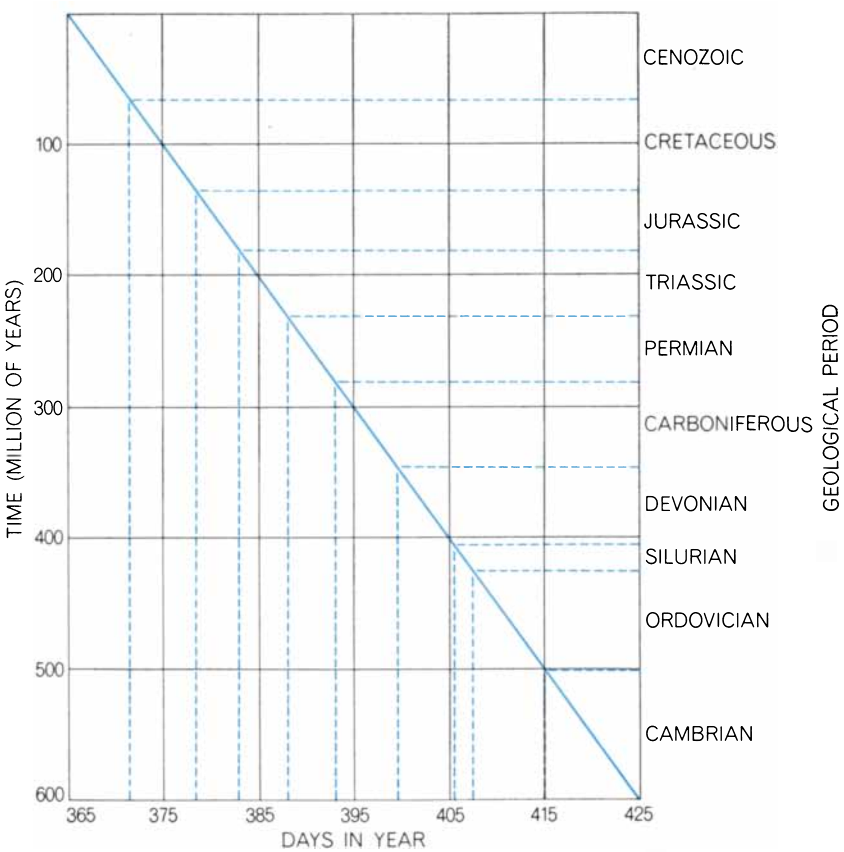
The earth now has an iron core with a radius about half that of the entire earth. Harold C. Urey of the University of California at San Diego has suggested that when the iron was cold, it was uniformly distributed throughout the earth; it has only slowly sunk to the center. Such an evolution would cause the day to shorten gradually, but by a much larger amount than on the basis that the earth began hot and has cooled.

R. A. Lyttleton of the University of Cambridge has recently revived a theory, originally put forward by W. H. Ramsey of the University of the Witwatersrand, that the earth's core is not iron but rock that is in a metallic phase because of the extremely high pressures inside the earth. Lyttleton supposes this phase change is less likely to occur at low temperatures than at high ones. Assuming that the earth was originally cold, he postulates that it then had no core. The decay of disseminated radioactive elements provided energy to heat the earth, and at the center conditions eventually became right for the change of a part of the silicate rock to a denser phase, which therefore occupied a smaller volume. As the temperature continues to rise in the interior of the earth, the core grows and the earth contracts more. Lyttleton believes this theory overcomes the shortcomings of the older theories in providing for more contraction of the earth's shell.

In contrast to these theories postulating a gradually shortening day, certain other theories assume that the earth has expanded and that the day has grown longer. An earth that has heated up will have expanded. The long ridges that run down the middle of several of the oceans offer some evidence that the earth has expanded and not contracted. The mid-Atlantic ridge and the Carlsberg ridge in the Indian Ocean have central valleys that are thought to be cracks resulting from a stretching of the crust.

Cosmological ideas have been brought into the discussion. It is conceivable that the universal force of gravity is not a constant but has been decreasing. Such an effect would cause the earth gradually to expand.

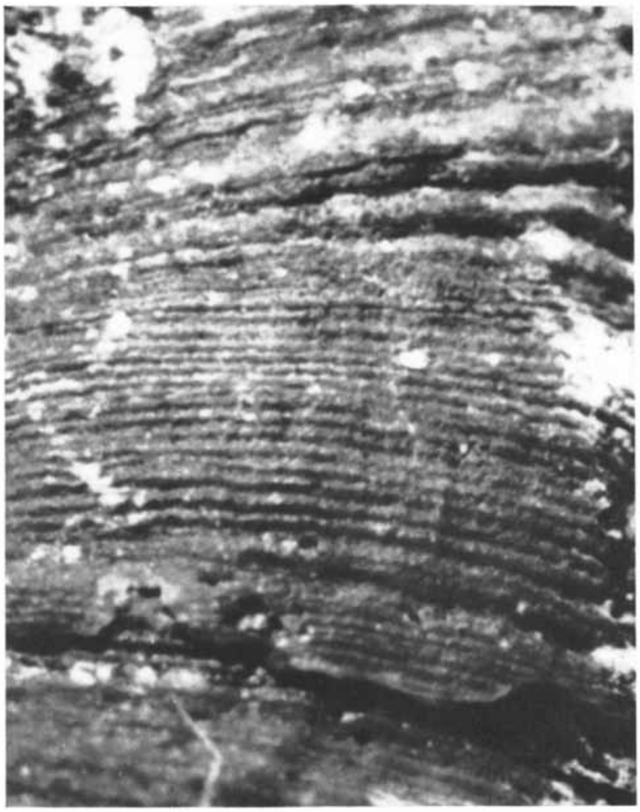
These various theories involve considerable disagreement over the length of the day in distant geological periods. Indeed, stated in terms of the length of the day in Devonian time (after allowance for the slowing of the earth by tidal friction), the theories call for a day ranging from 12 hours to 24 hours 40 minutes. Herein lies the promise of the corals. When many more corals have been studied, it should be possible to determine which of the theories is correct. Even now the boldest of the expanding-earth theories (the theory of Bruce C. Heezen of Columbia University and S. W. Carey of the University of Tasmania, who assume that the Atlantic Ocean is the result of a 40 percent expansion of the radius of the earth since Permian time, pulling apart the continents on each side of the ocean) can be disregarded. The drifting apart of the continents is now a well-established phenomenon, but its cause has been sought in ways other than expansion of the earth. One possible way is that large-scale flows in the mantle pushed the continents apart.



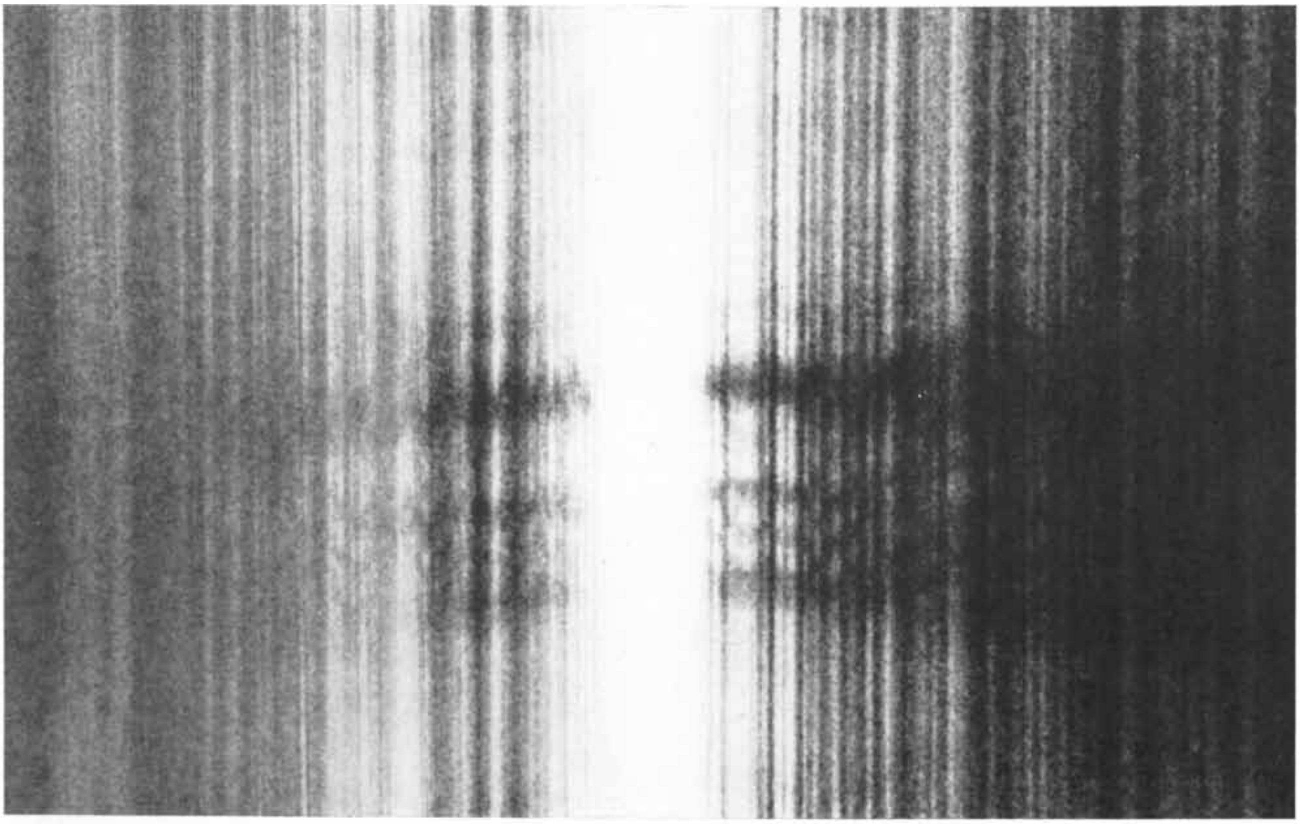
LENGTH OF YEAR in various geological periods is indicated according to computations of the effect of tidal friction, which has gradually slowed the earth's rotation and hence caused days to become longer. Counts of the bands on corals have agreed with these estimates.

An account of the possible relation of corals to the origin of the moon requires some background. The height of the tides raised by the moon on the earth varies inversely as the third power of the earth-moon distance. Accordingly if the earth and moon were closer in some past era than they are now, the tidal friction would have been greater then than it is today. Assuming that the friction of the tides depends only on the earth-moon distance, and knowing the rate at which the earth loses angular momentum to the moon, one can calculate the variation of the earth-moon distance throughout geologic time.

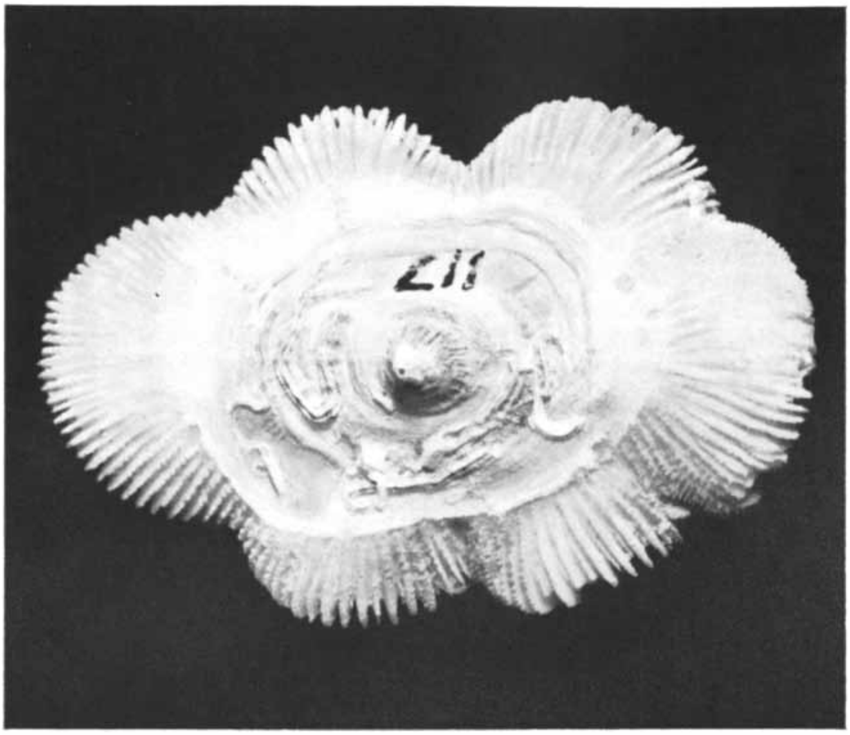
Such a calculation was made recently by Louis B. Slichter of the University of California at Los Angeles. At the



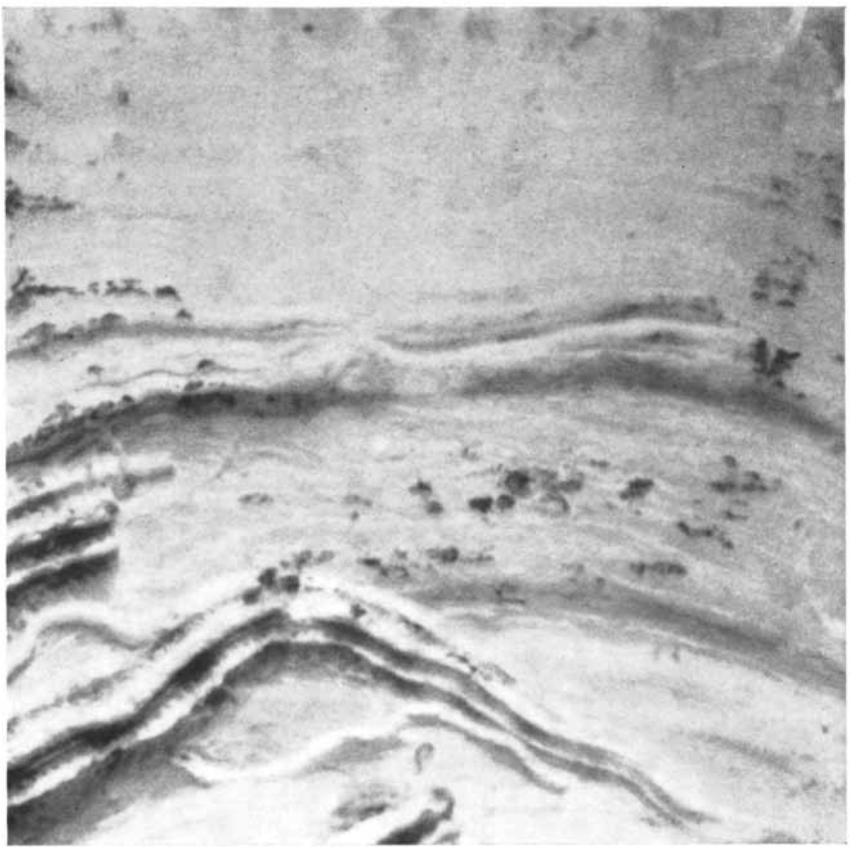
CONSISTENCY OF BANDING appears in closeup of fossil corals that are widely separated in age. The specimen at left dates from the Silurian period some 415 million years ago. At right is a fossil coral dating from the Jurassic period, about 140 million years ago.



DIFFRACTION BANDS were produced by a new technique for counting bands on corals. The technique resembles X-ray crystallography. The epitheca of a coral is photographed and the negative is used as a diffraction grating to obtain spectra indicating the frequency of the bands. Thus the counting of bands is made objective, and subjective factors that could influence the count are avoided.



MODERN CORAL from the Dry Tortugas Islands of Florida is *Manicina areolata*. Its annual growth rate is fairly well known. Wells found that each increment of annual growth contained about 360 "daily" bands. The modern corals thus serve as a check of the hypothesis that the most closely spaced bands on ancient fossil corals represent daily growth.



CLOSE VIEW of the specimen of *M. areolata* shows some of the fine growth bands. They are the faint horizontal lines and not the more prominent ridges, which are extraneous.

time he had only the value of the lunar tidal friction as determined from the astronomical observations of the past 2,000 years. Slichter's result showed that the earth and moon were very close together two billion years ago and were moving apart rapidly. This finding created a major puzzle about their relation before that, since the earth (and presumably the moon) has existed for some 4.5 billion years. The puzzle was not pressing then, however, because one could assume that the value of tidal friction over the past 2,000 years has been higher than normal and thus is untypical of long geological periods. Tidal friction exerts its strongest effects in shallow seas. We know that since the last ice age the melting of the polar ice caps has raised the height of the oceans, flooding many coastal areas and producing more extensive shallow seas. This phenomenon could create an abnormally high tidal friction at the present time.

The evidence from the Devonian corals, however, indicates that tidal friction was substantially the same then as it is now. Presumably, since the average value appears to have been fairly constant over many millions of years, one can use that value to extrapolate the earth-moon distance backward in time. With the loss of the varying-friction argument as an explanation of Slichter's finding, however, it becomes necessary to deal with that finding in some other manner.

If, as Slichter says, the earth and moon were close to each other two billion years ago and have separated since, where was the moon before that—in the first two to three billion years of the earth's existence? Three highly speculative answers have been given to the question. One is that the moon is a part of the earth that broke away from the region of what is now the Pacific Ocean. This idea was first put forward late in the 19th century by the British astronomer Sir George Darwin. He supposed the similarity between the density of the moon and that of the earth's mantle, together with the absence of continents in the Pacific hemisphere, might be explained by some instability of the primeval earth that increased to such an extent that the earth broke into two bodies.

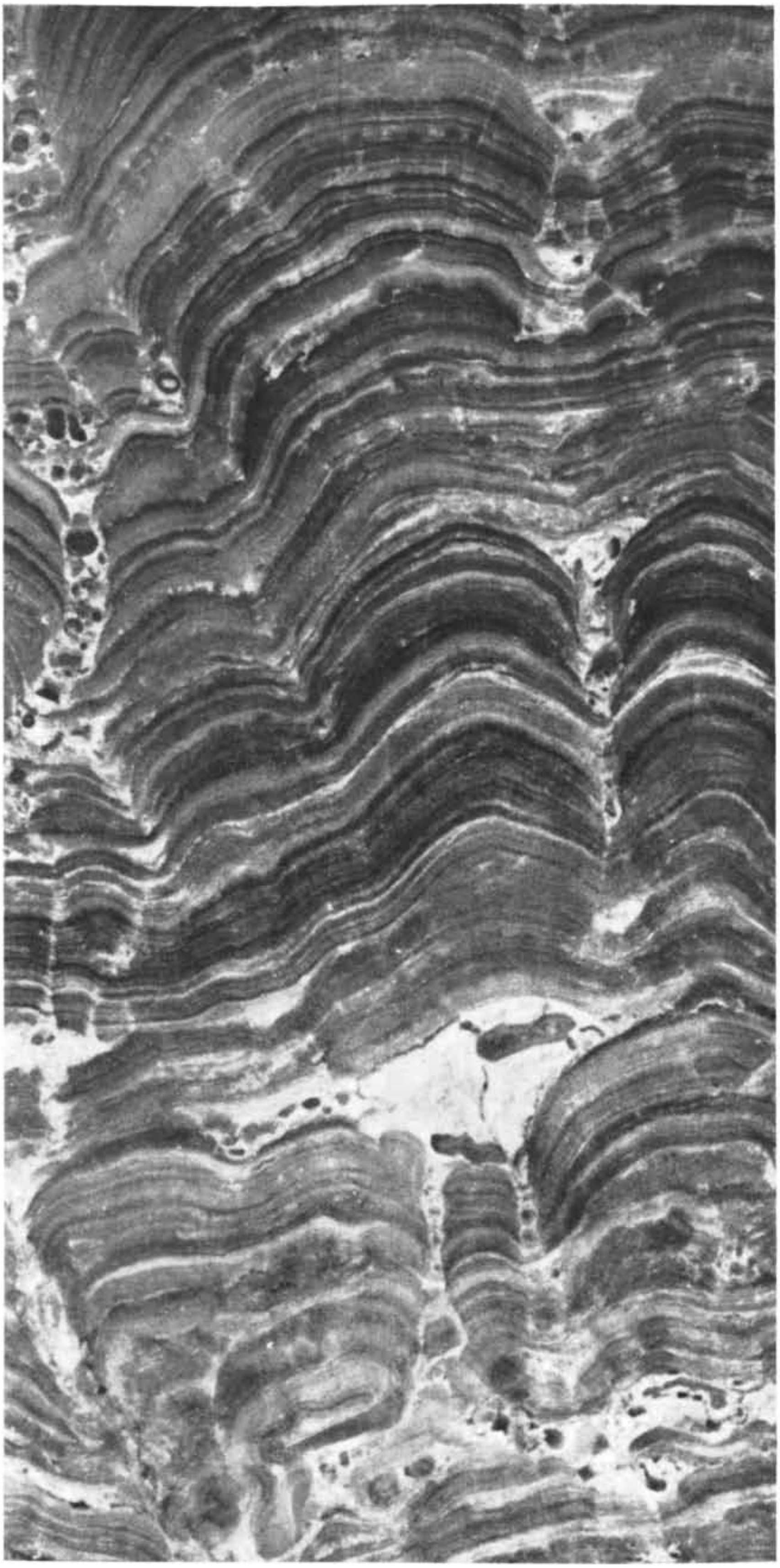
Another theory is that in the first half of the earth's existence the moon was moving around the earth in a retrograde orbit, that is, in a sense opposite to its present motion. In such a situation the effect of tidal friction would be to pull the moon inward rather than drive it outward. This idea supposes the moon was drawn in from a large distance, having previously been a stray body that happened to be captured by the earth's gravitational field; finally it came into orbit very close to the earth. In time, because of asymmetries in tidal friction, the direction of the moon's orbit was reversed; hence some two billion years ago the tidal friction began to drive the moon away from the earth.

Both theories assume that the moon was quite close to the earth about two billion years ago. In both cases it is hard to see how the geological record prior to such an event could have been preserved because of the huge tides that would have swept over the earth at the time of the close approach of the moon. Yet it is possible to find rocks of about the same age as this supposed catastrophic event; these rocks still show signs of processes of formation that are similar to those that formed corresponding rocks in recent times. It is therefore difficult to conceive that the earth and moon could have been close together two billion years ago.

A third theory, which would get around the difficulty presented by the Slichter calculations, is that the moon was formed in the vicinity of the earth by an accretion process, in which a small body sweeps up debris in its path. It is difficult to decide whether or not the mechanics of such a process are feasible. If they are, and the process took a long time, it could have produced a moon that would not have begun to raise appreciable tides on the earth until perhaps two billion years ago or later.

It seems clear that more observations on corals of different geological ages will make it possible to determine the length of the day and month throughout the geological past. Those data in turn will yield important information on the early history of the earth-moon system and may, in resolving the puzzle I have been describing, provide an important clue to the origin of the moon.

Corals may not be alone in this field. There are certain fossil algae, going back in age some 600 million years, that have layers similar to those in the corals. The layers may be the result of daily, monthly and annual variations of tides, temperature and sunlight. If these and other marine organisms have recorded time in the same way as the corals, we shall indeed have factual information on the early history of the earth.



FOSSIL ALGAE may possibly be used as paleontological clocks. This stromatolite, or laminated algal structure, has been etched to bring out layering that might have been formed by daily growth. It is enlarged five diameters. Specimen grew about one billion years ago on an intertidal mud flat of the Precambrian Belt Sea in what is now northwestern Montana.

THE ELECTRIC AUTOMOBILE

Air pollution and other drawbacks inherent in the internal-combustion engine make this early kind of car seem increasingly attractive. All depends on the improvement of batteries, and here there are advances

by George A. Hoffman

At the beginning of this century there were more electric automobiles than internal-combustion cars on the roads of the U.S. By the late 1920's the electric car had all but disappeared. The silent, stately vehicle could not compete with its noisy, gas-spewing rival in power, speed, range or convenience, and it retired gracefully to museums and the barns of classic-car enthusiasts. Today it appears that before the century is out the electric automobile may come back to supersede the gasoline-powered car.

Some engineers have never lost faith in the electric car, and the basic arguments for its revival are cogent and becoming stronger year by year. Chief among these is the increasingly dangerous pollution of our air by the millions of gasoline-burning vehicles invading our cities and countryside. We also face the inescapable fact that the supply of cheap gasoline will not last many decades longer at the present rate of consumption of fossil fuels. And while the cost of gasoline is rising, electricity is becoming more plentiful and cheaper. Only technical problems have stood in the way of producing an electric car that could replace the internal-combustion one. Solutions for these problems are now definitely in sight. The experimental development of improved motors and lightweight batteries of new kinds has brought the electric automobile within the range of feasibility.

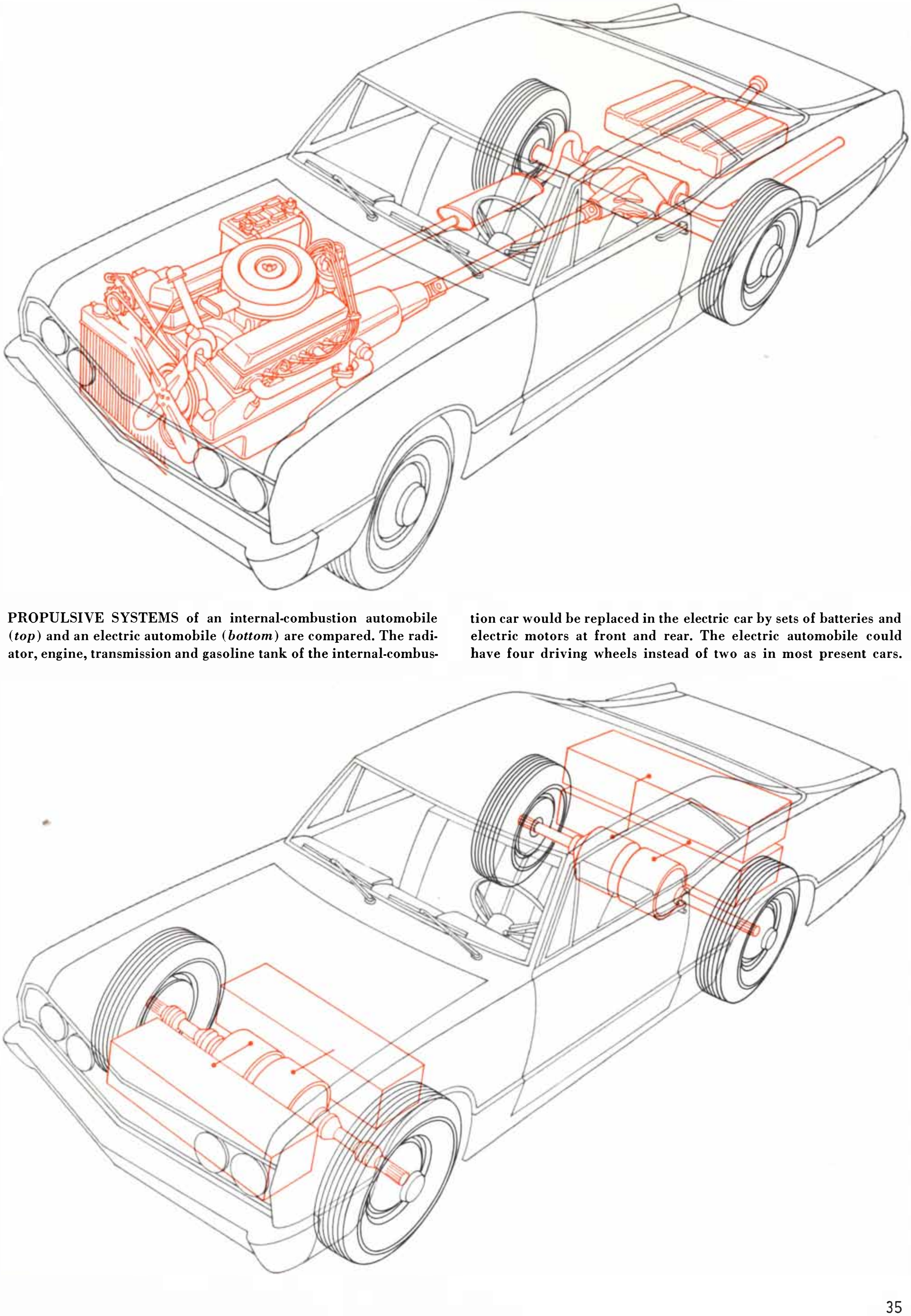
The design of such a car must be based in the first instance on the realization that the American public is highly resistant to radical change in its automobiles. The electric car will therefore have to conform as closely as possible (at least at first) to the pattern now popular in gasoline-powered cars—in style, size, performance, handling, comfort, variety of models offered and other features.

Let us begin by analyzing the weight requirements, since these determine the vehicle's size, passenger conveniences, riding qualities and the amount of propulsive power required. In the passenger cars of today, ranging in weight from 1,500 pounds (the small European car) to more than 5,000 pounds (the large American car), each major component bears a consistent ratio to the total weight of the automobile. The weight of the engine and transmission generally is roughly a fifth of the total weight, and that of the body (the shell, including glass and trim) is about half of the overall weight. The rest of the car's weight is accounted for by the suspension, wheels, tires, steering apparatus, battery and so on. The weight proportions of the main components of the automobile are the result of almost a century of development of cars in response to consumer preferences, and since they reflect consumer acceptance of seating and space provisions, comfort and riding qualities, we should adhere to these proportions as well as we can in designing an electric automobile.

The batteries and motors of an electric car will weigh considerably more than the engine and transmission of a gasoline-powered automobile. We can compensate for this, however, by dispensing with the weighty items in present cars that are not required in a vehicle employing electric traction [*see illustration on page 36*]. An electric car will need no transmission tunnel or hump in the middle of the floor; it will not require all the insulation now needed to shield the car's interior from the noise, heat and fumes of the engine; it will dispense with the radiator and grill; it will get rid of the fuel tank, fuel pump and plumbing, including the exhaust pipes and mufflers; it will have fewer instruments and a simpler dashboard; because it will have a lower center of gravity and equal distribution of weight on the front and rear wheels, it will save weight in the front suspension and in the steering mechanism. All together these savings will enable us to allot half of the car's weight to the batteries and motors without increasing the present total weight of the automobile.

We can now consider the power requirements. For the performance of electric automobiles the main consideration is the acceleration capability at moderate speeds (up to 30 miles per hour), because most automobile driving is and will remain in urban and suburban traffic. At such speeds no existing engine can deliver more than a fraction of its maximum advertised horsepower; in accelerating through 15 miles per hour, for example, the horsepower available at the wheels is only about a third to half of the maximum. It can be calculated that with the electric traction motors now available an electric car with the same horsepower as that which can be delivered by a gasoline-powered one at moderate speeds would give better than average performance up to 15 miles per hour, would equal the average in accelerating from zero to 30 miles per hour and would be only slightly below average in accelerating from zero to 60 miles per hour.

At low and moderate road speeds the performance of electric traction motors (driven at constant power) in applying torque to the axle and wheels parallels quite satisfactorily the per-



PROPULSIVE SYSTEMS of an internal-combustion automobile (*top*) and an electric automobile (*bottom*) are compared. The radiator, engine, transmission and gasoline tank of the internal-combustion car would be replaced in the electric car by sets of batteries and electric motors at front and rear. The electric automobile could have four driving wheels instead of two as in most present cars.

formance of the internal-combustion engine [*see illustration on opposite page*]. Therefore the electric car would respond to the driver's accelerator-pedal demands in stop-and-go traffic with about the same liveliness as present automobiles. The constant-power control of electric motors would also allow more efficient dissipation of the heat generated by the motors.

What top speed could an electrically driven car attain? Here we must make some calculations of the forces to be overcome in propelling the car: the aerodynamic drag (which increases as the square of the speed), the tire-rolling resistance and various internal frictional dissipative forces. The sum of these resisting forces multiplied by the speed is the required propulsive power. Matching this necessary power against the power that can be delivered by present electric traction motors of practicable weight, we can compute that an electrically driven car of the compact category could attain a top speed of about 90 miles per hour on level ground; a larger car could achieve 100 miles per hour. These calculations are essentially confirmed by an unpublicized experiment one of the major automobile manufacturers conducted two years ago. The company engineers took a compact model off its production line, replaced its gasoline engine with an electric motor of sufficient horsepower to match its previous performance, installed the lightest batteries available at the time and tested the hybrid vehicle on the proving grounds. The car was clocked at a top speed of more than 80 miles per hour on a straightaway. A performance of 100, 90 or even the 80 miles per hour achieved in this restricted test should surely be more than adequate for today's highways and traffic or for the conditions in the near future.

Electric motors obviously offer many operating advantages over the internal-combustion engine. There are versions of the electric motor now that operate without the use of brushes, so that there are fewer wearing parts and the motor would need almost no maintenance during the automobile's lifetime. Electric motors could be used in various arrays: a single sizable motor for the entire vehicle (placed at the front for front-wheel drive); two motors, one driving the front wheels and the other the rear wheels, or four smaller motors, one at each of the wheels. In the last case each motor might either be attached to the frame and drive the wheel through an axle with two universal joints or be placed within the rim of the wheel itself and drive it through planetary gears. The first of these two alternatives seems preferable, because the placement of the motor inside the wheel might result in a harsh ride owing to the increased weight of the wheel and would expose the tire to heat from the motor.

With direct connection of the motors to the wheels, the motors could be used for electrical dynamic braking, replacing the present mechanical system of frictional braking. The driver could apply the brakes with extremely light pres-

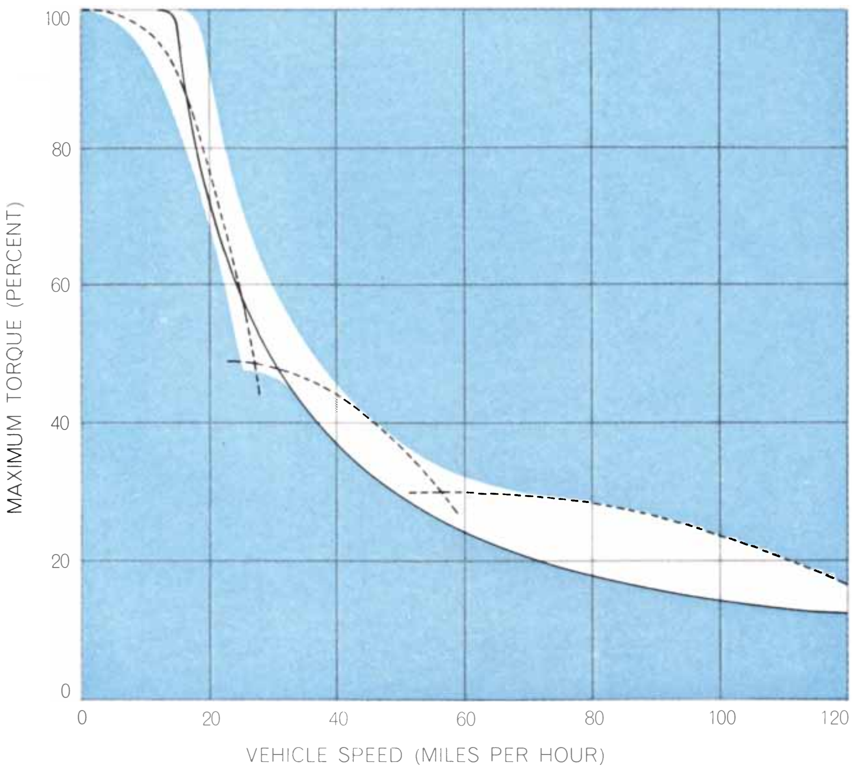
COMPONENT	PRELIMINARY WEIGHT RATIO (PERCENT)	CHANGES IN WEIGHT	WEIGHT REDUCTION	FINAL WEIGHT RATIO (PERCENT)
BODY	25	THICKNESS REDUCTIONS IN FRAME AND CHASSIS FROM REDISTRIBUTION OF CONCENTRATED WEIGHTS. ELIMINATION OF MID-FLOOR TRANSMISSION HUMP AND DRIVE-LINE TUNNEL.	1/6	21
TRIM	13	REDUCTION OF ACOUSTICAL AND THERMAL INSULATION. SIMPLIFICATION OF DASHBOARD FURNISHINGS AND INSTRUMENTS. ELIMINATION OF AIR-INTAKE GRILLWORK.	1/8	11.5
GLASS	3.5	NO ALTERATIONS.	0	3.5
FRONT SUSPENSION	3	EQUAL FRONT-REAR WEIGHT DISTRIBUTION. LOW CENTER-OF-GRAVITY BATTERY PACK CLUSTERED NEAR SPRING-BODY JUNCTION POINTS.	1/6	2.5
REAR SUSPENSION	2.5	EQUAL FRONT-REAR WEIGHT DISTRIBUTION. LOW CENTER-OF-GRAVITY BATTERY PACK CLUSTERED NEAR SPRING-BODY JUNCTION POINTS.	0	2.5
WHEELS	2.3	NO CHANGE.	0	2.3
TIRES	2.5	NO CHANGE.	0	2.5
STEERING	1.3	LIGHTER STEERING MECHANISM FROM LOW CENTER OF GRAVITY, EQUAL FRONT AND REAR WEIGHT, FOUR-WHEEL TRACTION.	1/10	1.2
ELECTRIC MOTORS	—		—	X
ENERGY STORAGE	—		—	Y

WEIGHT COMPOSITION of an internal-combustion automobile and an electric automobile would differ. The final ratios (*right*) total 47 percent plus X plus Y; X would be about 4 percent, so that 49 percent of the electric automobile's weight could be in batteries.

sure on the pedal, and they would act uniformly on all four wheels. Furthermore, some of the energy generated by the deceleration of the car might be recovered for charging the batteries.

The total weight of the electric motors would of course be considerably less than the weight of the present automotive engine and transmission. The internal-combustion power plant provides about a fiftieth of one horsepower (at low speed) for each pound of the car's total weight. Electric traction motors now being designed weigh only two pounds or less per horsepower. From these figures it can be calculated that to equal the power performance of the gasoline engine the electric motors for an automobile would need to have a combined weight of about 4 percent (2 × 1/50, or 1/25) of the total weight of the vehicle. This enables us to use most of the weight allowance we have allotted to the propulsion system (about 50 percent of the vehicle's weight) for the batteries.

The battery problem is the principal obstacle that has discouraged serious consideration of the electric automobile all these years. The batteries for propulsion determine the range of the vehicle—how far it can travel between recharges or refuelings—and therefore everything depends on how densely energy can be packed into them. The conventional lead-acid storage battery that is used to energize an automobile's electrical system (and to drive golf carts) is ruled out as a power source for driving an automobile because of its low capacity, or "energy density." It stores at most 10 watt-hours of electricity per pound of battery; consequently a battery of this type, built within the permitted weight allowance, would give an automobile a range of less than 40 miles under the most favorable driving conditions and less than 20 miles in city traffic. Better range can be obtained from the nickel-cadmium type of battery (used in cordless appliances and tools), but it is more expensive and still would allow a range of no more than 70 miles (or half that distance in stop-and-go traffic). Even the very costly silver-zinc batteries developed for the electrical systems of space vehicles are good for 30 watt-hours per pound, which would give an automobile a range of only 50 to 100 miles.

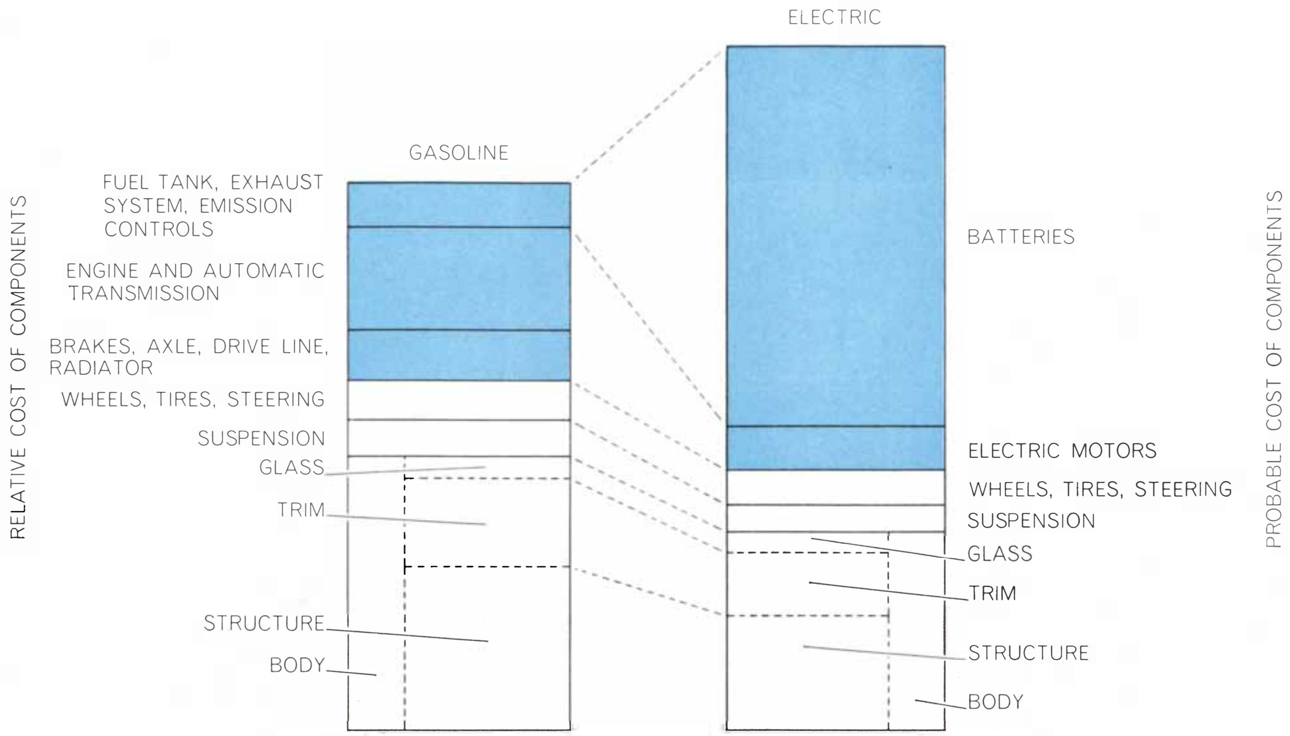


DRIVING CHARACTERISTICS of today's cars (*broken curves*) and a potential electric car (*solid curve*) are reflected in the torque, which is a measure of the energy applied at the driving wheels. These curves show that up to the middle range of speed the electric automobile would have essentially the same response to the driver as today's gasoline-powered cars.

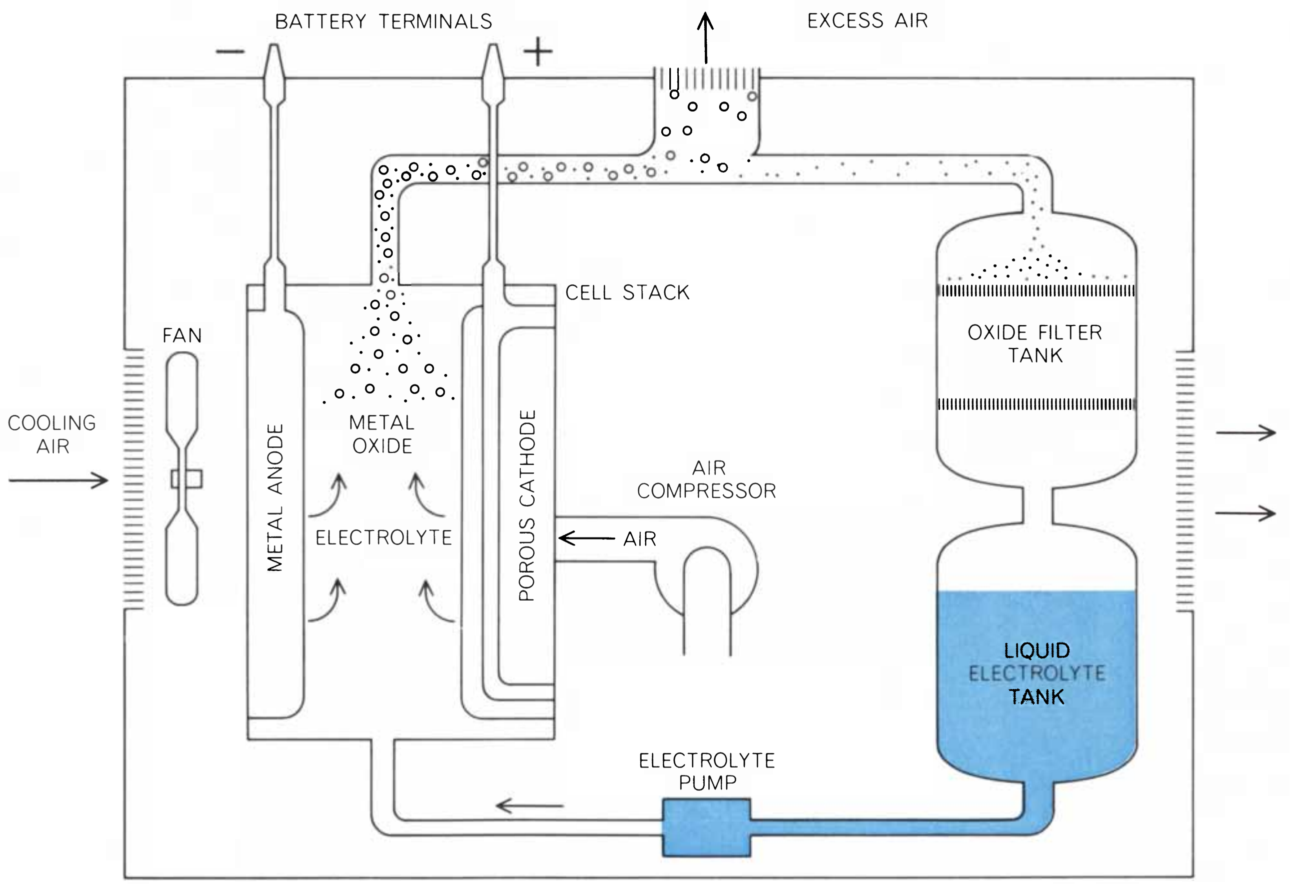
The innovation that now makes the electric automobile thinkable is a device called the air battery. Still in an early experimental stage, it employs a new principle. The fuel is a metal, and so far the favorite metal has been zinc. Air is pumped to the electrodes and serves as an oxidizing agent [*see bottom illustration on next page*]. The current in a metal-air battery is generated by the electrochemical combination of the metal with the oxygen in the pressurized air. This process of oxidation releases free electrons at the anode and produces an electric current. The product of the reaction precipitates into the circulating electrolyte fluid in the form of fine particles of the metal's oxide. The excess bubbles of air, now depleted of much of their oxygen, are vented to the outside of the battery, while the solid grains of oxide are transported, filtered and stored in a separate bank for spent fuel.

To recharge the battery the flow of electrolyte and free electrons is reversed by applying a potential across the terminals. The metal oxide is now carried by the electrolytic fluid from its storage tank back into the cell, where it is decomposed into pure oxygen and metal. The oxygen is vented to the atmosphere and the metal is electroplated onto the anode up to a desired thickness. At this point the battery is fully charged again and is ready once more to go into its energy-delivering cycle.

Experiments have already demonstrated that with zinc as the fuel this potentially inexpensive device can store and deliver more than 50 watt-hours of electricity per pound of battery. That would allow a range of about 80 to 160 miles for the car, depending on driving conditions [*see top illustration on page 39*]. The energy consumption of an automobile is governed mainly by two driving factors: the frequency and magnitude of accelerations and the speed of travel. Cruising at a steady, moderate speed, the car uses comparatively little power. In city or suburban driving, however, the automobile is being accelerated or decelerated during a majority of the time in its trip: from a third to two-fifths of the time it is being accelerated; during somewhat less than a third of the time it is being decelerated, and only about a third of the time is spent in constant-speed cruising and waiting at traffic lights or in tie-ups with the engine idling. This pattern accounts for the comparatively low gasoline mileage of a conventional car in traffic and for the relatively small range an electric automobile would have in



INITIAL COST of an electric car would be slightly higher than that of a gasoline-powered automobile. As indicated by this chart of the relative cost of components, the difference would arise mainly from the cost of batteries for the electric car. An electric car would cost less to operate, however, because it uses a cheaper source of energy and its motors require little or no maintenance.



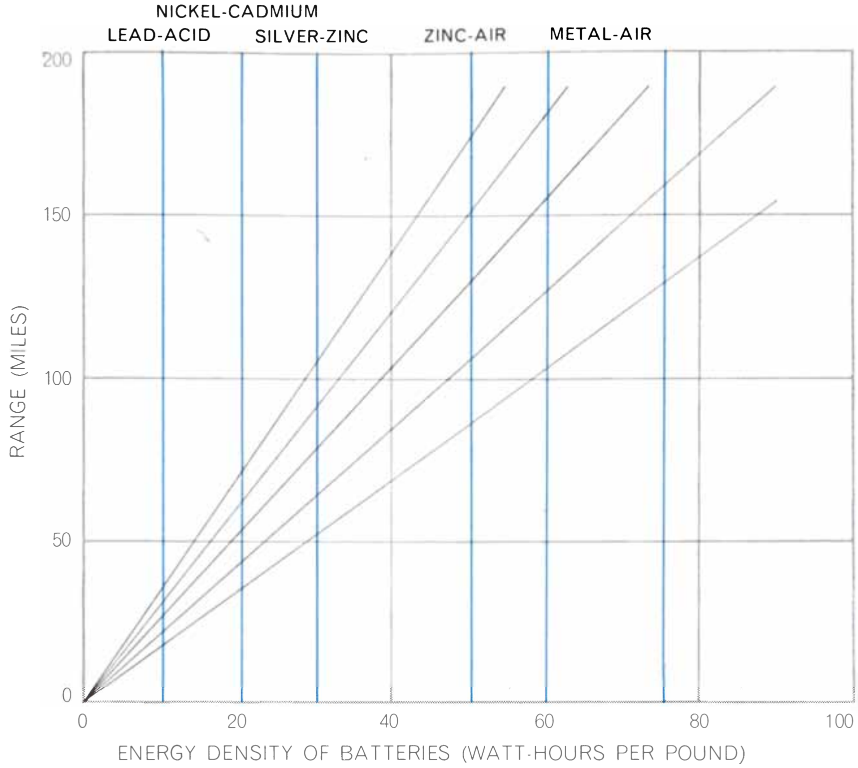
METAL-AIR BATTERY derives energy from the conversion of a metal to its oxide on exposure to pressurized air. The flow during a discharge cycle is depicted schematically, with the oxide particles represented as dots. For recharging, a voltage is applied across the terminals; the flow of particles is reversed so that they are carried by the electrolyte into the cell and electrolyzed into metal and oxygen. The metal is redeposited on the anode and the oxygen bubbles off at the cathode and out of the excess-air vent.

such driving. In steady cruising on an open road, on the other hand, an electric automobile driven by zinc-air batteries would have a range of better than 300 miles at 55 miles per hour or better than 150 miles at 90 miles per hour [*see bottom illustration at right*].

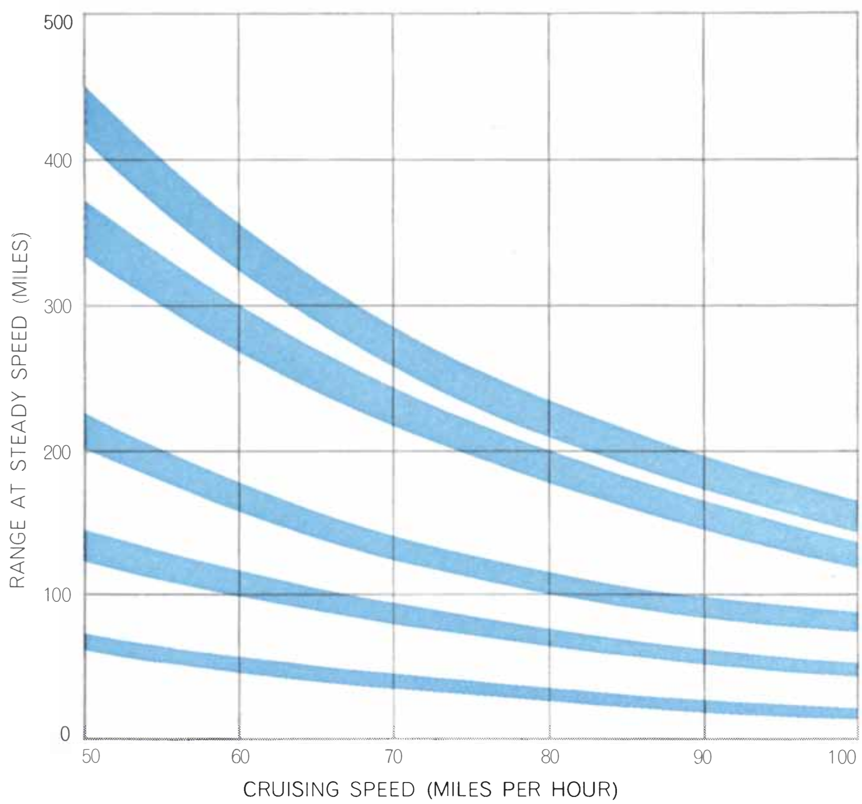
The figures I have been presenting indicate what is already possible with zinc-air batteries now under experimental development. It can safely be predicted that before long this development will produce metal-air batteries with an energy density of 60 watt-hours per pound or even higher. With that capacity an electric car could have a range of 180 to 210 miles between recharges under normal traffic conditions, and this would be comparable to the present range of automobiles between stops at the gas station. Looking further ahead, we can think of the possibility that the regenerative fuel cell (generating electricity, for example, by the reaction of hydrogen with the oxygen in the air) may someday be adaptable as a car battery. Such a fuel cell could achieve an energy density of 80 watt-hours per pound and give an automobile a range of better than 300 miles. The hydrogen-air battery is only a distant prospect at present, however, because no way has yet been found to recharge it, or make it regenerative, and to reduce its volume.

The refueling of automobiles driven by metal-air batteries would be no great problem. The batteries could easily be designed in the form of standardized packs that could be exchanged quickly at road stations corresponding to the present gas station: the spent batteries (or perhaps only the spent fuel elements) would be removed and replaced with fully charged units or fresh elements within a few minutes. Alternatively, the batteries could be recharged at a more leisurely pace with simple equipment in the home garage at night.

What about the cost of the electric automobile? Its power plant would cost perhaps one and a half times more per pound than that of the internal-combustion car, chiefly because of the comparative expensiveness of metal-air batteries. On the whole the purchase price of an electric automobile would probably be about a fourth higher than that of a gasoline car of the same size [*see top illustration on opposite page*]. This would be more than offset, however, by the car's lower operating costs for maintenance and fuel. The fuel savings, over gasoline, would be at least 50



RANGE BETWEEN RECHARGES of the batteries in an electric car depends on the energy density of the batteries and on the average speed of a trip in heavy traffic. Average speeds represented by the five slanting lines are, from top, 40, 35, 30, 25 and 20 miles per hour.



CRUISING RANGES of electric cars driven at steady speeds on open roads vary according to the energy density of the batteries and the speed. The colored bands represent, from the top, five types of battery: metal-air, zinc-air, silver-zinc, nickel-cadmium and lead-acid.

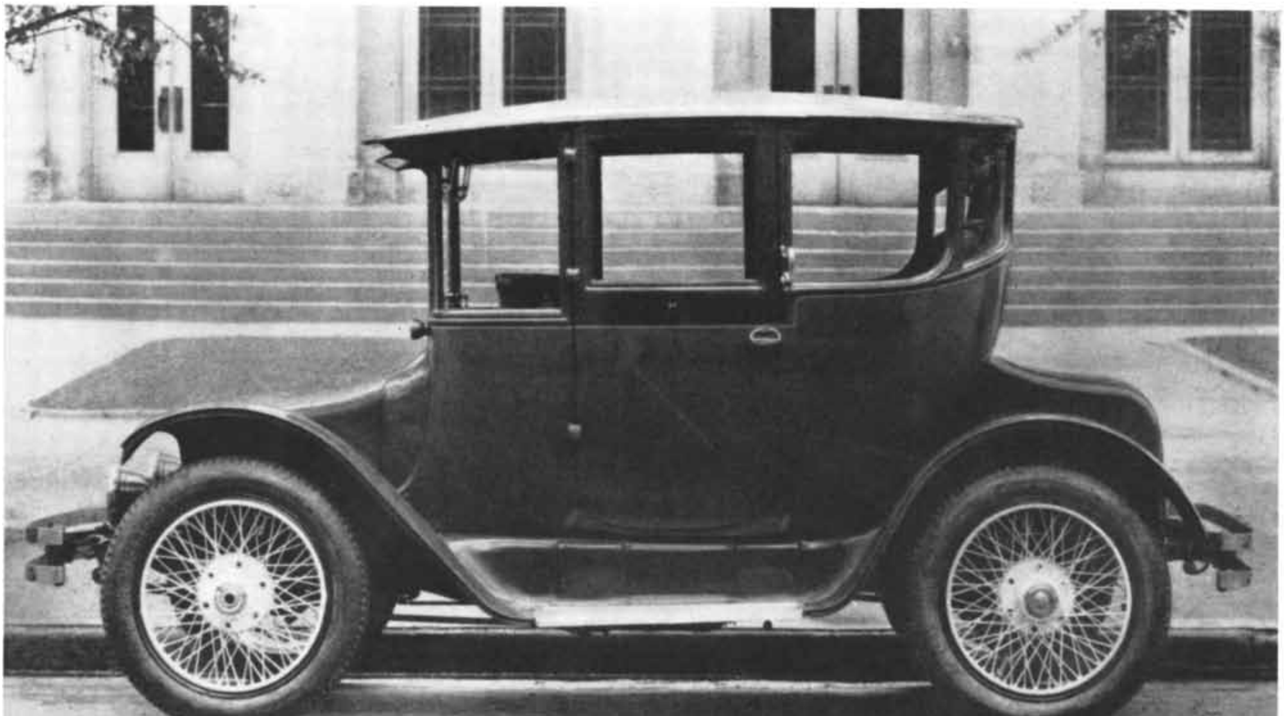
percent. The electric car would probably be more profitable from the manufacturer's point of view as well, because recent experience in our sophisticated new industries has shown that high profits can be made from the mass production of intricate devices made of exotic materials.

We can anticipate other important economic effects arising from the electric automobile. It would about double the consumption of electricity, since our automobiles now use as much energy as is produced by all the electric-power stations in the U.S. The doubling of the production of electricity may reduce its price by 10 to 20 percent, particularly in view of the fact that the recharging of batteries can take place mainly at night in the owner's garage, when other demands for electric power are low. Since electricity in the coming decades will be generated increasingly by nuclear fuels, the switch to the electric automobile will greatly reduce the pressure on our limited resources of petroleum.

The greatest economic saving would come from the clearing of the air. Air pollution, it has been estimated, cost the U.S. about $15 billion in economic losses in 1965. Fully half of this pollution (three-quarters in California) is attributable to the internal-combustion vehicles on our streets and highways. Some geophysicists calculate that, if present worldwide trends in the motorization of the population continue, within half a century the gasoline car may reduce the oxygen content of the atmosphere and load it with catastrophic concentrations of carbon dioxide and noxious gases. For our cities in particular a changeover to electrified transportation could mean tremendous savings in health and lives. If we traded in the gasoline vehicle for electric cars, trucks, buses and trains, the urban air could be restored almost to rural cleanliness.

We are so conditioned to the present automobile that it is difficult to imagine or appreciate what a change would be wrought in the quality of life by the switch to electricity. The roar of traffic in our communities might be reduced to a not too unpleasant hum (although tire noise would still be with us). The turn of a switch would start up our automobiles instantly, quietly, with full power and without cold-morning balkiness. Even traffic jams and red lights would be more bearable without the impatient and wasteful irritation of the idling engine. Breakdowns on the road would become far less common, as electric motors can run for thousands of hours without attention. We would ride in clean, sweet air even in tunnels (which would need much less artificial ventilation). In the course of time the removal of the gasoline engine would make it possible for the automobile to evolve into a vehicle that could be much more suitable to the human body and nervous system.

Obviously the modern electric automobile will not arrive overnight. Although laboratory investigators seem to be close to the goal of producing batteries that will make it practicable, the building of a full-scale electric car that could successfully replace gasoline-powered automobiles still appears to be several years away. It would then have to be sold to the public by intensive effort. Even after a radically new automobile has won acceptance it takes the automotive industry 12 to 15 years to tool up for manufacture of the car by the millions. Beyond that the gasoline automobiles still on the roads would linger on for another dozen years or so. Realistically, then, we must conclude that the internal-combustion, piston-engined automobile will continue to dominate our roads for the next 30 years or more. In the meantime the arrival of the electric car—indeed, whether or not it arrives at all in this century—will depend on how much support is given its development.



BYGONE ELECTRIC CAR is represented by this 1930 model, made by the Detroit Electric Car Company. By that time the electric car had all but given way to the gasoline-powered car, although the company continued to build cars on request for several years.

Random access at a distance

80 thin-layer chromatograms	**80 psychotic patients**
80 airports	**80 disc-electrophoresis patterns**
80 bubble-chamber events	**80 antenna radiation patterns**
80 stratigraphies	**80 common skin lesions**
80 microcircuits	**80 uncommon minerals**
80 cities	**80 kinds of surface finish**
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Eighty of anything can be depicted on 80 slides that go into a KODAK CAROUSEL Projector Slide Tray, and any one of them can be on the screen in no more than 4 seconds after the instructor or demonstrator up front, or the museum visitor out front, sets the dial to the number he wants and presses the button. Specification sheet for KODAK CAROUSEL Projector, Model RA-950, and name of dealer can be supplied by Eastman Kodak Company, Motion Picture and Education Division, Rochester, N.Y. 14650. You may have a use for it even more urgent than education, if anything can be. You may never even get to twist the dial and yet have the satisfaction of hooking up a few wires to knock the bottom out of the going price in the hardware market for graphic data storage and readout. In color, yet. Just as easy.

Very nice acrylamide

Disc electrophoresis, the widely used technique for fingerprinting with magnificent resolution the protein patterns in human serum, in birds' eggs, and wherever else characterization by protein makeup makes sense, was first publicized in 1962 to the world scientific community by us in the ordinary course of pushing EASTMAN Organic Chemicals. We still don't know why we got the chance, but we are proud that it was given us. We have not been especially proud of the quality of the key EASTMAN Organic Chemical that the technique employs, *Acrylamide*. Too often, practitioners of disc electrophoresis have advised us that they have fallen into the habit of first purging it of a small accumulation of acrylic acid. We would have felt far worse if any had told us that a purer grade was available elsewhere, or if there had been complaint from the originators of disc electrophoresis, with whom we remain in good contact.

This is now mentioned in order to announce a special electrophoresis grade of *Acrylamide* (EASTMAN X5521) with acid content below 0.01% at $5.60 for 25 g., $18.85 for 100 g. When informed of this, one of the originators commented, "Very nice." We had expected more enthusiasm.

Reprints of the papers on disc electrophoresis theory and technique are still available from Distillation Products Industries, Rochester, N.Y. 14603 (Division of Eastman Kodak Company), as is a copy of List No. 44 of EASTMAN *Organic Chemicals.*

Optical memory, ready for shipment, cheap

Business in KODAK IR Phosphor Screens was fine as long as we advertised them, but then we got to wondering if the game was worth the candle. When the advertising slacked off, so did the sales.

They are cards coated with SrS:Eu,Sm and sealed in plastic. Left to lie around under daylight or fluorescents, they store up energy which is re-emitted as an orange glow when the card is hit by infrared. The infrared stimulation spectrum peaks around 1μ. Well worth the price* when interested in making an infrared laser beam visible.

Now comes a new reason for interest in the item. *Proceedings of the IEEE* (54:425, 1966) carries a letter to the editor that beefs up its importance somewhat. Dr. Richard A. Soref of the Sperry Rand Research Center has been inspired to look at it as an erasable optical memory offering random access, high capacity, destructive readout (when the infrared hits it), and several hours of storage time. He comes up with the following estimates, which† we hope will be regarded as tantalizing:

With 1.15μ emission from a He-Ne laser focused to 3000 W/cm^2, 5 x 10^5 bits of data per second could be serially read out and erased. With 1.06μ Nd^{+++} emission, the erasure efficiency should double. Spatially, the phosphor has a minimum element size of 4 x 10^{-4} cm^2. Writing to exploit this packing density would take 0.8W at 0.488μ from an argon ion CW laser, and the reading would take 1.2W of CW Nd^{+++} laser light.

Order KODAK IR *Phosphor Screens from Eastman Kodak Company, Apparatus and Optical Division, Rochester, N.Y. 14650 (716-325-2000, ext. 5166).*

Same address is being kept busier by the discovery that KODAK IRTRAN 4 Optical Material is the top choice in a window material for the CO_2 lasers that have focused attention at 10.6μ in the heart of the great clear $8\text{-}14\mu$ atmospheric window. IRTRAN 4 Material contributes virtually no absorption of its own in this spectral region. It takes the necessary optical quality and retains the vital flatness and parallelism at elevated temperature. A drop of rain or sweat won't pit it.

IRTRAN 2 Material is even more rugged and costs less if you can afford a bit more absorbance.

We furnish either one with plano-plano surfaces or, for confocal reflection in the cavity, plano-concave of long radius. No size request of the many to date has strained our capacity.

*2" x 3"—$25	8" x 10"—$95	20" x 24"—$375
4" x 5"—$49	14" x 17"—$195	

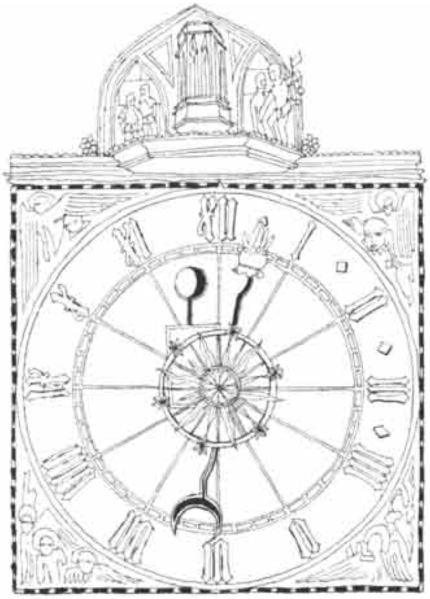
†In combination with electro-optic light deflectors (*IBM J. Res. Dev.*, 8:64, 1964; *Bell Sys. Tech. J.*, 43:821, 1964).

Prices subject to change without notice.

The hope of doing each other some good prompts these advertisements

Kodak

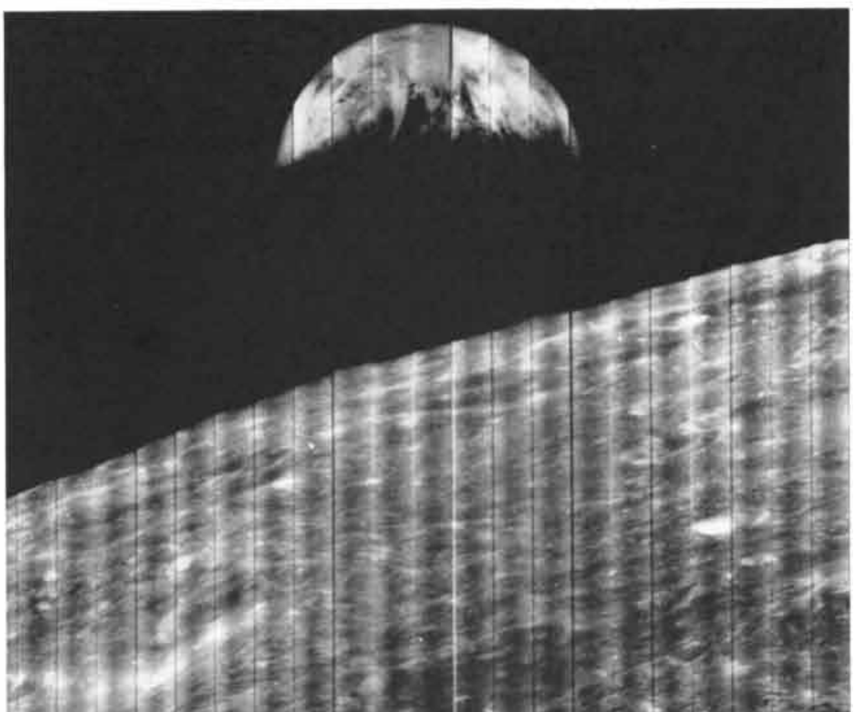
SCIENCE AND



The Earth from the Moon

The first picture of the entire earth, with the moon in the foreground, was an unexpected bonus provided by *Lunar Orbiter I,* which was placed in orbit around the moon on August 14 (*see illustration below*). Like *Surveyor,* which landed softly on the moon in July, *Lunar Orbiter* was a success on its first mission. Both American spacecraft, however, were beaten to their goal by Russian machines. A Russian craft landed on the moon and returned the first closeup photographs of the surface in February, and a Russian vehicle was placed in orbit around the moon in April but returned no pictures. A few days after the 850-pound *Lunar Orbiter I* began circling its target it was joined by a camera-carrying Russian spacecraft weighing 3,608 pounds.

The flight of *Lunar Orbiter I* was almost perfect. Its initial orbit ranged from 117 to 1,159 miles above the surface of the moon. Later the low point was reduced to about 26 miles. Although the vehicle's medium-resolution camera worked flawlessly, the high-resolution camera developed a fault that blurred most of its pictures. The objective of *Lunar Orbiter I* was to photograph potential sites for a manned landing near the moon's equator. The



QUARTER EARTH (*top*) appears in this photograph made from *Lunar Orbiter I* as it would be seen by an astronaut coming around the "back" of the moon (*bottom*). If the earth's surface features had not been obscured by cloud patterns, Antarctica would have been visible at the left end of the crescent. Visible on the moon are several large craters.

spacecraft was built by the Boeing Company under the direction of the Langley Research Center of the National Aeronautics and Space Administration.

Dead Secret

The notion that there was a "secret of the atomic bomb" that was essential to any nation seeking to make one appears to have been further dispelled by two recent developments. The first is testimony by two scientists intimately involved in the wartime work at Los Alamos that the secret "cross-section sketch" introduced in the espionage trial of Julius and Ethel Rosenberg and Morton Sobell in 1951 was worthless as a description of the bomb. The second is the assertion in Moscow that the U.S.S.R. began work on an atomic bomb in 1942 and was well along in the project before the U.S. exploded its first bomb in 1945.

The two scientists are Henry Linschitz, professor of chemistry at Brandeis University, and Philip Morrison, professor of physics at the Massachusetts Institute of Technology. In affidavits submitted in support of Sobell's move for a new trial they addressed themselves particularly to the secret evidence. David Greenglass, who had been a machinist at Los Alamos, testified that he had given the sketch and explanatory remarks to Julius Rosenberg in 1945. On representation by the prosecution that a "replica of the sketch" offered at the trial depicted "a cross-section sketch of the atom bomb," and on motion of the defense, the court had impounded this piece of evidence and the subsequent testimony by Greenglass concerning it. The court declared, when it sentenced the defendants Rosenberg to death, that their conduct had put "into the hands of the Russians the A-bomb years before our best scientists predicted Russia would perfect the bomb...."

On motion by Sobell, who is serving a 30-year sentence in Federal prison, the secret portion of the trial record has been opened to public inspection. Linschitz said the sketch and explanation "give a garbled, ambiguous and highly incomplete description of the plutonium bomb of 1945." He found it "astonishing" that "despite so many authoritative statements to the contrary by scientists over the past two decades, the layman still clings to the misconception that there is *a* 'secret' or key 'formula' for the construction of an atomic bomb." Linschitz declared: "The construction of an atomic bomb... involved no single 'secret' in the scientific sense. It did involve a highly complex set of technical tricks, devices and processes, combined of course with an immense and versatile industrial capability.... It is not possible in any technologically useful way to condense the results of a two-billion-dollar development effort into a diagram, drawn by a high-school-graduate machinist on a single sheet of paper."

Morrison depreciated both the sketch and the testimony given by John A. Derry in the Rosenberg trial. Derry was the only witness presented to authenticate the sketch after the Government had advertised but never called J. Robert Oppenheimer, George B. Kistiakowsky and Harold C. Urey as witnesses. The sketch, according to Morrison, omitted "two important spherical components of that bomb, without which it could not operate." Morrison said that if Derry had seen "the actual atomic bomb under development at Los Alamos 'many times,' as he stated, he ought to have added 'and it did not look like that.'" According to Morrison, Derry lacked the scientific background to justify him as an authenticating witness and had not been involved in "the technical aspects of the project."

The development in Moscow was the publication by a physicist, Igor N. Golovin, of a biography of the late Igor V. Kurchatov, who directed the Russian bomb project. Golovin wrote that the U.S.S.R. began its bomb project in June, 1942, having "already learned that in Germany and the United States priority work connected with development of a new, high-powered weapon was being carried out in strictest secrecy." The U.S. exploded its first atomic bomb in July, 1945; the Kurchatov group achieved a chain reaction in December, 1946, and the first Russian bomb was exploded in 1949.

The Misuse of Antibiotics

The wide use of 18 antibiotic drugs as growth-inducing additives to animal feeds or as food preservatives has been declared hazardous by an investigating committee appointed by the Food and Drug Administration. In the committee's opinion public health is actually or potentially threatened in four ways: (1) when antibiotic residues are ingested by humans, they may destroy the intestinal bacteria that assist digestion; (2) the residues may produce allergic reactions in humans; (3) they may counteract the effectiveness of other antibiotics being administered as treatment for some human disease, and (4) most serious of all, they could promote the development of resistant strains of disease organisms in humans and animals alike.

Singled out for mention were the application of chlorotetracycline to raw poultry, shrimp, scallops and fish to prevent spoilage, the similar application of oxytetracycline to raw poultry and the feeding of chloramphenicol to animals that produce meat, eggs or milk. In the last instance current regulations merely require a "not recommended" labeling. In actuality the length of time that residues of chloramphenicol persist in milk and animal tissues has not yet been determined; the committee calls for a "not to be used" labeling. The committee recommends that further studies be made to determine exactly when the last significant traces of other antibiotic food additives are naturally eliminated from the animals that are fed them and that the Administration establish equivalent "holding periods" between the last such feeding and the animals' movement to market.

The X-Ray Sky

An X-ray telescope carried above the bulk of the earth's atmosphere by a balloon has detected evidence of another kind of feature in the emerging picture of the sky at very short wavelengths: an extended source of X rays near the direction of the north galactic pole. The new source appears to coincide with the cluster of galaxies in the constellation Coma Berenices, a comparatively nearby cluster with a high density of galaxies but no strong radio sources. The discovery of the extended source was reported recently in *Physical Review Letters* by Elihu Boldt, Frank B. McDonald, Guenter Riegler and Peter Serlemitsos of the Goddard Space Flight Center of the National Aeronautics and Space Administration.

The telescope used by the NASA group is a complex device consisting of three different types of X-ray detector operating along the same axis. The detection system is capable of resolving a discrete X-ray source with an angular diameter of about one degree of arc. The Coma source was detected in the course of a balloon flight launched on January 13 from Holloman Air Force Base in New Mexico. Data obtained during the flight indicate that the source has an angular diameter of about four or five degrees of arc. As X-ray sources go, it is considered a fairly strong emitter, comparable in flux received at the top of the atmosphere to the Cygnus XR-1 source, one of the brightest X-ray emitters in the sky. It is not yet clear whether the X-ray emission from the extended source represents the cumulative effect of a number of individual X-ray-emitting galaxies in the Coma cluster or radiation from intergalactic material in the cluster as a whole.

The Last of the Screwworm Fly

A unique biological campaign begun a decade ago by the Department of Agriculture to rid the nation of the screwworm fly, a livestock pest costing $100 million a year, has ended in complete success. The female screwworm fly lays its eggs in an open wound or skin abrasion of cattle, sheep and goats, including the unhealed navel of newborn stock. When the larvae hatch, they feed voraciously and often fatally on the blood and tissue of the host before dropping to the ground and metamorphosing into adult flies. The campaign, begun in Florida in 1957, required the rearing of screwworm larvae by the millions. When the larvae had metamorphosed into pupae, they were given a dose of radiation strong enough to sterilize them but leave them otherwise unharmed. The sterile males that emerged from the pupae then competed with normal males for mates among the screwworm fly population; females that copulated with irradiated males produced only sterile eggs (see "The Eradication of the Screw-Worm Fly," by Edward F. Knipling; SCIENTIFIC AMERICAN, October, 1960).

By 1959 the flies were extinct in southern Florida, one of four regions in the southern U.S. where the insects lived the year round. The campaign was continued in the three remaining areas—southeastern Texas, the Sonora border region of New Mexico and Arizona, and the Lower California border of Arizona and California—from 1962 to the present. This past spring the last of the three areas was declared free of screwworm flies. In cooperation with the Mexican government a wide zone along that nation's northern frontier has been neutralized by the broadcast release of further millions of sterile screwworm flies, thus guarding against the pest's

Tactical Radio: A report from General Dynamics

In old suspense movies there always seemed to be a sequence in which the fleeing suspect tunes his car radio to the police band, hears: "Car 64, fugitive headed your way—intercept." Whereupon, suspect swings away and escapes.

Even today, by and large, if police car A wants to reach squad car B one mile away, willy-nilly, cars C, D, and E, all tuned to the same channel, have to listen too. And so can lots of unofficial ears.

This problem is compounded a thousandfold by modern military tactical requirements. Hundreds of squads, vehicles, and individuals may be operating separately over a wide area, all scrambled up with enemy units.

On occasion a commander must broadcast orders to a hundred squads at once. But he may also need to talk to a single intelligence scout hidden hundreds of miles away. Or an individual unit may have to call another unit with information or to call for support, without hundreds of ears, friend or foe, all automatically listening too.

Radio sets just that selective are now being delivered or developed by General Dynamics. Small and rugged enough to go anywhere a man can go, and simple to operate, the new radios are a key to modern tactical mobility.

From 2 to 74,000:

World War II walkie-talkies had one or two channels. The new sets have from 28,000 to 74,000 different channels for voice or teletype communication. A generation ago, a mere 12 channels called for a large fixed installation. Now one with some 45,000 channels will be carried on a man's back. The biggest one can fit the back seat of a jeep.

The enormous number of channels permits direct "calling numbers" for hundreds, even thousands, of other radios within sending and receiving range. Each set, in fact, has a number of different calling numbers that can be changed in prearranged groups every day, every hour or in rapid sequence on a moment's notice to aid security.

The new combat radios are based primarily on an old principle—single sideband transmission. It took developments of the past decade, however, in both solid-state electronics and ultra-miniature packaging to make practical such sets for mobile ground use.

On an oscilloscope, an AM (amplitude modulation) radio wave looks like a single line. Actually that line is made up of three distinct parts: a central carrier and two sidebands.

The central carrier is generated at a specific frequency—in effect its "address." When modulated, (that is, the message added) two sidebands come into being to carry the actual information. Both bear identical "intelligence."

Less becomes more:

SSB techniques filter out the central carrier and one redundant sideband. The message is sent on the remaining sideband, which contains all the essential information.

Only one-quarter of the power is now required to send a signal the same distance. Alternatively, the same amount of power needed for a full AM band will send an SSB message at least four times as far.

And with greater clarity.

"Noise" or static, comes from any electrical interference—power lines, vehicle engines, a storm 100 miles away. The carrier section of standard AM is particularly vulnerable. By using only one sideband, two-thirds of the static potential is avoided.

Radio tuning traditionally depended upon quartz crystals, each of which vibrates at an individual wave length. With enough of them, a large number of channels has always been theoretically possible. The number of fragile and expensive crystals that could be carried in combat was limited.

Today's sets still use crystals but in conjunction with electronic or electromechanical oscillators and synthesizers that can create thousands of different rates of vibration—or separate channels—and can change from one to another within fractions of a second.

Big becomes small:

New packaging techniques have been equally important. For instance, big tuning capacitors were originally the size of a pair of clenched fists. Now their function has been squeezed into a diode the size of a match head. Sets in development are only one-fiftieth the size and weight of World War II sets that had only a tiny fraction of today's channels, range or clarity.

Once upon a time there was room to spare on our radio airways. Today, channels jam closer and closer; interference has become a serious problem. General Dynamics' new sets are today filling military needs. Future civilian applications, however, could double the number of channels available for voice or data communication within the space now taken up by AM transmissions.

General Dynamics is a company of scientists, engineers and skilled workers whose interests cover every major field of technology, and who produce: aircraft; marine, space and missile systems; tactical support equipment; nuclear, electronic, and communication systems; machinery; building supplies; coal, gases. *Reprints of this series are available.*

GENERAL DYNAMICS

One Rockefeller Plaza, New York, New York 10020

New multi-thousand channel radios provide direct and clear communication among hundreds of widely separated fighting units, each with many "calling-numbers."

reentry into the U.S. The total cost of the eradication campaign is estimated at $32 million, about a third of the annual loss before the campaign.

The Department of Agriculture is already using the same technique against other insect pests. Melon flies and fruit flies have been eliminated from two Pacific islands, and the Mexican fruit fly has been held in check along the California-Mexico border. Tests in Africa show that male tsetse flies can be sterilized by radiation without otherwise being seriously affected. The hope therefore exists that sterilization may be used against these insects, which as the vectors of sleeping sickness in both humans and animals continue to prevent the development of wide areas of Africa and South America.

Faster Fourier Analysis

A technique that brings about substantial reductions in the time needed to do Fourier series analyses on a computer has been put into a computer program by the International Business Machines Corporation. The company said the technique achieved a logarithmic reduction in the number of calculations that must be made in such an analysis, which is widely used to study complex wave patterns generated by earthquakes, sources of light, atoms and many other sources. By means of the program, according to IBM, it will be possible to expand investigations in such fields as radio astronomy, the detection of nuclear explosions and the prediction of weather.

Standard Fourier analysis begins with the transformation of a wave pattern into a series of points on a graph. It is then necessary to apply the basic Fourier formula to the values of the points and go through a long series of multiplications and additions. The number of multiplications and additions is twice the square of the number of points; 1,000 points would require two million calculations.

The new program is based on a mathematical technique called the Cooley-Tukey algorithm, after James W. Cooley of IBM and John W. Tukey of Princeton University and the Bell Telephone Laboratories. This algorithm converts the basic Fourier formula into two simpler formulas. With them 1,000 points would require about 40,000 calculations, or 50 times fewer than before; similarly, 10 million calculations would be reduced 100 times and two billion calculations 1,000 times. In terms of computer time the reduction is as much as 1,000 times and sometimes more. For example, a Fourier analysis of 36,000 points that takes a computer 11 hours with the present program would take 36 seconds with the new program.

Great Lakes Megalopolis

The urban industrial area extending from Milwaukee and Chicago on Lake Michigan eastward past Detroit and Cleveland to Pittsburgh shows evidence of constituting a second American "megalopolis"—larger than, although not yet as heavily developed as, the northeastern megalopolis that runs from Boston past New York, Philadelphia, Baltimore and Washington to Norfolk, Va. This is the conclusion reached in a recent paper by Philip Costas and Catherine Nagashima, staff members of the "city of the future" project conducted by the Research Division of C. A. Doxiadis' Athens center for the study of human settlements.

Since 1961, when the French geographer Jean Gottmann defined the urbanized eastern seaboard of the U.S. as a megalopolis, interested students have examined other parts of the world in search of other examples. The populous arc extending from Tokyo to Fukuoka in Japan, a similar western European concentration from the Benelux nations to the Ruhr valley and the northern part of the Indian subcontinent from the Afghanistan border to Calcutta are now deemed by some to be emergent megalopolises, as are portions of Florida and California. The Costas-Nagashima study, recently summarized in the center's journal *Ekistics*, suggests that the Great Lakes megalopolis already exists and that its time lag in growth compared with the northeastern megalopolis, a matter of 50 years in the mid-19th century, is now less than 25 years.

Noting that the northeastern and Great Lakes megalopolises will eventually link up, the authors point out that the Appalachian mountains are a major barrier between Pittsburgh and the Philadelphia-Washington area. They suggest that instead the connecting link will develop eastward from Buffalo, via Syracuse and Utica to the Albany-Troy area and thence to Massachusetts and Connecticut. As for the Canadian side of the Great Lakes, they already consider the Ontario cities of London, Hamilton and Toronto as being linked to Buffalo and envision an eventual extension north by east that will include Ottawa, Montreal and Quebec. When a southern extension to Cincinnati is added to the Great Lakes megalopolis, the authors forecast

Now aerospace designers can calculate fracture toughness of aluminum with new Alcoa data

Consider a piece of high-strength aluminum alloy in elastic tension. What happens if a small shell fragment goes through it, or a fatigue crack appears? Whatever the cause, either a rapid fracture results, or it doesn't. The trick is to design aircraft and rockets that can sustain such damage, without designing in unnecessary weight—a difficult task with only qualitative information.

Now Alcoa Research Laboratories is providing engineers and designers with never-before-available quantitative data. Tables, graphs and procedures for calculating the fracture toughness of aluminum alloys are now available, along with criteria for selecting toughest alloys and tempers—the distillation of years of testing. Alcoa's new 48-page book evaluates 124 combinations of configuration, alloy and temper.

If you are working on light, high-strength structures, you should find this information useful. Write to Aluminum Company of America, 901-K Alcoa Building, Pittsburgh, Pa. 15219. Ask for Alcoa Research Laboratories' Technical Paper No. 18, *Fracture Characteristics of Aluminum Alloys* by J. G. Kaufman and Marshall Holt.

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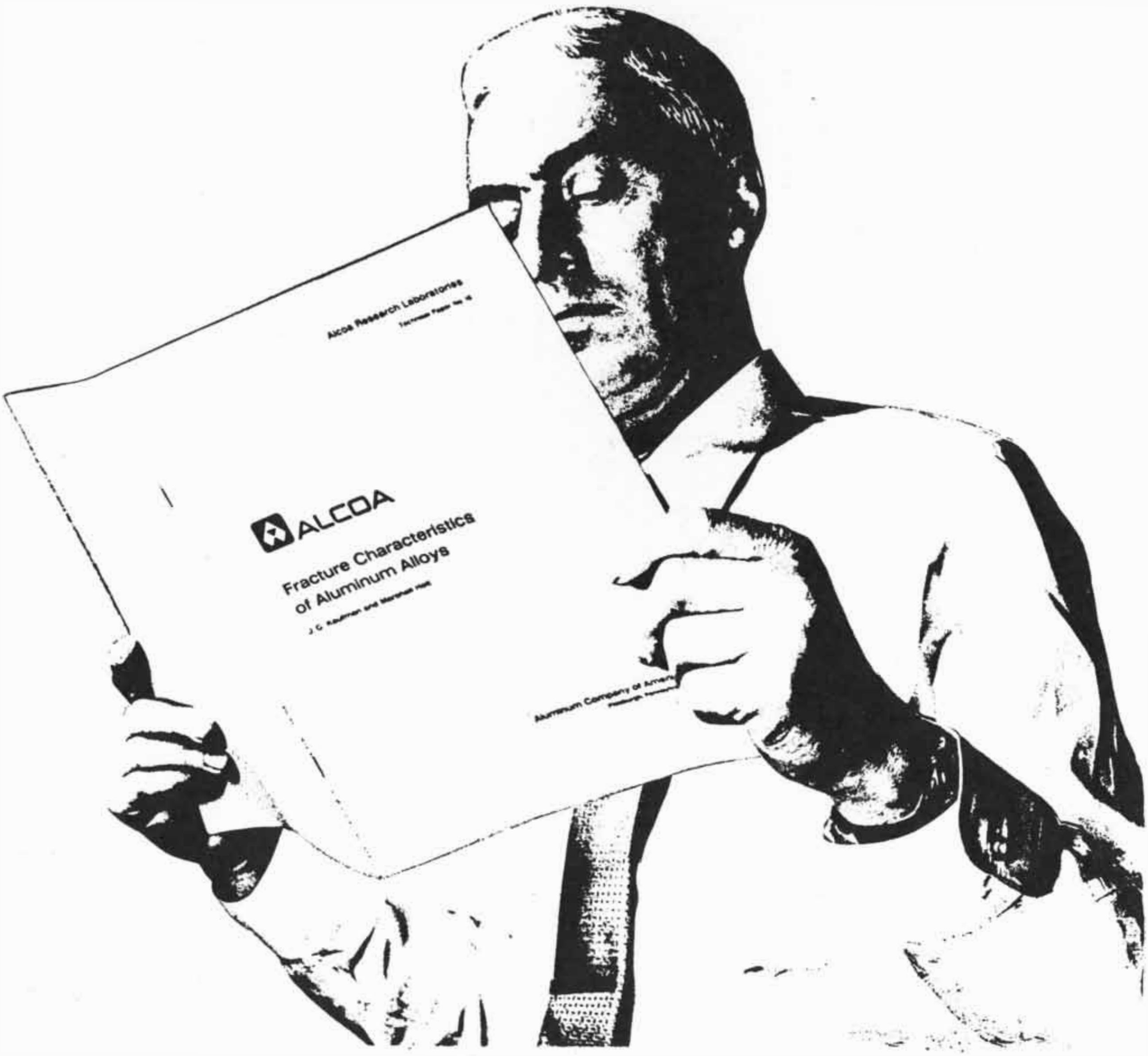


an A.D. 2000 population in excess of 120 million for the entire region, in contrast to less than 90 million for the northeastern megalopolis.

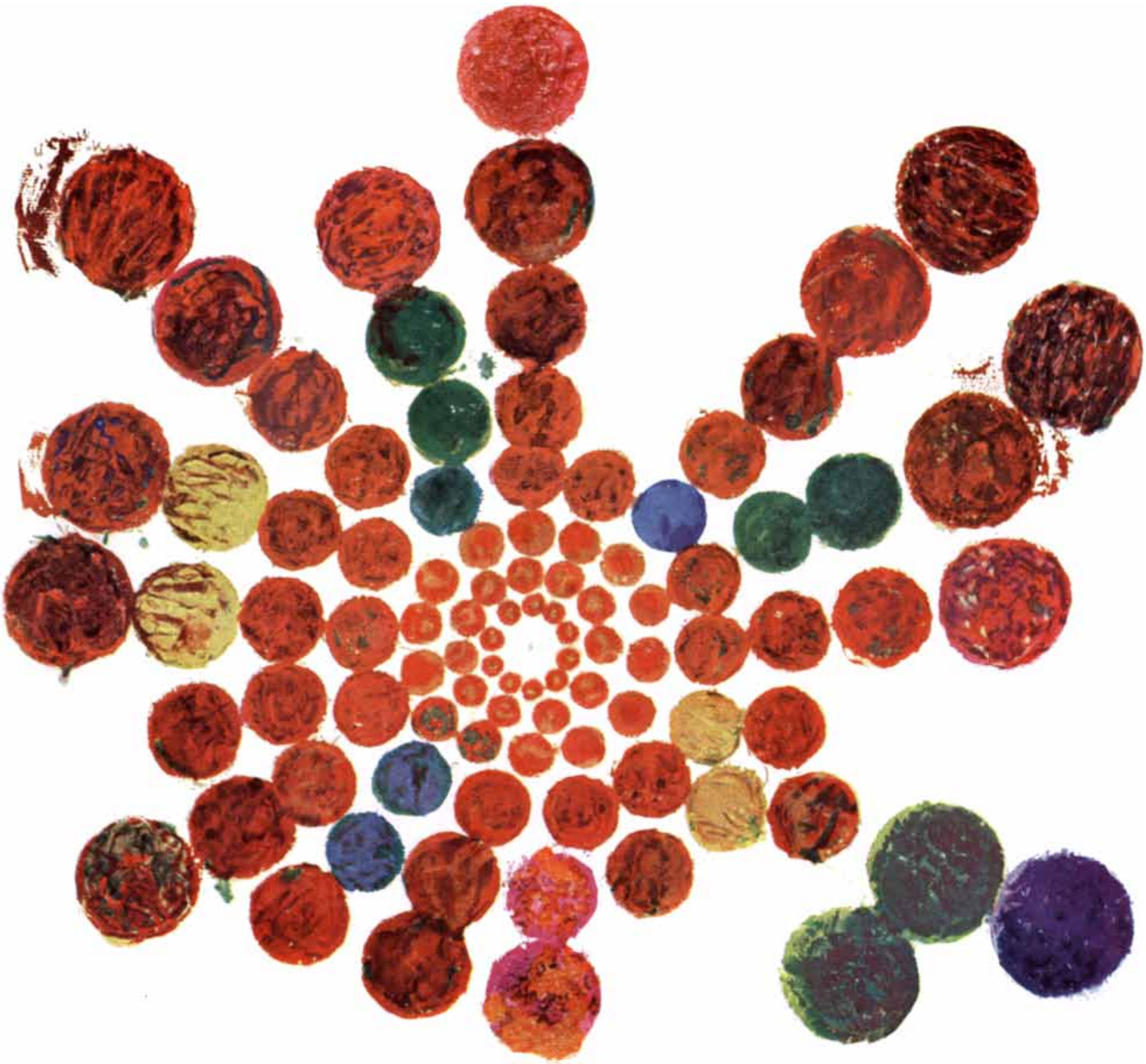
High-Energy Liquid Laser

The first laser to use an inorganic fluid as the light-amplifying medium has been built by Adam Heller at the General Telephone & Electronics Laboratories, Inc. The device has been successfully pulsed at room temperature, producing an infrared beam with an energy comparable to that of solid-state lasers of similar size under identical operating conditions. It is only the second liquid laser of any kind; the first, also built at GT&E Laboratories by a group headed by Alexander Lempicki, used a liquid containing a rare-earth ion bound in a chelate, or "cage," of organic molecules. The large amount of energy absorbed by the organic cage fundamentally limited the chelate laser's performance.

Writing in a recent issue of *Applied Physics Letters,* Lempicki and Heller report that the "gain" of the new laser (its ability to amplify light) is so high that under certain conditions it is possible to achieve laser action without the usual end mirrors. The liquid used in the laser consists of a bluish powder of neodymium oxide dissolved in a solution of selenium oxychloride. The liquid is contained in a glass tube, which can be of almost any useful size or shape. The principle behind the new laser is the use of solvents that do not contain light atoms (such as hydrogen). The absence of light atoms greatly increases the brightness of the solutions, since the active ions are more likely to emit photons of light than to dissipate their energy in heating the solvent.

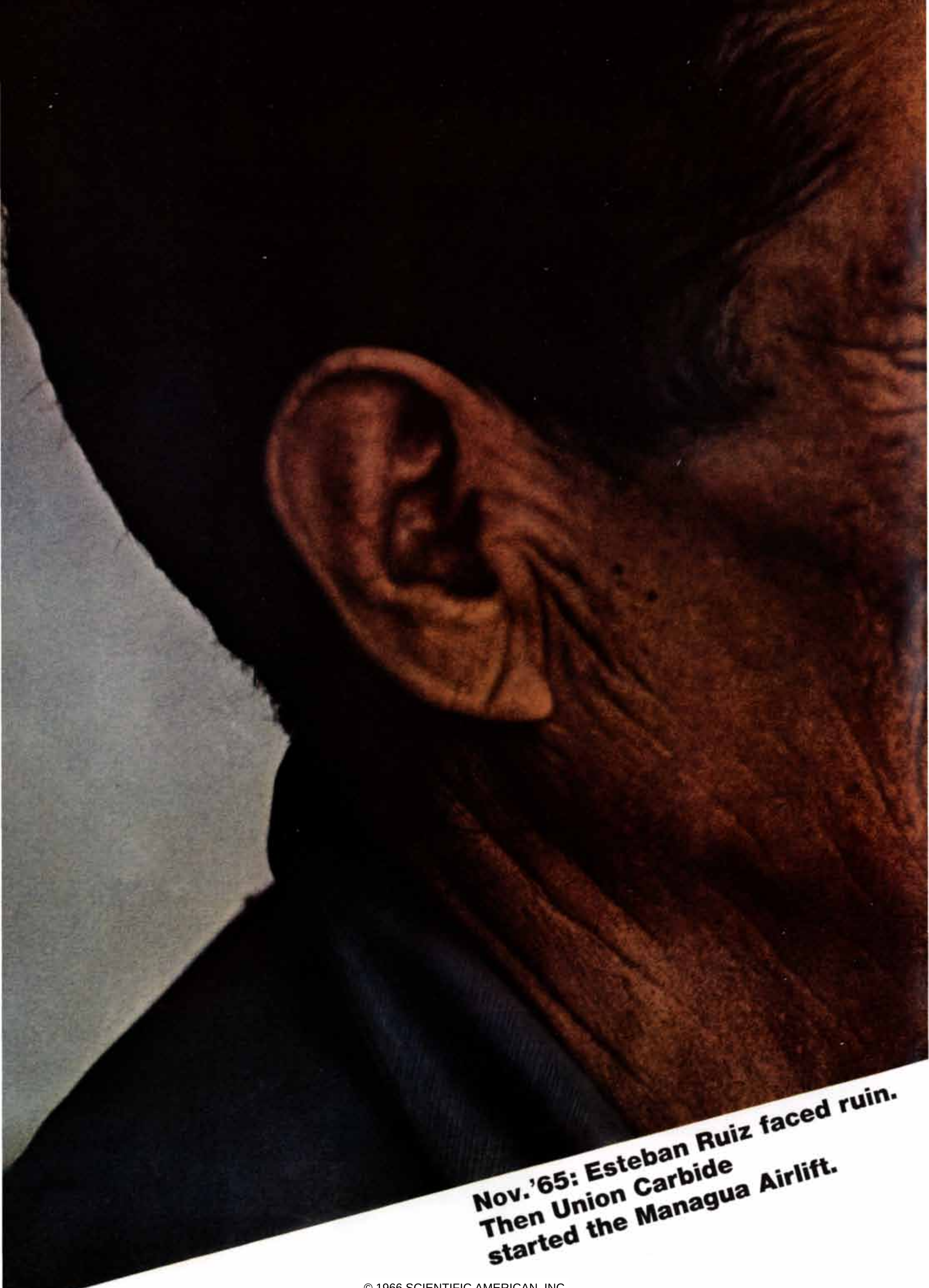
As is not the case with crystalline lasers, there is no practical limit to the length of the liquid laser. Since the energy output of a laser is proportional to the volume of the active medium, the ultimate energy output of the liquid laser is expected to be higher than that of the crystalline lasers. Although the eventual applications of the new liquid laser are not known, it appears that it may compete with glass lasers in generating high-energy pulses. The major advantages of the liquid laser for pulsed operation are that it dissipates heat more efficiently than a crystalline laser does and, of course, it does not crack. The liquid laser may also be useful in applications demanding a continuous source of coherent radiation.

At UOP environmental engineering is important...

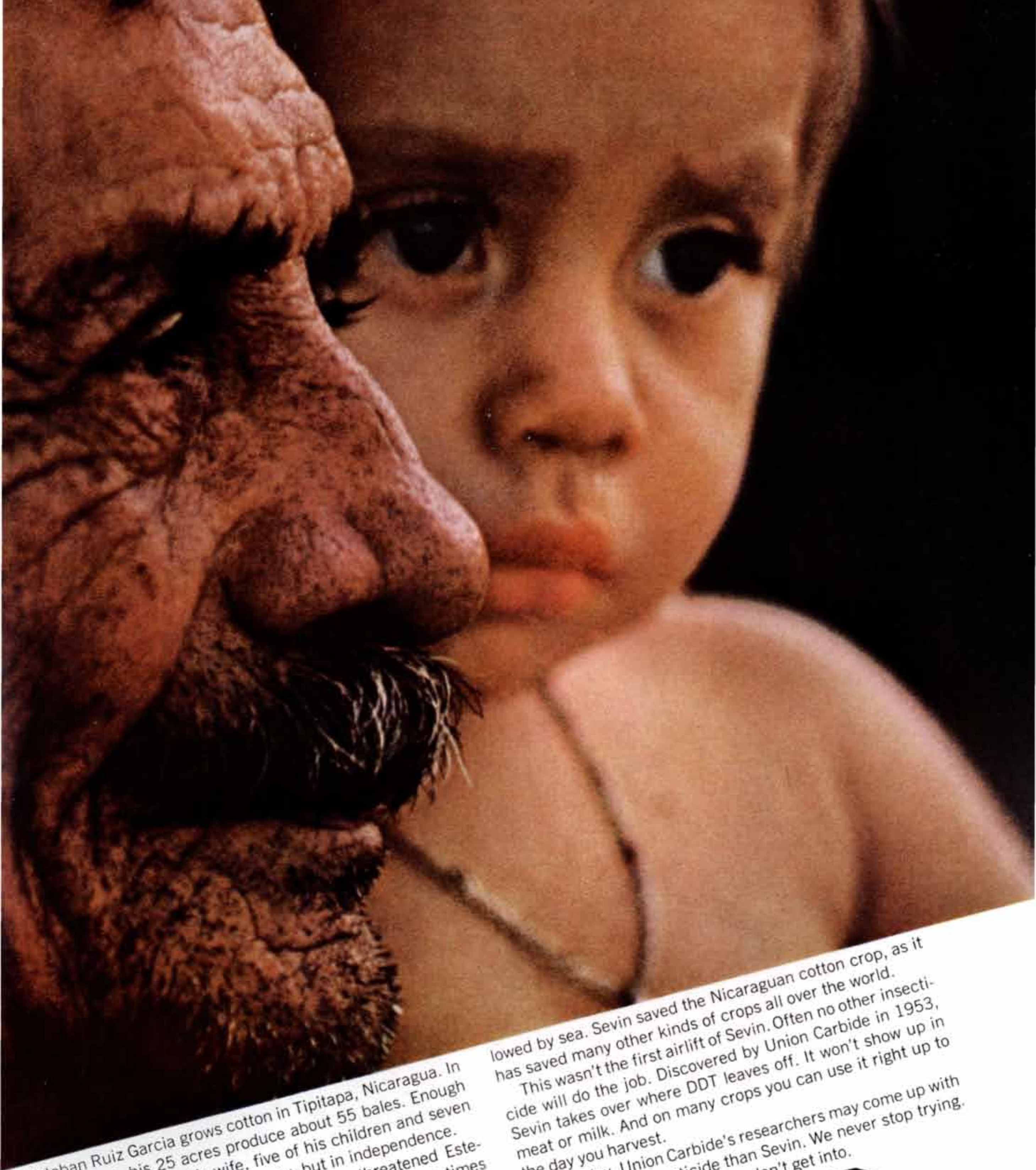


As man has industrialized, potential problems due to pollution of air and water have increased. Industry and government officials have joined in efforts to solve mounting concerns. □ UOP, respected for its technical achievements in the petroleum and chemical industries, has taken a broad position of leadership to alleviate these problems. We offer the widest selection of air correction equipment and systems, and provide a complete range of air pollution control services from consultation and source testing to equipment design and field start-up. □ Our work in environmental engineering is not limited to the control of pollutants in the atmosphere or recovery of valuable material in process streams. UOP also is active in water management—providing chemicals, equipment and services used in commercial water conditioning, including screens and filters used in food processing, mining, architectural applications and general water treatment. □ Competent technical help in solving your air and water correction problems is available now. Environmental engineering is another example of UOP's contribution to technological progress. UOP, 30 Algonquin Rd., Des Plaines, Illinois 60016.

keep your eye on the growing UOP



Nov.'65: Esteban Ruiz faced ruin.
Then Union Carbide
started the Managua Airlift.



Esteban Ruiz Garcia grows cotton in Tipitapa, Nicaragua. In a good year, his 25 acres produce about 55 bales. Enough to support Esteban, his wife, five of his children and seven of his grandchildren. Not in luxury, but in independence.

In November 1965, an invading army threatened Esteban's land. Bollworms. By the millions. Eating five times their own weight every day.

Esteban needed help, and so did his neighbors. And 2,000 miles away, Union Carbide started it moving. 50 tons of Sevin insecticide were flown to Managua. 225 tons followed by sea. Sevin saved the Nicaraguan cotton crop, as it has saved many other kinds of crops all over the world.

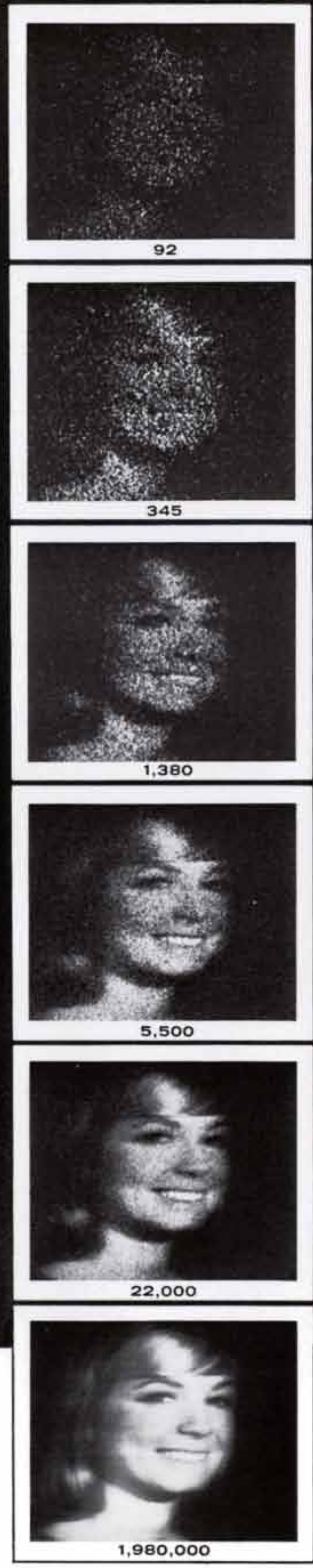
This wasn't the first airlift of Sevin. Often no other insecticide will do the job. Discovered by Union Carbide in 1953, Sevin takes over where DDT leaves off. It won't show up in meat or milk. And on many crops you can use it right up to the day you harvest.

Someday, Union Carbide's researchers may come up with an even better insecticide than Sevin. We never stop trying. And there's precious little we don't get into.

UNION CARBIDE

THE DISCOVERY COMPANY

The same scene—first produced photographically (above) and, then, electronically. Indicated under the illustrations in the series at right are the number of photons per square centimeter (in the highlights) required to form the images by scintillations.



Light can be as feeble as the arrival of a single photon. Hence, to see on the threshold of total darkness, the ideal photosensitive device should convert every individual photon into a usable response. Such a device would have a quantum efficiency of 100%. By comparison, the unaided human eye has a quite small entrance pupil and a QE of about 5%; the photographic camera has more flexible optics but a photographic film has a QE of only about 0.1%. At extremely low light levels, therefore, to permit vision when the eye alone cannot see, it is often necessary to use electronic intensification which allows a much higher quantum efficiency and faster optics.

A perceived image is the result of a rain of photons on the retina or other image-sensing surface...with more photons impinging on the bright areas of the image and fewer on the dark. Thus, a perfect image intensifier is one which effectively uses the signal from each incident photon, and which positions the responses in the same pattern in which the photons arrive. Nevertheless, even with a perfect intensifier, it still would not be possible to distinguish an image when too few photons arrive on the viewing surface.

An electron tube image intensifier consists of a primary photocathode which emits electrons with a density distribution similar to the light image focused on it. An electron lens focuses this electron image onto a two-dimensional electron current amplifier and a second lens focuses the intensified electron image onto a phosphor screen or other receptor.

A three-stage image intensifier is shown in Figs. 1 and 2. The two-dimensional current amplification is obtained by cascading phosphor-photocathode intensifier screens. Each screen has a gain of 50 or more so that the combination has a current gain of two or three thousand. The three-stage image intensifier can provide a light flux intensification in the order of 100,000, sufficient to produce a visible flash of light on the output phosphor screen from essentially every electron emitted from the first photocathode. Additional stages of intensification further increase the amount of light amplification to almost any desired degree.

The intensified electron image can be focused onto the storage target of an image orthicon, resulting in an extremely sensitive television camera tube. The limiting resolution curves of typical low-light-level RCA image orthicons and an image-intensifier orthicon are presented in Fig. 3. The curve for the image-intensifier orthicon shows that 10^{-7} footcandle of light incident on the photocathode (equivalent to a starlit night) is required to produce an image (Fig. 4) of 390 TV lines per picture. At 10^{-8} footcandle (equivalent to a heavily overcast night remote from ground glow), picture resolution decreases to about 225 TV lines per picture (see Fig. 5)—obviously poorer picture quality... but adequate under certain conditions for research and military applications. This picture was taken under such conditions. To the unaided eye, even dark-adapted, the scene would appear to be in total darkness.

Spectral response characteristics for several widely-used photocathode materials are shown in Fig. 6. The most sensitive is the multi-alkali material (S-20 spectral response): $Na_2KSb(Cs)$. At "blue" wavelengths, its quantum efficiency is as high as 30% or more... although QE falls to less than 5% at "red" wavelengths. Now under development at RCA, however, are promising new materials that could substantially increase quantum efficiency over the entire visible spectrum. Such materials, with multi-stage intensifier devices, should permit usable pictures to be made that more closely approach the threshold of total darkness. This is only one of the many research programs at RCA which will lead to improvements in scotoscopes and in the many electronic television and radio equipments now produced by RCA.

Why do we need light amplifiers to see in the dark? For many reasons.

Fluoroscopy and X-ray cinematography. X-ray exposure can be reduced by a factor of nearly 30 by use of a light intensifier... as opposed to exposure required for fluoroscopic viewing with the unaided eye.

Scientific imaging. Nuclear particle tracks in bubble chambers...which last only milliseconds...can be photographed, preserved and studied by means of RCA light-amplification devices. Similar tracks in phosphor systems can also be made visible as can minute flashes of light produced in Cerenkov radiators. Such phenomena—otherwise unobservable because of their transiency—give scientists new information about the essential nature of matter. Biologists have found use for these devices to view faintly luminous organisms, for microscopy, and for other low-light-level observations.

Deep astronomical observations. When the U.S. puts a spaceborne astronomical laboratory into orbit—above the atmosphere—it can focus on deep, unknown areas of space from which come, perhaps, only five or six photons per day. Cumulative exposure of months may reveal usable images of what existed billions of years ago.

Scotoscopy. The military—and many industrial installations—have many and obvious uses for devices that see in the dark...using only available light rather than detectable infrared or radar probes.

How can RCA help you? Perhaps you have problems of viewing scenes in virtual darkness. If so, RCA can help you.

Tell us your problem by letter or phone. Consult your RCA Field Representative or contact RCA Commercial Engineering, Harrison, New Jersey—(201) 485-3900. Because whatever it is... chances are—RCA knows how.

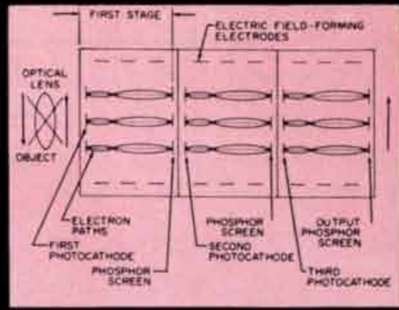


Fig. 1


Fig. 2

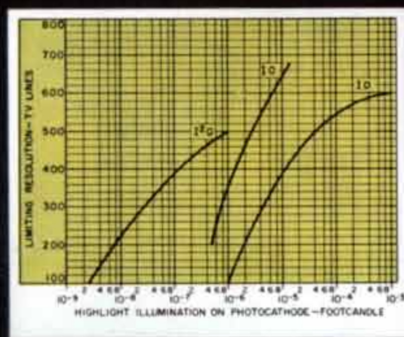


Fig. 3


Fig. 4


Fig. 5

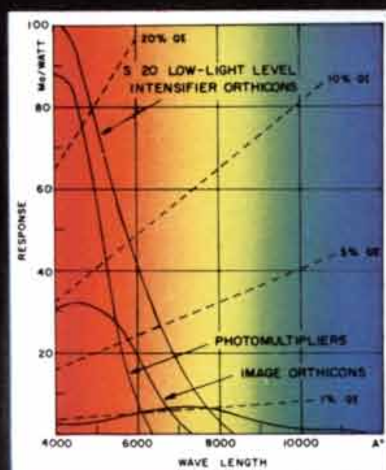


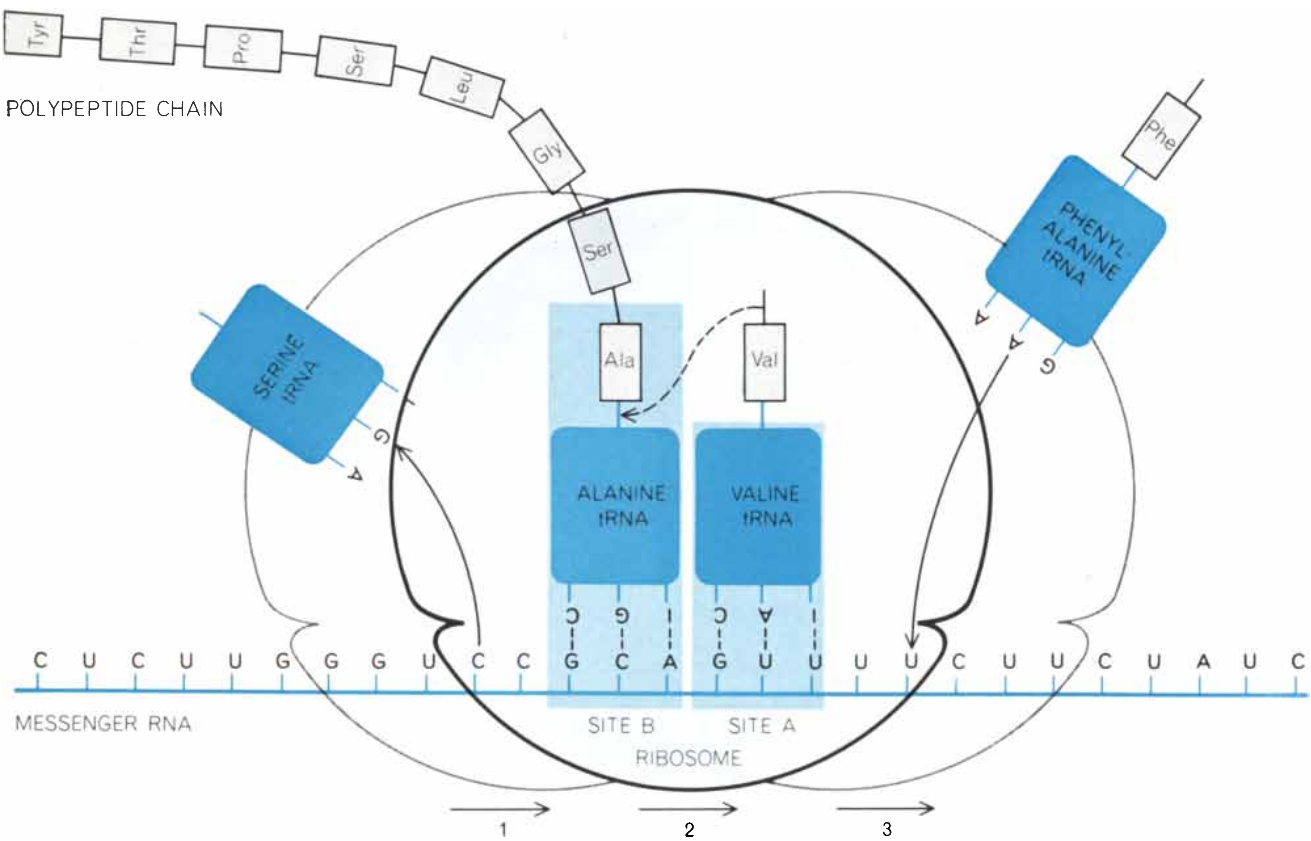
Fig. 6

THE GENETIC CODE: III

The central theme of molecular biology is confirmed by detailed knowledge of how the four-letter language embodied in molecules of nucleic acid controls the 20-letter language of the proteins

by F. H. C. Crick

The hypothesis that the genes of the living cell contain all the information needed for the cell to reproduce itself is now more than 50 years old. Implicit in the hypothesis is the idea that the genes bear in coded form the detailed specifications for the thousands of kinds of protein molecules the cell requires for its moment-to-moment existence: for extracting energy from molecules assimilated as food and for repairing itself as well as for replication. It is only within the past 15 years, however, that insight has been gained into the chemical nature of the genetic material and how its molecular structure can embody coded instructions that can be "read" by the machinery in the cell responsible for synthesizing protein molecules. As the result of intensive work by many investigators the story



SYNTHESIS OF PROTEIN MOLECULES is accomplished by the intracellular particles called ribosomes. The coded instructions for making the protein molecule are carried to the ribosome by a form of ribonucleic acid (RNA) known as "messenger" RNA. The RNA code "letters" are four bases: uracil (U), cytosine (C), adenine (A) and guanine (G). A sequence of three bases, called a codon, is required to specify each of the 20 kinds of amino acid, identified here by their abbreviations. (A list of the 20 amino acids and their abbreviations appears on the next page.) When linked end to end, these amino acids form the polypeptide chains of which proteins are composed. Each type of amino acid is transported to the ribosome by a particular form of "transfer" RNA (tRNA), which carries an anticodon that can form a temporary bond with one of the codons in messenger RNA. Here the ribosome is shown moving along the chain of messenger RNA, "reading off" the codons in sequence. It appears that the ribosome has two binding sites for molecules of tRNA: one site (*A*) for positioning a newly arrived tRNA molecule and another (*B*) for holding the growing polypeptide chain.

AMINO ACID	ABBREVIATION
ALANINE	Ala
ARGININE	Arg
ASPARAGINE	AspN
ASPARTIC ACID	Asp
CYSTEINE	Cys
GLUTAMIC ACID	Glu
GLUTAMINE	GluN
GLYCINE	Gly
HISTIDINE	His
ISOLEUCINE	Ileu
LEUCINE	Leu
LYSINE	Lys
METHIONINE	Met
PHENYLALANINE	Phe
PROLINE	Pro
SERINE	Ser
THREONINE	Thr
TRYPTOPHAN	Tryp
TYROSINE	Tyr
VALINE	Val

TWENTY AMINO ACIDS constitute the standard set found in all proteins. A few other amino acids occur infrequently in proteins but it is suspected in each case that they originate as one of the standard set and become chemically modified after they have been incorporated into a polypeptide chain.

of the genetic code is now essentially complete. One can trace the transmission of the coded message from its original site in the genetic material to the finished protein molecule.

The genetic material of the living cell is the chainlike molecule of deoxyribonucleic acid (DNA). The cells of many bacteria have only a single chain; the cells of mammals have dozens clustered together in chromosomes. The DNA molecules have a very long backbone made up of repeating groups of phosphate and a five-carbon sugar. To this backbone the side groups called bases are attached at regular intervals. There are four standard bases: adenine (A), guanine (G), thymine (T) and cytosine (C). They are the four "letters" used to spell out the genetic message. The exact sequence of bases along a length of the DNA molecule determines the structure of a particular protein molecule.

Proteins are synthesized from a standard set of 20 amino acids, uniform throughout nature, that are joined end to end to form the long polypeptide chains of protein molecules [*see illustration at left*]. Each protein has its own characteristic sequence of amino acids. The number of amino acids in a polypeptide chain ranges typically from 100 to 300 or more.

The genetic code is not the message itself but the "dictionary" used by the cell to translate from the four-letter language of nucleic acid to the 20-letter language of protein. The machinery of the cell can translate in one direction only: from nucleic acid to protein but not from protein to nucleic acid. In making this translation the cell employs a variety of accessory molecules and mechanisms. The message contained in DNA is first transcribed into the similar molecule called "messenger" ribonucleic acid—messenger RNA. (In many viruses—the tobacco mosaic virus, for example—the genetic material is simply RNA.) RNA too has four kinds of bases as side groups; three are identical with those found in DNA (adenine, guanine and cytosine) but the fourth is uracil (U) instead of thymine. In this first transcription of the genetic message the code letters A, G, T and C in DNA give rise respectively to U, C, A and G. In other words, wherever A appears in DNA, U appears in the RNA transcription; wherever G appears in DNA, C appears in the transcription, and so on. As it is usually presented the dictionary of the genetic code employs the letters found in RNA (U, C, A, G) rather than those found in DNA (A, G, T, C).

The genetic code could be broken easily if one could determine both the amino acid sequence of a protein and the base sequence of the piece of nucleic acid that codes it. A simple comparison of the two sequences would yield the code. Unfortunately the determination of the base sequence of a long nucleic acid molecule is, for a variety of reasons, still extremely difficult. More indirect approaches must be used.

Most of the genetic code first became known early in 1965. Since then additional evidence has proved that almost all of it is correct, although a few features remain uncertain. This article describes how the code was discovered and some of the work that supports it.

Scientific American has already presented a number of articles on the genetic code. In one of them ["The Genetic Code," October, 1962] I explained that the experimental evidence (mainly indirect) suggested that the code was a triplet code: that the bases on the messenger RNA were read three at a time and that each group corresponded to a particular amino acid. Such a group is called a codon. Using four symbols in groups of three, one can form 64 distinct triplets. The evidence indicated that most of these stood for one amino acid or another, implying that an amino acid was usually represented by several codons. Adjacent amino acids were coded by adjacent codons, which did not overlap.

In a sequel to that article ["The Genetic Code: II," March, 1963] Marshall W. Nirenberg of the National Institutes of Health explained how the composition of many of the 64 triplets had been determined by actual experiment. The technique was to synthesize polypeptide chains in a cell-free system, which was made by breaking open cells of the colon bacillus (*Escherichia coli*) and extracting from them the machinery for protein synthesis. Then the system was provided with an energy supply, 20 amino acids and one or another of several types of synthetic RNA. Although the exact sequence of bases in each type was random, the proportion of bases was known. It was found that each type of synthetic messenger RNA directed the incorporation of certain amino acids only.

By means of this method, used in a quantitative way, the *composition* of many of the codons was obtained, but the *order* of bases in any triplet could not be determined. Codons rich in G were difficult to study, and in addition a few mistakes crept in. Of the 40 codon compositions listed by Nirenberg in his article we now know that 35 were correct.

The Triplet Code

The main outlines of the genetic code were elucidated by another technique invented by Nirenberg and Philip Leder. In this method no protein synthesis occurs. Instead one triplet at a time is used to bind together parts of the machinery of protein synthesis.

Protein synthesis takes place on the comparatively large intracellular structures known as ribosomes. These bodies travel along the chain of messenger RNA, reading off its triplets one after another and synthesizing the polypeptide chain of the protein, starting at the amino end (NH_2). The amino acids do not diffuse to the ribosomes by themselves. Each amino acid is joined chemically by a special enzyme to one of the codon-recognizing molecules known both as soluble RNA (sRNA) and transfer RNA (tRNA). (I prefer the latter designation.) Each tRNA molecule has its own triplet of bases, called an anticodon, that recognizes the relevant codon on the messenger RNA by pairing bases with it [*see illustration on page* 55].

Leder and Nirenberg studied which amino acid, joined to its tRNA molecules, was bound to the ribosomes in the presence of a particular triplet, that is, by a "message" with just three letters. They did so by the neat trick of passing the mixture over a nitrocellulose filter that retained the ribosomes. All the tRNA molecules passed through the filter except the ones specifically bound to the ribosomes by the triplet. Which they were could easily be decided by using mixtures of amino acids in which one kind of amino acid had been made artificially radioactive, and determining the amount of radioactivity absorbed by the filter.

For example, the triplet GUU retained the tRNA for the amino acid valine, whereas the triplets UGU and UUG did not. (Here GUU actually stands for the trinucleoside diphosphate GpUpU.) Further experiments showed that UGU coded for cysteine and UUG for leucine.

Nirenberg and his colleagues synthesized all 64 triplets and tested them for their coding properties. Similar results have been obtained by H. Gobind Khorana and his co-workers at the University of Wisconsin. Various other groups have checked a smaller number of codon assignments.

Close to 50 of the 64 triplets give a clearly unambiguous answer in the binding test. Of the remainder some evince only weak binding and some bind more than one kind of amino acid. Other results I shall describe later suggest that the multiple binding is often an artifact of the binding method. In short, the binding test gives the meaning of the majority of the triplets but it does not firmly establish all of them.

The genetic code obtained in this way, with a few additions secured by other methods, is shown in the table below. The 64 possible triplets are set out in a regular array, following a plan

SECOND LETTER

FIRST LETTER	U		C		A		G		THIRD LETTER
U	UUU	Phe	UCU		UAU	Tyr	UGU	Cys	U
	UUC		UCC	Ser	UAC		UGC		C
	UUA	Leu	UCA		UAA	OCHRE	UGA	?	A
	UUG		UCG		UAG	AMBER	UGG	Tryp	G
C	CUU		CCU		CAU	His	CGU		U
	CUC	Leu	CCC	Pro	CAC		CGC	Arg	C
	CUA		CCA		CAA	GluN	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU		ACU		AAU	AspN	AGU	Ser	U
	AUC	Ileu	ACC	Thr	AAC		AGC		C
	AUA		ACA		AAA	Lys	AGA	Arg	A
	AUG	Met	ACG		AAG		AGG		G
G	GUU		GCU		GAU	Asp	GGU		U
	GUC	Val	GCC	Ala	GAC		GGC	Gly	C
	GUA		GCA		GAA	Glu	GGA		A
	GUG		GCG		GAG		GGG		G

GENETIC CODE, consisting of 64 triplet combinations and their corresponding amino acids, is shown in its most likely version. The importance of the first two letters in each triplet is readily apparent. Some of the allocations are still not completely certain, particularly for organisms other than the colon bacillus (*Escherichia coli*). "Amber" and "ochre" are terms that referred originally to certain mutant strains of bacteria. They designate two triplets, UAA and UAG, that may act as signals for terminating polypeptide chains.

that clarifies the relations between them.

Inspection of the table will show that the triplets coding for the same amino acid are often rather similar. For example, all four of the triplets starting with the doublet AC code for threonine. This pattern also holds for seven of the other amino acids. In every case the triplets *XYU* and *XYC* code for the same amino acid, and in many cases *XYA* and *XYG* are the same (methionine and tryptophan may be exceptions). Thus an amino acid is largely selected by the first two bases of the triplet. Given that a triplet codes for, say, valine, we know that the first two bases are GU, whatever the third may be. This pattern is true for all but three of the amino acids. Leucine can start with UU or CU, serine with UC or AG and arginine with CG or AG. In all other cases the amino acid is uniquely related to the first two bases of the triplet. Of course, the converse is often not true. Given that a triplet starts with, say, CA, it may code for either histidine or glutamine.

Synthetic Messenger RNA's

Probably the most direct way to confirm the genetic code is to synthesize a messenger RNA molecule with a strictly defined base sequence and then find the amino acid sequence of the polypeptide produced under its influence. The most extensive work of this nature has been done by Khorana and his colleagues. By a brilliant combination of ordinary chemical synthesis and synthesis catalyzed by enzymes, they have made long RNA molecules with various repeating sequences of bases. As an example, one RNA molecule they have synthesized has the sequence UGUGUGUGUGUG.... When the biochemical machinery reads this as triplets the message is UGU–GUG–UGU–GUG.... Thus we expect that a polypeptide will be produced with an alternating sequence of two amino acids. In fact, it was found that the product is Cys–Val–Cys–Val.... This evidence alone would not tell us which triplet goes with which amino acid, but given the results of the binding test one has no hesitation in concluding that UGU codes for cysteine and GUG for valine.

In the same way Khorana has made chains with repeating sequences of the type *XYZ*... and also *XXYZ*.... The type *XYZ*...would be expected to give a "homopolypeptide" containing one amino acid corresponding to the triplet *XYZ*. Because the starting point is not clearly defined, however, the homopolypeptides corresponding to *YZX*... and *ZXY*... will also be produced. Thus poly-AUC makes polyisoleucine, polyserine and polyhistidine. This confirms that AUC codes for isoleucine, UCA for serine and CAU for histidine. A repeating sequence of four bases will yield a single type of polypeptide with a repeating sequence of four amino acids. The general patterns to be expected in each case are set forth in the table on this page. The results to date have amply demonstrated by a direct biochemical method that the code is indeed a triplet code.

Khorana and his colleagues have so far confirmed about 25 triplets by this method, including several that were quite doubtful on the basis of the binding test. They plan to synthesize other sequences, so that eventually most of the triplets will be checked in this way.

The Use of Mutations

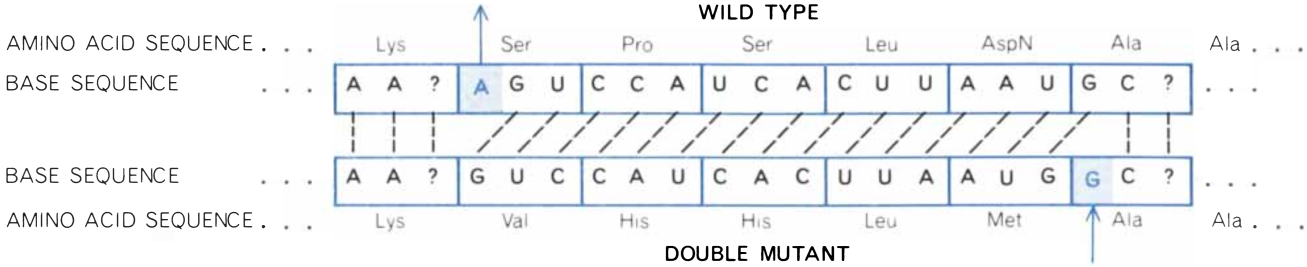
The two methods described so far are open to the objection that since they do not involve intact cells there may be some danger of false results. This objection can be met by two other methods of checking the code in which the act of protein synthesis takes place inside the cell. Both involve the effects of genetic mutations on the amino acid sequence of a protein.

It is now known that small mutations are normally of two types: "base substitution" mutants and "phase shift" mutants. In the first type one base is changed into another base but the total number of bases remains the same. In the second, one or a small number of bases are added to the message or subtracted from it.

There are now extensive data on base-substitution mutants, mainly from studies of three rather convenient proteins: human hemoglobin, the protein of tobacco mosaic virus and the *A* protein of the enzyme tryptophan synthetase obtained from the colon bacillus. At least 36 abnormal types of human hemoglobin have now been investigated by many different workers. More than 40 mutant forms of the protein of the tobacco mosaic virus have been examined by Hans Wittmann of the Max Planck Institute for Molecular Genetics in Tübingen and by Akita Tsugita and Heinz Fraenkel-Conrat of the University of California at Berkeley [see "The Genetic Code of a Virus," by Heinz Fraenkel-Conrat; Scientific American, October, 1964]. Charles Yanofsky and his group at Stanford University have characterized about 25 different mutations of the *A* protein of tryptophan synthetase.

RNA BASE SEQUENCE	READ AS						AMINO ACID SEQUENCE EXPECTED
$(XY)_n$	. . .	X Y X	Y X Y	X Y X	Y X Y	. . .	αβαβ
$(XYZ)_n$	. . .	X Y Z	X Y Z	X Y Z	. . .		ααα
	. . .	Y Z X	Y Z X	Y Z X	. . .		βββ
	. . .	Z X Y	Z X Y	Z X Y	. . .		γγγ
$(XXYZ)_n$	. . .	X X Y	Z X X	Y Z X	X Y Z	. . .	αβγδαβγδ
$(XYXZ)_n$	. . .	X Y X	Z X Y	X Z X	Y X Z	. . .	αβγδαβγδ

VARIETY OF SYNTHETIC RNA's with repeating sequences of bases have been produced by H. Gobind Khorana and his colleagues at the University of Wisconsin. They contain two or three different bases (*X*, *Y*, *Z*) in groups of two, three or four. When introduced into cell-free systems containing the machinery for protein synthesis, the base sequences are read off as triplets (*middle*) and yield the amino acid sequences indicated at the right.



"PHASE SHIFT" MUTATIONS help to establish the actual codons used by organisms in the synthesis of protein. The two partial amino acid sequences shown here were determined by George Streisinger and his colleagues at the University of Oregon. The sequences are from a protein, a type of lysozyme, produced by the bacterial virus T4. A pair of phase-shift mutations evidently removed one base, A, and inserted another, G, about 15 bases farther on. The base sequence was deduced theoretically from the genetic code.

The remarkable fact has emerged that in every case but one the genetic code shows that the change of an amino acid in a polypeptide chain could have been caused by the alteration of a single base in the relevant nucleic acid. For example, the first observed change of an amino acid by mutation (in the hemoglobin of a person suffering from sickle-cell anemia) was from glutamic acid to valine. From the genetic code dictionary on page 57 we see that this could have resulted from a mutation that changed either GAA to GUA or GAG to GUG. In either case the change involved a single base in the several hundred needed to code for one of the two kinds of chain in hemoglobin.

The one exception so far to the rule that all amino acid changes could be caused by single base changes has been found by Yanofsky. In this one case glutamic acid was replaced by methionine. It can be seen from the genetic code dictionary that this can be accomplished only by a change of *two* bases, since glutamic acid is encoded by either GAA or GAG and methionine is encoded only by AUG. This mutation has occurred only once, however, and of all the mutations studied by Yanofsky it is the only one not to back-mutate, or revert to "wild type." It is thus almost certainly the rare case of a double change. All the other cases fit the hypothesis that base-substitution mutations are normally caused by a single base change. Examination of the code shows that only about 40 percent of all the possible amino acid interchanges can be brought about by single base substitutions, and it is only these changes that are found in experiments. Therefore the study of actual mutations has provided strong confirmation of many features of the genetic code.

Because in general several codons stand for one amino acid it is not possible, knowing the amino acid sequence, to write down the exact RNA base sequence that encoded it. This is unfortunate. If we know which amino acid is changed into another by mutation, however, we can often, given the code, work out what that base change must have been. As an example, glutamic acid can be encoded by GAA or GAG and valine by GUU, GUC, GUA or GUG. If a mutation substitutes valine for glutamic acid, one can assume that only a single base change was involved. The only such change that could lead to the desired result would be a change from A to U in the middle position, and this would be true whether GAA became GUA or GAG became GUG.

It is thus possible in many cases (not in all) to compare the nature of the base change with the chemical mutagen used to produce the change. If RNA is treated with nitrous acid, C is changed to U and A is effectively changed to G. On the other hand, if double-strand DNA is treated under the right conditions with hydroxylamine, the mutagen acts only on C. As a result some C's are changed to T's (the DNA equivalent of U's), and thus G's, which are normally paired with C's in double-strand DNA, are replaced by A's.

If 2-aminopurine, a "base analogue" mutagen, is added when double-strand DNA is undergoing replication, it produces only "transitions." These are the same changes as those produced by hydroxylamine—plus the reverse changes. In almost all these different cases (the exceptions are unimportant) the changes observed are those expected from our knowledge of the genetic code.

Note the remarkable fact that, although the code was deduced mainly from studies of the colon bacillus, it appears to apply equally to human beings and tobacco plants. This, together with more fragmentary evidence, suggests that the genetic code is either the same or very similar in most organisms.

The second method of checking the code using intact cells depends on phase-shift mutations such as the addition of a single base to the message. Phase-shift mutations probably result from errors produced during genetic recombination or when the DNA molecule is being duplicated. Such errors have the effect of putting out of phase the reading of the message from that point on. This hypothesis leads to the prediction that the phase can be corrected if at some subsequent point a nucleotide is deleted. The pair of alterations would be expected not only to change two amino acids but also to alter all those encoded by bases lying between the two affected sites. The reason is that the intervening bases would be read out of phase and therefore grouped into triplets different from those contained in the normal message.

This expectation has recently been confirmed by George Streisinger and his colleagues at the University of Oregon. They have studied mutations in the protein lysozyme that were produced by the T4 virus, which infects the colon bacillus. One phase-shift mutation involved the amino acid sequence ...Lys—Ser—Pro—Ser—Leu—AspN—Ala—Ala—Lys.... They were then able to construct by genetic methods a double phase-shift mutant in which the corresponding sequence was ...Lys–Val–His–His–Leu–Met–Ala–Ala–Lys....

Given these two sequences, the reader should be able, using the genetic code dictionary on page 57, to decipher uniquely a short length of the nucleic acid message for both the original protein and the double mutant and thus deduce the changes produced by each of the phase-shift mutations. The correct result is presented in the illustration above. The result not only confirms several rather doubtful codons, such as UUA for leucine and AGU for serine, but also shows which codons are actually involved in a genetic message. Since the technique is difficult, however, it may not find wide application.

Streisinger's work also demonstrates what has so far been only tacitly as-

ANTICODON	CODON
U	A G
C	G
A	U
G	U C
I	U C A

"WOBBLE" HYPOTHESIS has been proposed by the author to provide rules for the pairing of codon and anticodon at the *third* position of the codon. There is evidence, for example, that the anticodon base I, which stands for inosine, may pair with as many as three different bases: U, C and A. Inosine closely resembles the base guanine (G) and so would ordinarily be expected to pair with cytosine (C). Structural diagrams for standard base pairings and wobble base pairings are illustrated at the bottom of this page.

sumed: that the two languages, both of which are written down in a certain direction according to convention, are in fact translated by the cell in the same direction and not in opposite directions. This fact had previously been established, with more direct chemical methods, by Severo Ochoa and his colleagues at the New York University School of Medicine. In the convention, which was adopted by chance, proteins are written with the amino (NH_2) end on the left. Nucleic acids are written with the end of the molecule containing a "5 prime" carbon atom at the left. (The "5 prime" refers to a particular carbon atom in the 5-carbon ring of ribose sugar or deoxyribose sugar.)

Finding the Anticodons

Still another method of checking the genetic code is to discover the three bases making up the anticodon in some particular variety of transfer RNA. The first tRNA to have its entire sequence worked out was alanine tRNA, a job done by Robert W. Holley and his collaborators at Cornell University [see "The Nucleotide Sequence of a Nucleic Acid," by Robert W. Holley; SCIENTIFIC AMERICAN, February]. Alanine tRNA, obtained from yeast, contains 77 bases. A possible anticodon found near the middle of the molecule has the sequence IGC, where I stands for inosine, a base closely resembling guanine. Since then Hans Zachau and his colleagues at the University of Cologne have established the sequences of two closely related serine tRNA's from yeast, and James Madison and his group at the U.S. Plant, Soil and Nutrition Laboratory at Ithaca, N.Y., have worked out the sequence of a tyrosine tRNA, also from yeast.

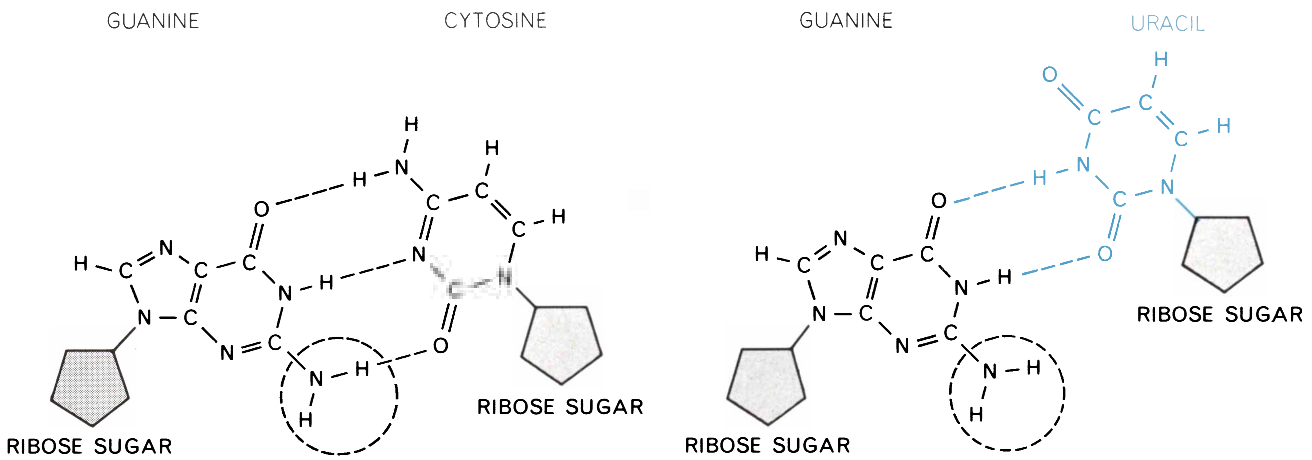
A detailed comparison of these three sequences makes it almost certain that the anticodons are alanine–IGC, serine–IGA and tyrosine–GΨA. (Ψ stands for pseudo-uridylic acid, which can form the same base pairs as the base uracil.) In addition there is preliminary evidence from other workers that an anticodon for valine is IAC and an anticodon for phenylalanine is GAA.

All these results would fit the rule that the codon and anticodon pair in an antiparallel manner, and that the pairing in the first two positions of the codon is of the standard type, that is, A pairs with U and G pairs with C. The pairing in the third position of the codon is more complicated. There is now good experimental evidence from both Nirenberg and Khorana and their co-workers that one tRNA can recognize several codons, provided that they differ only in the last place in the codon. Thus Holley's alanine tRNA appears to recognize GCU, GCC and GCA. If it recognizes GCG, it does so only very weakly.

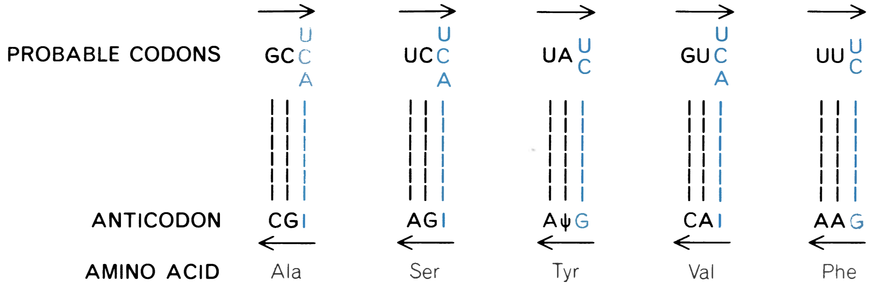
The "Wobble" Hypothesis

I have suggested that this is because of a "wobble" in the pairing in the third place and have shown that a reasonable theoretical model will explain many of the observed results. The suggested rules for the pairing in the third position of the anticodon are presented in the table at the top of this page, but this theory is still speculative. The rules for the first two places of the codon seem reasonably secure, however, and can be used as partial confirmation of the genetic code. The likely codon-anticodon pairings for valine, serine, tyrosine, alanine and phenylalanine satisfy the standard base pairings in the first two places and the wobble hypothesis in the third place [*see illustration on page 62*].

Several points about the genetic code remain to be cleared up. For example, the triplet UGA has still to be allocated.



STANDARD AND WOBBLE BASE PAIRINGS both involve the formation of hydrogen bonds when certain bases are brought into close proximity. In the standard guanine-cytosine pairing (*left*) it is believed three hydrogen bonds are formed. The bases are shown as they exist in the RNA molecule, where they are attached to 5-carbon rings of ribose sugar. In the proposed wobble pairing (*right*) guanine is linked to uracil by only two hydrogen bonds. The base inosine (I) has a single hydrogen atom where guanine has an amino (NH_2) group (*broken circle*). In the author's wobble hypothesis inosine can pair with U as well as with C and A (*not shown*).



CODON-ANTICODON PAIRINGS take place in an antiparallel direction. Thus the anticodons are shown here written backward, as opposed to the way they appear in the text. The five anticodons are those tentatively identified in the transfer RNA's for alanine, serine, tyrosine, valine and phenylalanine. Color indicates where wobble pairings may occur.

The punctuation marks—the signals for "begin chain" and "end chain"—are only partly understood. It seems likely that both the triplet UAA (called "ochre") and UAG (called "amber") can terminate the polypeptide chain, but which triplet is normally found at the end of a gene is still uncertain.

The picturesque terms for these two triplets originated when it was discovered in studies of the colon bacillus some years ago that mutations in other genes (mutations that in fact cause errors in chain termination) could "suppress" the action of certain mutant codons, now identified as either UAA or UAG. The terms "ochre" and "amber" are simply invented designations and have no reference to color.

A mechanism for chain initiation was discovered fairly recently. In the colon bacillus it seems certain that formylmethionine, carried by a special tRNA, can initiate chains, although it is not clear if all chains have to start in this way, or what the mechanism is in mammals and other species. The formyl group (CHO) is not normally found on finished proteins, suggesting that it is probably removed by a special enzyme. It seems likely that sometimes the methionine is removed as well.

It is unfortunately possible that a few codons may be ambiguous, that is, may code for more than one amino acid. This is certainly not true of most codons. The present evidence for a small amount of ambiguity is suggestive but not conclusive. It will make the code more difficult to establish correctly if ambiguity can occur.

Problems for the Future

From what has been said it is clear that, although the entire genetic code is not known with complete certainty, it is highly likely that most of it is correct. Further work will surely clear up the doubtful codons, clarify the punctuation marks, delimit ambiguity and extend the code to many other species. Although the code lists the codons that *may* be used, we still have to determine if alternative codons are used equally. Some preliminary work suggests they may not be. There is also still much to be discovered about the machinery of protein synthesis. How many types of tRNA are there? What is the structure of the ribosome? How does it work, and why is it in two parts? In addition there are many questions concerning the control of the rate of protein synthesis that we are still a long way from answering.

When such questions have been answered, the major unsolved problem will be the structure of the genetic code. Is the present code merely the result of a series of evolutionary accidents, so that the allocations of triplets to amino acids is to some extent arbitrary? Or are there profound structural reasons why phenylalanine has to be coded by UUU and UUC and by no other triplets? Such questions will be difficult to decide, since the genetic code originated at least three billion years ago, and it may be impossible to reconstruct the sequence of events that took place at such a remote period. The origin of the code is very close to the origin of life. Unless we are lucky it is likely that much of the evidence we should like to have has long since disappeared.

Nevertheless, the genetic code is a major milestone on the long road of molecular biology. In showing in detail how the four-letter language of nucleic acid controls the 20-letter language of protein it confirms the central theme of molecular biology that genetic information can be stored as a one-dimensional message on nucleic acid and be expressed as the one-dimensional amino acid sequence of a protein. Many problems remain, but this knowledge is now secure.

Solid Noble Gases

The simplest systems available for the study of a wide range of solid-state phenomena may be the crystal structures that are formed at very low temperatures by noble-gas atoms

by Gerald L. Pollack

In trying to understand a set of related physical phenomena it is often useful to ask, in the manner of the late Enrico Fermi: What is the hydrogen atom of the problem? A number of experimental and theoretical investigations conducted over the past decade suggest that the "hydrogen atom"—the simplest system—for the study of many solid-state phenomena may be the solid noble gases. The crystal structures that are formed at very low temperatures by noble-gas atoms have the essential features of more complex solids, but in prototype form. Hence when one calculates some property—say the heat capacity of an argon crystal—and the result disagrees with experiment, it is easier to know where to look for the trouble than it is in the analogous situation for complicated organic crystals or even metal crystals. It is basically for this reason that the solid noble gases have attracted increasing attention.

The mere existence of solid noble gases may come as a surprise to some readers. In actuality it was not long after the British group consisting of Lord Rayleigh, William Ramsay and William M. Travers had discovered argon, neon, krypton and xenon in the 1890's that these rare constituents of the atmosphere were first liquefied and then solidified. The noble gas helium, the most difficult of all the elements to liquefy and solidify, was first liquefied by the Dutch physicist Heike Kamerlingh Onnes in 1908. Helium was finally solidified in Kamerlingh Onnes' laboratory in 1926, just a few months after his death.

In this article I should like to describe some of the more important and actively pursued problems in the physics of the solid noble gases, problems involving such basic properties as vapor pressure, thermal expansivity, heat capacity and crystal growth. For some of these properties I shall briefly review what is known for solids in general and show what we gain in understanding from the study of solid noble gases.

The noble elements with which we are concerned are argon, neon, krypton and xenon. They appear at the far right of the periodic table of the elements, immediately following the halogens and immediately preceding the alkali metals. By this criterion helium and radon ought to be included also. The force between helium atoms is so weak, however, and the quantum-mechanical energy of the atoms is so large in comparison, that the latter predominates. That is why it is so difficult to make helium atoms cohere closely enough to form a solid. In order to solidify helium a pressure of at least 25 atmospheres is required; unless this pressure is applied helium will remain gaseous or liquid no matter how low its temperature. As for radon, it is so rare and so strongly radioactive that it has attracted very little work since its discovery by the German physicist Friedrich Ernst Dorn in 1900. This is unfortunate; as we shall see below, there is special interest in the heavier noble gases, and data on radon would be valuable.

The occurrence of a noble-gas element at the end of each period in the periodic table reflects the stable, closed-shell configuration of the electrons in a noble-gas atom. The name "noble" came to be applied to these elements because they are inert compared with other elements. In fact, until recently it had been thought that noble-gas atoms could be bonded to form only one or two different molecules. Now many more compounds containing these atoms have been synthesized and a full chemistry of the "inert" gases is developing [see "The Chemistry of the Noble Gases," by Henry Selig, John G. Malm and Howard H. Claassen; SCIENTIFIC AMERICAN, May, 1964].

Of the four basic types of solid (molecular, ionic, metallic and covalent) the crystal structures formed by the solid noble gases fall into the category of molecular solids [*see illustration on page 66*]. Molecular solids have two main features. First, all the sites in the crystal lattice are occupied by identical molecules (in this case atoms). Second, the lattice molecules interact with weak forces, principally van der Waals forces (named after the Dutch physicist J. D. van der Waals), which decrease inversely as the sixth power of the distance between molecules. In comparison the force between two charged ions in an ionic crystal or a metallic crystal decreases more slowly: inversely as the square of the distance between ions.

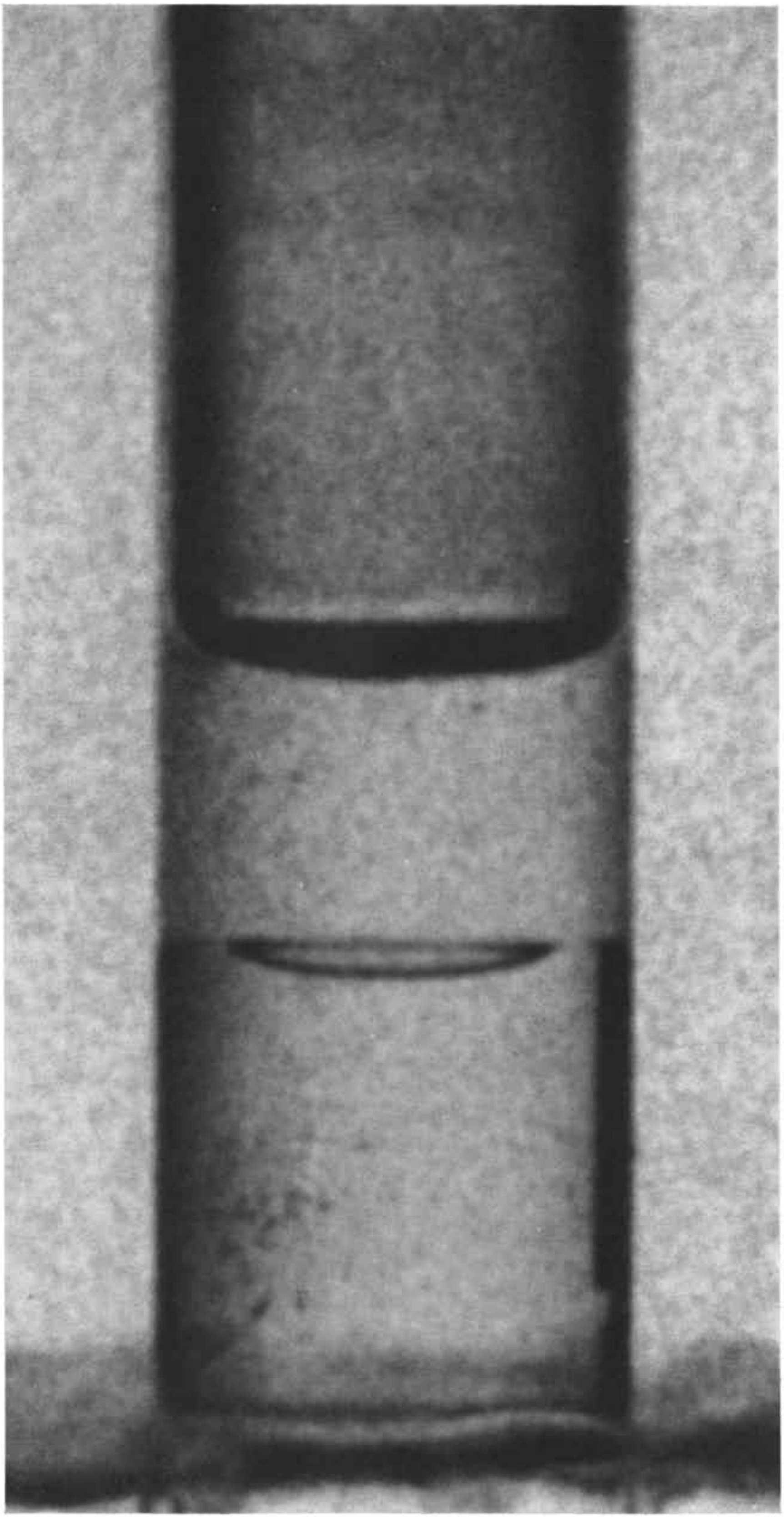
Recent work by Laurens Jansen and his co-workers at the Battelle Institute in Geneva has made it clear that the distinction between molecular solids and covalent solids is not sharp. The exchange, or sharing, of electrons between neighboring molecules, a characteristic of covalent crystals, also occurs to some extent in noble-gas crystals. In the crystal lattice of argon, for example, this exchange accounts for about .1 percent of the energy holding the crystal together. The importance of electron exchange increases when the atoms are brought closer together by either increasing the pressure or lowering the temperature.

The advantages of testing theoretical calculations on solid noble gases can be examined more quantitatively with the help of "potential curves": curves that relate the potential energy involved in the interaction of two neighboring identical atoms to the distance between the atoms [*see top illustration on page 67*]. The rate of change of the potential-energy function with distance is the attracting force between the atoms. In practice, of course, the interaction of two individual atoms is difficult to measure, and information about such potential functions must usually be deduced indirectly from the properties of bulk samples.

Potential curves are useful for understanding atomic interactions because they are easy to interpret intuitively. Consider the curve for one argon atom approaching another [*see top illustration on page 67*]. At any given separation the approaching atom behaves as though it were moving on the curve under the influence of gravity, somewhat like a car on a roller coaster. Where the potential curve is almost flat—for example at the large separations on the extreme right in the illustration—the argon atoms attract each other only weakly and tend to move together very slowly. On the other hand, if an argon atom is placed at a distance from another argon atom corresponding to the bottom of the "well" of the potential curve, it will remain there at rest. The attracting force at this point is zero, since the potential energy does not change with separation distance there. Actually this point is close to the smallest interatomic separation distance observed in argon crystals. If an atom at the bottom of the well were to be slightly displaced in either direction, it would oscillate around the minimum, just as a marble would oscillate in a bowl with a similar cross section. This oscillation corresponds to raising the energy of the atom, say by raising the temperature of the crystal.

As the temperature increases, the oscillations in the bowl increase in amplitude until finally the atom has enough energy to move off to the right and escape the attracting force of its neighbor. This corresponds to melting of the crystal, or, more accurately, to subliming. Many modern theories of melting are essentially sophisticated expressions of this idea.

Once the general shape of a potential curve is determined it can be characterized quantitatively by two factors: the depth of the well (ε) and the separation distance at which the potential is zero (σ). The well depth ε corresponds to the minimum energy necessary for one atom to escape from its neighbor. One can calculate the temperature that roughly corresponds to the energy ε. When the solid is at this temperature,

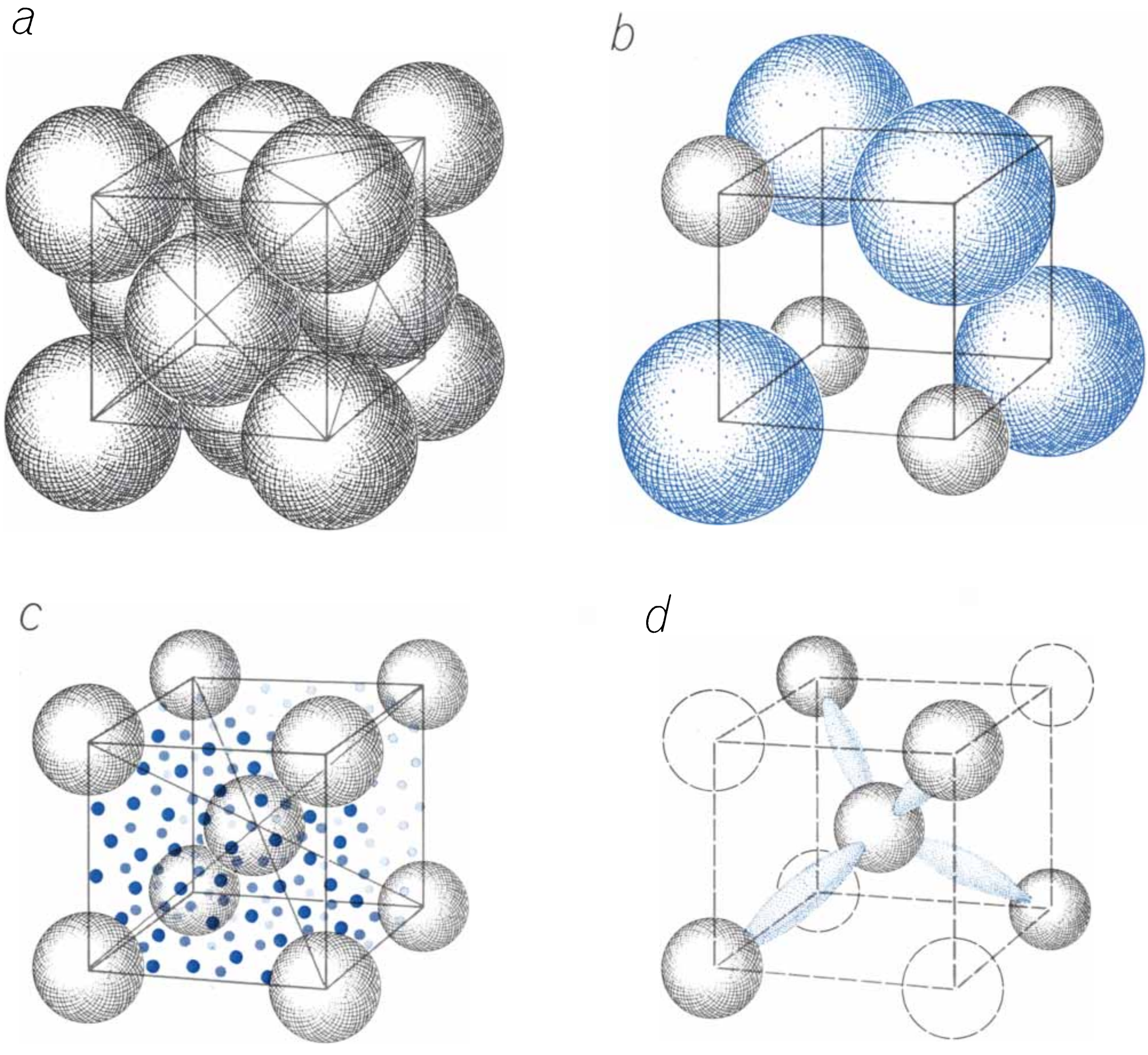


SOLID ARGON is grown in a glass chamber that is slowly lowered into a bath of liquid nitrogen boiling at 77 degrees Kelvin (degrees centigrade above absolute zero). The solid argon occupies roughly the bottom third of the chamber. Pure argon gas (*top third of chamber*) is continuously supplied to replace the condensing gas. The vapor first liquefies and the resulting liquid (*middle third of chamber*) freezes into a solid from the bottom up. All three phases are quite transparent to visible light; the translucent appearance of the part containing the argon gas is caused by condensation on the inner wall of the chamber.

something roughly akin to melting takes place: the crystal should break apart completely.

The distance σ is equal to the hard-core radius of the interacting atoms. The steep rise at the left for the noble-gas potential curves corresponds to the strong repulsions the atoms exert on each other when they get very close together. Another distance factor useful in characterizing the interatomic potential is r_o, the distance from the center of one atom to the equilibrium position of its neighbor. This is a convenient measure of the range of the interatomic force. For mathematical convenience it is usually best to express potential curves with only two factors: ε and σ. Choosing them fixes r_o.

The characteristic and simplifying features of the potential curves for noble gases are the small well depths (in other words, neighboring noble-gas atoms are only loosely held together) and the small range of the attracting force (in other words, as noble-gas atoms become separated from their neighbors by distances greater than r_o their interaction forces diminish rapidly). Before we go on to specific examples of how these potential curves can be used to calculate solid properties, let us first examine another side of the coin.



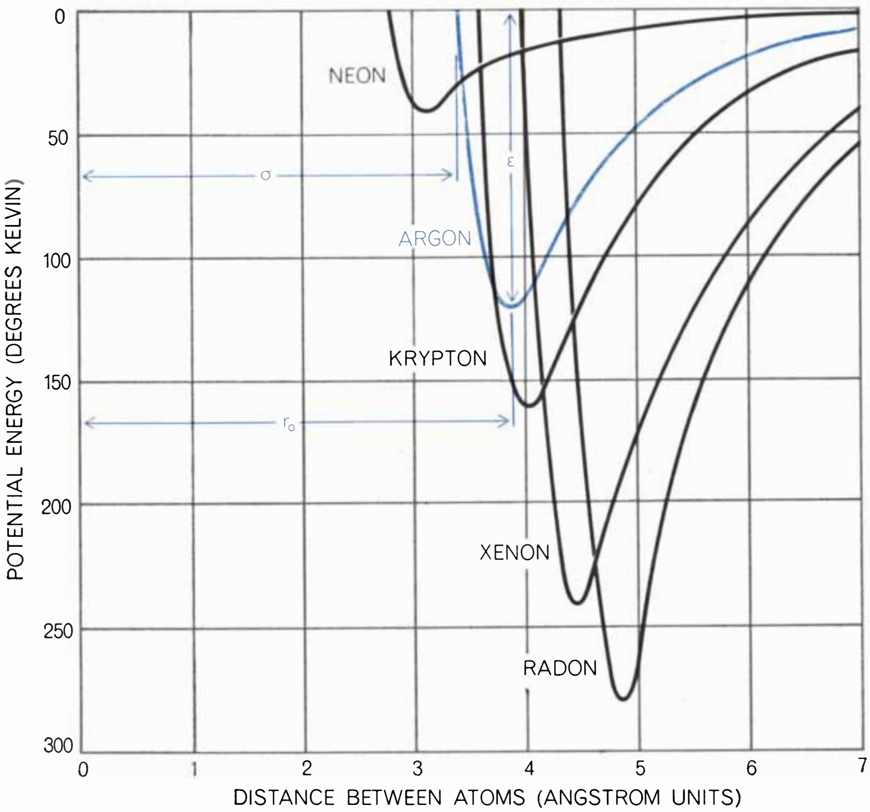
CRYSTAL STRUCTURES of the four basic types of solid are illustrated on this page. The molecular solid formed by argon atoms (*a*) has two main features. First, all the sites in the crystal lattice are occupied by identical particles. Second, the lattice particles interact with weak forces. The argon crystal consists of a large "face-centered cubic" lattice: one atom at each corner of the unit cube and one atom at the center of each face. In an ionic solid, represented here by sodium chloride, or ordinary table salt (*b*), alternate lattice sites at each corner of the unit cube are occupied by sodium ions (*black*) and chlorine ions (*color*). These charged particles strongly attract each other and strongly repel identical particles. In a metallic crystal of pure sodium (*c*) all the lattice sites in the "body-centered cubic" structure are occupied by identical sodium ions. In the space between the sodium ions there is an electron "gas" composed of electrons that are free to move in an applied electric field. The free electrons contribute an attracting force that offsets the repelling force between the ions, so that the metal crystal is stable. In a covalent solid, represented here by diamond (*d*), the atoms are held together by covalent bonds (*color*), or the sharing of electrons between adjacent atoms. In diamond each carbon atom is located symmetrically at the center of four identical atoms, which form the corners of a tetrahedron. This multiple connectiveness of strong bonds is at the root of the hardness of diamond.

Theoretical tractability is often bought only at the expense of experimental intractability; although some properties can be calculated rather easily, they can be measured only with difficulty.

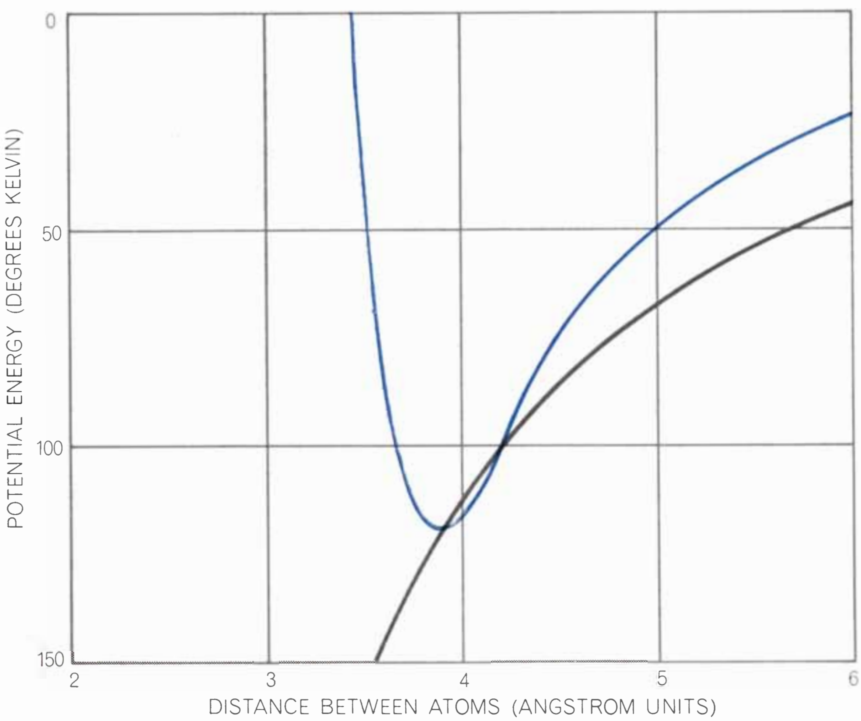
The central experimental difficulty in studying solid noble gases arises from the very low temperatures that must be maintained and measured when one is working with these solids. If one expresses the potential well depths as temperatures in degrees Kelvin (degrees centigrade above absolute zero), one obtains the following values: for argon, about 120 degrees Kelvin; for neon, about 36 degrees K.; for krypton, about 160 degrees K., and for xenon, about 228 degrees K. The equilibrium separation distances for these potential minimums, on the other hand, all fall at values close to one another in the neighborhood of four angstrom units (four hundred-millionths of a centimeter). Actually the respective crystals melt at temperatures well below those calculated, because not all bonds need to be broken to form a liquid from a solid and because some atoms have enough energy to escape the crystal lattice even at very low temperatures.

The temperature and pressure at which the solid, liquid and gaseous phases of a substance are in equilibrium is known as the triple point of the substance. In the phase diagram for argon at the bottom of the next page the curve that separates the solid phase from the liquid phase at temperatures higher than the triple-point temperature is called the melting curve. For the noble elements with which we are concerned this melting curve rises sharply. In order to study solid argon at room temperature (300 degrees K.), for example, it is necessary to apply a pressure of about 15,000 atmospheres. All of this means that unless one wants to study special high-pressure effects, requiring special apparatus and techniques, the temperature range of interest for the solid noble gases falls below their triple points. The actual triple points of the noble elements are given in the table on page 69, along with their respective boiling points and some comparison points for other cryogenic substances.

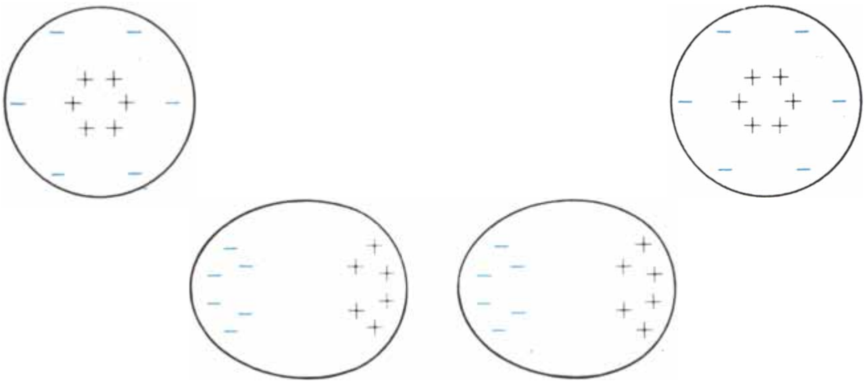
The simplest way to keep a large volume of a substance cold is to surround the containing vessel with a cryogenic liquid that is boiling at the desired temperature. This method is particularly useful when large amounts of energy are to be expended in the substance at a constant temperature, for instance in X-ray diffraction experi-



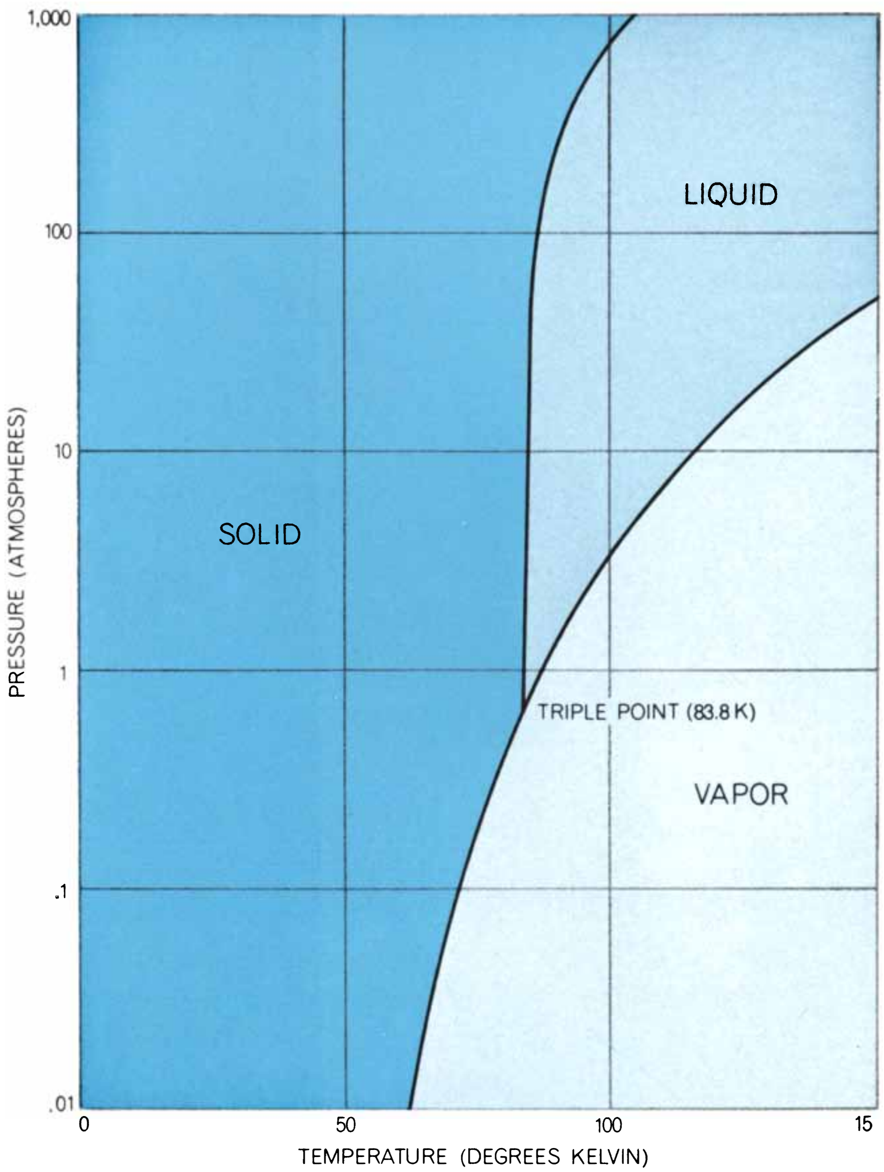
POTENTIAL CURVES of the five noble gases that can be solidified at atmospheric pressure are useful for understanding the interactions of two neighboring identical atoms. A potential curve can be characterized by two factors: the depth of the potential well (ε) and the separation distance at which the potential is zero (σ). The symbol r_0 denotes the distance from the center of one atom to the equilibrium position of the neighboring one.



ENLARGEMENT of the "true" potential curve for argon (*color*) is shown with the Coulomb potential curve for argon (*black*), which arises from electrostatic forces that can exist between two ions of opposite charge. For a noble gas the "true" potential function can be described in terms of Coulomb-like potentials among simple distributions of charges.



ELECTROSTATIC FORCE does not ordinarily exist between two argon atoms that are far apart (*top*), since the centers of both positive and negative charges lie at the center of each atom and are equidistant from the charges of the other atom. As the two atoms approach each other, however, their stable charge configurations may become equivalent to two dipoles (*bottom*); this in turn influences the attracting potential they experience.



PHASE DIAGRAM FOR ARGON shows the characteristically steep melting curve that separates the solid phase from the liquid phase at temperatures higher than that at the triple point (the point at which the solid, liquid and gaseous phases are in equilibrium). This means that unless one wants to study special high-pressure effects, the temperature range of interest in the study of the solid noble gases falls below their respective triple points.

ments. At such low temperatures only a few cryogenic coolants are available; the proper combination of a weak attracting force and a low mass is not encountered frequently in nature. One must also bear in mind that the experimental measurements of the properties of the solid noble gases must yield extremely accurate data in order to discern the small effects predicted by theory.

I have mentioned that two ions interact with a force that is proportional to the inverse square of the distance between them. The potential energy for such a force is inversely proportional to the distance; this relation is represented by the black curve accompanying the argon potential curve in the bottom illustration on the preceding page. This interaction potential, called the Coulomb potential after the 18th-century French physicist Charles Augustin Coulomb, is the same for all pairs of charged particles, whether they are ions or ping-pong balls. Under certain circumstances such electrostatic forces can also exist between two uncharged bodies. For example, if the positive and negative charges in a body with no net charge are suitably distributed, a wide range of potentials is possible.

Consider the case of an isolated argon atom [*see top illustration at left*]. Since the total positive charge (the charge of the nucleus) equals the total negative charge (the charge of the electrons), the atom is electrically neutral. Moreover, the centers of both positive and negative charges lie at the center of the atom. Two such atoms that are far apart will exert no electrostatic force on each other, since the attraction of the positive charge on one to the negative charge on the other exactly equals the repulsion of the like charges.

As the two atoms approach each other, however, the mobile negative charge on one atom may become displaced so that the centers of positive and negative charges are not coincident; this atom is then said to have a dipole moment, which is the simplest charge configuration next to a single charge. Such a charge distribution can arise from an increase in the energy of the atom, resulting, say, from a collision with another particle. A little reflection shows that a dipole in one atom tends to form a similar dipole in the other atom, because the increased attraction of closer, opposite charges more than offsets the decreased repulsion of more distant, like charges. Thus as the two argon atoms approach each other their stable charge configurations may be equivalent to two dipoles; this in turn influences the attracting potential the atoms experience.

The problem of determining the "true" potential function for a molecule in a crystal lattice is usually a difficult one; most molecules are composed of many different atoms and these interact with the atoms of other molecules in a complicated way. If the particles in the lattice are single atoms such as argon, however, the problem becomes somewhat simpler because considerations of relative orientation are then unimportant. For this situation the "true" potential function can be accurately described by the electrostatic dipole effect of a pair of argon atoms. This accounts in large part for the quickened experimental interest in the crystal structures of the solid noble gases.

Several interesting properties of noble-gas crystals depend critically on the quality of the particular crystal used in the experiment. A perfect noble-gas crystal would consist of a large "face-centered cubic" lattice: one atom at each corner of the unit cube and one atom at the center of each face [*see illustration on page 66*]. Real crystals deviate from this ideal in many ways and for many reasons. For example, X-ray diffraction studies of argon crystals conducted by Charles S. Barrett and Lothar Meyer at the University of Chicago have shown that small amounts of impurities in the argon can shift the structure from face-centered cubic to "hexagonal close-packed." Other experimental evidence indicates that even in pure argon crystals some hexagonal close-packed structure is mixed in with the predominant face-centered cubic structure.

Fortunately it is possible to grow quite imperfect noble-gas crystals with properties that are close to those of a perfect crystal or that differ from a perfect crystal in some simple way. For this reason one can generally make do with noble-gas samples consisting of single crystals.

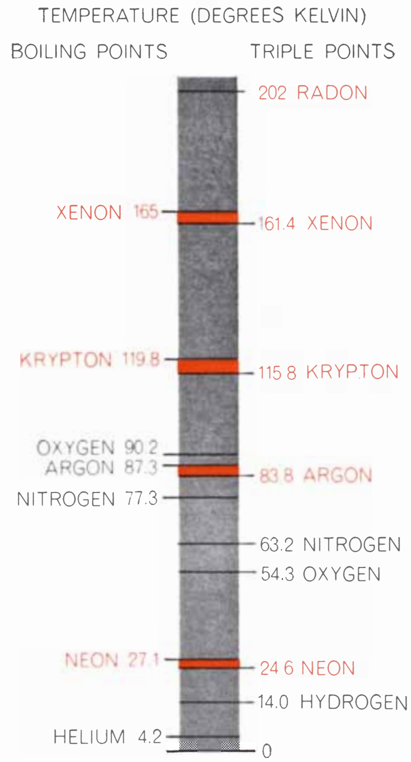
An adequate definition of a single crystal is singularly elusive; one man's single crystal is another man's polycrystal. It is probably safe to define a single crystal as a solid in which the lattice orientation is reasonably constant. Such a crystal can still contain impurities, although not too many of them or too large ones—that would distort the lattice. The crystal can also have vacant sites in its lattice, interstitial atoms and a variety of other defects that are difficult to eliminate in practice but do not basically disturb the lattice orientation.

A class of properties that depend strongly on the quality of a given crystal involves the transport of energy or matter from one end of the crystal to another. Important properties of this kind include thermal conductivity (involving the transport of heat energy) and diffusivity (involving the transport of atoms). As a rule in such transport properties any disruption in the crystal lattice, such as occurs in the region where two or more single crystals of different orientation join, speeds mass transport and slows energy transport.

Large single crystals of argon, neon, krypton and xenon have proved to be extremely difficult to grow. The essence of the trouble seems to lie with the short-range, weak van der Waals forces that make these solids so interesting in the first place. To see why this is so let us examine the crystallization process.

Picture a crystal being formed by condensation of atoms from a vapor. Atoms collide with the cold walls of a container, lose their energy and stick to the walls. Other atoms then collide with them, lose their energy and in turn stick to them. The continuation of the process builds up a solid. Actually crystals can be grown either by the solidification of a liquid or by deposition from a vapor. The latter holds for growth at pressures below the triple-point vapor pressure and is easier to visualize. (It is the "hydrogen atom" of the crystal-growth problem.) In practice, however, most noble-gas crystals are grown by freezing a liquid.

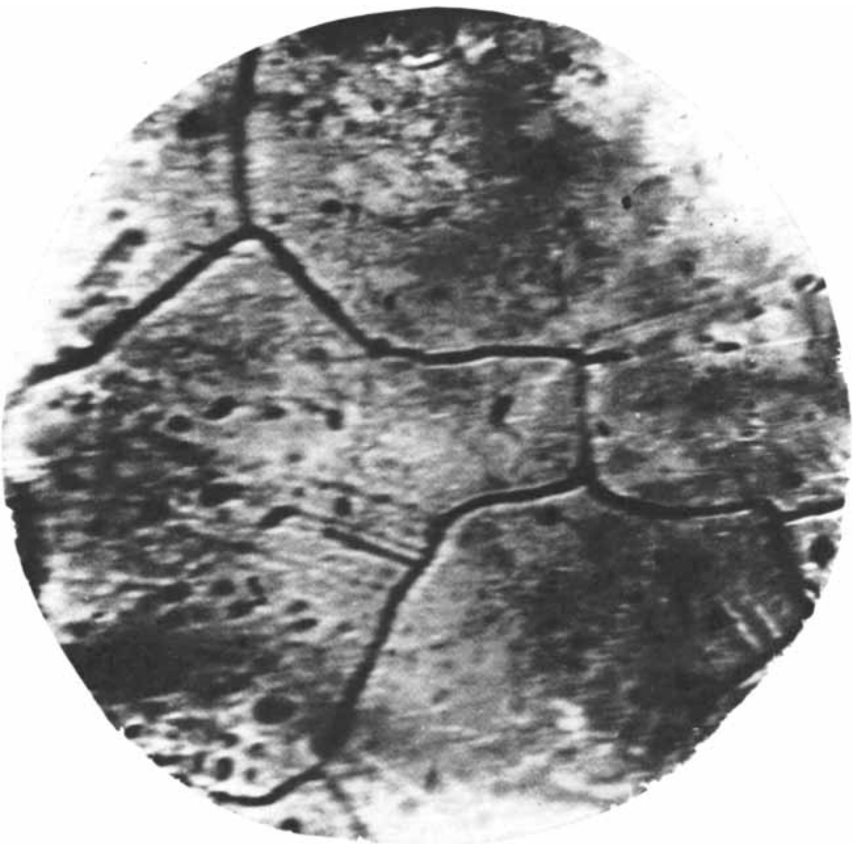
Suppose now that a few atoms, say 100, have stuck to the container walls and formed a rudimentary single crystal perhaps 25 angstroms on a side. In order for this single crystal to become 10 million times larger (that is, an inch on a side) the atoms that are still in the vapor and soon to condense must condense onto this block in the proper lattice positions. The atoms in the block exert forces on the condensing atoms when the condensing atoms come near enough; the potential energy is at a minimum at the lattice sites. If these forces are strong and long-range, the atoms still in the vapor and far from the crystal will be pulled down onto the proper lattice sites and the formation of a single crystal will be furthered one more step. This is what happens in metals, for example. If the forces are weak and short-range, as in noble gases, however, then the atoms condensing from the vapor will have a correspondingly smaller tendency to condense on a lattice site and may easily condense in another position either on the solid or near it, thus forming the nucleus of a new crystal with an orientation different from that of the original crystal.



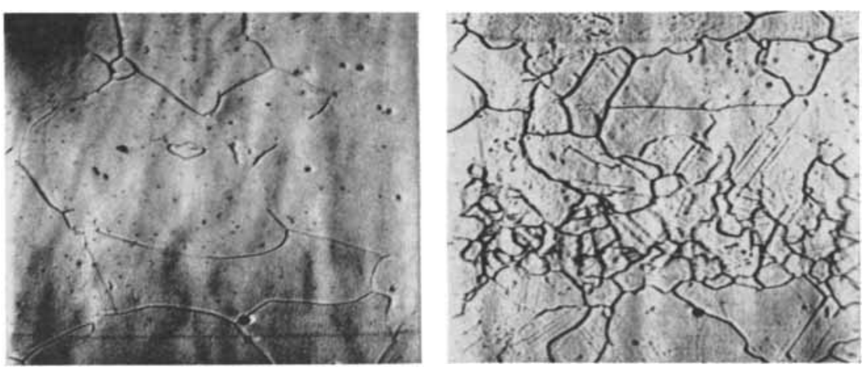
TRIPLE POINTS of the five noble elements that have triple points are presented in this table, along with their respective boiling points (except that of radon) and some comparison points for several other cryogenic elements. Helium has no triple point.

A solid that contains many crystals with differing orientations is a polycrystal. A measure of how readily a polycrystal forms is called the nucleation probability, that is, the probability per unit area and unit time that a new crystal will be started. It is clear that the kind of van der Waals forces noble-gas atoms exert on each other lead to high nucleation probabilities. According to current crystal-growth theories, the nucleation probability depends on the square of the well depth and the temperature at which the crystal is grown. Estimating with this formula, the nucleation probability for argon crystals is about 25 times larger than the nucleation probability for copper crystals under analogous circumstances.

Notwithstanding all these problems, single crystals of noble-gas elements are extremely interesting and useful objects for solid-state experimentation. We therefore spent considerable effort in our laboratory at the National Bureau of Standards trying to grow single crystals of argon as large as possible. The work is now continuing with the help of some adventurous, but also painstaking, graduate students at Michigan State University. We have learned that crystal growth is still very much an art, and that by judicious manipulation of geometry, temperature gradients, pressure at growth, growth rate and other variables the effects of high nucleation probability can be somewhat lessened. Although we have not been able to grow single crystals alone, we have been able to grow single crystals about a centimeter on a side in a polycrystalline block. We have used solid argon, because high-purity argon is readily available and is the least costly of the noble gases. Experimental and theoretical experience indicate that the results for argon can be neatly carried over to the other noble-gas solids.



SINGLE CRYSTALS OF ARGON at the surface of a polycrystalline solid have been sharply demarcated from each other by the metallurgical technique of thermal etching. The faces of the single crystals are called grains and the more highly disordered regions between the grains (*dark lines*) are grain boundaries. As a result of the high degree of symmetry in the face-centered cubic lattices of the argon crystals, the grain boundaries tend at their trijunctures to intersect at angles of 120 degrees. Lighter striations visible on the single-crystal faces are probably slip lines, that is, lines demarcating regions in the crystal that have the same orientation but are slightly displaced. Photograph was made by E. N. Farabaugh of the National Bureau of Standards. Diameter is about two millimeters.



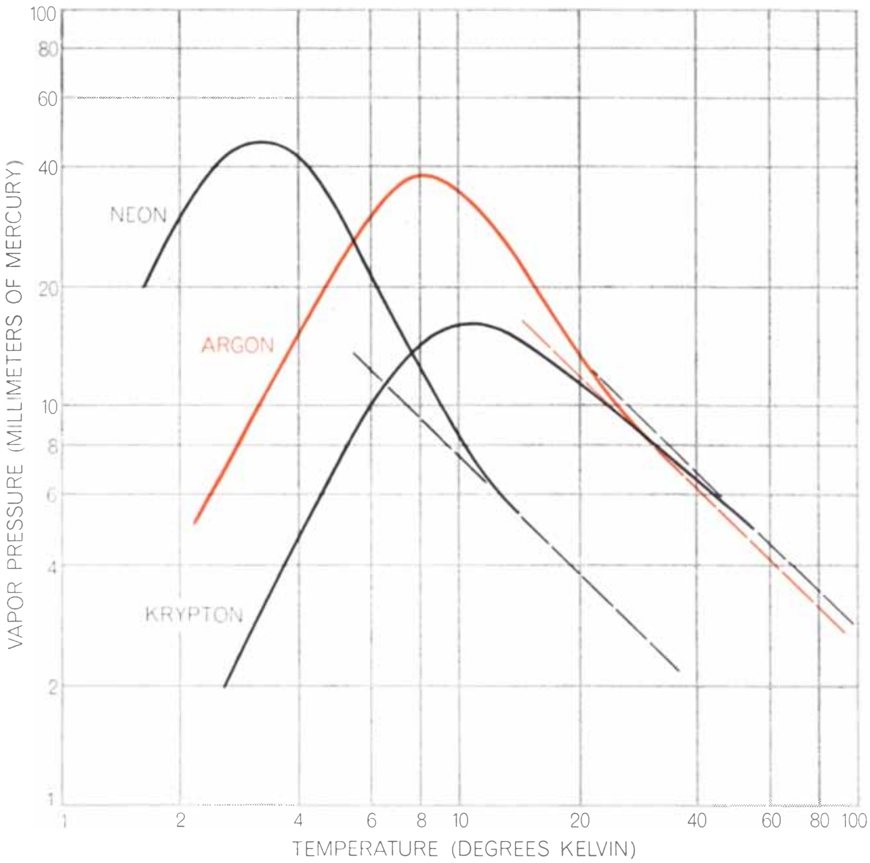
SURFACE ETCH PATTERNS for two argon crystals grown identically in all respects but growth rate are compared. The more quickly grown crystal (*right*) shows smaller average grain sizes and more slip lines than the more slowly grown crystal (*left*). It is from such photographs that one determines optimum growth conditions for large single crystals.

The argon crystals are grown in a glass chamber that is slowly lowered into a bath of liquid nitrogen boiling at 77 degrees K. [*see illustration on page 65*]. Pure argon gas is continuously supplied to the chamber to replace the condensing gas and the pressure is thus maintained at about one atmosphere inside the chamber. This means that the vapor first liquefies and the resultant liquid (called the melt) freezes into a solid from the bottom up. The interface between the solid and the liquid argon is at approximately 83.8 degrees K.; the interface between the liquid argon and the argon vapor is at approximately 87.3 degrees K., and the interface between the liquid nitrogen and the nitrogen vapor is at approximately 77 degrees K.

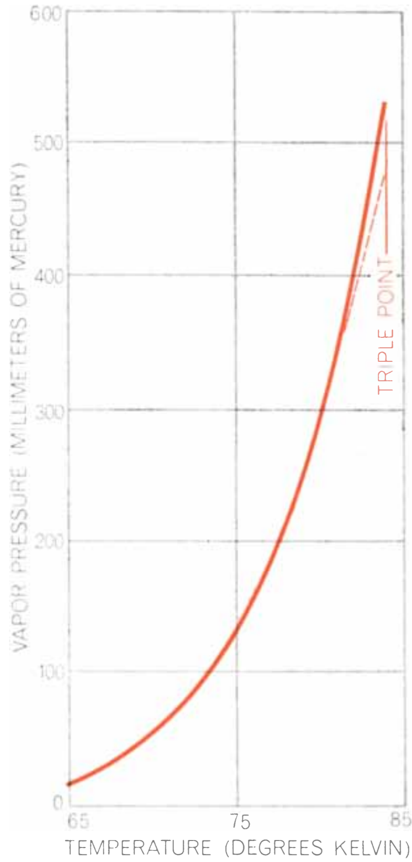
It is evident in the illustration that all three phases are quite transparent to visible light. In fact, solid argon has been used for a long time by spectroscopists as an inert matrix in which to embed molecules whose absorption and emission spectra are of special interest. The idea here is that the solid argon, which freely transmits light from short ultraviolet wavelengths to long infrared wavelengths, serves as a spectroscopically inert "host" background against which the absorption of the "guest" molecules can be easily detected [see "Frozen Free Radicals," by Charles M. Herzfeld and Arnold M. Bass; Scientific American, March, 1957].

Since most of the techniques used for growing noble-gas crystals have been adapted from metallurgy, it is natural to use analogous methods to analyze the argon solids. The most powerful tool for examining the quality of a single crystal is X-ray diffraction, but this requires removing the specimen from its growth chamber and mounting it suitably. This is a delicate procedure, although it is being used in successful experiments in the laboratory of R. O. Simmons at the University of Illinois. We chose a somewhat simpler technique, also common in metallurgy, called thermal etching.

The idea behind thermal etching is simple. Consider a solid surface and suppose part of this surface belongs to a single crystal and part belongs to



THERMAL-CONDUCTIVITY CURVES for argon, neon and krypton are compared. The thermal energy in an insulator is carried through the lattice by conceptual entities called phonons. In the broken parts of the curves the thermal conductivity is inversely proportional to the absolute temperature; in this region the phonons are scattered from each other in a way characterized as "umklapp" processes (from the German word meaning literally "flop over"). In a perfect crystal the rise in thermal conductivity as the temperature falls would continue indefinitely. In samples in which there are small crystals, however, phonons begin to collide with grain boundaries and other defects rather soon. This causes the "turndown" in the thermal-conductivity curves as the temperature decreases.



EFFECT OF VACANCIES on the sublimation pressure of solid argon is exaggerated in this graph. The sublimation pressure of a solid is a measure of the tendency for atoms to escape from the surface of the solid. The sublimation pressure for a real argon crystal (*broken line*) is about 1 percent lower than the sublimation pressure for a perfect argon crystal (*solid line*) owing to vacancies.

another single crystal. Between these single-crystal faces there is a region that is more highly disordered and in which the solid has no long-range orientation. In this situation the single crystals are called grains, and the region between the grains is a grain boundary [*see illustrations on opposite page*].

If the crystals are heated slightly under low pressure, some surface atoms will acquire enough energy to escape from the potentials of their neighbors and enter the vapor phase. The solid is then said to be subliming. Now, the atoms on single-crystal surfaces are bonded tightly compared with the atoms in the boundary region, so that the boundary atoms tend to leave the surface more rapidly. Thus after a short time a line becomes visible between the single-crystal grains, owing to the indentations left behind by the subliming atoms. As evaporation proceeds the patterns become stronger until finally the single-crystal faces are demarcated from each other by etched grain boundaries. The size of the grains is therefore a measure of the size of the single crystals in the solid.

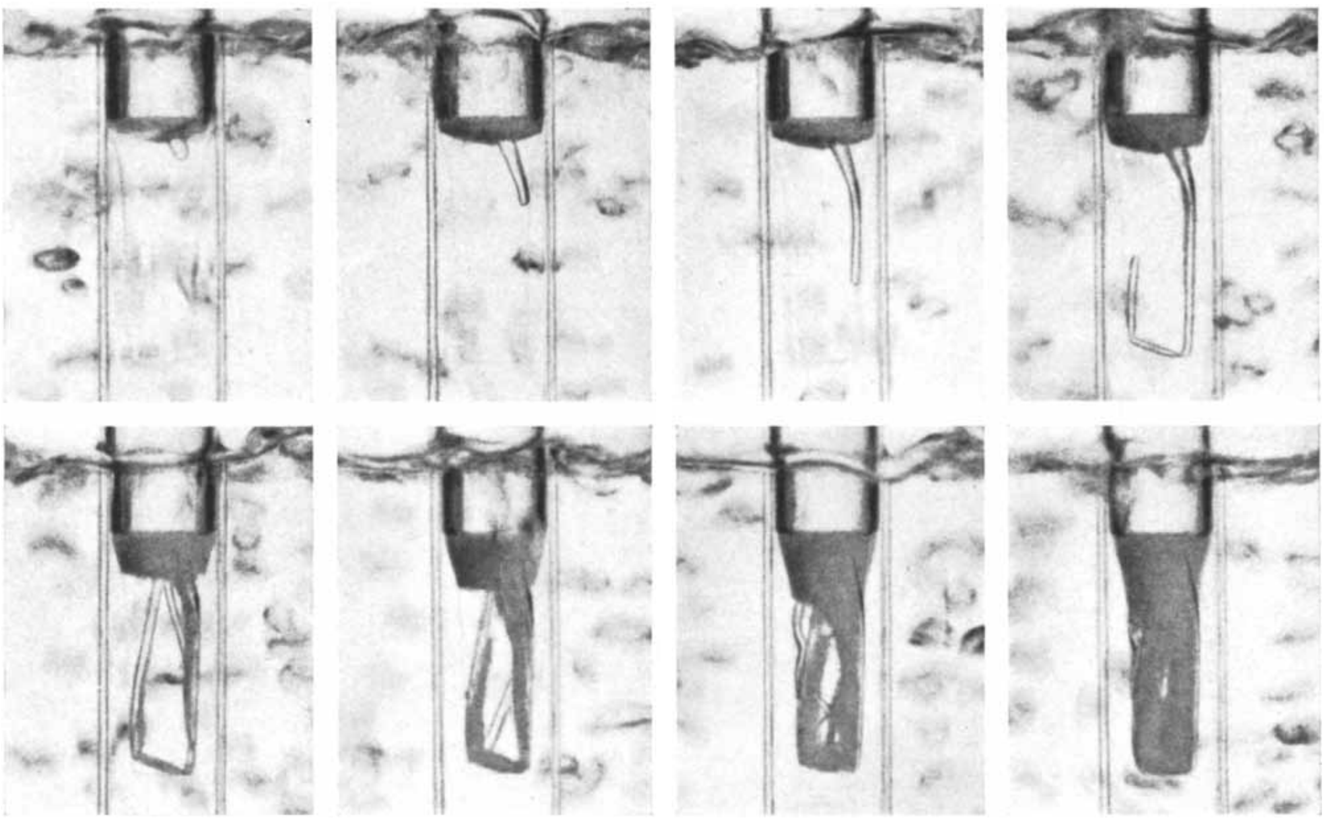
In addition to the preferential evaporation just described, there is another mechanism by which grain boundaries are etched, called selective migration. Not all the atoms pick up enough energy to escape the solid completely. Some atoms merely have enough energy to move along the surface. In order to minimize surface potential energy more molecules from between the grains tend to migrate onto single-crystal faces than vice versa. This tends to reinforce the formation of surface etch patterns. It is not yet clear which of the two mechanisms predominates, although some light may be shed on the subject by examining etch patterns on the surfaces of voids formed inside transparent noble-gas solids.

It is from photographs such as the ones on the opposite page that we determine optimum growth conditions for large single crystals. One of our findings is that grain area increases approximately linearly with decreasing growth rate. Unfortunately this simple rule breaks down as the single-crystal size gets close to the size of the growing chamber. Larger growing chambers require more elaborate cooling techniques in order to maintain uniform temperatures. In the course of these crystal-growth experiments many other interesting phenomena were observed. Further study of the "vapor snakes" shown in the photographs on the next page has been particularly interesting.

An example of an experiment for which currently obtainable noble-gas crystals are large enough is the measurement of thermal conductivity. The experimental procedure is straightforward. A small difference in temperature is maintained between the ends of a solid that is at some intermediate average temperature; the rate of transfer of heat energy from the warmer end to the colder end is proportional to the thermal conductivity [*see illustration at left on preceding page*]. The thermal energy in an insulator is carried through the lattice by conceptual entities called phonons, analogous to the photons associated with light energy. These phonons collide with each other and with impurities and other defects in the crystal, losing energy in both ways. If the phonons did not lose energy, thermal energy would travel through solids as waves analogous to sound waves.

Every thermal-conductivity curve has three major parts. To be specific, let us examine the curve for neon in the illustration at the left on the preceding page. In the broken part of the curve the thermal conductivity is inversely proportional to the absolute temperature; in this region the phonons are scattering from each other in the way characterized as "umklapp" processes (from the German word meaning literally "flop over"). Such a phonon cannot travel far without being scattered; indeed, the farther a phonon travels without losing energy in a collision, the larger the thermal conductivity. As the temperature decreases, the thermal conductivity increases, because phonons sufficiently energetic to take part in umklapp processes become scarcer. This is an especially interesting part of the curve since it helps in understanding just what the energy distribution in phonons is. Here is where the difficulty arises. In a perfect crystal the increase in thermal conductivity as the temperature falls would continue indefinitely. In a large single crystal it would continue until the mean free paths of the phonons became as long as the crystal. In samples in which there are small crystals, however, phonons begin to collide with grain boundaries and other defects rather soon. This causes the "turndown" in the thermal-conductivity curve as the temperature decreases. For neon crystals the thermal conductivity begins decreasing at mean free paths of only a ten-thousandth of a centimeter. Our new experiments should allow observation of mean free phonon paths 10,000 times longer than this in noble-gas crystals.

Another class of solid-state effects for whose study solid noble gases have been particularly interesting is crystal vacancies. These effects are present in all real solids, but in general they appear in combination with so many more complicated effects that their contribution cannot be filtered from the obtainable data. Vacancies in a crystal are simply unoccupied lattice sites. Although vacancies may be considered defects, or departures from a perfect lattice, they are generally not so far-reaching in their consequences as, say, grain boundaries. If a perfect crystal could be put together for an instant at some temperature above absolute zero and then left alone, vacancies would soon begin to form spontaneously but grain boundaries would probably never form. The reason for this is that the energy of the lattice particles, which de-



"VAPOR SNAKES" were observed by the author in the course of his crystal-growth experiments with argon. The liquid-nitrogen level appears at the top of these photographs, which were selected from a motion-picture film. The splotches were caused by bubbles in the boiling liquid nitrogen. Within the growing chamber the vapor phase (*top*) is separated from the liquid phase by a thick, snowy crust. Below the crust the liquid is trapped in a deep well formed by the crystalline argon. The solid-liquid interface is only faintly visible because the indexes of refraction of the two phases are approximately the same. In the first frame a spherical vapor bubble has formed in the liquid under the crust as a result of partial solidification of the liquid. In succeeding frames the vapor snake propagates through the liquid, rebounding off the crystalline walls. The core of the snake is gaseous and its solid sheath extends over the tip. In the last frame of the series the entire volume of the well has been converted from a liquid to a crustlike solid.

termines the macroscopic temperature, is statistically distributed among the particles. Accordingly not all atoms vibrate equally around their equilibrium positions, and indeed some of them will have enough energy to break loose from the potential field of their neighbors and either escape the crystal entirely, if they have sufficient energy, or else lodge at some interstitial site. The number of atoms that have enough energy to leave their original sites and hence create a lattice vacancy in this manner increases with temperature, so that an argon crystal at equilibrium near its triple point has about 1 percent of its sites vacant. One can in fact construct theories in which the dissolution of the crystal as it melts is the result of exceeding some critical fraction of vacant sites.

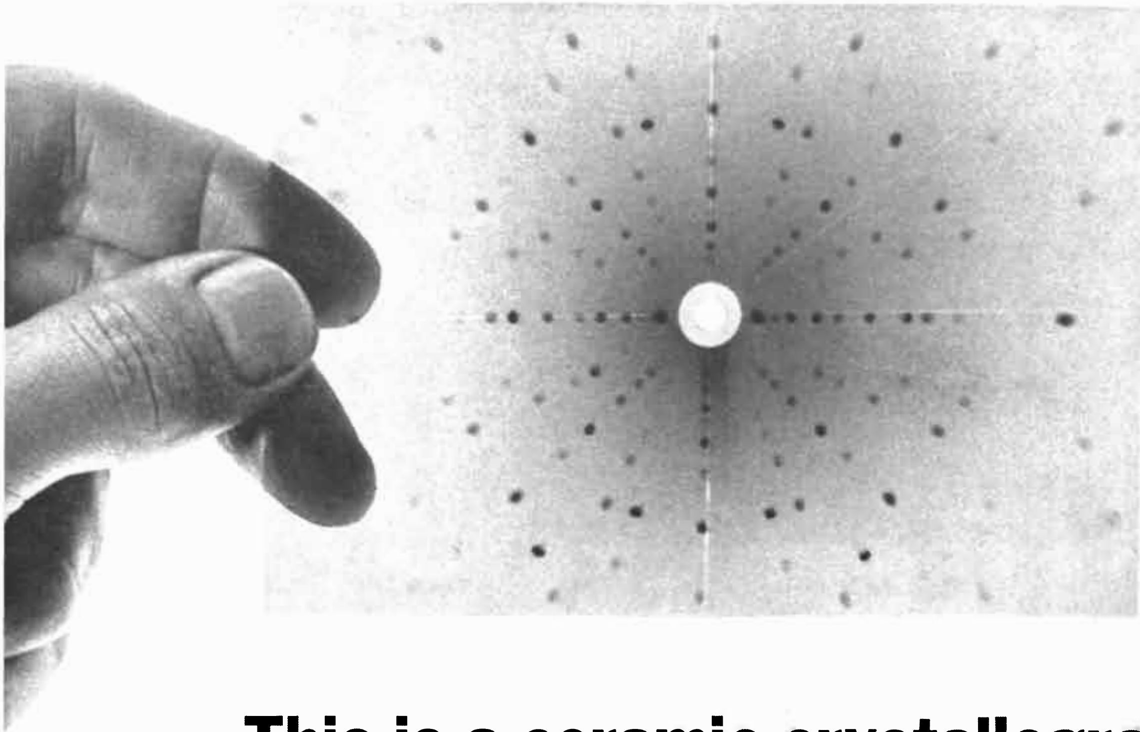
Let us now return to our model for thermal conductivity. I mentioned earlier that thermal energy is carried through the crystal by phonons and that these are representations of ordered vibrations of lattice particles. Now, the potential field at atoms adjoining a vacant site is different from the field near fully occupied sites, so that vibrations near such a part of the lattice are disturbed. In phonon language this turns out to mean that phonons are scattered from vacancies; in other words, the energy transfer through the lattice is impeded by vacancies. The thermal conductivity, therefore, decreases when the temperature of the crystal falls low enough, so that the mean free phonon paths approach the distance between vacancies. This is the same kind of effect as that caused by phonon scattering from grain boundaries. It turns out, however, that the temperature dependence of the decreasing thermal conductivity is different for different kinds of defects, so that in any specific case one can determine whether the scattering is from point defects (vacancies or impurities), line defects or higher-order defects.

The effect of vacancies on the vapor pressure, or sublimation pressure, of a solid is much more difficult to observe and in fact has received only preliminary confirmation. The difficulty here, as in finding the static lattice energy of a metal, is that there are two effects, one increasing the sublimation pressure and one decreasing it. It is only the difference between these effects that is observable.

The sublimation pressure of a solid is really just a measure of the tendency for atoms to escape from the surface of the solid. Consider a single vacancy on the surface of a crystal. The surface atoms surrounding the vacant site each have only eight nearest neighbors compared with the nine they would have if the vacant site were occupied. This means that they tend to escape from the surface somewhat more easily, since the net potential well that each is in is only about eight-ninths as deep as it would be if the vacant site were occupied; this tends to raise the sublimation pressure.

There is an associated effect that more than compensates. The atom that would be occupying the now vacant site and would therefore have been available for escaping the surface and contributing to the vapor pressure cannot do so. Instead the atom below it is available. That atom, however, can only escape with difficulty because it has 11 nearest neighbors instead of the nine nearest neighbors the vacancy has. This tends to decrease the sublimation pressure. The net result of the two effects is that the sublimation pressure for a real crystal is lower than the sublimation pressure for a perfect crystal, owing to vacancies [*see illustration at right on page 71*]. The decrease in vapor pressure is most apparent when the vacancy concentration is high, for example near the triple-point temperature. The mathematical theory of the process shows that the effect on vapor pressure enters in the same form as in the theory for determining the fraction of vacant sites. Thus in argon the sublimation pressure near the triple point is expected to be 1 percent lower because of vacancies. From the exact shape of the actual sublimation-pressure curves one can determine the energy required to create a vacancy, a key factor in calculating solid-state properties. There has been increasing evidence recently that this energy is considerably higher than had been thought.

I have tried to present here some of the reasons why solid noble gases are of particular interest and some of the directions in which work on them has been proceeding. We have seen how several of the properties of solids are derivable from interatomic potentials and which features of the potentials are important for future study. In most textbooks solid noble gases are very briefly treated in chapters on simple solids. It is precisely because they are so simple, however, that the noble-gas solids are such a fruitful field of study; only a few new concepts are needed to start work, and an understanding of what goes on in these crystals can be remarkably refined.



This is a ceramic crystallogram. Exposure time: 45 minutes Development time: 30 minutes

Polaroid announces the XR-7 system for x-ray crystallography.

Every crystal has its atoms arranged in a network around several intersecting axes. Just how this network is structured will determine the crystal's properties. How the crystal will conduct heat or light or electricity, for example.

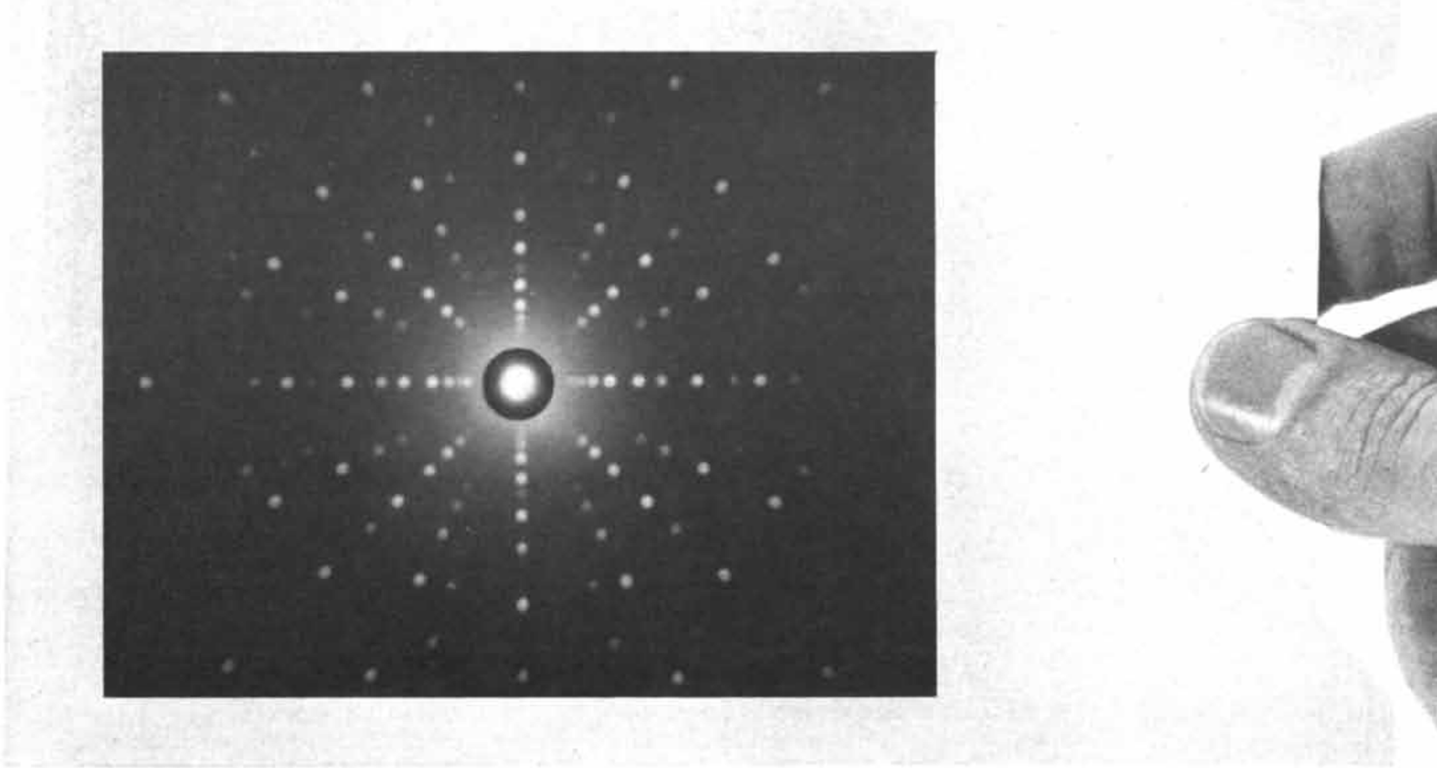
This atomic structure can be photographed. It's done by sending a beam of x-rays through the crystal (where they bounce off the atoms) and recording the pattern that emerges on film. The resulting picture is called a crystallogram.

Until now, crystallograms have been made with conventional x-ray film. The film has to be loaded in a darkroom. It needs very long exposures (hours in many cases). And it has to go through conventional darkroom developing and drying. That's a long time for one picture. When you consider that the first few crystallograms serve only to orient the crystal properly, you can see why it sometimes takes a whole day or more to analyze just one crystal.

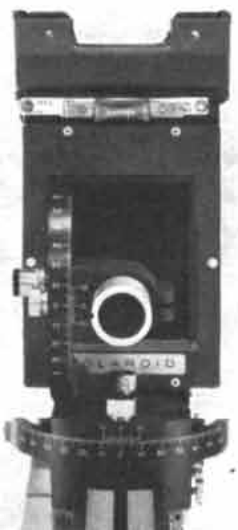
With the XR-7 system, Polaroid has come up with a dramatic shortcut. A crystallogram can now be made in 5 minutes, for instance, instead of an hour. In 45 seconds instead of 30 minutes. And so on.

The system, which is actually quite simple, has been designed for operation with most x-ray diffraction units and cameras. It is built around the capabilities of exceptionally sensitive (3000-speed) Polaroid Type 57 4x5 Land film.

The main part of the system is the Polaroid XR-7 cassette—essentially, a device to hold and expose the film. (The 4x5 film packet slides right into it.) When loaded, the inside of the cassette is a three-layer sandwich consisting of a lead-backed intensi-



This is a ceramic crystallogram. Exposure time: 4 minutes Development time: 10 seconds



fying screen with a special phosphor coating, the 4x5 film negative, and a unique air-filled pillow.

During exposure, the x-rays strike the intensifying screen which fluoresces and converts the x-ray information into visible light. This, in turn, exposes the 4x5 negative which the pillow holds in perfect contact with the screen.

After exposure, the packet is pulled out and the finished picture is peeled apart 10 seconds later. All darkroom time is completely eliminated. And because the film is so sensitive, exposures can be measured in minutes and seconds rather than hours and half hours. This unparalleled speed of the XR-7 system is, of course, its primary advantage. But that's not all.

With on-the-spot pictures, the crystallographer can make changes in crystal orientation right away. And can go on taking pictures in one continuous operation until he gets the alignment he wants.

The extreme sensitivity of the film offers still two more advantages. One, it permits using relatively low operating voltages. And two, it permits using greater distances between the crystal and the film plane (this produces an easier-to-read picture with larger and more widely separated diffraction spots). Because increased distances require longer exposures, nothing over 3 cm has ever been practical before. The XR-7 system can be used at 5 cm as well and a 5 cm extension comes with it.

What will this remarkable system mean to the people who work with it? Field tests have given us a good idea. They've already shown it can increase overall productivity anywhere from 2 to 8 times. Which amounts to a virtual revolution in x-ray crystallography.

Polaroid Corporation

NIGHT BLINDNESS

It has long been known that poor vision in dim light can be improved with vitamin A. Experiments with rats have now clarified exactly what it is the vitamin does

by John E. Dowling

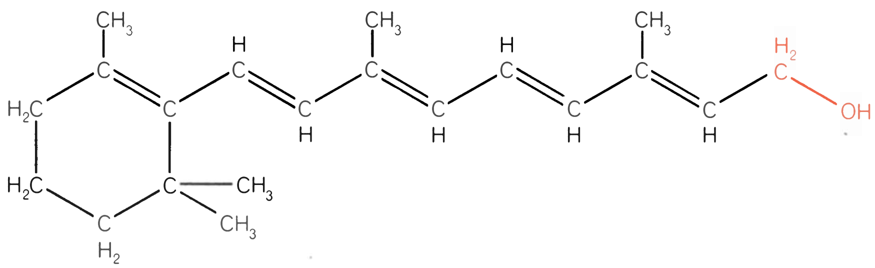
Night blindness—insensitivity of the eye to dim light—is one of the oldest diseases known to man, and a cure for the disease has also been known since early times. Medical papyruses of ancient Egypt prescribed the eating of raw liver as a specific for restoring night vision. Early in this century investigators identified the curative factor in liver as vitamin A. Beginning in the 1930's, George Wald of Harvard University and other workers went on to elucidate in detail the critical role played by vitamin A in vision [see "Eye and Camera," by George Wald; SCIENTIFIC AMERICAN, August, 1950].

In his classic study Wald showed that the visual pigment in the rods, the retinal cells responsible for vision in dim light, is a complex called rhodopsin that consists of the aldehyde form of vitamin A (also called retinene and retinaldehyde) joined to a large protein molecule named opsin. This pigment, on absorbing light, initiates excitation of the rod cell. The absorption of light also splits the rhodopsin molecule into vitamin A aldehyde and opsin, and the pigment is thereby "bleached" from purplish red to yellow. The chemical conversion of the vitamin A aldehyde into vitamin A can also be detected by a change in the color of the retina from yellow to white [*see illustration on the cover of this issue*].

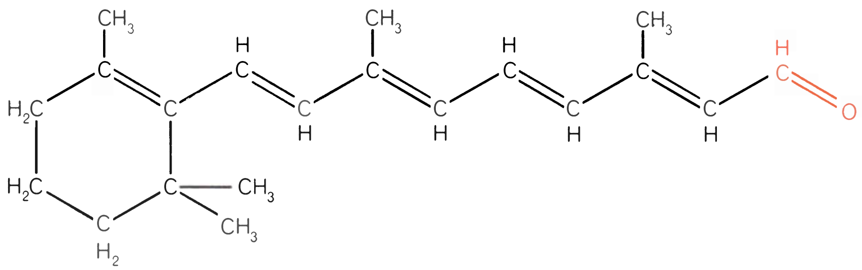
It then became evident that a deficiency of vitamin A would prevent rod cells from synthesizing sufficient rhodopsin and thus would produce night blindness. It has since been shown that a deficiency of the vitamin also reduces the sensitivity of the retinal cone cells, which serve for vision in ordinary light (such as daylight), because vitamin A is necessary for the synthesis of their visual pigments. The loss of cone sensitivity, however, is not usually great enough to be noticed in daylight; it is only in the faint light of nighttime that a person deficient in vitamin A becomes blind.

Soon after Wald's discovery investigators proceeded to test the visual effects of vitamin A deficiency, and of treatments with the vitamin, on human volunteers. Two puzzling findings emerged. Although some of the subjects who were fed an A-deficient diet showed signs of night blindness within a few days, others retained their normal visual sensitivity for months or even

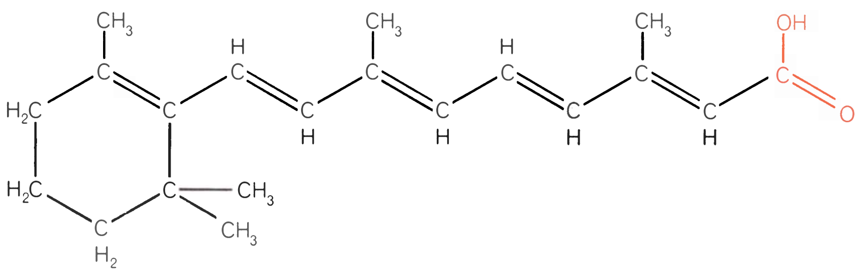
VITAMIN A



VITAMIN A ALDEHYDE



VITAMIN A ACID



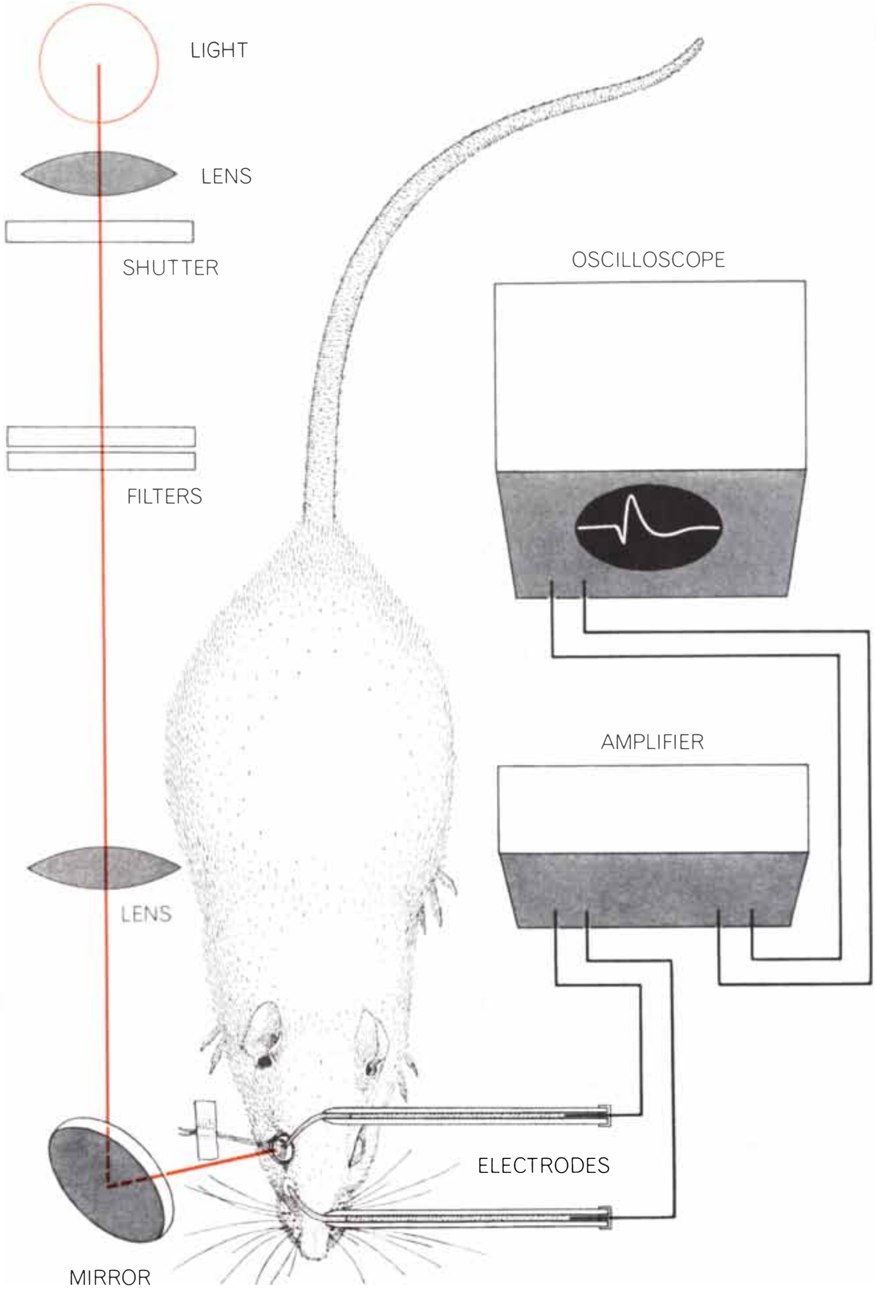
CHEMICAL STRUCTURES of three different molecular forms of vitamin A are depicted here; the parts of the molecules that differ are in color. The aldehyde form of vitamin A combines with a large protein molecule (opsin) to form a complex (rhodopsin) that is the visual pigment in the rods, the retinal cells responsible for vision in dim light. Vitamin A acid keeps rats healthy but is not converted into vitamin A or vitamin A aldehyde in rat tissues.

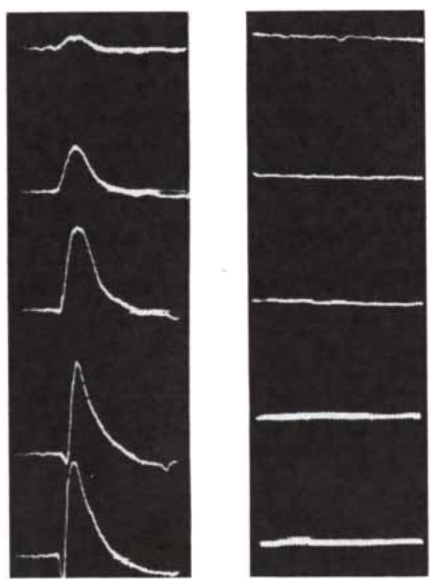
years. Secondly, of those who developed night blindness, some quickly recovered normal vision after vitamin A was restored to their diet, but in others the recovery was slow and occasionally was not complete even many months later. Not surprisingly, in view of the latter finding, the experiments with human subjects were discontinued.

A search began for possible explanations of these curious results. Thomas Moore of the Dunn Nutritional Laboratory in Cambridge, England, discovered one significant clue: adult human beings vary considerably in the amount of reserve vitamin A stored in their liver. Consequently a person with a large reserve might show no signs of deficiency for months after going on an A-deficient diet, whereas one with little storage of the vitamin would show effects almost immediately.

The second question—why some affected persons responded promptly to treatment with vitamin A while others did not—was less easy to answer. There were one or two suggestive findings. In the 1930's Katherine Tansley of University College London and others had found in experiments with animals that the visual cells in the retina degenerated when the animals were kept on an A-deficient diet for a prolonged period. More recently Ruth Hubbard of Harvard learned that opsin is rather unstable compared with rhodopsin. It seemed, therefore, that in the absence of a supply of vitamin A aldehyde for re-forming rhodopsin, opsin might break down with a consequent degeneration of the visual cell.

It was in the light of these findings that, as a student in Wald's laboratory at Harvard, I undertook a study of nutritional night blindness. As our experimental animal we used the rat, the retina of which contains mostly rod cells. We began by measuring the depletion of vitamin A, rhodopsin and opsin from the animal's body when it was fed a diet deficient in the vitamin. The results ran true to our expectations. First the animal drew on the store of vitamin A in its liver; in young rats this supply lasted about three to four weeks, and during that time the vitamin level in the animal's blood and the levels of rhodopsin and opsin in the retina remained normal. After the vitamin A reserve in the liver was used up the level of the vitamin in the blood fell precipitously. Within a few days the level of rhodopsin in the eye also began to decline; two to three weeks later the opsin level began to fall.



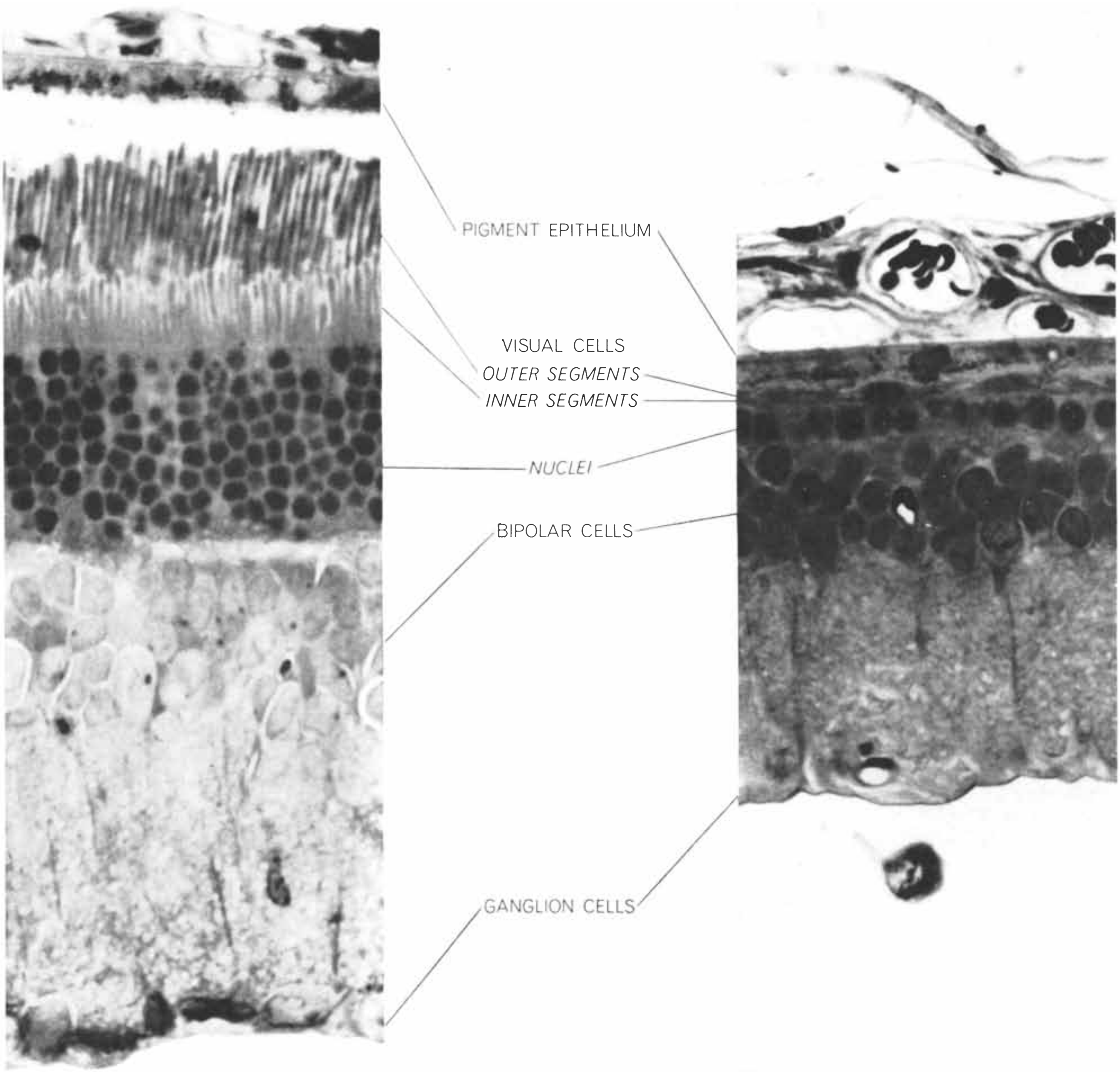


ELECTRORETINOGRAM (ERG) is used by the author to measure the visual sensitivity of rats' eyes to flashes of light of varying intensity. The optical system delivers a flash of light lasting a fiftieth of a second to the eye of an anesthetized rat. Cotton-wick electrodes inserted in the ends of glass pipettes filled with salt solution are placed on the edge of the cornea and on a shaved area of the cheek (the same as if the electrode were placed on the back of the eye). The eye's electrical response to a flash of light is amplified and recorded on an oscilloscope. Visual sensitivity is determined by the threshold of light intensity to which the eye will respond with a minimum ERG. The two sets of oscilloscope traces at right show the ERG responses of a normal rat (*left*) and a rat that has been on a vitamin-A-deficient diet for 10 months (*right*). The second rat is blind. Its loss of visual sensitivity increased exponentially, or at a logarithmic rate.

How did this depletion correlate with the animal's vision? As a measure of its visual sensitivity we resorted to the electroretinogram (ERG), a gross electrical response of the retina to a flash of light. Cotton-wick electrodes are placed on the eye of the anesthetized animal, and the eye's electrical response to a flash of light is amplified and recorded on an oscilloscope. The eye's sensitivity is determined by the threshold of light intensity to which it will respond with a minimum ERG.

During the first three to four weeks of a rat's subsistence on the vitamin-A-deficient diet, while the rhodopsin level in the eye remained normal, there was no detectable loss of visual sensitivity. By the fifth week, with a decline in the rhodopsin level, the ERG response also began to decline: it took more light to evoke the minimal electrical reaction. By the eighth week, when the rhodopsin level had dropped to 15 to 20 percent of normal, the ERG threshold had risen by a factor of almost 1,000, that is, the light intensity had to be 1,000 times stronger to produce a response. In general, as the rhodopsin level fell, the loss of visual sensitivity increased exponentially, or at a logarithmic rate.

Up to this point there was apparently no permanent damage to the eye. The retina could be restored to yield a normal ERG response within a few days simply by giving the rat a large dose of vitamin A. Thus the eye's loss and recovery of sensitivity was uncomplicated, in the sense that it paralleled the usual behavior of the organ in adapting to the dark after adapting to bright light. We found, by using the ERG test, that during the process of dark adaptation the sensitivity of the rat's eye bears a loga-



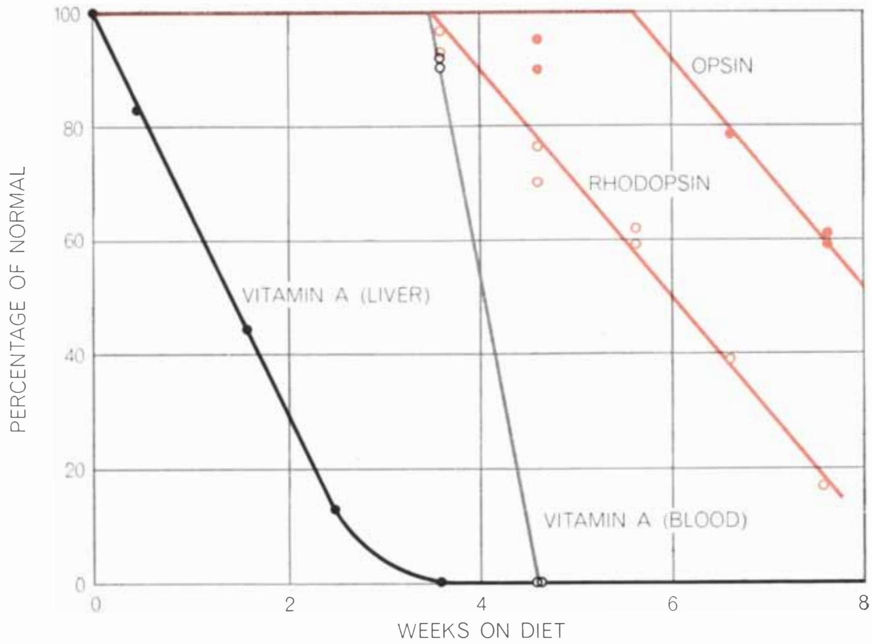
VISUAL CELLS in a rat's retina degenerate when the animal is kept on a vitamin-A-deficient diet for a prolonged period of time. The retina shown in cross section at left is from a normal rat. The retina at right is from a totally blind rat that had been on a vitamin-A-deficient diet for 10 months. Its visual cells had been almost completely destroyed and could not have been regenerated later.

rithmic relation to the rhodopsin level, just as it does when the rhodopsin level is depleted by vitamin A deficiency. W. A. H. Rushton of the University of Cambridge has found that a similar relation between the logarithm of visual sensitivity and pigment concentration holds during the dark adaptation of the rods and cones in the human eye [see "Visual Pigments in Man," by W. A. H. Rushton; SCIENTIFIC AMERICAN, November, 1962].

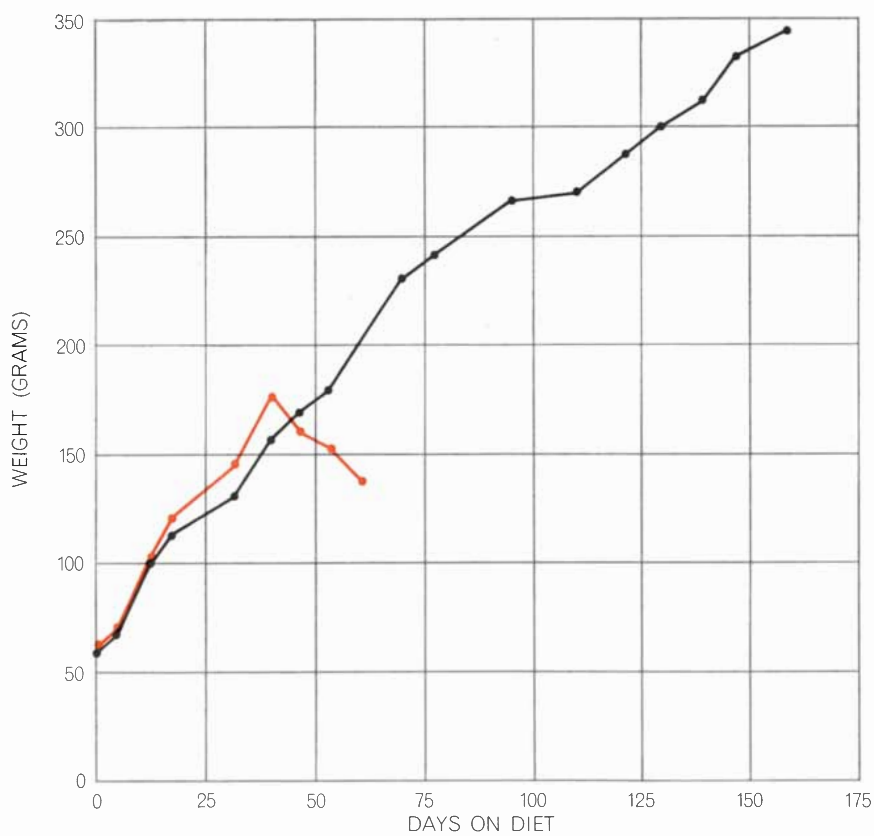
What happens when the rat is kept on a vitamin-A-deficient diet beyond eight weeks? Investigation of the visual effects here runs into a serious difficulty: the problem of keeping the animal alive. Vitamin A is essential for maintaining epithelial tissues throughout the body, and a severe, prolonged deficiency will destroy the animal's health and eventually kill it. After eight to nine weeks on an A-deficient diet rats lose weight drastically, have difficulty breathing and become highly susceptible to infection; usually they do not survive beyond 10 to 12 weeks on such a diet. Fortunately we found a way to circumvent this difficulty. It was suggested by certain experiments reported by Moore in his superb book *Vitamin A,* published in 1957. Moore noted that two Dutch organic chemists, J. F. Arens and D. A. Van Dorp, had made the finding that a compound called vitamin A acid, which apparently was not converted into vitamin A in the tissues of rats, was highly effective in keeping the animals healthy. This looked like a possible answer to our problem. Perhaps we could maintain rats on the vitamin A acid and observe a decline in their vision because they lacked the vitamin itself.

This was, indeed, the way the experiment turned out. On a diet deficient in vitamin A but with a supplement of the acid, rats grew normally and remained generally healthy but became severely night-blind. After about two months on the deficient diet the visual cells in their retinas began to degenerate, and this breakdown was correlated with a loss of opsin from the retina. By about the tenth month the visual cells were almost completely destroyed. At that point the animals were totally blind; their eyes gave no ERG response to light at any intensity. Treatment with doses of vitamin A failed to restore sight to the animals. Visual cells, like other cells in the nervous system, cannot be regenerated once they are lost.

Before full destruction of the cells



PROGRESSIVE DEPLETION of vitamin A, rhodopsin and opsin in the body of a rat fed a diet deficient in vitamin A is represented in this graph. The rat first drew on the store of vitamin A in its liver; in young rats this supply lasted about three to four weeks, and during that time the vitamin level in the animal's blood and the levels of rhodopsin and opsin in the retina remained normal. After the vitamin A reserve in the liver was used up the level of vitamin in the blood fell precipitously. Within a few days the level of rhodopsin in the eye also began to decline; two or three weeks later the opsin level began to fall.



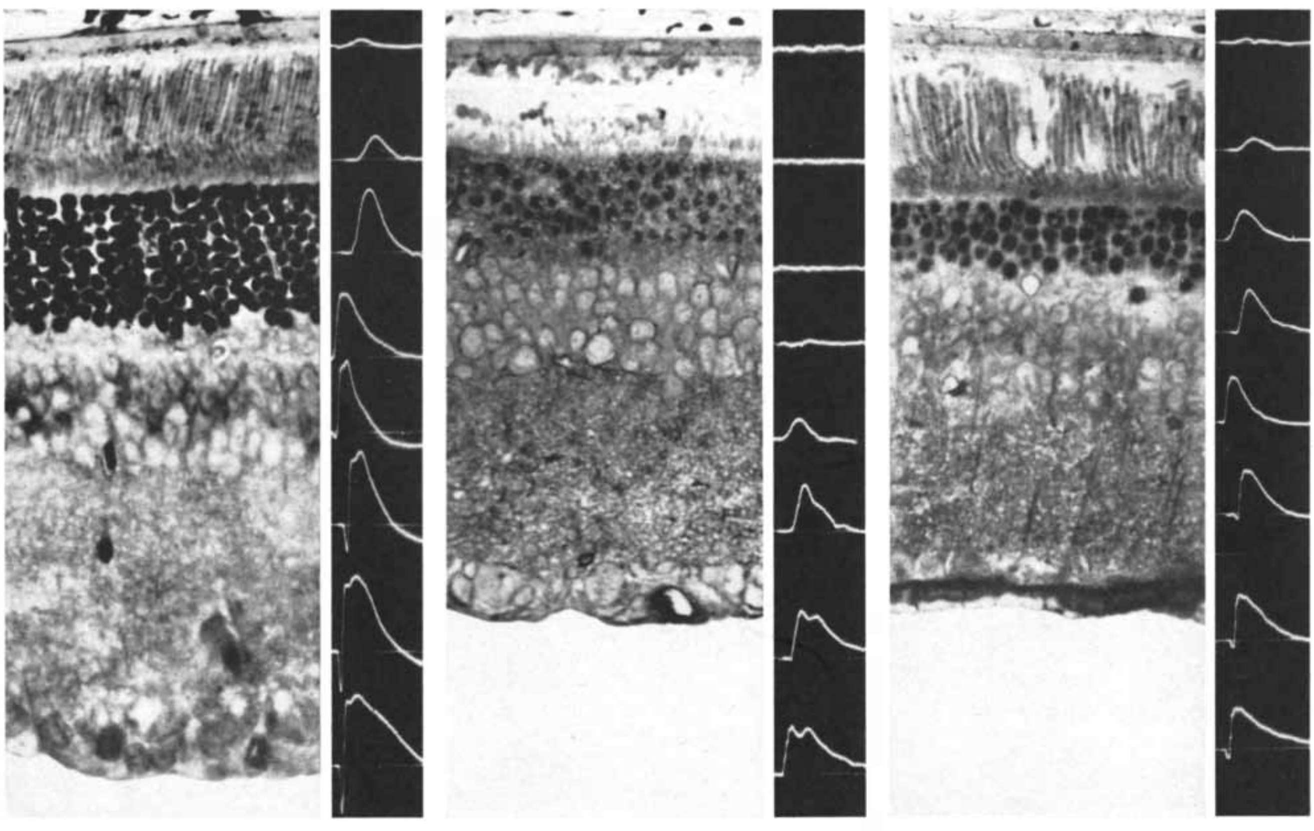
SUPPLEMENT OF VITAMIN A ACID given to a rat on a vitamin-A-deficient diet enabled the rat to grow normally and remain healthy while becoming severely night-blind (*black curve*). A rat on an identical diet without the vitamin A acid died (*colored curve*).

occurs, some recovery is possible. If a rat is given vitamin A at the six-month stage, for example, when the visual cells are only partly damaged, it can regenerate missing cell structures and regain a certain degree of night vision [*see illustration below*]. The ERG response of such an animal, however, is only about half the size of the normal ERG, which suggests that probably about half of the visual cells in the retina were lost beyond repair.

The breakdown of the A-deprived visual cell begins in the outer part of the cell, which contains the visual pigment. A study with the electron microscope that I carried out with Ian Gibbons at Harvard showed that the disks in the outer region, which give the cell its rod shape, swell and break apart into vesicles and tubules [*see upper illustration on page 84*]. The outer structure of the cell consequently loses its rod shape and becomes a spherical blob. Eventually it disappears altogether. If the animal is treated with vitamin A therapy while the inner part of the cell is still intact, it will regenerate the outer structure in a manner that is strikingly similar to the growth of an embryonic visual cell during its normal development [*see lower illustration on page 84*]. Cilia-like structures grow out from the cell interior, slowly enlarge and become filled with membrane-covered disks that are characteristic of the outer part of the visual cell. The process of regeneration takes about two weeks, the same length of time the normal embryonic visual cell takes to differentiate its outer structure.

After the studies of nutritional night blindness, Richard L. Sidman of the Harvard Medical School and I decided to look into the hereditary forms of night blindness. In man the most common of these inherited disorders is the disease known as retinitis pigmentosa. The genetic disorder cannot be attributed to any shortcoming in the diet, yet it shows striking similarities to nutritional night blindness. The eye gradually loses visual sensitivity, the visual cells degenerate and eventually complete blindness results. The parallel to the progressive blinding that results from vitamin A deficiency is so close that it seemed the inherited disorder might be due to a genetic defect in the metabolism of vitamin A or the synthesis of the visual pigments. Sidman and I undertook to investigate this hypothesis.

Our experimental subject, as before, was the rat. In this animal the inherited disease is carried by a recessive gene, and the disorder (called inherited retinal dystrophy) shows itself only in individuals that have received the defective gene from both parents. The disease begins to show its effects at about the 18th day of the young animal's life; tests by means of the ERG disclosed that its visual sensitivity gradually declines until by the age of 60 days the ERG response has disappeared. We reasoned that if the defect was related to vitamin A metabolism or rhodopsin synthesis, the decline in visual sensitivity should be paralleled by a decline in the rhodopsin content of the visual cells. To our great surprise we found that there was actually an *increase* of the rhodopsin level in the animals' eyes during the early stages of the disease. Rats with the inherited night blindness had much



RECOVERY FROM NIGHT BLINDNESS is represented here in two different ways. The micrographs show cross sections of the retinas of a normal rat (*left*), a severely night-blind rat fed a vitamin-A-deficient diet with a vitamin-A-acid supplement for approximately six and a half months (*center*) and a partially recovered rat fed the identical vitamin-deficient, acid-supplemented diet for six and a half months and then given vitamin A for another 16 days (*right*). The accompanying ERG responses show that only about half of the normal ERG potential is recovered, which suggests that about half of the visual cells at right were lost.

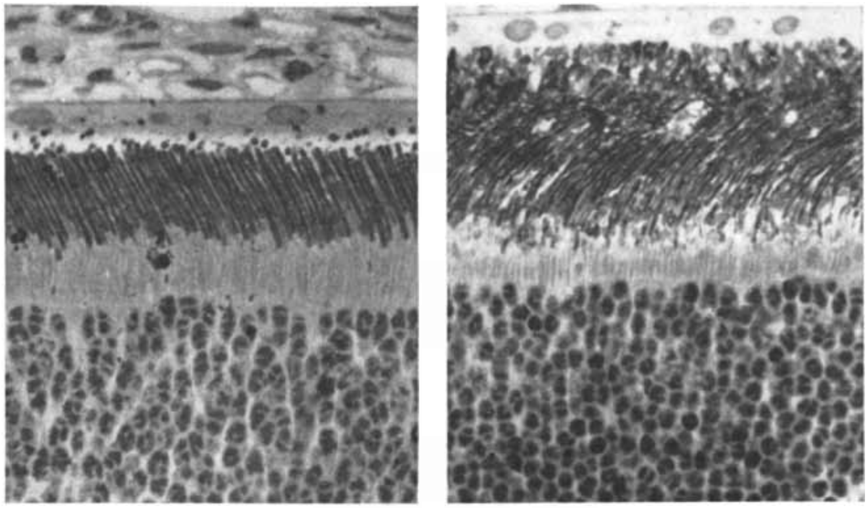
more rhodopsin than is ever found in normal animals!

Along with the excess of rhodopsin there was a considerable overdevelopment of the outer structure of the visual cells. In a rat with the inherited disease this zone at 22 days of age, for example, was almost twice as large as it is in the normal eye [*see top illustration at right*]. It was divided into two layers: an inner layer containing structures in the normal rodlike form and an outer layer filled with spiral-shaped bodies instead of disks. It appeared that the diseased retinas produced an overabundance of material that formed distorted structures.

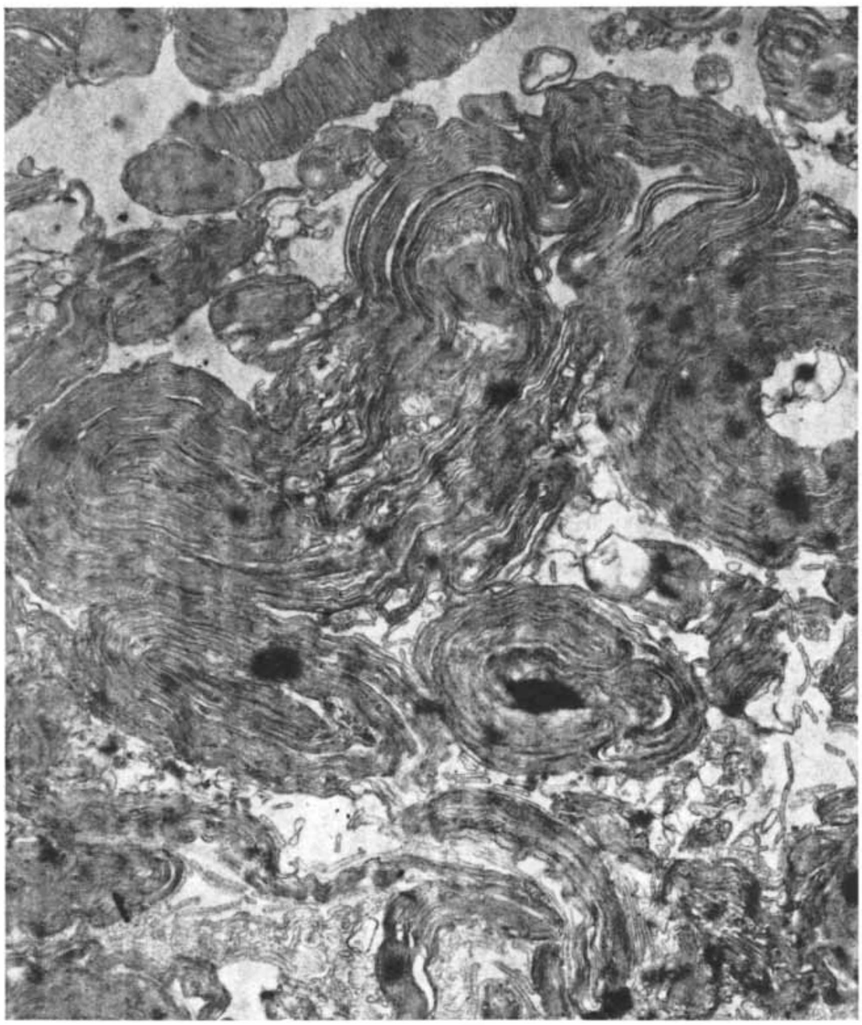
Evidently the inherited disease arises from some failure of metabolic control. In any event, the cause of the blindness is so unrelated to the simple case of vitamin A deficiency that we could see there was little hope of finding a simple cure in the form of therapeutic feeding. One of our observations, however, opened up an interesting new line of investigation. We found that when animals with the inherited disease were kept in darkness or dim light, the accumulation of rhodopsin in their visual cells was enhanced. This suggested that the progress of the disease might be influenced by the amount of light to which the eye was exposed.

To test this idea we reared groups of rats bearing the genetic defect under different conditions: one group was kept in darkness or in dim light 24 hours a day, the other was kept in the ordinary daily cycle of alternating daylight and darkness. The rats kept in darkness showed a much slower deterioration of visual sensitivity than those that were exposed to normal light. At the age of 60 days, when the latter animals had lost all sensitivity to light, the animals that had been kept in the dark still showed a considerable ERG response to light. In fact, they continued to give an ERG response up to the age of 120 days. Microscopic examination of the retinas also showed that the degeneration of the visual cells proceeded more slowly in the animals kept in darkness.

This finding led us to ask the question of what effect prolonged exposure to bright light might have on the normal eye. During World War II, Selig Hecht of Columbia University and his co-workers demonstrated that daily exposure to several hours of bright sunlight on the beach slightly impaired the dark-adapting abilities of human subjects. The effects were cumulative, and after several such sessions of expo-



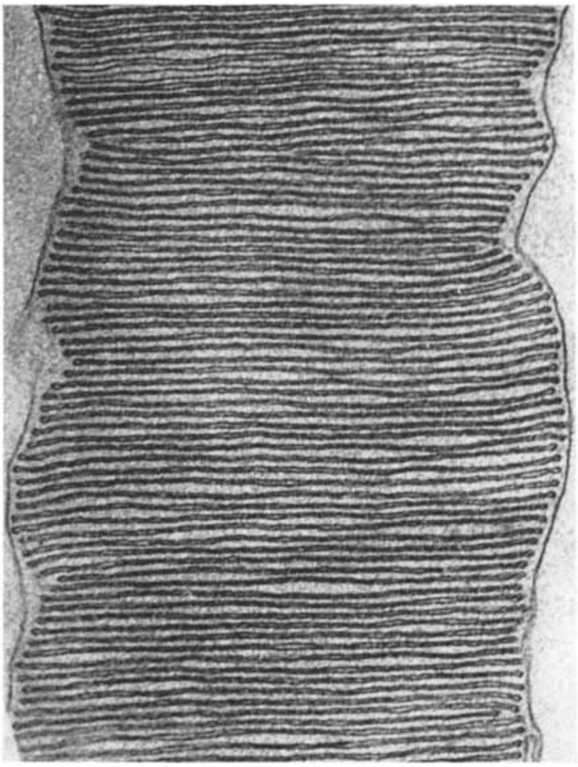
OVERDEVELOPED OUTER SEGMENTS of the visual cells in a 22-day-old rat with an inherited form of night blindness known as a retinal dystrophy (*right*) are almost twice as large as the outer segments in the eye of a normal 22-day-old rat (*left*). The inherited disease, which apparently arises from some failure of metabolic control, is also characterized by a decrease in ERG response and an increase in the rhodopsin content of the visual cells.



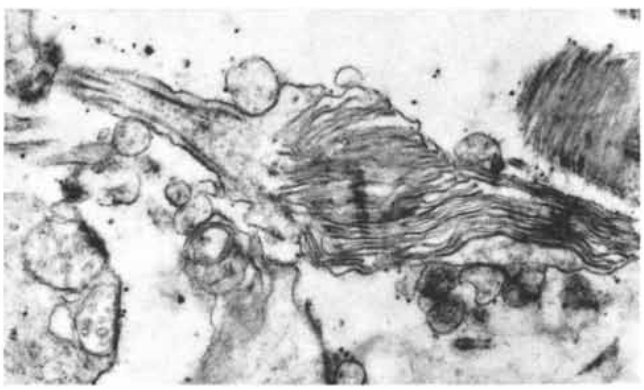
ENLARGEMENT of a small area near the surface of the outer segments of the visual cells in a rat with inherited night blindness reveals the spiral-shaped bodies that characterize this layer. The distorted structures appear to be formed by an overabundance of material produced by the diseased retina. An inner layer containing disks in the normal rodlike form (*not shown in this electron micrograph*) underlies the layer of distorted retinal structures.

sure it took the subjects several days to recover their normal capacities for dark adaptation. In the laboratory where I am now working, at the Wilmer Ophthalmological Institute of the Johns Hopkins University School of Medicine, Robert Mittenthal and I recently conducted a similar experiment on rats. We found that albino rats with normal vision that were kept around the clock in light of ordinary brightness (two 75-watt fluorescent lamps) developed severe night blindness after only three to five days of exposure to this light. These animals, given long periods (up to three months) of dark adaptation afterward, recovered very little of their normal sensitivity to light, according to ERG measurements. The visual cells in their retinas were almost completely destroyed by several days of constant exposure to light. Werner K. Noell of the State University of New York at Buffalo School of Medicine has reported similar results in experiments he conducted with both pigmented and albino rats: short periods of exposure to bright light destroyed the visual cells in his animals also.

Probably the lighting to which human beings are customarily exposed rarely produces any permanent damage to normal eyes. It seems possible, however, that people with inherited night blindness (such as retinitis pigmentosa) or other retinal diseases may be more sensitive to excessive light. Thus the possibility exists—and it is well worth testing—that wearing dark glasses, particularly in bright light, may be helpful to such persons, much as dim light prolongs visual responses in rats with inherited blindness.



DEGENERATION of the outer segments of the rods in a rat's retina is the first stage in the breakdown of a vitamin-A-deprived visual cell. The electron micrograph at left shows the disks, enlarged about 45,000 diameters, in the outer region that give the normal cell its rod shape. In the electron micrograph of an A-deficient cell at right the disks, enlarged about 30,000 diameters, are swollen and broken apart into vesicles and tubules. The outer structure has consequently lost its rod shape and become a spherical blob.



REGENERATION of the outer segments of a rod is possible if the animal is treated with vitamin A therapy while the internal part of the cell is still intact. The regeneration of the outer structure, which takes about two weeks, is strikingly similar to the growth of an embryonic visual cell during its normal development. Cilia-like structures grow out from the cell interior and form disks enclosed in membranes (*electron micrograph at right*). In both electron micrographs the outer segments of the rod are to the right.

(Good Lord!)

Does the Rover 2000 TC really require "erotic references for proper description"? [See № 4 below.]

AS YOU MAY RECALL, here is what Car and Driver magazine had to say in their May, 1966 road test report on the Rover 2000 TC. At any rate it does no harm to repeat it. Italics theirs, numbers ours:

1] *"We have driven a Rover 2000 TC for nearly 3000 miles, on all kinds of roads and in every kind of weather, and we believe that it is absolutely the best sedan that has ever been presented in the pages of this magazine...it is an automotive milestone."*

2] "We recorded acceleration times for the 2000 TC that are better—up to about 70 mph—than those of the Porsche 912, for instance."

3] "It will maintain effortless cruising speeds in excess of anything U.S. laws will allow—yet it offers fuel economy that would do justice to a tiny austerity sedan."

4] "...bending it into a high-speed corner imparts a sensation that requires erotic references for proper description."

5] "When you're settled in your seat, with everything adjusted to your taste, you have a well-fitted, made-to-measure feeling that is quite unique."

6] "It is a supremely comfortable four-passenger sedan...Its trim and appointments and the quality of its finish throughout are equal to any of the six luxury cars we tested last year. The ride is satin-smooth...Below 80 mph the interior is virtually silent..."

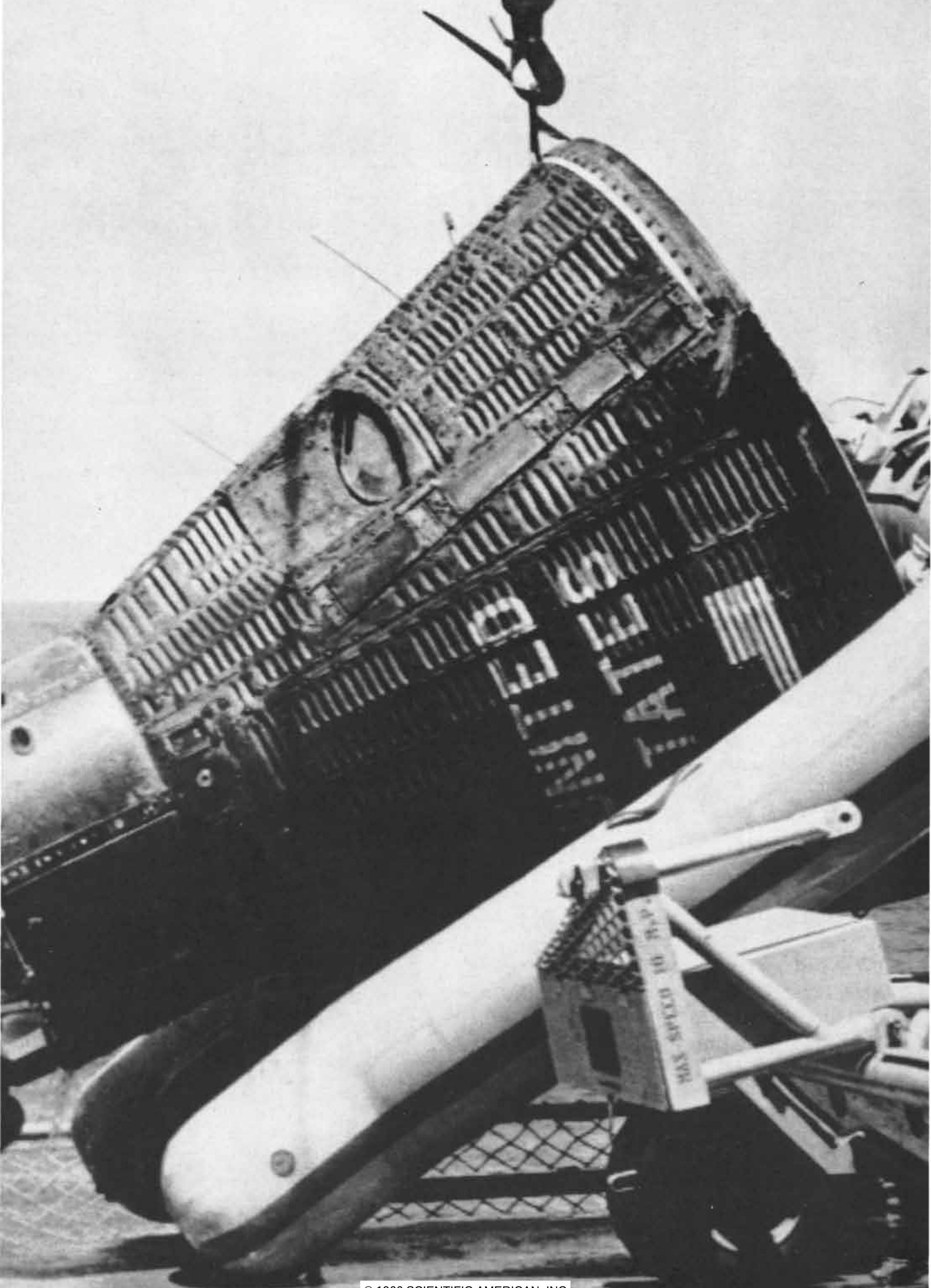
7] "And it stops. Oh dear, does it stop! Our normal series of panic stops from eighty to zero were the fastest we've ever recorded and so smooth and stable that we were almost bored by the time we finished our third run."

8] "With all this, it is a bona fide 'safety' car—one designed specifically to avoid accidents whenever they *can* be avoided, and to provide the greatest possible protection to its occupants when they cannot."

9] "We...think that every so-called safety expert and every member of top management in the domestic auto companies should be required to spend a month with the Rover 2000 TC, as we did. This car...is a rare combination of virtually everything one should have in an automobile."

Test drive the 2000 TC yourself. Price: $4195. *(Technical specifications and prices subject to change without notice.)*

The Rover Motor Co. of N. America Ltd., Chrysler Bldg., New York, N.Y. 10017



A diamond helped bring it back

You're looking at the Gemini V spacecraft after splashdown. Its heat shield's basic configuration includes a fiber glass honeycomb core with approximately 250,000 cells filled with a poured Dow Corning ablative material. The entire shield is encircled with a ring of Fiberite, a thick, dense, and highly abrasive material.

Shaping the honeycomb dome created what seemed an impossible problem. The best carbide cutting tools available wore out too quickly, and edge chip-out resulted. The conclusion was reached that only one material was capable of machining the heat shield to exact tolerances and at long runs—diamond.

McDonnell Aircraft Corp., St. Louis, Mo., specified a single-point diamond with an exposure of 1/32 inch. The tool was operated at white-heat stage, without coolant; the workpiece moved at maximum speeds, traveling 30 surface miles at every complete pass from periphery to center, without interruption.

But don't think you have to machine Gemini heat shields to take advantage of diamond tools. People are discovering that diamond tools often make the "impossible" jobs routine. That's why diamond grinding wheels, dressing tools and lapping compounds are being used more and more widely.

Are you frightened by the cost of diamond tools? Forget it. If you cut, sharpen, grind or smooth *anything*, you can probably use diamond tools profitably. Your tool and wheel maker can show you how. Or write to this magazine for more information.

De Beers

World's leading source of natural *and* synthetic diamonds for industry . . . backed by the Diamond Research Laboratory

Shannon, Ireland

The Origins of the Copernican Revolution

In trying to establish the length of the year, needed to reform the Christian calendar, Copernicus may have seen that a turning earth can solve a crucial problem that a turning sky cannot

by Jerome R. Ravetz

Historians agree that the Copernican revolution, which replaced an earth-centered cosmos by an infinite universe, was one of the most momentous of all changes in human thought. We now appreciate that this was not a single event but a lengthy process. It called for a substantial group of cosmographers and speculative philosophers to popularize and develop the heliocentric system. It then required such men as Galileo and Kepler, who made it the foundation of a new natural philosophy, and finally Newton, who provided a coherent world mechanics based on universal gravitation.

In this historic sequence the role of Nicolaus Copernicus himself seems to recede backward in time and significance. Compared with Giordano Bruno, Galileo and Kepler, Copernicus seems quite conservative, and when historians discover earlier speculations on the earth's motions (such as those of Nicole Oresme in the 14th century), his achievement is reduced to that of a link in a chain, and perhaps not even a very impressive link. The debunking campaign has recently reached the point where one scholar has described Copernicus as a "mediocre astronomer" and a well-known author dismisses him as "the timid canon."

This excess of revaluation, or rather devaluation, may be a result of incomplete knowledge of what Copernicus actually accomplished in his *De Revolutionibus Orbium Coelestium*, compounded by Copernicus' failure to set down clearly and concisely what made him believe the earth really rotates on its axis and revolves in orbit around the sun. A few details of his work, plucked out of their technical context and popularized, are not a firm basis for any useful historical judgment. Copernicus' actual views are further obscured by the preface to *De Revolutionibus*, which is now known to have been inserted by a truly timid ecclesiastic, Andreas Osiander; it asserts that the rotating and revolving earth is to be regarded as nothing more than a hypothesis—a mathematical convenience for simplifying the description of planetary motions.

If we could unravel the mystery of the origins of the Copernican revolution in Copernicus himself, we could proceed beyond guesses in our attempts to appreciate his relation both to his predecessors and to his successors. The discipline of the history of science is now maturing to the stage where we can hope to do so; historians are learning to ask the kinds of questions that will illuminate the paths of scientific discovery. To ask "Which anomalies in the Ptolemaic system made Copernicus reject it?" or "Whence came the marvelous insight that showed him the truth?" is to invite no answer or a purely speculative one. But to ask "What kinds of problems could Copernicus have been studying whose investigation would lead him to the new cosmology?" gives us something solid to look for in the scanty surviving documents. From such an inquiry we may also come to understand why it needed a great astronomer to establish a revolutionary cosmology as more than a vague and idle speculation. In my own work on the problem I have built on the detailed and penetrating studies of the Polish school of Copernican scholars, and I have also derived help and encouragement from them. I am particularly indebted to J. Dobrzycki, without whose assistance the work could never have been done.

When we look for Copernicus' problems, we must at least temporarily ignore Galileo's and Bruno's. We must expect Copernicus to be "conservative" to the extent that he based his work on what was current late in the 15th century, but we should also expect him to see farther and penetrate deeper than those on whose shoulders he stood.

In my reconstruction I suppose Copernicus started with the problems he saw at the foundations of the astronomy of his time, problems whose solution was necessary for its reform. I also assume that he was guided by strong methodological principles, chief among them that astronomers should do more than "save the phenomena," a phrase applied to tinkering with hypothetical models to account for observations; they should also find coherence and harmony in the structure and motions of the celestial bodies.

During the lifetime of Copernicus (1473–1543) astronomy was just emerging from a state of semicompetent technique. Although the *Almagest*, Ptolemy's fundamental treatise on astronomy, had been translated from the Greek into Latin in the 13th century, it is unlikely that more than a few people in any generation were competent to study it in any detail. At the popular level astronomy was applied to almanacs and eclipse tables. At the universities it was studied as the basis of "mathematical physic" or medicinal astrology. Neither of these uses demanded much precision of prediction, and none was forthcoming.

On the other hand, the problems of reforming the lunar-solar Christian calendar were acute. At the Council of Nicaea of 325, Easter was defined as the first Sunday after the first full moon on or after the vernal equinox. For computing the date of Easter the vernal equinox was fixed at March 21, and full moons were calculated according to a 19-year cycle. (The time required for the moon to sweep out its full cycle of motions in the sky is now known to be 18.6 years.) By the 12th or 13th century anyone moderately competent in astronomy knew that the vernal equinox was occurring around March 11 or 12 and that the full moons of the traditional computation bore no relation to those observed. Easter Sunday as computed and celebrated bore no relation to the Easter Sunday defined by the council and accepted by the Church. Therefore "calendar reform" was a far more intricate undertaking than simply removing a leap year every few centuries. The motions of the moon were known to be complex, and it was believed those of the sun were also; for example, there appeared to be evidence that the length of the solar year varied over the centuries.

To attempt a reform in ignorance of the laws of these variations was to invite disaster. Astronomers were repeatedly requested to lay the basis for reforming the calendar, but only after the work of Copernicus was there any hope of accomplishing the task.

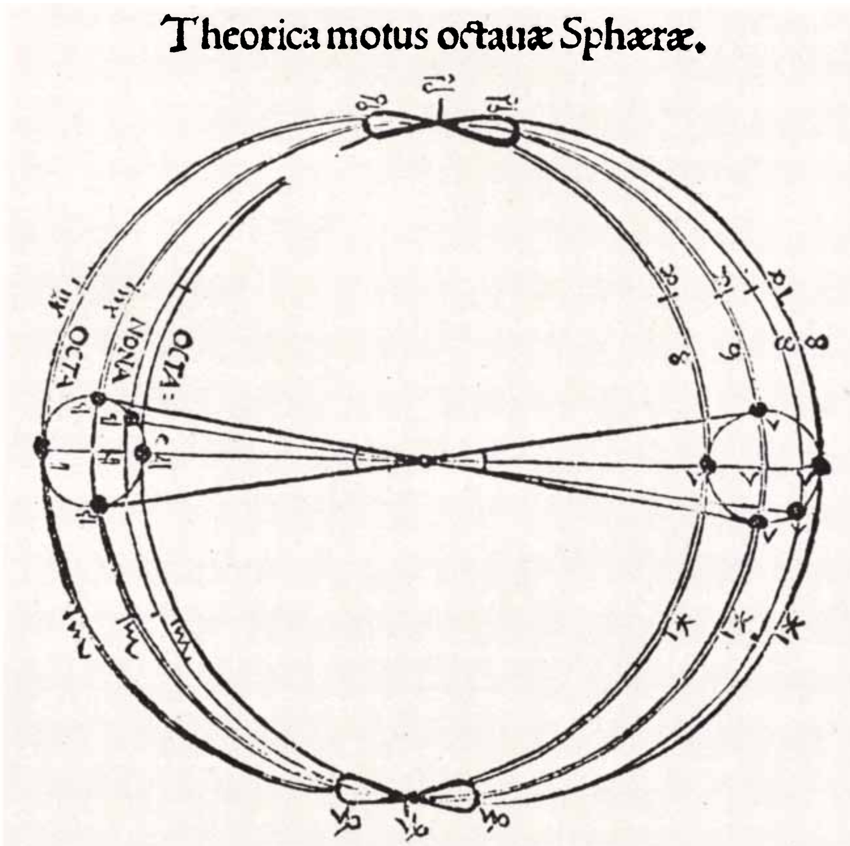
The problems of calendar reform were intimately related to those of improving observational astronomy. All predictions of positions of the planets were taken from adaptations of the Alfonsine tables, a work prepared for Alfonso X of Castile and published in 1272. Every astronomer knew that the tables were seriously inaccurate, but no one before Copernicus could undertake the task of recasting them. Part of such a task was a study of the slow variations in the elements, or basic characteristics, of the presumed orbit of the sun, and a study of this kind could not be done well without a reconsideration of the basic frames of reference in observational astronomy.

The basic large unit of astronomical time is the year. Unfortunately this basic unit can be variously defined and even more variously measured. From ancient times two definitions had been known: the solar year, measured by the sun's return to a particular point on its path (a crossing of the celestial equator, or a passing through a "tropical" point), and the sidereal year, measured by the sun's return to a particular fixed star [*see illustration on next page*]. Because one cannot see stars when they are close to the sun, the latter definition lends itself only to indirect measurement. For this reason, among others, Ptolemy rejected it.

The two "years" were known to be different in length because of another phenomenon: apparent changes in the longitude of the fixed stars, where longitude is measured along the ecliptic from its intersection with the celestial equator, a point known as the equinox [*see top illustration on page 92*]. This phenomenon too had various interpretations. For Ptolemy it was the result of a slow rotation of the stellar sphere along the ecliptic in the same direction as the sun's apparent motion in its yearly orbit, a "motion of the eighth sphere in consequence" [*see top illustration on page 94*]. For Hipparchus, who first discovered the phenomenon, it was a displacement of the equinoxes in the direction of the sky's apparent daily rotation, a motion described as being in precedence, hence a "precession of the equinoxes."

On either of these theories the rate of change of stellar longitudes affects the length of the solar year. If the sphere of fixed stars is rotating slowly and carries with it the orbit of the sun, the sun will be brought back to the equinox more quickly; thus the shortening of the year will be proportional to the speed of rotation of the stellar sphere. But if the motion is the motion of the equinoxes themselves, they move to meet the sun as it comes around and also produce a shortened year. Therefore the theory and calculation of the length of the year and of the change of stellar longitudes are intimately related.

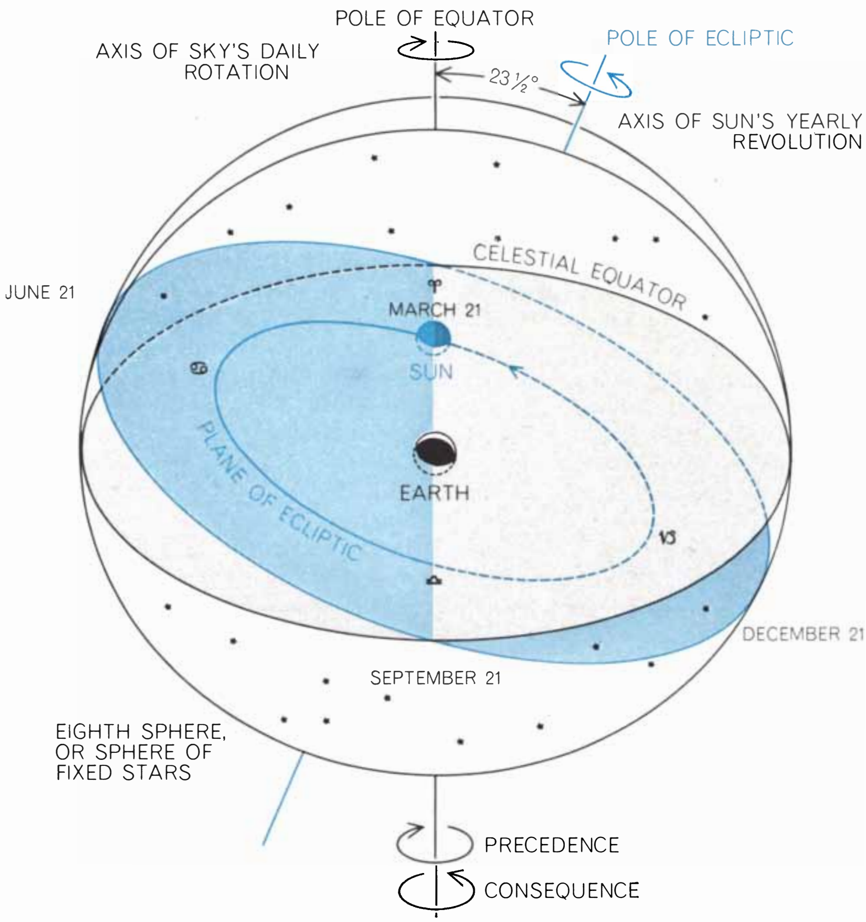
The two explanations are by no means equivalent. They involve quite different notions of the elements of the framework of the heavens, and, as I shall show, they also have different cosmological consequences. The distinction between them was well known until the

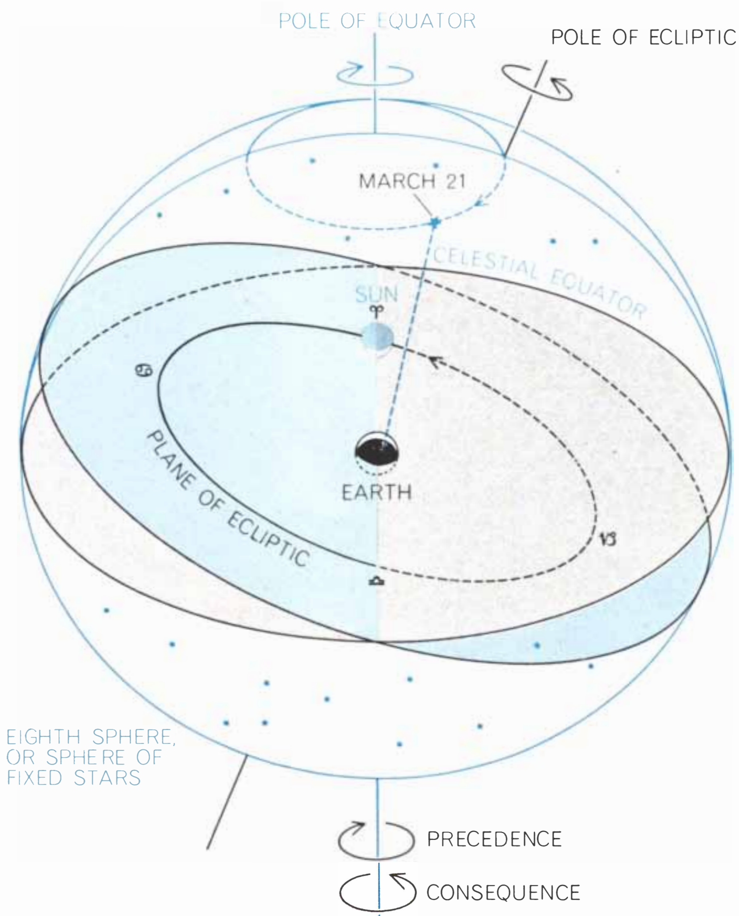


COMPLEX MOTION OF "EIGHTH SPHERE," the sphere of the fixed stars, was a major preoccupation of astronomers from the time of Ptolemy until the triumph of the Copernican revolution. This diagram, depicting the standard theory for the motion of the eighth sphere, is taken from an edition of Georg Peurbach's *Nova Theorica Planetarum* published in 1528. This was the most influential intermediate-level textbook of astronomy of the late 15th and early 16th centuries. The diagram shows a ninth sphere (*nona*) rotating uniformly about the pole of the ecliptic; on it the eighth sphere (*octa*) has a reciprocating motion designed to reproduce the supposed irregularities in the changes of stellar longitudes. It is the author's thesis that because Copernicus accepted these irregularities as real he was led to reject the motion of the eighth sphere and to seek new frames of reference.

17th century but seems to have been forgotten when the geocentric cosmology was finally abandoned. Copernicus gave calendrical problems and those of frames of reference pride of place in his justifications of his cosmological system. From his earliest writings it is possible to conjecture a sequence of steps whereby a consideration of these problems forced him to accept the rotation of the earth as a physical fact.

Another class of problems much debated in the period leading up to the time of Copernicus included those we would today classify under the heading of astrophysics. They involved the shape and structure of the heavens and the mechanisms by which the planets moved. It was accepted on all sides that "spheres" were involved, but there was a sharp division over their nature and their precise arrangement. The orthodox teaching was derived from Aristotle: for each body (the sun, the moon and the five visible planets) there was a system of concentric spheres, each rotating on an axis attached to the sphere outside it so that the compounded motions of the innermost sphere produced something like the observed motion. For the planets this motion resembles a figure eight, superposed on a constant motion "in consequence" so as to yield the characteristic "retrograde motion." Such a system was philosophically sound but





LENGTH OF YEAR can be defined in two ways: as the time required for the sun to return to a given position in the sky and as the time required for a fixed star to return to a given position. Historically the solar year (*top illustration at left*) was taken to be the time required by the sun to return to the vernal equinox, traditionally March 21. At the vernal equinox (and also on the autumnal equinox, September 21) the sun "crosses" the celestial equator and the length of day and night are equal. The time required for a star to return to a given position (*bottom illustration at left*) is called the sidereal year. In ancient times it was usually defined as the time required for the sun to "return" to a particular fixed star, but since stars cannot be seen in the daytime sky, early astronomers would try to establish the position of a star that was readily visible the night before or after the vernal equinox. The star shown in the illustration is assumed to be one visible in the early-morning hours of March 21; thus it is on the front half of the sphere of fixed stars, as pre-Copernican astronomers would have drawn it. Actually the length of the year, both solar and sidereal, was commonly measured by fixing the position of the star Alpha Virginis at the autumnal equinox.

quite incapable of reproducing even qualitatively the motions of any but the most regularly behaved planets.

The other main approach came through Arabic sources from Ptolemy's *Hypotheses of the Planets.* There each planetary system had a hollow spherical shell lying eccentric to the earth, and inside it rolled a smaller sphere bearing the planet. Carried by the smaller sphere, the planet thus traced out a series of epicycles. This structure gave a very reasonable physical realization of the mathematical models of the *Almagest* and hence was capable of reproducing the motions with the accuracy that was attainable by any observer of the period. Like the models of the *Almagest,* however, this system needed the "equant": an off-centering trick for imparting to the planets, which were supposedly moving at constant speed, the appearance of nonuniform motion. Few astronomers were altogether happy with the celestial imperfection the equant implied.

The dilemma over the two rival cosmological systems, each imperfect in its own way, was compounded when one considered the structure of the heavens as a whole. The accepted "motions of the eighth sphere"—the sphere of fixed stars—were considered to be complex, and extra spheres had to be invented to reproduce them. These, rather than the motions of the planets, were the focus of astronomical debate in the 15th and 16th centuries. Although the extra spheres moved extremely slowly, they were next in the heavens to the *primum mobile* (the prime mover), a vast sphere that was believed to lie at a distance of some 10,000 earth radii and to wheel around the earth once every 24 hours.

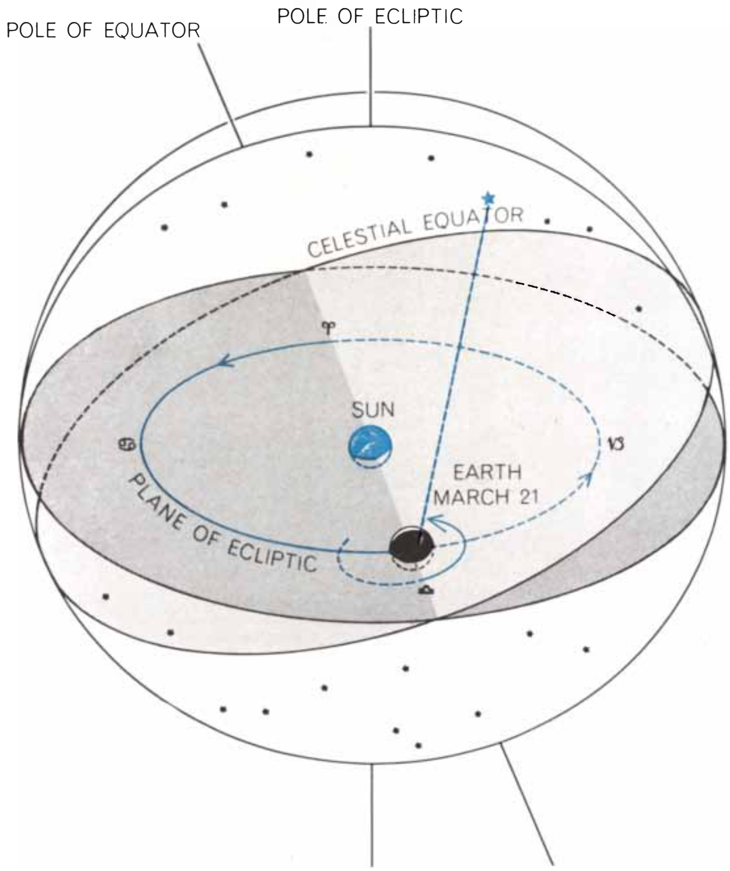
Among the lower spheres all was not straightforward. It was clear that the "outer" planets Mars, Jupiter and Saturn were above the sun and the moon was below it. Where were Venus and Mercury? Putting them below the sun would serve to fill the great space between it and the moon, but then Venus would require a huge epicycle. Moreover, one would expect to see transits—passages of Mercury and Venus across the face of the sun—and none were observed. From antiquity came a suggestion that the orbits of Mercury and Venus were centered on the sun, but this would make them anomalous among the planets.

These difficulties, along with others, were enough to make Copernicus speak of a "multiplicity of systems" and of a "monster" passing for a system of the world. He could not have been speaking of increasingly complicated refinements of the mathematical models of the *Almagest* (as many recent authors have supposed), for the simple reason that they did not exist until some time after his death. It appears to me that a consideration of these problems of structure could well have led Copernicus on from his conviction of a rotating but central earth to the full heliocentric system.

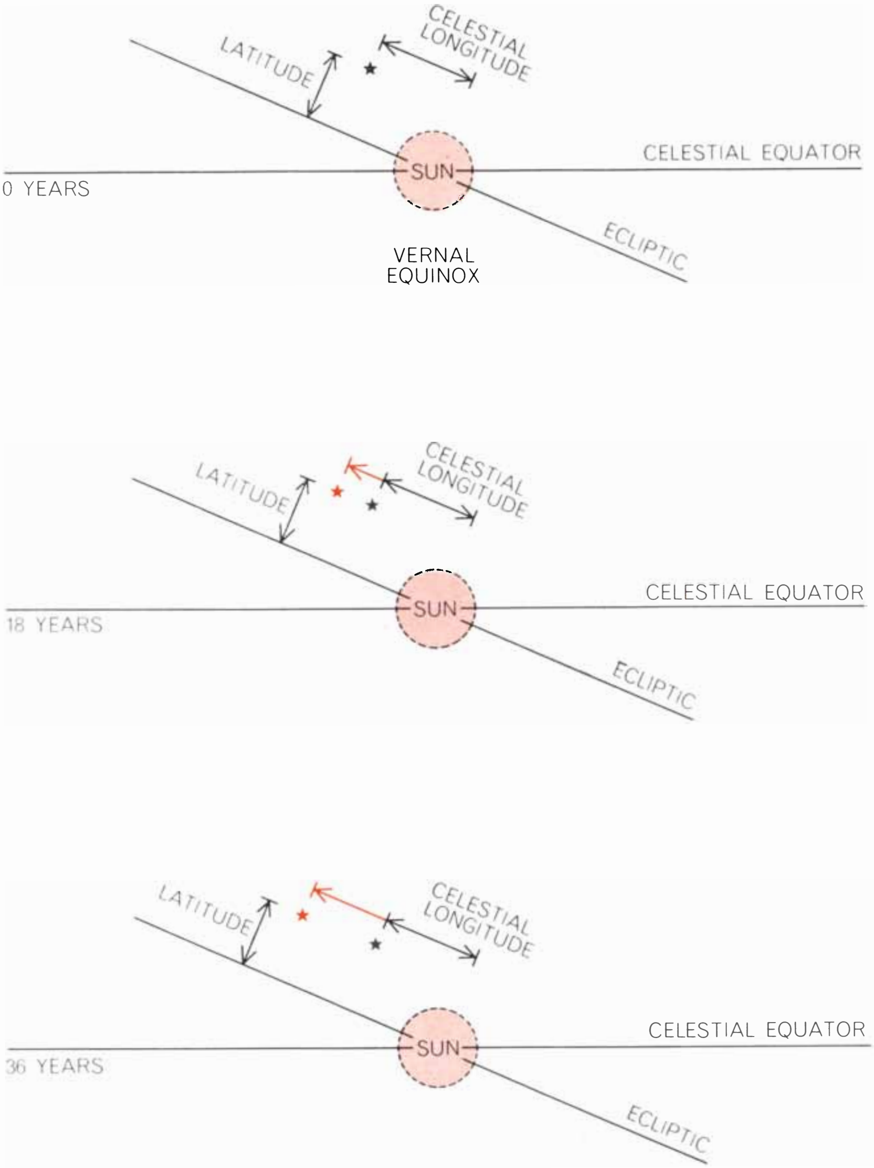
At this point we must recognize a difficulty. Both sets of problems I have discussed were, in a sense of the term that is accepted by many, unscientific. The variations in the length of the year, and in the rate of change of stellar longitudes, on which Copernicus based his earlier work (and which he also attempted to explain fully in *De Revolutionibus*) were in fact nonexistent, merely the result of errors in observation over the centuries. And most of the problems of structure vanish with the destruction of the geocentric system and the replacement of compound circular motions by Keplerian ellipses.

Can truth come out of such error? Must we suppose the Copernican revolution was based on erroneous observations and vacuous theoretical problems? I fear that it is so. Had the problems of astronomy been different or differently construed at the end of the 15th century, an astronomer with the genius of Copernicus would have proceeded differently and would perhaps even have left the revolution in cosmology to someone else. But things were as they were. It was simply beyond the power of any astronomer of Copernicus' time to decide which observations of earlier workers were completely trustworthy. And although Copernicus tried to be critical in making the selections on which he based his analyses, the errors were too deeply embedded to be removed.

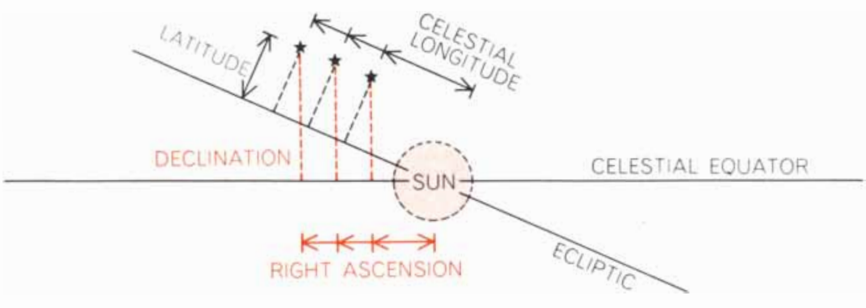
As a young man Copernicus attended the Jagiellonian University of Cracow (which is just now celebrating its 600th anniversary). It was one of the leading universities of Europe, having many foreign students and being in close contact with humanistic circles in



POST-COPERNICAN UNIVERSE established the sun at the center and in effect placed the earth in what had been the sun's orbit. This illustration shows how a post-Copernican astronomer might have redrawn the diagrams on the opposite page. As far as an observer on earth is concerned there is no simple and direct way to distinguish between the two schemes.



CHANGING STELLAR LONGITUDES account for the difference in length between the solar year and the sidereal year. As measured from the vernal equinox, stars appear to drift eastward about 50 seconds of arc per year. In 36 years this amounts to a distance about equal to the diameter of the sun. The phenomenon can be detected from a slow change in the date of the annual first appearance of stars over the horizon. Hipparchus, who first recorded the phenomenon, ascribed it to a precession, or westward motion, of the equinoxes.



TWO COORDINATE SYSTEMS have been used in astronomy from early times. Both use the vernal equinox, shown here by the position of the sun, as the starting point for establishing positions in the east-west direction. This position is given as celestial longitude when measured along the ecliptic and right ascension when measured along the celestial equator. The respective terms for the north-south positions are latitude and declination. The diagram shows how the stellar longitudes are seen to change while the latitude remains constant.

Italy. In addition it was the center of a large and lively school of astronomy, in which all the cosmological problems were debated. Copernicus quickly learned the standard curriculum and went as far in astronomy as his masters could take him. He could not have been familiar, however, with the *Almagest;* at the time there was no text of the work in print or even in wide circulation. Indeed, even the *Epitome in Almagestum* prepared by Georg Peurbach and Johann Müller (Regiomontanus), left in manuscript at the latter's death, was not available in Cracow. Copernicus did not see the *Epitome* until it was printed in 1497, and this fact provides useful evidence for dating his earliest work. The first sketch of his cosmology, the unpublished *Commentariolus,* shows no trace of acquaintance with the *Epitome.* The numerical data are all taken from the Alfonsine tables, and they are inferior in accuracy and precision to what was available in the *Epitome.* Hence we can be fairly certain that Copernicus conceived and worked out his profound innovation while he was still at Cracow. It was very much a young man's stroke of genius, which then took a lifetime to consolidate.

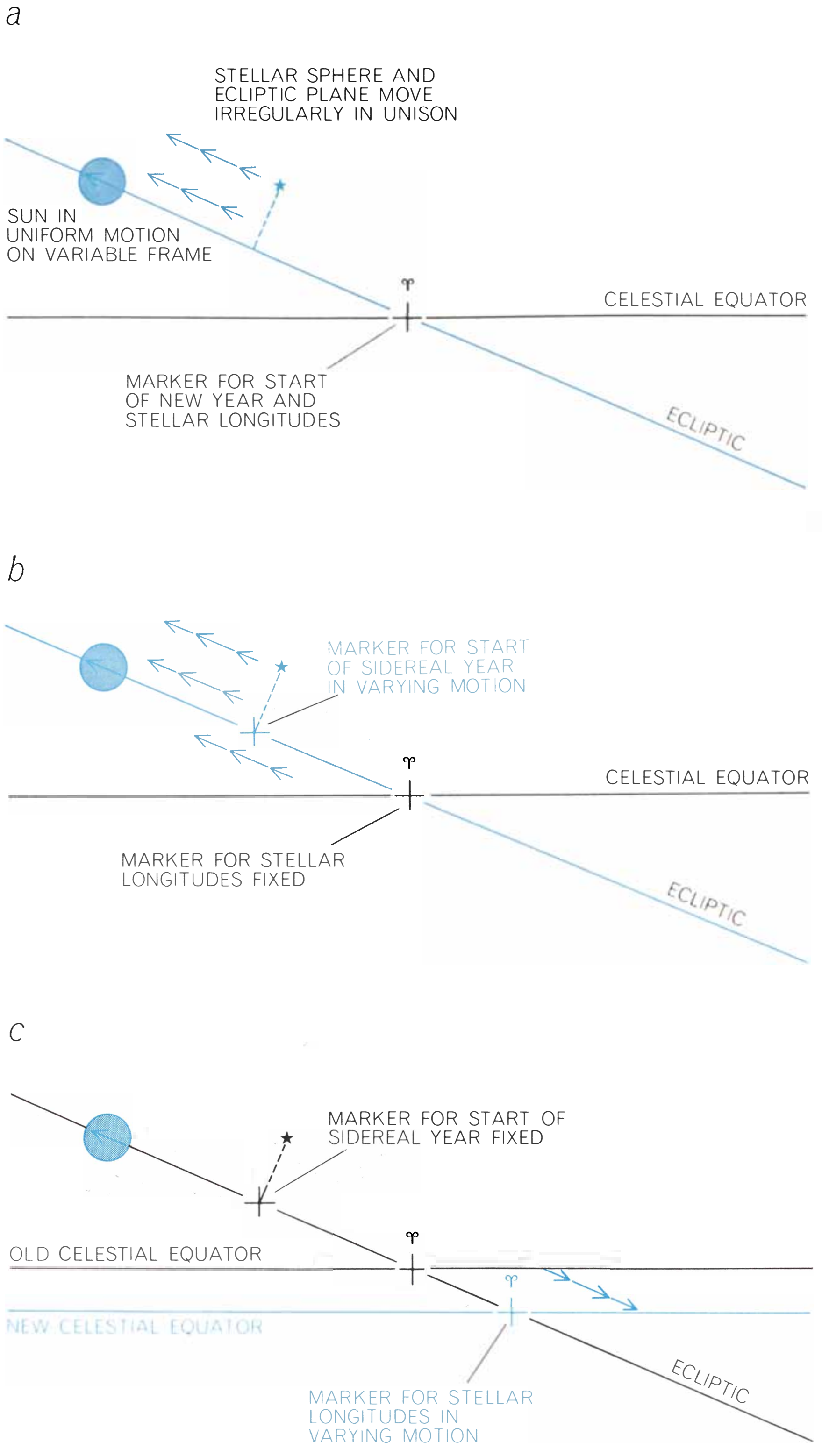
Near the beginning of the *Commentariolus* Copernicus discusses the problems of the change of stellar longitudes and the definition of the year. He starts by reviewing the different estimates of the length of the solar year, and later he announces that his own measurement of the length of the sidereal year is the same as that of the ancient Egyptians. The clear implication is that the length has been constant. In my conjectured reconstruction of Copernicus' path of discovery I take this as the first (supposedly) hard fact on which all else hinged. From this "fact" it is obvious that the constant sidereal year, rather than the variable solar year, is the true measure of astronomical time. But if one chooses this as the basic measure, what is one to make of the irregular changes in stellar longitudes? If one keeps the system of an irregularly moving stellar sphere carrying with it the sun's orbit, then one's fundamental measure of time is a motion along an irregularly moving orbit. This is strictly incoherent; as Copernicus later said of time: "The measure and the thing measured are interchangeable." Thus the stellar sphere can have only its daily rotation; the changes in stellar longitudes must be explained by a motion of the equinoctial points [*see illustration on opposite page*].

Copernicus argues accordingly at some length in this crucial early passage.

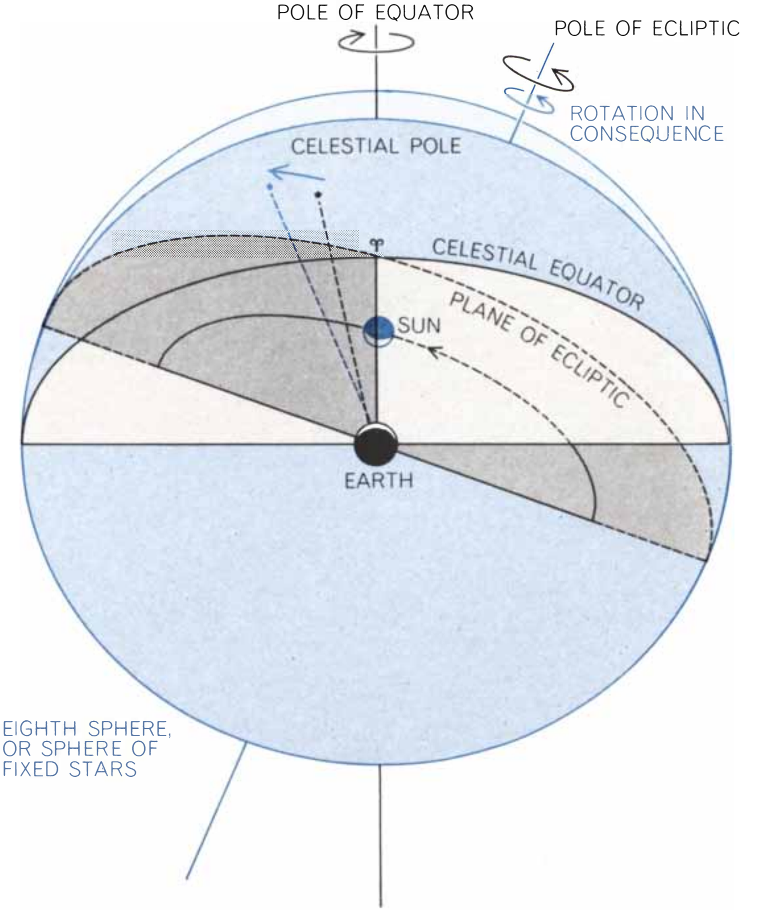
There are only two simple ways to produce a motion of equinoctial points. One way is for the plane of the ecliptic to move while the plane of the celestial equator remains fixed [*see bottom illustration on next page*]. The second way is just the reverse: for the equatorial plane to move while the ecliptic plane remains fixed [*see illustration on page* 95]. If the ecliptic were simply to rotate in its own plane, its intersection with the equator would of course remain unchanged.

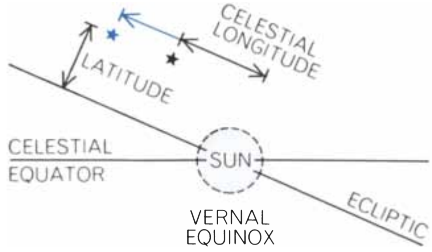
These alternatives would have been obvious to Copernicus. He would also have seen immediately that the first possibility—a motion of the ecliptic—would produce gross changes in stellar latitudes, which were measured from the ecliptic, and such changes had never been observed. Therefore Copernicus would have concluded that it was the celestial equator that had to move. But if the celestial equator moves, then its pole must move as well. And in the geostatic world system this is the pole of the daily rotation of the heavens. A motion of the equinoxes in this system would imply a perceptible change in the elevation and orientation of the celestial pole over the centuries. That is, the center of rotation of the heavens would slowly shift away from a point directly over the north pole of the earth. Such a change would have been recorded if it had occurred, and none had been.

If Copernicus truly followed a path such as this one to such a point, he reached here the watershed between the old and the new cosmology. To abandon the precession of the equinoxes would for him mean abandoning hope in a rational science of astronomy. How could it be saved? He needed a celestial pole fixed with respect to an observer on earth, and a celestial equator moving along the celestial sphere. The solution could come with the brilliant insight that the observed celestial pole—the observed axis of the sky's daily rotation and not any particular star that might coincide with it—would be fixed for an observer on a rotating earth, and that the celestial equator, as the outward projection of the earth's equator, could move as the axis of the rotating earth slowly changed its orientation [*see illustration on page* 97]. Thus the rotation of the earth on a slowly tilting axis was necessary and sufficient to fix the frames of reference for a coherent science of astronomy. Because of this

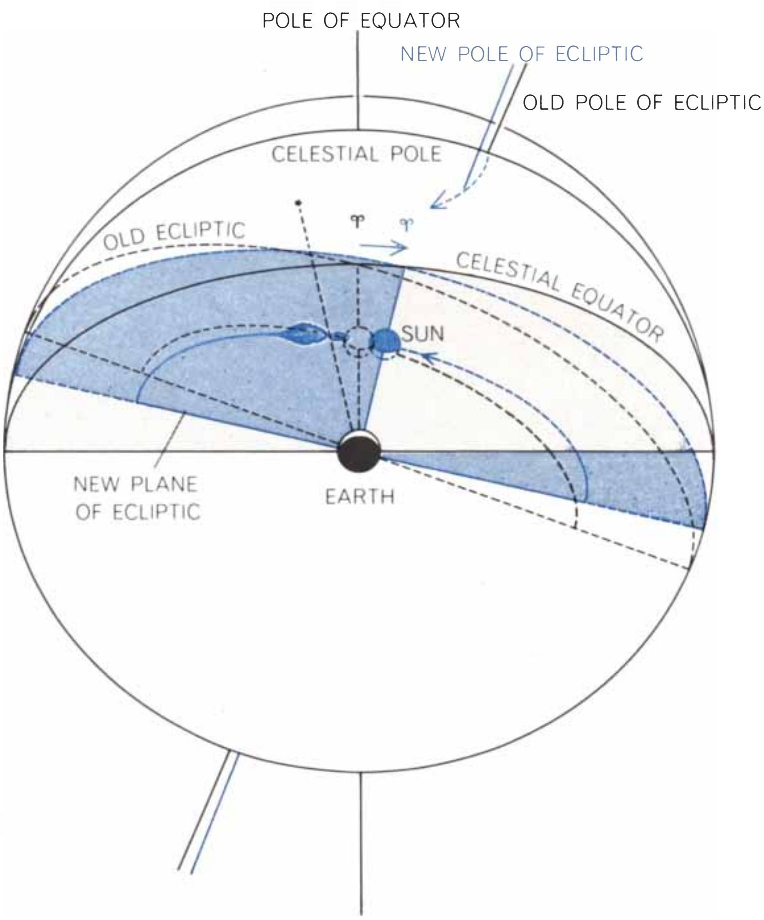


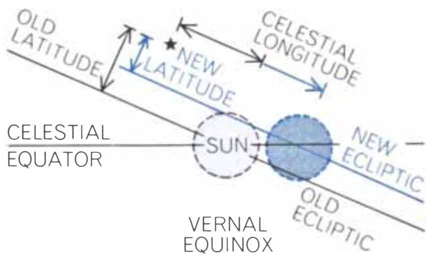
COPERNICUS' PATH OF DISCOVERY, as reconstructed by the author, hinged on his belief that the length of the sidereal year is constant (correct) but that changes in stellar longitudes and the length of the solar year vary irregularly (incorrect) and in unison (correct). This can be explained by supposing that the stellar sphere and the ecliptic plane, conceived as the track bearing the uniformly revolving sun, move together (*a*). It is clear, however, that if the framework for the sidereal year is moving erratically (*b*), it is not a good basis for a fundamental unit. The solution is to have the stellar sphere and the ecliptic stationary, except for their supposed daily rotation (which Copernicus would not have abandoned immediately), and to allow the equinoctial points to move. This would have led Copernicus to infer the movement of the celestial equator (*c*). Because the available data were faulty, he was obliged to assume that the celestial equator moved irregularly. His basic inference, however, was correct and ultimately led him to the heliocentric theory.





MOTION OF EIGHTH SPHERE was proposed by Ptolemy in the second century to explain the changes in celestial longitude that made the solar year shorter than the sidereal year. The same phenomenon was earlier construed by Hipparchus as a precession of the equinoxes, a slow westward displacement of the equinoctial points (*see illustrations below and on opposite page*). For Ptolemy the equinoctial points were fixed in space whereas the eighth sphere moved slowly "in consequence," or counter to the direction of its high-speed daily rotation. The rotation in consequence, however, was around the pole of the ecliptic. Only in this way could there be a change in celestial longitude without introducing a change in latitude, as shown in detail above.





MOTION OF ECLIPTIC provides a possible mechanism for explaining the precession of the equinoxes. If the ecliptic plane tilted upward in the direction of the vernal equinox, as depicted at left and diagrammed schematically above, the result would be an increase in the celestial longitude of all the stars in the eighth sphere. The sphere itself would remain fixed, except, of course, for its daily rotation. This hypothesis was undoubtedly considered by Copernicus as well as by earlier astronomers but would have been rejected because it would have entailed a marked change in the latitudes of the fixed stars, and this was not observed. On this hypothesis the ecliptic pole would rotate slowly around the celestial pole.

the rotation would not be merely hypothetical or speculative for Copernicus; it would be a necessary fact of the physical world.

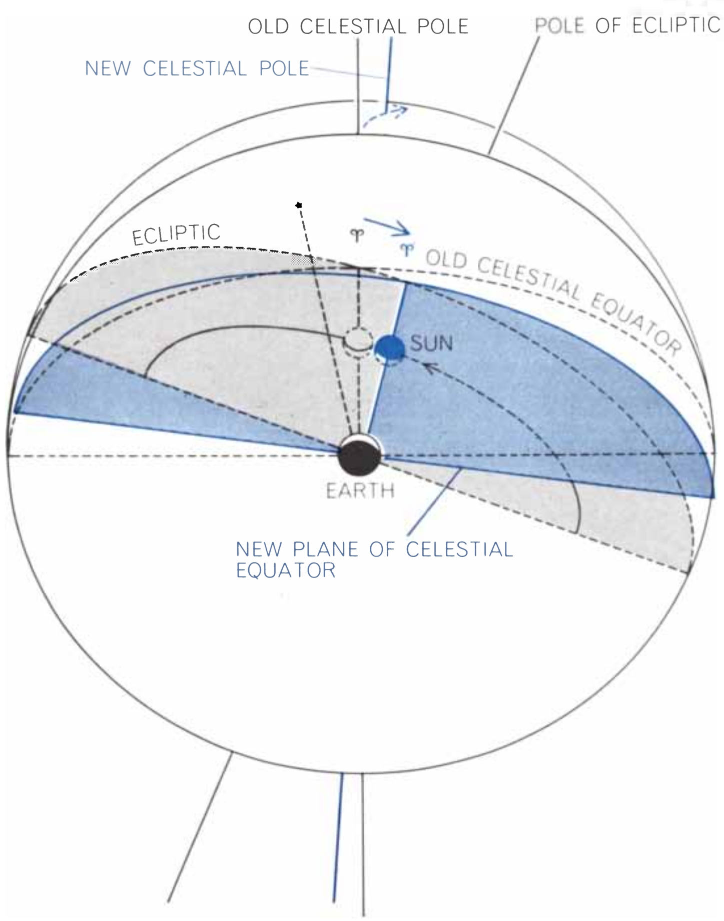
This "rational reconstruction" of the first stage of the Copernican revolution is inevitably oversimplified. I cannot take into account the many false leads Copernicus must have followed on these and related problems, and his difficulties in conceiving the successive stages of the problem. But there are bits of evidence from the writings of earlier and contemporary astronomers to show that he was not alone in considering these matters, and that all lesser men were hopelessly confused and lost before they even came close to a solution. Because there were so many hazards and pitfalls besetting the exploration of a problem on the fringe of the scientific competence of the time only a master craftsman could steer his way through to a coherent solution.

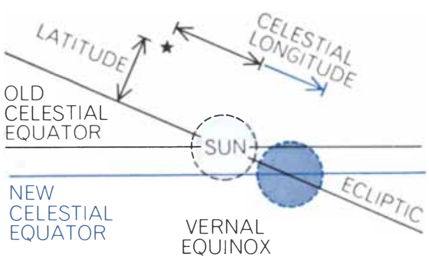
Since historians of astronomy are almost unanimous in agreeing that the Copernican and Ptolemaic systems are observationally equivalent, it may seem impossible that observations made from the earth could have forced the conclusion of a rotating earth. The equivalence, however, is between short-term mathematical models for the planets. These are compounded of rotating vectors in a plane, which "commute," that is, can be interchanged. The phenomena dealt with here are described by the rotations of spheres that, as it happens, do not commute.

On the basis of a firm belief in a rotating earth, Copernicus could have a new look at the problem of the structure of the heavens. From the *Commentariolus* we have an introductory passage describing the unsatisfactory state of affairs as Copernicus learned it. And in Chapter 10 of Book 1 of *De Revolutionibus* is an argument that may well reflect the sequence of stages to the full heliocentric cosmology.

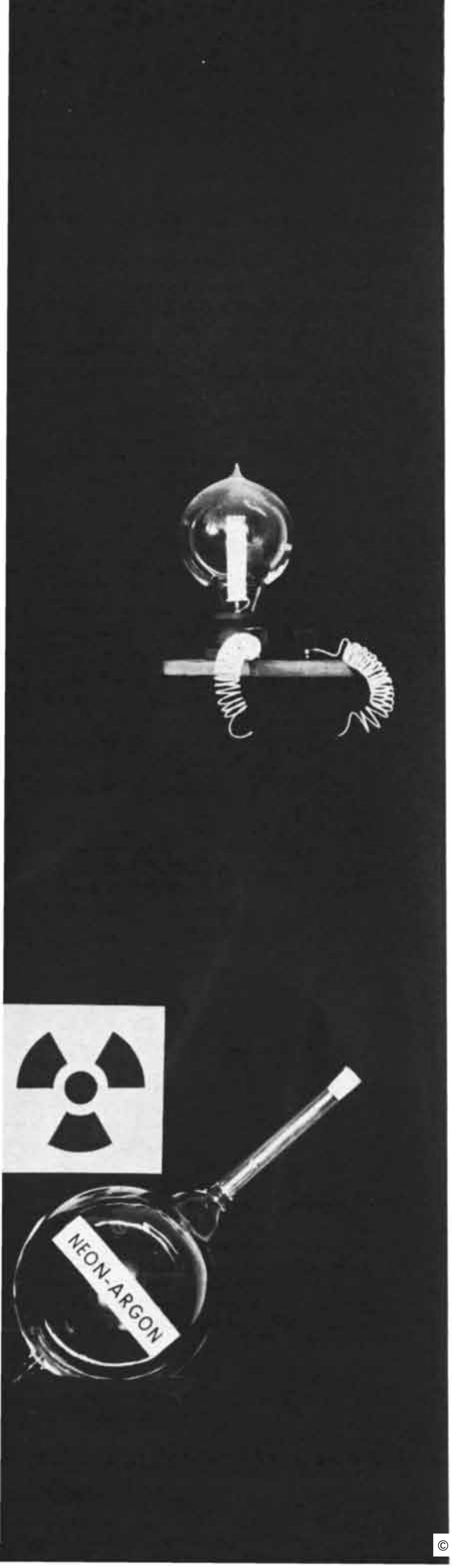
This starts with a demonstration of Copernicus' view that the problems of structure (particularly the location of Mercury and Venus) are insoluble within the framework of the accepted cosmology; all attempts to produce a rational structure yield only incoherence. Then Copernicus takes up the well-known suggestion that Mercury and Venus have their orbits centered on the sun. Next he considers the "outer" planets (Mars, Jupiter and Saturn); since they were known to vary in brightness, he argues that it is reasonable to believe they too execute orbits around the sun. It is clear also that their orbits have radii larger than the distance between the earth and the sun.

Insofar as the inner planets are concerned this change makes no real difference to the mathematical models of the orbits. For the outer planets, however, the epicycle model (a shorter, faster rotating arm hinged on a longer, slower one) must be replaced by a "movable eccentric" model (a longer, slower arm rotating backward, hinged to the shorter, faster one). The mathematical equivalence of simplified versions of the two models had been known to the ancients; Tycho Brahe later based his "compromise" cosmology on just this device. (In Tycho's scheme the sun circled the earth and the other planets circled the sun.) If Copernicus' model at this stage resembled Tycho's model, Copernicus would see a common feature in all the orbits of the planets: an





MOTION OF CELESTIAL EQUATOR is the only other simple hypothesis for explaining the precession of the equinoxes. As the diagram above shows, it provides the observed change in stellar longitudes without affecting stellar latitudes. In this respect it cannot be distinguished observationally from a motion of the eighth sphere in consequence. Copernicus, however, was led to reject the motion of the eighth sphere on other grounds (*see illustration on page 93*). He would have quickly seen that a change in the position of the celestial equator, and hence of the celestial pole, would have different observational consequences, depending on whether the earth is stationary or rotating (*see illustration on page 97*).



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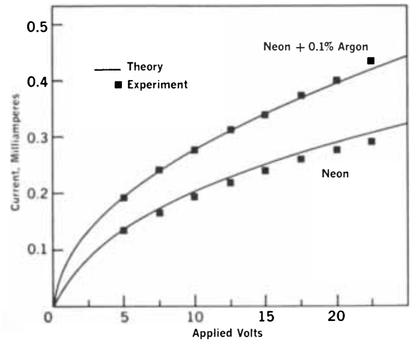


Characteristics of tubes filled with gases ionized by fission fragments. Resulting current is a function of ion generation rate, which is increased greatly (from 1.8 to 2.6 x 10^{16} ions per cm^3 per sec) by small addition of argon.

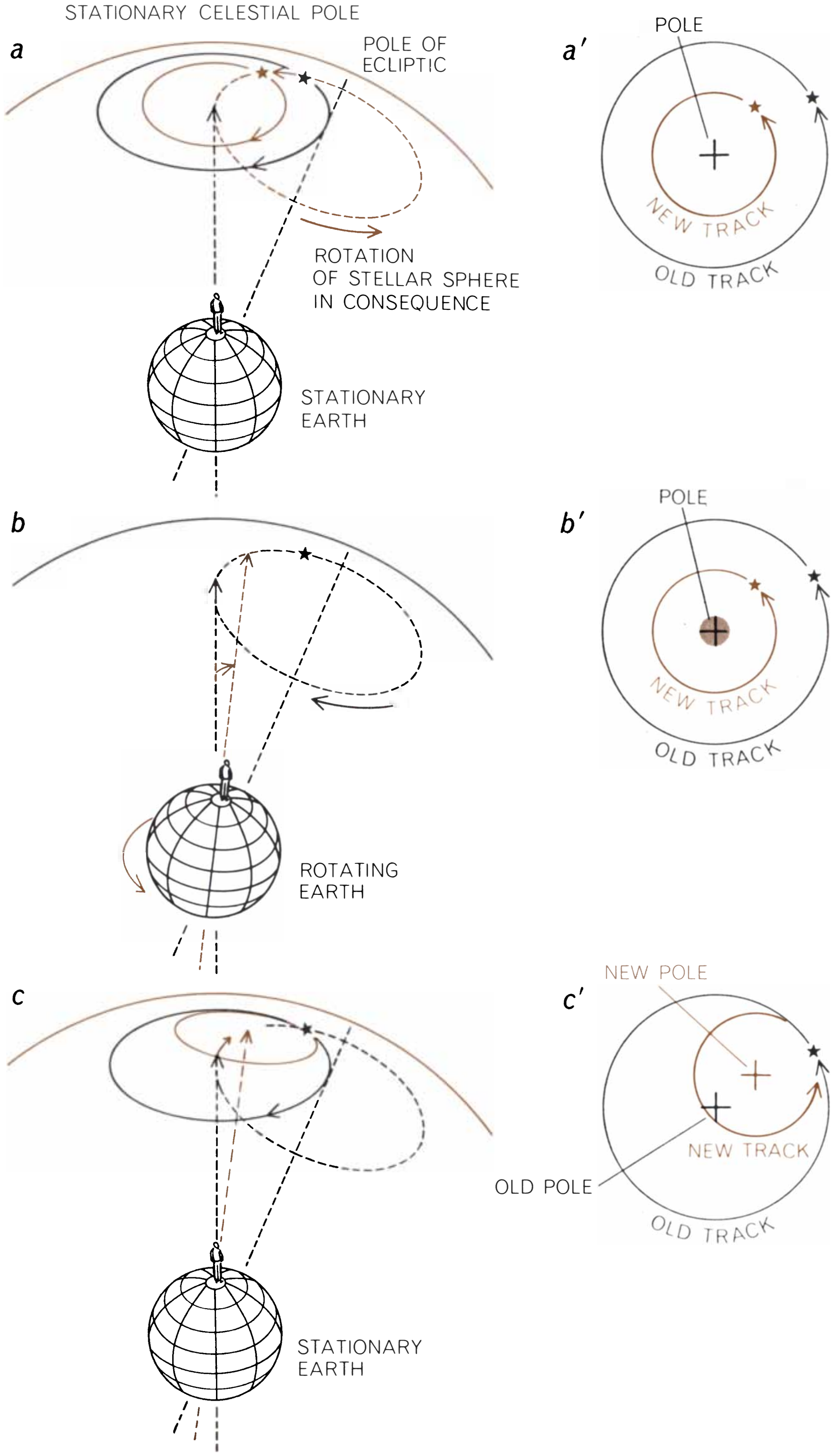
arm centered on the earth, rotating in phase with the sun. The second arm would rotate fastest for Mercury, slower for Venus, still slower for Mars, and so on out to the motionless stellar sphere (whose apparent motions—the daily rotation and the slow motion in consequence—now belong to the rotating earth and its axis). This would fit an accepted principle for the relation of the planets' distances and speeds ascribed to Euclid, which we now accept in a more precise form as Kepler's third law. No other existing system fitted so well, and so this model would serve as confirming evidence for the one being considered.

In such a model the sun's orbit would be the basic orbit for the entire system. If Copernicus paused and worked out some detailed mathematical models at this stage, he would naturally give prominence to the sun's orbit. Here we may have the explanation for the anomalous privileged position later given the earth's orbit around the sun, called the "great circle" in the mature heliocentric theory. Working through such a stage would also give Copernicus motivation for replacing the equant device of the Ptolemaic theory; when planets circle the sun, there is no place for an equant.

The last hurdle may also have been taken in connection with the problem of structure. In this section of *De Revolutionibus* Copernicus refers to a gap between Venus and Mars that must be filled—and filled by the earth-moon system. Now, in the quasi-heliocentric system we have just imagined Copernicus to have reached, this gap was filled by the stationary earth with its companion the moon.

It may have occurred to Copernicus in a flash of insight that putting the earth in motion would radically simplify the structure he had erected so far. Or the ancient principle of decreasing speeds with increasing distances may have pointed the way. In this intermediate system the elements of the harmonious sequence of decreasing mean speeds of planets were coupled with a common annual revolution about the sun. Between Venus and Mars lay the earth, with zero speed. This was clearly anomalous [*see illustrations on next page*]. The earth should have a period of revolution between the nine months of Venus and the two years of Mars.

The choice is obvious: Make it a year. But a period of a year for a revolution of the earth implies a constancy of the sun, and at a stroke the



SLOW MOVEMENT OF CELESTIAL POLE would change the observed position and tracks of polar stars. These changes, however, would be indistinguishable for two of the three hypotheses shown here: Ptolemy's belief (*a*) that the eighth sphere is moving "in consequence" and Copernicus' belief (*b*) that the earth is rotating and that a slow tilt in its axis could account for the movement of the celestial pole without changing the axis of the sky's apparent daily rotation. Since Copernicus rejected elaborate motions of the eighth sphere he could argue that if the celestial equator and poles were somehow to be carried to new positions while the earth remained stationary (*c*), the observed tracks of polar stars (*c′*) would be contrary to historical observations. These observations supported an apparently fixed celestial pole toward which nearby stars seemed to move slowly over the centuries (*a′*, *b′*). The present pole star, Polaris, was about three degrees from the North Pole in the time of Copernicus and nearly 30 degrees from the pole in the time of Ptolemy.

	SUN	MERCURY	VENUS	EARTH	MARS	JUPITER	SATURN
PERIOD OF EXCENTRIC	1 YEAR	1 YEAR	1 YEAR	0	1 YEAR	1 YEAR	1 YEAR
PERIOD OF DEFERENT	0	80 DAYS	9 MONTHS	0	2 YEARS	12 YEARS	30 YEARS

PRELIMINARY COPERNICAN SCHEME, attributed by the author to Copernicus, visualized all the planets except the earth in orbit around the sun, with their customary periods of rotation. The sun in turn traveled around a stationary earth, carrying the five other planets with it, in its customary period of one year. In the table above the annual revolution of the sun and planets is called the period of the excentric; the period of rotation of each planet around the sun is called the period of the deferent. These are terms adapted from the ancient geocentric theory in which the deferent was the average distance of each planet from the earth and the excentric was the radius of the epicycle, or small circle, that each planet was believed to describe as it traveled along its average orbit.

	SUN	MERCURY	VENUS	EARTH	MARS	JUPITER	SATURN
PERIOD OF EXCENTRIC	0	0	0	0	0	0	0
PERIOD OF DEFERENT	0	80 DAYS	9 MONTHS	1 YEAR	2 YEARS	12 YEARS	30 YEARS

FINAL COPERNICAN SCHEME was derived, the author believes, from Copernicus' recognition that the earth lies between Venus and Mars and therefore to assign it a zero period of deferent (*see illustration above*) was anomalous. A reasonable period would be between the nine months of Venus and the two years of Mars. A deferent period of one year was an obvious choice. In this case, however, one could just as well immobilize the sun and set all the excentric periods to zero. The Copernican revolution could begin.

annual motion of the other planets is removed. Harmony is complete.

If this train of reasoning led Copernicus to consider the earth's revolution seriously, then the many other advantages of the heliostatic system would suggest themselves almost immediately. Copernicus' conviction of the physical reality of the system would be firm and his lifework established.

Regardless of the accuracy of this reconstruction (and I have been obliged to omit further details and other evidence in the interest of brevity), we can use the early date of the *Commentariolus* and the ideas of Chapter 10, Book 1 of *De Revolutionibus* to illuminate Copernicus' later career. If he arrived in Italy in 1497 with an early draft of the *Commentariolus* in his pocket, he would naturally be welcomed as a colleague by the distinguished astronomer Comenicus Maria de Novara; also it would be fitting for him to lecture on astronomy at Rome in 1500. He would undertake the study of Greek in order to search among classical authors for a pedigree for his theory. In Neoplatonic circles in northern Italy he would find approval for his enthroning of the sun. It is unlikely that in all Italy he would encounter anyone possessing the technical competence to challenge his astronomical system.

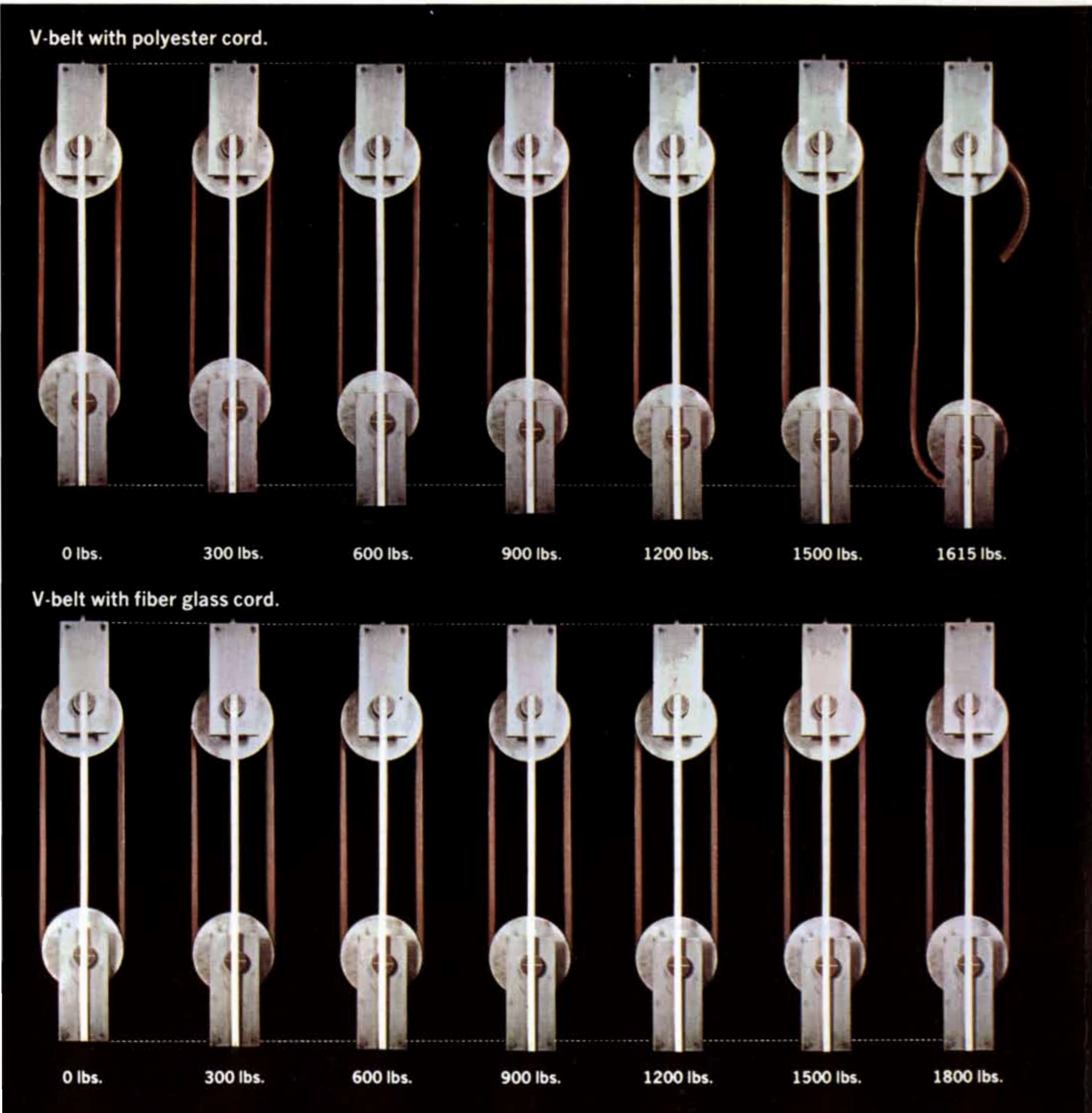
On his return to Poland, Copernicus started to work up a full treatise on the basis of the sketched models of the *Commentariolus*. He soon had to modify this because of the complications revealed by his own observations. Copernicus is commonly given little credit as an observational astronomer because only a few score of his observations are recorded. These, however, are the critical ones for the establishment of his system. He devised a sophisticated apparatus for measuring the position of the sun, and his observations of the planets were sufficient for him to discover an irregularity in their motions undetected by all his predecessors.

The "four times nine years" in which Copernicus' masterpiece took shape separated the isolated and aging canon in his 60's from the brilliant young man of Cracow and Bologna. The tasks of setting out an accurate system of astronomy were entirely different from the heroic endeavors of discovery. *De Revolutionibus* had to be, like the *Almagest*, a fully articulated system of the world, proceeding logically from cosmological assumptions through the basic measurements of the elements of the frames of reference to a stepwise construction of soundly based mathematical models for predicting the phenomena. In all this detail the early insights survive only as buried fragments. They are nonetheless there to be found if one perseveres.

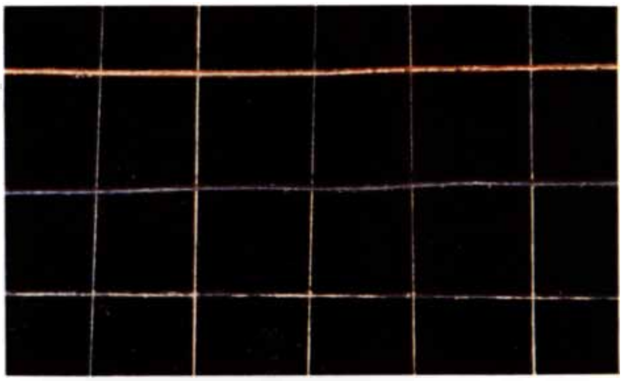
Thus we see why the revolution in cosmology had to have for its firm basis the work of a man who was revered by his immediate successors as "the restorer of astronomy" and "the Ptolemy of our age." If the idea of a heliocentric universe was to be more than a philosophical speculation, it had to be forged in the course of the detailed investigation of real and basic astronomical problems. Whoever successfully pursued such problems had to be more than a master craftsman of the science as it then existed; the task needed someone who could recast the foundations of the science itself. The metaphysical commitment necessary for such an undertaking did not have to be extravagant sun worship or circle mysticism. Rather it was the belief that astronomers have to do more than merely "save the phenomena"; they should exhibit the rationality and harmony of God's creation. Such an astronomer was Nicolaus Copernicus; out of his attempt to restore the ancient science of astronomy came the birth of a new world.

Stretchless V-belts: now a reality.

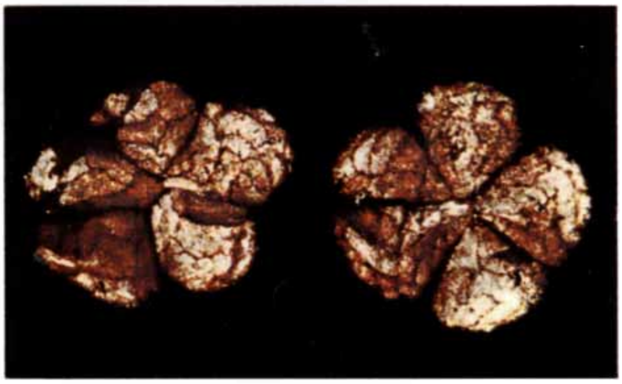
V-belt with polyester cord stretches 12 percent before breaking. At same tension, V-belt with fiber glass cord stretches only 2 percent.



Uniroyal found a way to mold fiber glass cord into rubber. Result: V-belts and other products with greater tensile strength and practically no stretch.



Fiber glass filaments are several times thinner than human hair. Vertical lines are fiber glass; horizontal lines are (top to bottom) red, black and blond hair. Enlarged 8 times.



Cross section shows fiber glass cords embedded in a V-belt. Each cord consists of 51,000 filaments encapsulated in a special rubber (brown coloring). Enlarged 15 times.

Even a small improvement in a product as universally used as V-belts represents a significant achievement. The use of fiber glass in V-belts is much more than that.

Tension decay has always been the major problem with V-belt drives. As a belt stretches, slippage increases with a resulting loss of power. In extreme cases, belts lose so much tension they turn over in their grooves and destroy themselves.

To avoid the problem, belts have to be constantly retensioned.

One solution is to use steel cord in place of rayon or polyester. Steel, however, has only limited application because it tends to cut through the rubber.

A more practical answer is glass cord which, pound for pound, is stronger than steel. When formed into ultra-thin filaments (typical diameter is 0.000375 inch) glass acts like natural or synthetic fibers.

Uniroyal (you may know us as United States Rubber Company) perfected the fiber glass cord V-belt after several years of research. Not only was the belt we developed a superior product, but it could sell at the same price as polyester cord V-belts.

In the last two years more than three million V-belts with fiber glass cord have been built and sold by Uniroyal under the registered "Fibrex" tradename. Fibrex V-belts have exceeded expectations. Not only do they reduce the need for retensioning, they also stand up well in difficult applications. (In comparative tests, Fibrex V-belts outlasted other V-belts by a factor of better than two to one.)

One reason is the greater consistency of Fibrex V-belts. Polyester-cord V-belts not only stretch from three to six times as much, they also stretch inconsistently. This means that one belt on a multiple V-belt drive might be under twice as much tension as the others. This is the belt that does most of the work and the one that is likely to fail rapidly.

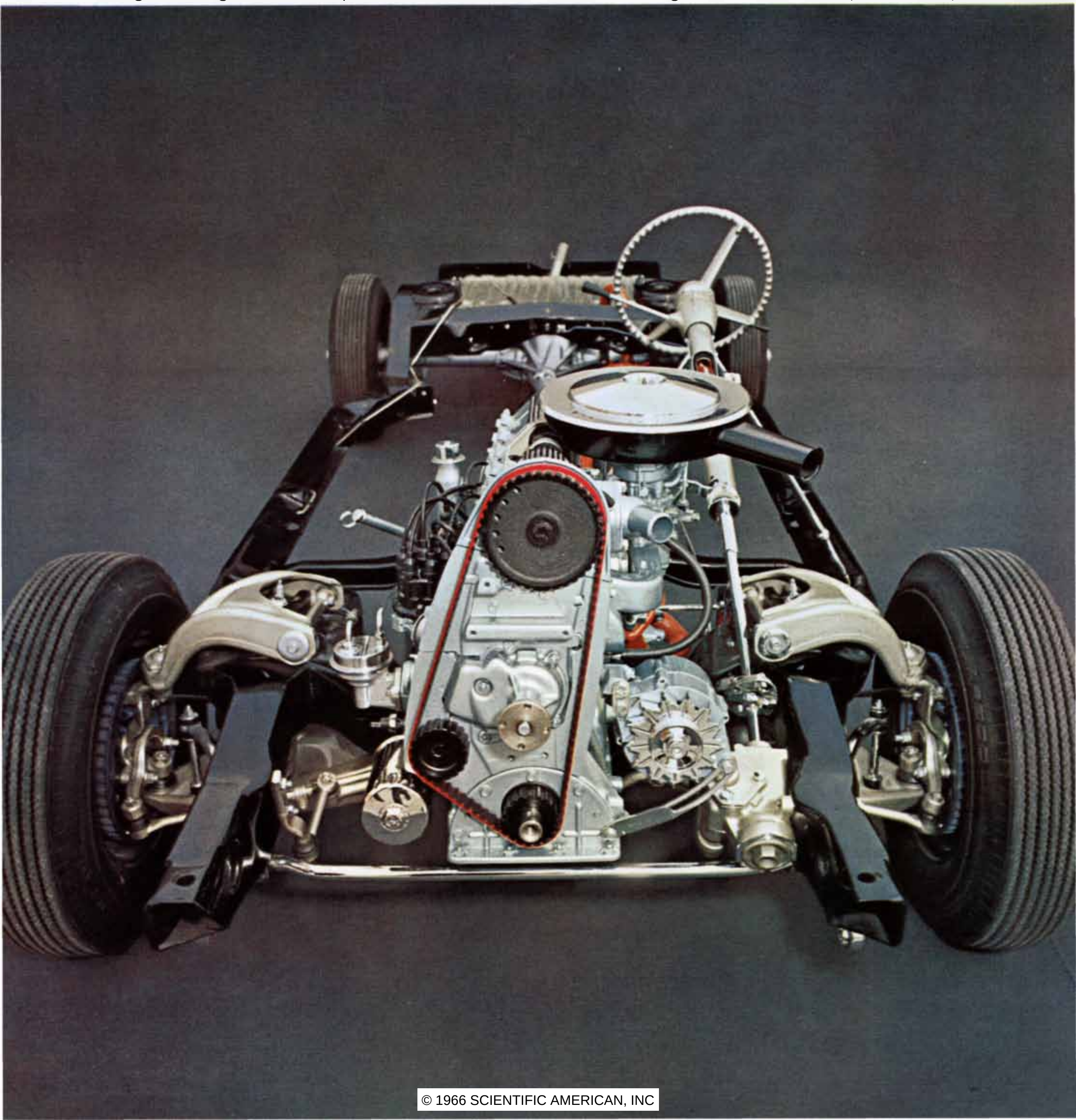
Fibrex V-belts have very uniform tensile characteristics. In tests like the ones at the left, stretch at 1500 pounds varied from 1.5 to 2.0 percent. For polyester V-belts, the variation was 4.5 to 11.8 percent.

Fibrex V-belts are also stronger. Tensile strength, on the average, is 24 percent higher than polyester V-belts.

Continued...

Stretchless V-belts: now a reality.

Strength of fiber glass cord made possible Detroit's first overhead camshaft engine with a rubber drive (shown in red.)



UNIROYAL
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V-belts are not the only Uniroyal product to take advantage of the strength and "stretchless" qualities of fiber glass.

A natural application is the timing belt invented by Uniroyal some 17 years ago. Fiber glass makes the timing belt a more versatile power transmission drive.

The timing belt was a key factor in the development of the first overhead camshaft engine mass-produced in the United States. This camshaft drive is quieter and more economical than a gear or chain drive. It should require less maintenance.

Uniroyal timing belts, sold under the registered "PowerGrip" tradename, are used for many products including electric typewriters, sewing machines, gasoline pumps, office machines, television sets, appliances, outboard motors and power tools.

Timing belts are also in use for special applications such as cyclotrons and sonar equipment for atomic submarines.

Another fiber-glass-in-rubber application is a petroleum discharge hose developed by Uniroyal for the military. This new hose is one-third the weight of standard MIL-H-11588C hose.

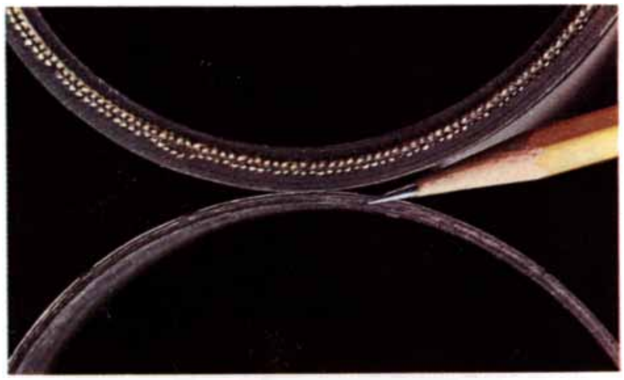
Four-inch diameter hose of the new design withstands pressures up to 900 psi as compared with a little over 600 psi for standard hose. The new hose weighs only 12 ounces a foot versus 40 for the standard hose.

To build the new hose, Uniroyal developed a machine that takes thin strips of rubber and fiber glass and winds them into finished hose. This unique construction method also contributes to the great strength of the hose.

Uniroyal makes a lot more industrial products than V-belts, timing belts and hose. If you have a problem that one of our many rubber, chemical or plastic products might solve, we'd like to hear from you.

Write to: Uniroyal, Technical Advisory Service, 1230 Avenue of the Americas, New York, N.Y. 10020.

We may not be the biggest rubber company, but we're the most inventive. And we have almost 1,500 patents to prove it.



Wall thickness of new military hose with fiber glass reinforcement is less than one-third that of conventional military hose, yet burst strength is up to 50 percent higher.

Thinness and flexibility of new fiber glass hose allows it to be easily folded for storage. Space conservation and weight reduction are important factors for military applications.

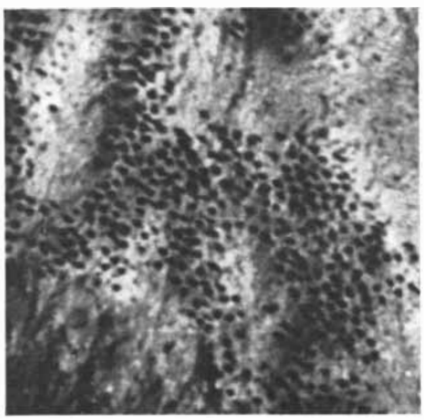
Uniroyal holds more patents than any other rubber company.

The Navigation of Penguins

The Adélie penguin travels hundreds of miles from its breeding grounds over virtually featureless land and water and returns to the same nest. How it does so is investigated by experiment

by John T. Emlen and Richard L. Penney

It has long been known that the domesticated pigeon can find its way home after having been transported to a strange location, and experiments conducted in recent years have shown that a number of wild bird species possess the same ability. A series of experiments conducted recently in Antarctica has demonstrated that one wild bird's ability to travel almost straight across hundreds of miles of featureless antarctic landscape depends on a "clock" and a "compass" working in combination. The experiments were conducted with a flightless bird, the Adélie penguin (*Pygoscelis adeliae*). Their results may help to answer the question that inevitably arises in discussions of bird navigation: How do the animals do it? In this article we shall relate why both an unusual field area and an unusual bird were selected for the experiments, relate the outcome of our studies and conclude with a summary of the questions concerning bird navigation to which there now appear to be complete or partial answers.



PENGUIN ROOKERY at Cape Crozier in Antarctica has a summer population of some 300,000 Adélie penguins. The aerial photograph on the opposite page shows a part of the rookery; each of the black dots is the shadow of single or paired birds. The area indicated in color is shown enlarged above. Most of the birds used in the authors' studies of penguin navigation were adult or juvenile inhabitants of the rookery at Cape Crozier.

Early in the nesting season of 1959 five adult male Adélie penguins were captured and banded at an Adélie rookery near Wilkes Station in Antarctica and flown 1,200 miles to McMurdo Sound. The birds were then released; in effect they were being asked if they could find their way home. The majority answer was yes: when the Wilkes rookery penguin population assembled the following spring, three of the five kidnapped males waddled up the beach from the sea to establish their claim at the very nesting sites from which they had been so abruptly taken 10 months earlier. By what route they had traveled home no one knows, but their performance added the Adélie penguin to the lengthening list of bird species able to navigate over long distances. The achievement has an extra dimension; most bird navigators fly, but the penguins had walked, tobogganed on their bellies or swum the entire way.

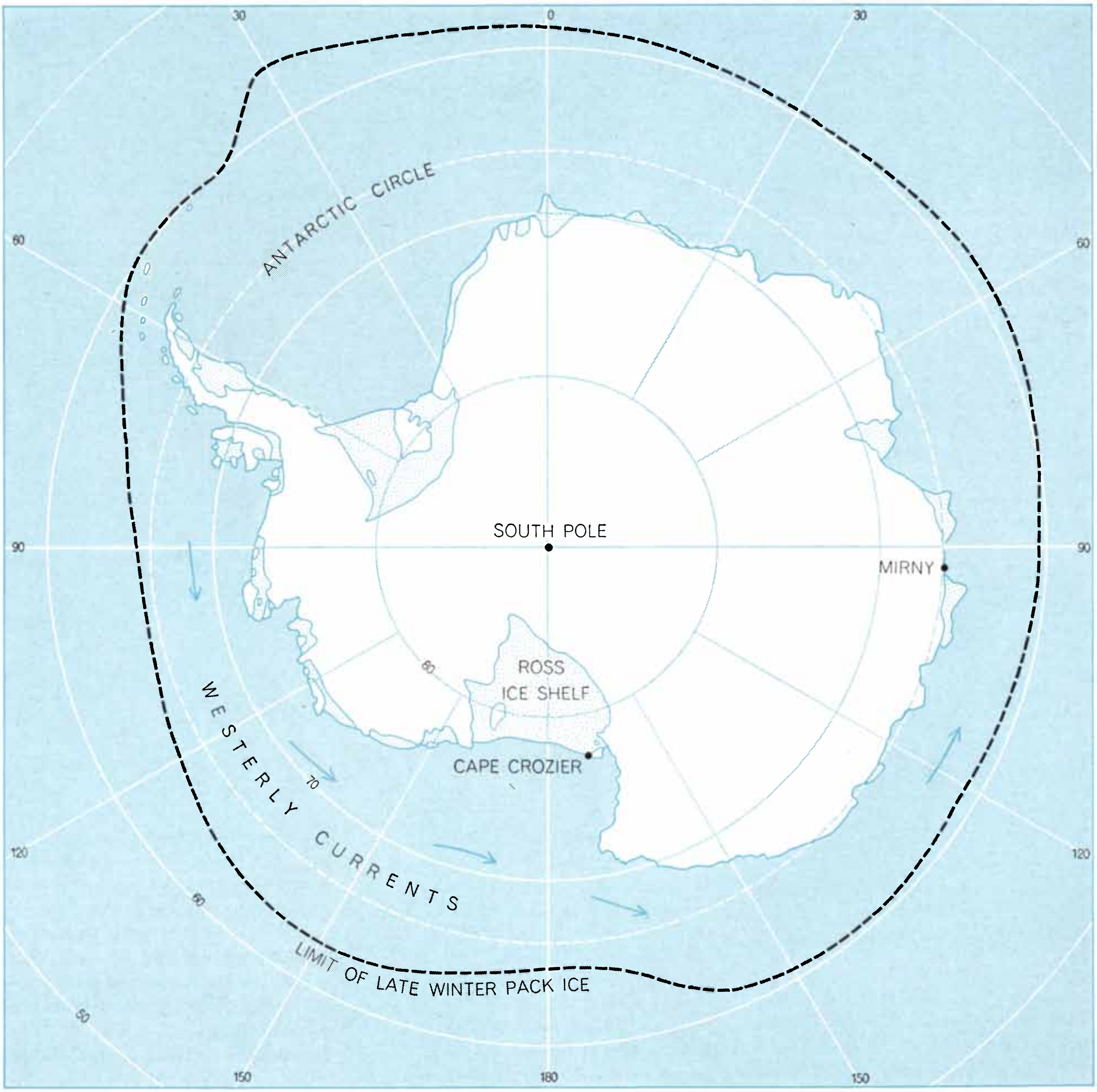
The observation that migratory birds return to the same nesting sites year after year almost always raises questions that are phrased in terms of how the migrants find their home. The late Gustav Kramer's discovery that captive birds could orient themselves by means of the sun was hailed as a major research breakthrough at the time of his first experiments in Germany 15 years ago. Here was a new insight into a compass-like mechanism that might explain birds' navigational abilities. As Kramer and others pointed out, however, neither bird nor man nor any other animal is able to find the way home from a strange place with the aid of a compass alone. A man who undertakes true bicoordinate navigation needs both a compass and the equivalent of a map on which both his present position and his destination are located; at the very least a bird needs some kind of information about its position with respect to home at some point during its journey. Nonetheless, many investigators who are attempting to discover the cues that may tell navigating birds the direction of home have begun to wonder if the birds have access to such information after all.

One of the more troublesome problems connected with studies of bird navigation gave us a reason for selecting Antarctica as an experimental site. This is the difficulty involved in keeping track of experimental birds and recording their performance. If a bird is placed in a circular cage during its migrating season, it will provide information on some aspects of orientation. But if the bird is released from the cage in the hope of obtaining more information, control of the experiment flies out the window with the bird. Although free-flight experiments making use of birds fitted with telemetering devices that radio their position are currently yielding interesting results, at the time our antarctic experiments were undertaken the advantages offered by a flightless bird that travels overland in an environment free of obstacles and disturbances were compelling.

In addition to being a slow enough traveler on land to be followed easily, the Adélie penguin has a number of other assets as an experimental animal. First, it is a migratory bird with a demonstrated homing ability; each spring and fall Adélies travel hundreds of miles between the outer fringe of the antarctic pack ice and their rookeries on the coast of the continent. Second, it thrives in subzero weather and shuns all food for weeks on end during the nesting season. Third, it is abundant and easily captured at its rookeries. Fourth, because its normal range is along the coastal fringe of the continent, individual birds are not likely to be familiar with any landmarks in inland areas. Finally, the Adélie's back is broad, black and conspicuous in the polar snowscape, and on most snow surfaces its tracks can be followed and charted in detail [*see illustration on page 112*].

The experimental advantages of Antarctica itself, in addition to its vast stretches of generally featureless interior, include 24-hour daylight during the summer season. Furthermore, the meridians of longitude come closer and closer together until they meet at the South Pole; therefore a comparatively short journey east or west along the coast may cover dozens of degrees of longitude. With the excellent facilities provided by the Navy and the scientific-support arm of the Antarctic Research Program, it was possible to move captured penguins readily to locales many miles and many degrees of longitude distant from their home.

The subjects in most of our tests came from a thriving Adélie rookery at Cape Crozier, where some 300,000 birds gather each nesting season. We netted and moved the penguins 20 at a time to our test areas. There they were banded (on the wing) and housed

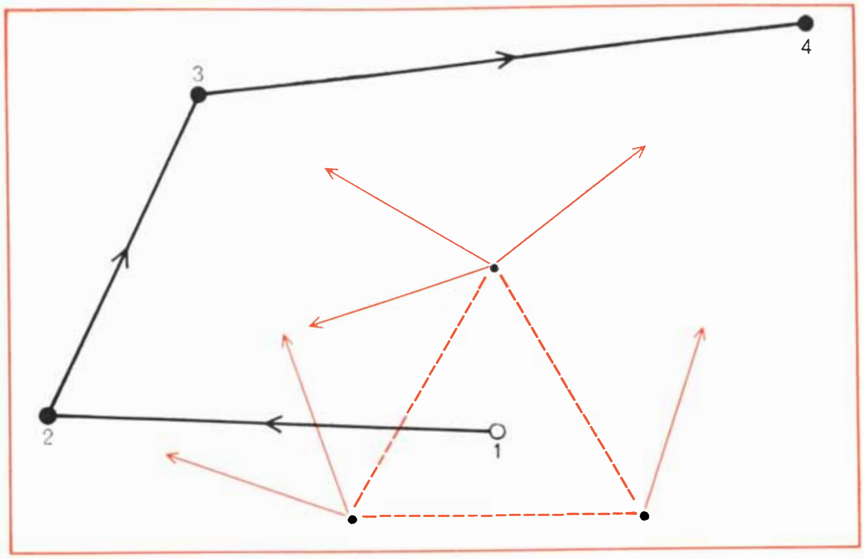


ANTARCTICA was selected as a location for the authors' studies both because Adélie penguins are hardy and accomplished migrants and because moving captive birds a comparatively short distance to the east or west placed them in a completely novel environment that contained a minimum of familiar navigation cues. Each fall the birds travel from any one of a number of coastal rookeries such as Cape Crozier north to the open water along the edge of the pack ice. When spring comes, they return to their home rookeries.

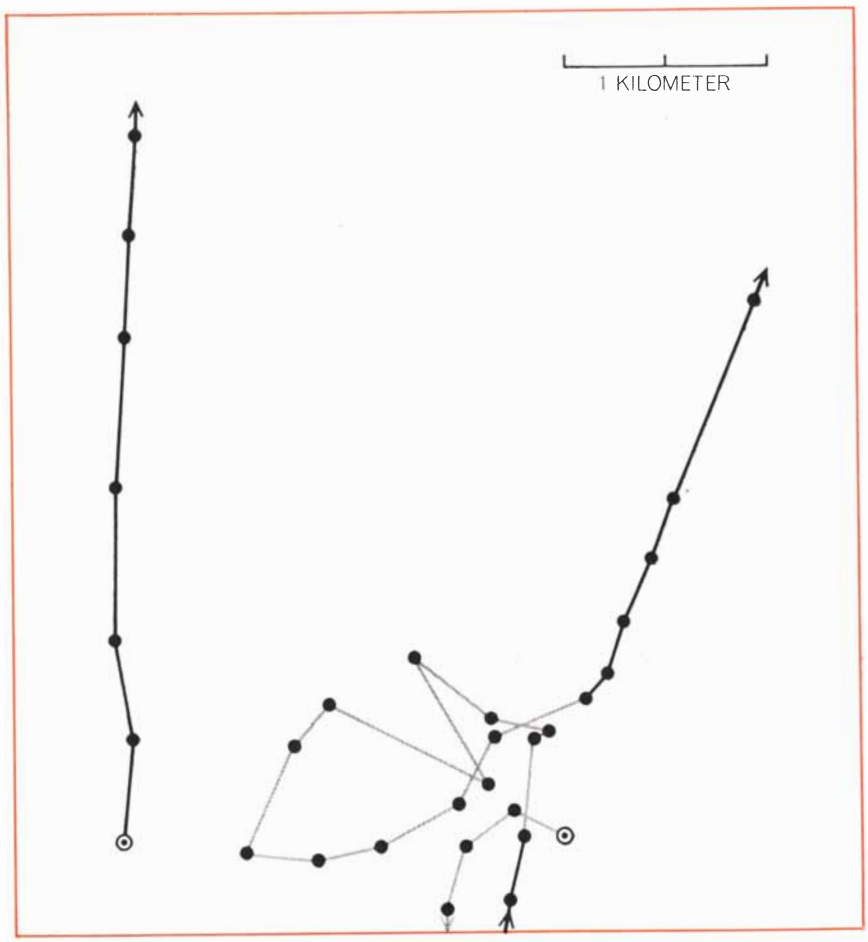
in pits excavated in the snow until it was their turn to be tested. Our principal test site was located in the middle of the 150,000-square-mile Ross Ice Shelf, some 180 miles southeast of Cape Crozier, at a point where the 180th meridian and the 80th parallel of south latitude intersect. Here a featureless white landscape stretches northward 105 miles to the Ross Sea and extends unchanged even farther southward and eastward. Only to the west is the flat terrain eventually broken by glacier-crowned mountain ranges, and these were out of sight 180 miles from our camp. Although the snow surface close at hand is wrinkled by irregular wind furrows, the distant line where sky and land meet is monotonously level.

In order to record the direction in which the penguins traveled when they were released we set up three tall tripods so that they formed the points of an equilateral triangle 200 meters on a side. A surveyor's transit was placed at the top of each tripod. At the midpoint of the triangular area we dug a small release pit with a cover that could be pulled clear with a tug on a length of cord that extended to an inconspicuous white shelter some distance away. When all was in readiness, we would remove a bird from its storage pit, put it in the release pit and set the cover in place. We then retired to our shelter and pulled the cord; the bird promptly jumped up to the surface, ready either to travel or, as sometimes happened, to lie down and go to sleep.

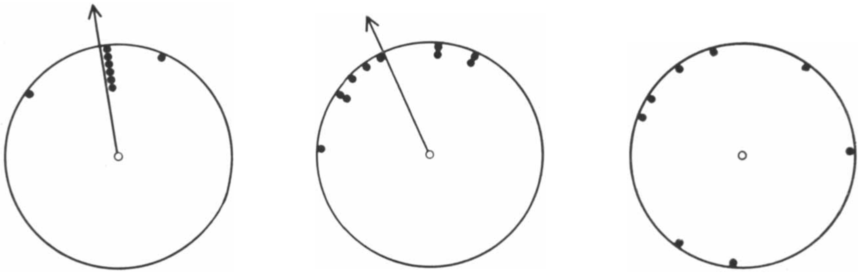
Usually the newly freed bird would make a few short dashes in various directions and then stand and peer at the limited scenery: the three transit tripods, our shelter and the antarctic sun. After a few minutes the bird would set off again, this time in a definite direction from which it rarely veered. Every five minutes two observers would take simultaneous azimuth readings, using the two transits that were best situated for the purpose. These readings enabled us to plot the bird's course over a distance of one to three miles and usually for 20 to 40 minutes, by which time our subject would have disappeared over the horizon [*see top illustration at right*]. Sometimes we extended the record by following a bird's tracks for as many as 16 miles from the release site. We also fitted a few penguins with radio transmitters and recorded their direction of travel for 50 miles or so. The bulk of our most useful data, however, was obtained by visually tracking 174 penguins during the first one to three miles of their journey. Most of our subjects



TRACKING SYSTEM required visual checks on the position of each bird at five-minute intervals after it was released from a pit located at the midpoint of an equilateral triangle with sides 200 meters long (*1*). A transit was located at each point of the triangle; readings from the two best-situated instruments (*arrows*) allowed the bird's position to be recorded until it vanished over the horizon. Some birds were subsequently tracked as far as 16 miles across the snow. A few birds fitted with radio transmitters were monitored up to 50 miles.



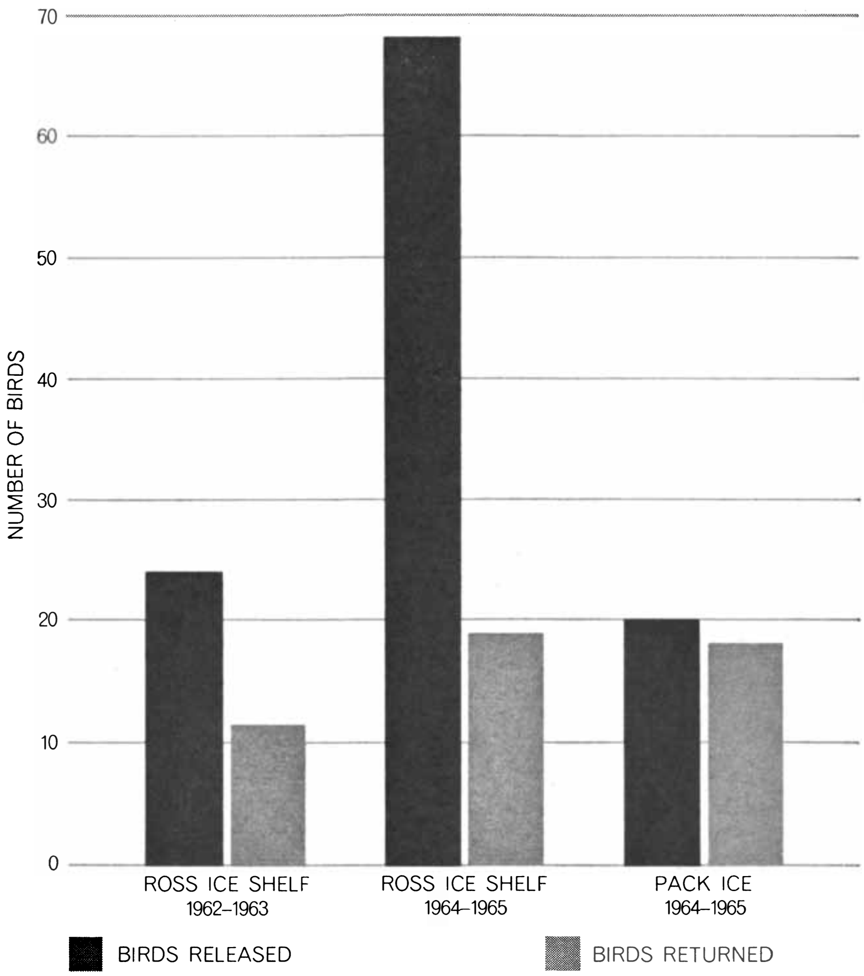
CLEAR AND CLOUDY SKIES caused the tracks illustrated in this diagram. Each dot represents the position of an Adélie penguin at five-minute intervals following its release (*bull's-eye*). In sunlight one bird (*left*) started on and held to a straight course until out of sight. Released under a cloudy sky, a second bird (*right*) headed the opposite way (*gray line*) but reappeared (*black*) when the sky cleared. More clouds left the bird moving at random until sunlight again headed it on much the same course as the first bird's.



DEPENDENCE ON THE SUN as a compass was demonstrated by recording the penguins' movements in varying weather conditions. Each dot near the edges of the three circles represents the direction in which one bird left the test area; the arrows (*left and center*) show the mean heading. Thin clouds that veiled the sun (*center*) reduced the penguins' ability to orient themselves. When the sun was obscured (*right*), they were totally disoriented.

were birds from Cape Crozier released at the test site on the Ross Ice Shelf, but we also released birds at this site that had been captured at a rookery near Mirny Station, the Russian antarctic headquarters on the Queen Maud Coast. We also shifted release sites, liberating some Cape Crozier penguins on Marie Byrd Land (at 120 degrees west longitude), on the Victoria Land plateau (at 155 degrees east longitude), at a camp on the pack ice offshore from Cape Crozier and even at the South Pole.

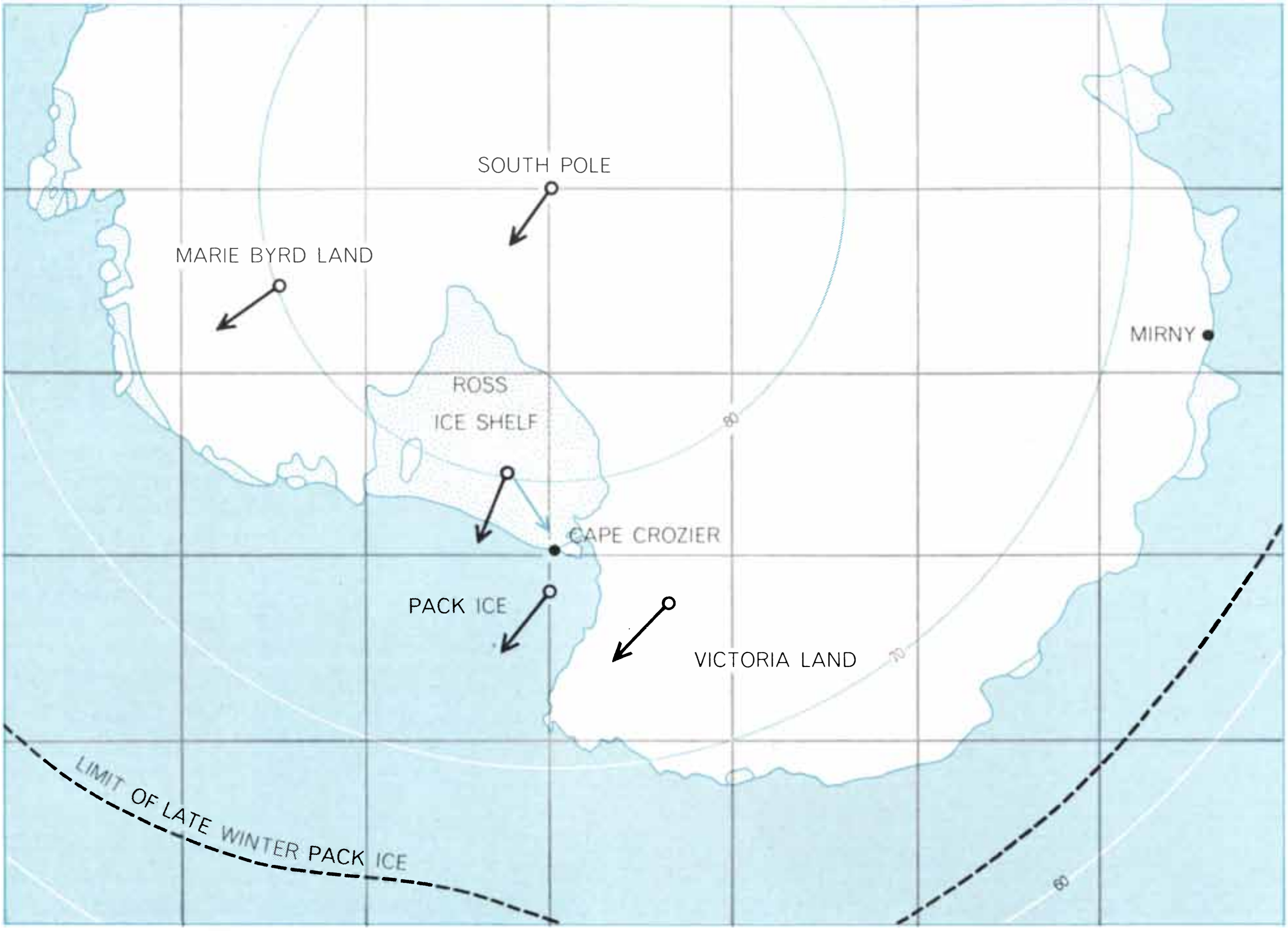
One of the first things we learned was that under clear skies our penguins characteristically selected and followed a straight line of travel for as long as we could see them. They often took small jogs right or left of the line, but these slight deviations were usually corrected in two seconds or so. When we plotted each bird's path as observed at five-minute intervals and compared the length of the plotted path with that of a straight line connecting the starting point and the last observed position, we found that the paths actually traveled by 62 penguins were only 1.025 times longer than the straight-line distances. In fact, nearly 90 percent of the birds achieved a "straightness index" of better than 1.009.



HOMING ABILITY of Adélie penguins is attested not only by their annual migrations but also by the eventual return to Cape Crozier of many of the birds that were transported to areas as far as 200 miles away. Use of the sun as a compass, although it enabled the penguins to orient consistently in unfamiliar territory, is not enough to explain their homing skill.

The importance of a clear sky and a good image of the sun to penguin orientation was soon demonstrated. When the sun was veiled by thin clouds (even though we could judge its position in the sky to within a few degrees), the performance of the departing penguins became erratic. When heavy clouds obscured the sun, the birds were completely disoriented and their selection of departure directions became random [*see top illustration at left*]. A dramatic demonstration of the birds' dependence on the sun was provided by one penguin whose movements we were able to follow for a four-hour interval that included two periods of overcast and two of clear sky. Heavy clouds covered the sun when the bird was released; it soon moved off in a direction exactly opposite to that taken by most birds under a clear sky and was lost from view about a mile away. Half an hour later it reappeared on the horizon, where there was now a patch of sunshine. As the sky cleared above us the bird continued to toboggan in our direction, approaching and passing our observation post. When it had traveled less than half a mile beyond us, clouds covered the sun again; it stopped and after a considerable pause set off at a right angle to its previous heading. It wandered irregularly and sometimes hesitantly for the next two hours, which remained cloudy. Then, as the sun broke through again, the bird resumed its interrupted direction of travel and passed out of sight over the horizon.

Navigation that uses the sun as a guide is by no means as simple as it may seem at first. The sun does more than rise in the east and set in the west. Its daily journey across the sky is complicated by an azimuthal motion that continuously alters its position with respect to landmarks on the horizon. In the



FIVE RELEASE POINTS, situated to the east, west, north and south of Cape Crozier, were used by the authors for their tests. Regardless of where they were released, birds from Cape Crozier all chose escape routes that were roughly parallel and approximately north-northeast with respect to a north-south line passing through Cape Crozier (*black arrows and gray grid*). When birds from the Russian antarctic station of Mirny were transported to the Ross Ice Shelf and released, they first chose escape routes almost perpendicular to those of Cape Crozier birds (*colored arrow*). When plotted with respect to a north-south line passing through Mirny, this heading also proved to be north-northeast. Other penguins from Mirny, kept on the Ross Ice Shelf for a few weeks, readjusted their "biological clock." When released, they chose the same general escape direction taken by the birds from the Cape Crozier rookery.

polar summer, when the sun neither rises nor sets, almost all its motion is azimuthal. To hold a constant course while one's "sun compass" swings around the horizon calls for continuous access to information on the passage of time, yet we found that the penguins were not affected by the sun's shifting azimuth. Birds that were released early in the morning set off northward, even though at that time a northerly heading was about 90 degrees to the left of the sun; at noon their northward departure was straight toward the sun; in the afternoon they still headed north, although by then such a heading was about 90 degrees to the right of the sun. Moreover, once the birds selected a course, they showed no tendency to fix on and follow the sun in its inexorable counterclockwise march along the horizon. This ability to be guided by the sun and yet to compensate for changes in its azimuthal position with the passage of time is the strongest kind of evidence that the Adélie penguins possess the timing mechanism commonly called a "biological clock."

Although the penguins' general heading after release was northward, it could more accurately be described as north-northeasterly rather than due north. Some considerations of polar geography are a necessary preliminary to discussion of this point. When one is standing on the South Pole, all true compass directions are north. In polar areas, therefore, it is useful to forget about true compass headings and instead to calculate directions on the basis of a rectangular grid. Such grids take the meridian on which the user is located as their central vertical line. In the illustration above, for example, the grid is oriented to the meridian that runs from the South Pole through the Cape Crozier rookery. Analyzing the penguins' travel directions in terms of this grid, we found that no matter where birds from Cape Crozier were set free they all set off in much the same north-northeast direction. This meant, of course, that they seldom headed for "home" at all. When Cape Crozier penguins were released on the Ross Ice Shelf or at Byrd Station, which are to the east of Cape Crozier, their heading pointed them far to the right of a homing course; when released in Victoria Land, to the west, their heading was about 90 degrees to the left of home. As for the penguins we released on the pack ice some 125 miles offshore, they set off on a north-northeast heading that took them directly away from the Cape Crozier rookery.

The fact that all the Cape Crozier birds, wherever they were released, pursued essentially parallel courses regardless of the actual direction of their home rookery is further evidence that the cue that guided all the birds was far more

POSITION READING is taken by a member of the authors' party, who stands atop a stepladder in the middle of the Ross Ice Shelf. The escape paths pursued by 54 penguins released during clear weather varied from a straight line by a factor of less than 1 percent.

ESCAPING PENGUIN ignores another bird's path as it heads across the Ross Ice Shelf. Adélie penguins travel two to three miles per hour; the fastest did eight miles per hour.

remote than anything connected with their home or, for that matter, with any localized terrestrial cue. The sun, some 93 million miles away, was their compass, and they could use it unerringly because their biological clocks served to correct for its azimuthal changes. At the same time, it was clear that the Cape Crozier penguins did not head for home. Their movements were oriented in terms of a common direction of escape rather than an approach toward a common goal.

The cooperation of our Russian colleagues at Mirny, 2,000 miles and 90 degrees of longitude away, enabled us to make a further test of our conclusion. Forty Adélie penguins were captured at Mirny and flown to the Ross Ice Shelf. When we released 20 of them, the birds set off north-northeast, but north-northeast only with respect to a grid centered on their home meridian at Mirny. Their actual course with respect to the local grid was northwest, so that their route lay almost at right angles to that of the Cape Crozier penguins.

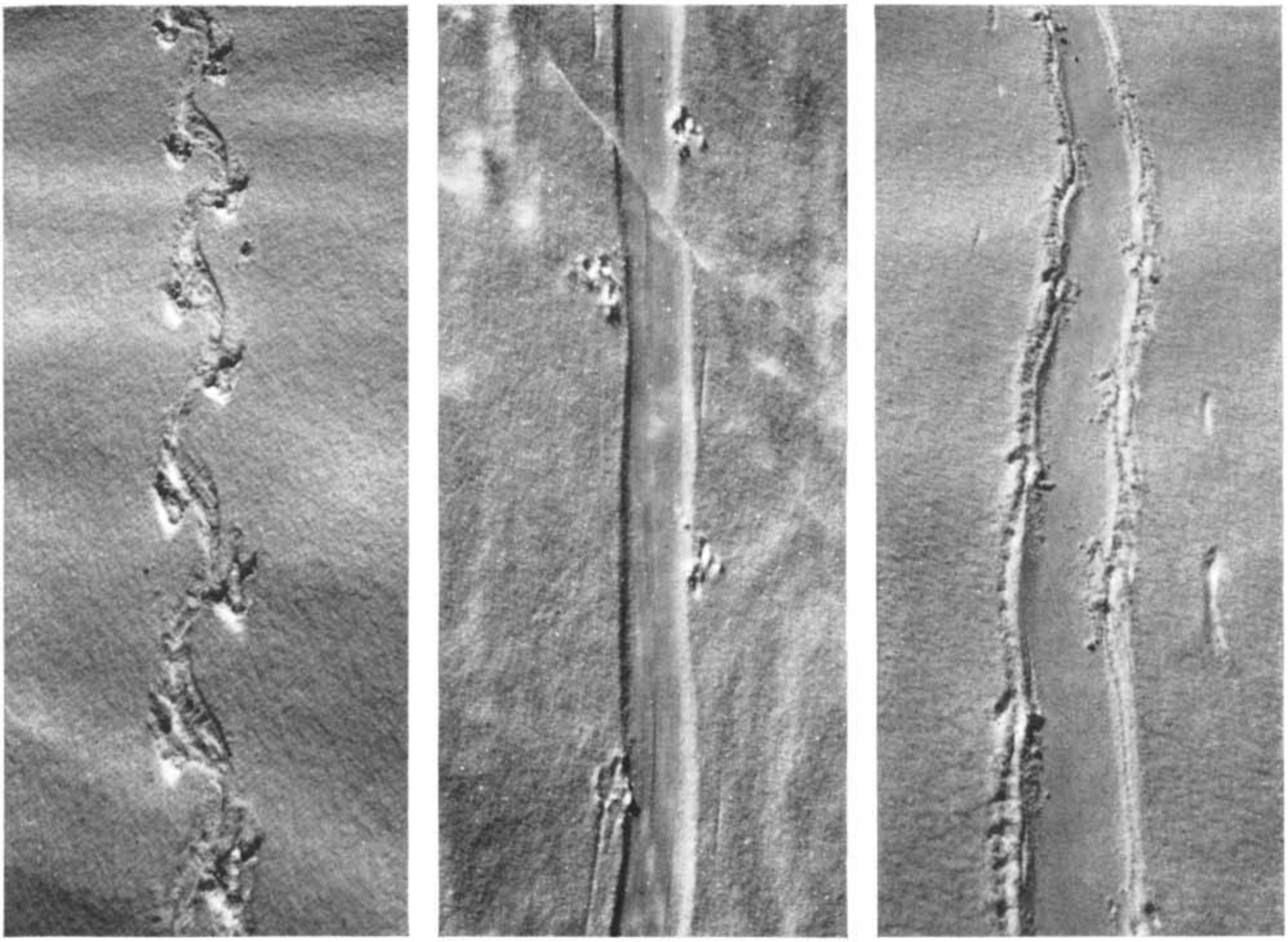
What functional explanation can be found, in terms of survival value, for the generally northward escape route taken by the Adélie penguins we captured at various rookeries? Northward, to be sure, is always seaward in Antarctica; an attractively simple explanation is that movement northward would carry a lost penguin along the shortest route to the sea—the species' only source of food. There is also another consideration. For migratory birds such as the Adélie penguin a sun compass "set" to a home meridian would tend to reduce lateral dispersal of any one rookery's population and ensure that the same group of penguins returned from the fringes of the pack ice to the same stretch of coast each year. Indeed, the home meridian—regarded as a reasonably broad corridor with one end in the coastal rookery and the other in the food-rich waters at the edge of the pack ice—may be what "home" is to an Adélie penguin. The bird's annual movements inward or outward along the corridor could be the result of physiologically controlled negative or positive responses to the same basic orientation cue or cues.

What accounts for the slight but unmistakable easterly vector that turns the outward journey from true north to north-northeast? At the end of our first season's work in Antarctica we were prepared to dismiss it as a chance variation. Further and stronger evidence of the easterly vector gathered in 1964 made it impossible to ignore. One possible answer suggests itself at present: The coastal currents in both the Cape Crozier and the Mirny areas are westerly. A penguin adrift on the offshore pack ice would be slowly carried westward out of its home zone unless it compensated by moving to the east from time to time. Similarly, a bird moving from the coast to the outer fringe of the pack ice would be borne toward the west if its line of march were true north instead of north-northeast. One observation that lends weight to our suggestion that the easterly vector is a compensation for westerly coastal currents is that the Mirny birds released on the Ross Ice Shelf showed a stronger easterly bias than the Cape Crozier birds released there. The westerly currents off the Mirny coast are known to run strong.

The contrast between the escape headings chosen by Cape Crozier and Mirny birds immediately raises two questions. It seems safe to assume that a penguin's ability to select an escape direction when transferred to a strange environment is something innate. But what about the specific direction selected? Is this innately determined or is it a function of the environment in which the bird was raised? And can external influences alter the setting of the bird's compass?

We decided to see what information the escape behavior of two-month-old, inexperienced penguins might provide concerning the first of these questions. We captured a number of Cape Crozier chicks, some near the nests where they had been hatched and others on the beach that borders the rookery. When they were released on the Ross Ice Shelf, all of them headed off generally north-northeast on a straight course, although they showed somewhat greater variations in their selection of departure directions than did the adult Adélies.

The chicks' possession of a directional preference cannot, however, be taken as proof that the response is innate in the species. From the day they emerge from their eggs the Adélie penguins at Cape Crozier look down a steep slope that faces the Ross Sea to the northeast. Below, adult penguins are constantly entering and leaving the water, returning with food for the ravenous chicks (who, when their hunger is unsatisfied, will often pursue a parent part of the way back to the water). The same northeasterly direction is the one in which the chicks themselves will move once they



PENGUIN'S PROGRESS on land can vary from a brisk waddle (*left*), in which the bird's oscillating tail leaves a serpentine track in the snow, to a swift tobogganing, sometimes propelled by the feet alone (*center*) and sometimes assisted by wing strokes (*right*).

become independent of the nesting area. North-northeast thus becomes a significant direction to the birds as they mature. It seems plausible that such an upbringing, in which the topographic cues that come to mean "seaward" are constantly associated with the celestial cues that represent north-northeast, might allow the celestial cues to persist and function in situations where the topographic ones are no longer available.

As for the second question, we would have found it surprising if our birds had proved impervious to the environmental influences that are known to reset the biological clocks of many Temperate Zone animals within a period of a week or so. Yet, compared with the day-and-night cycle of the Temperate Zone, the cues available in the continuous daylight of the antarctic summer are notably weak ones. To put the matter to a test we kept the remaining 20 of the 40 birds from Mirny penned under the open sky on the Ross Ice Shelf for periods that ranged from 18 to 27 days. These birds had arrived with their clock synchronized to a time zone some 88 degrees to the west (equivalent to the six-hour time difference between London and New Orleans). At the end of their three- to four-week detention the 20 Mirny birds selected local north-northeast as their departure direction. Their clock—and thus their compass—had been reset; the resetting turned them 55 degrees to the right and pointed them in the same general escape direction as the one selected by the "local" Cape Crozier birds.

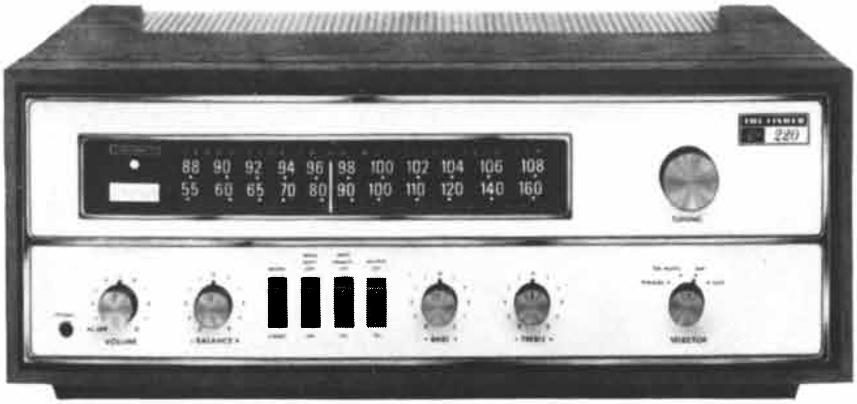
This finding leaves us in something of a dilemma. If all the Adélie penguins in the Antarctic can reset their clock as easily as the 20 birds from Mirny did, our earlier speculation that a constant local escape orientation would be useful in maintaining population-specific coastal zones may not be warranted. Any birds that wandered toward the lateral boundary of their population's corridor would be in danger of adapting to the new conditions there. The unifying interrelation of breeding grounds and feeding area that is provided by a common compass setting would therefore be lost to them. For the moment we can only suggest that unconfined birds may not reset their clock as readily as birds that are artificially detained do.

We have seen that the Adélie penguin can navigate with the sun as a directional cue and with an inherent timing mechanism as compensation for the sun's position changes from hour to hour. We have also seen that the consistent escape direction chosen by released birds is a northerly one that under normal circumstances would possess considerable survival value by leading a lost bird to the nearest feeding ground at sea. Unfortunately these two observations tell us little about the question that faced us at the outset: How do the birds find their way home? The fact that so many of our experimental subjects did reach their home rookeries indicates that Adélie penguins possess something by way of navigational equipment in addition to the sun-compass orientation they demonstrated during the release experiments.

Cape Crozier birds released on the Ross Ice Shelf consistently headed far to the right of their true homeward direction, but at least half of them were back at Cape Crozier within 25 days. Of the 20 Cape Crozier birds we turned loose on the pack ice many miles offshore, 15 were back home within two weeks even though all had started off in exactly the opposite direction. How did the three birds from Wilkes Station and at least two of the birds from Mirny find their way home over thousands of intervening miles in time for the next nesting season? For that matter, how do millions of Adélie penguins do much the same thing in their annual migrations?

We can only speculate that a homing bird must receive new information at some point on its long trek. We suspect that the birds receive this new information when they reach the point at which open water enables them to swim and feed after a long period of deprivation. What a homing bird does and what cues it uses at this or any other critical point in its travels, however, are unknown. A simple 180-degree reversal in direction of travel, still depending on the sun compass, would be a maneuver useful to a penguin that had finally penetrated to the seaward fringe of the pack ice. Birds within 75 miles or so of the coast might also make use of visual cues such as the 13,000-foot peak of Mount Erebus on Ross Island. But at this stage in our investigations it is fruitless to speculate further.

To sum up, we have shown that the Adélie penguin uses a sun compass for orientation when released in a strange environment. We surmise that the same sun compass may guide the birds back from the open water to their breeding grounds after some other as yet undetermined cue or cues have reversed their direction of travel. A number of questions remain to be answered. We may, however, already have the answer to one of them. The antarctic winter is the season during which Adélie penguins spend their time away from land; when they leave the polar ocean at all, they perch on the ceaselessly shifting and drifting floes of the offshore pack ice. The antarctic winter is also a time of nearly total darkness, just as summer is a time of 24-hour-long daylight. How do these competent little navigators keep track of their position during the long dark period? We suspect that in the Adélie penguins' winter habitat the sun's brief appearance low on the horizon each noon is a strong enough cue to keep the birds' sun compass correctly set throughout the long polar night.



MATHEMATICAL GAMES

Can the shuffling of cards (and other apparently random events) be reversed?

by Martin Gardner

Shuffling is the only thing which Nature cannot undo.

—Sir Arthur Eddington, *The Nature of the Physical World.*

Eddington was probably wrong. In 1964 physicists discovered that certain events, involving the weak interaction of fundamental particles, appear not to be time-reversible [see "Violations of Symmetry in Physics," by Eugene P. Wigner; Scientific American, December, 1965]. This year they found some more one-way-only microevents that involve electromagnetic and possibly nuclear forces. It seems likely that nature does these things in only one time direction, unless there are galaxies or regions of the cosmos where matter is not only reflected and charge-reversed (that is, where it is antimatter) but also moving in a time direction opposite to our own. No one knows yet what connection all this has, if any, with the macroworld in which shuffling processes provide the only physical basis for what Eddington called the "arrow of time."

Apart from the newly discovered anomalies, all fundamental laws of physics, including the laws of quantum physics, are time-reversible. You can change the sign in front of t from plus to minus, and the formula describes something nature can do. But when a large number of objects, from molecules to stars, are moving randomly, the statistical laws of probability introduce the time arrow. If gas A and gas B are in the same container but separated by a partition, and the partition is removed, the molecules of the two gases shuffle together until the mixture is homogeneous. It never unshuffles. As far as individual molecules are concerned, there is no reason why each could not be given a direction and velocity that would "undo" the mixture. It doesn't happen because the probability of such a sorting is virtually zero. Here, Eddington argued (and most physicists agreed), is the only reason why a dropped egg never puts itself together again and hops back up to the edge of the wall. Probability laws decree that the billions of molecules that scatter randomly during such an event will move so as to increase the entropy (the measure of a certain kind of disorder) of the total system. The universe, prodded by probability, shuffles along the time axis in one direction only.

The shuffling of a deck of cards is, as Eddington pointed out, a splendid paradigm of Nature's one-way shuffle habits. Arrange a deck so that the top 26 cards are red, the bottom 26 black. The situation is analogous to the container of two gases. Shuffle the deck 10 times and the red-black order is obliterated. Why is it that continued shuffling does not sort the deck back into red-black halves? Because there are 52! different ways a deck can be arranged. (The exclamation mark is the factorial sign indicating the product of $1 \times 2 \times 3 \times 4 \times \ldots$ and so on up to 52. It is a number of 68 digits beginning with 8.) Of these 52! permutations, the number that exhibit a complete red-black separation, although very large, still constitute such a small fraction of 52! that one could shuffle for thousands of years without expecting to hit a single one of them.

The curious thing about shuffling cards is that a shuffle's efficiency—its power to introduce randomness into an ordered deck—actually depends on the clumsiness of one's fingers. Unless the cards drop in a disorderly way the shuffle doesn't really shuffle. Consider, for example, the "overhand" shuffle. The deck is held by its ends, in the right hand, and the left thumb "milks" the cards off the top in small packets of random size. A perfect overhand shuffle, in which the thumb takes one card at a time, does not destroy the order of the deck at all. It just reverses it. A second perfect overhand shuffle restores the original order.

The more familiar "riffle" shuffle, performed on a table, also fails to do its job if done perfectly. The perfect riffle shuffle, known to American magicians as the "faro shuffle" and to English magicians as the "weave shuffle," is one in which the cards drop one at a time, and alternately, from the two thumbs. The deck must, if it contains an even number of cards, be divided exactly in half before the shuffle begins, and as nearly in half as possible if it contains an odd number of cards. With odd decks the smaller half (one card fewer) shuffles into the larger one so that the top and bottom cards of the larger half become the top and bottom cards of the deck after the shuffle is completed. With even decks you have a choice of dropping first the bottom card of either half. If the first card to fall is from the half that was formerly the bottom of the deck, the cards previously at the top and bottom will remain at the top and bottom. Magicians call this the "out-shuffle" because the top and bottom cards remain on the outside. If the first card to fall is from what was formerly the top half of the deck, the former top and bottom cards go *into* the deck to positions second from top and bottom. Magicians call this the "in-shuffle." For odd decks, a faro is an out-shuffle if the deck is cut so that the top card goes to the larger half, thereby remaining on top after the shuffle. It is an in-shuffle if the top card goes to the smaller half.

A deck of n cards, given a repeated series of faro shuffles of the same type, will return to its original order after a finite number of shuffles. If n is odd, the deck returns to its initial state after x shuffles, where x is the exponent of 2 in the formula $2^x = 1$ (modulo n). "1 (modulo n)" means that the number has a remainder of 1 when it is divided by n. For example, if a joker is added to a full deck, making 53 cards, the formula becomes $2^x = 1$ (modulo 53). We must find an integral value of x such that 2^x has a remainder of 1 when divided by 53. If we go up the ladder of the powers of 2 (2, 4, 8, 16, 32...), we do not reach a number that is 1 (modulo 53) until we come to 2^{52}. This tells us that 52 in-shuffles (or 52 out-shuffles) are required to restore the order of a 53-card deck.

If the deck is even, the situation is a bit more complicated. The number of out-shuffles needed to restore the original order is $2^x = 1$ [modulo $(n-1)$]. The number of in-shuffles that does the trick is $2^x = 1$ [modulo $(n+1)$]. This sometimes makes a big difference. For the normal pack of 52 cards, 52 in-shuffles restore order. But $2^8 = 1$

(modulo 51), so that only eight out-shuffles are needed!

The illustration at the right gives the number of faro shuffles of both types required to restore the order of a deck of any size from two to 52 cards. Note that for an odd deck the number is always the same for either type of shuffle, and equal to the number of out-shuffles required for a deck of one more card. For an even deck the number of out-shuffles is the same as the number of in-shuffles for a deck of two cards fewer. This reflects the fact that the top and bottom cards are never disturbed during out-shuffles and so you are in effect merely in-shuffling the rest of the deck.

Since it is difficult to perform perfect riffle shuffles even clumsily (only a skilled card expert can simulate a genuine shuffle), we can best test the accuracy of this chart by reversing time and doing faro shuffles backward. (*Perfect* shuffles are easy to undo!) Card magicians call this maneuver a "reverse faro." Simply fan through a deck as shown in the illustration on the next page, jogging alternate cards up out of the deck [*dotted lines in top drawing*]. With practice this can be done rapidly. After all the cards have been jogged apart, strip the half-decks apart and put one on the other. If you replace the cards so that the top card remains on top, you have performed an "out-sort." If the top card goes into the deck, you have done an "in-sort." Each operation is obviously the inverse of the corresponding faro. It is now a simple matter to test any part of the chart, for if n faros of a certain type restore an order, then n reverse faros clearly will do the same thing.

It is best to experiment with ordered sets of cards that are held face up so that you can see how the pattern shifts with each sort. Observe, for example, that in certain cases where an even number of sorts restore the order, the cards become arranged in reverse order after half of the sorts are completed. Try 10 cards with values from ace to 10, and in serial order. Ten in-sorts restore the original order, but after five in-sorts the deck is in reverse serial order. A deck of 52 cards similarly reverses its order after 26 in-sorts. Note also the curious fact that each time an in-sort is made with the 52-card deck the 18th and 35th cards trade places. Edward Marlo, a Chicago card expert who has written treatises on the faro, has exploited this fact in many clever card tricks.

Alex Elmsley, a British computer programmer who is also a skilled card ma-

NUMBER OF CARDS IN DECK	NUMBER OF FARO SHUFFLES REQUIRED TO RESTORE ORDER	
	OUT-SHUFFLES	IN-SHUFFLES
2	1	2
3	2	2
4	2	4
5	4	4
6	4	3
7	3	3
8	3	6
9	6	6
10	6	10
11	10	10
12	10	12
13	12	12
14	12	4
15	4	4
16	4	8
17	8	8
18	8	18
19	18	18
20	18	6
21	6	6
22	6	11
23	11	11
24	11	20
25	20	20
26	20	18
27	18	18
28	18	28
29	28	28
30	28	5
31	5	5
32	5	10
33	10	10
34	10	12
35	12	12
36	12	36
37	36	36
38	36	12
39	12	12
40	12	20
41	20	20
42	20	14
43	14	14
44	14	12
45	12	12
46	12	23
47	23	23
48	23	21
49	21	21
50	21	8
51	8	8
52	8	52

The number of shuffles required to restore order to a deck of from two to 52 cards gician, was one of the first to explore the intricate mathematics of the faro from a conjurer's point of view. Writing in 1957 in *Ibidem,* a Canadian magic journal, he told the amusing story of how he had hit on a remarkable formula. He had earlier coined the terms "in-shuffle" and "out-shuffle," and in his notes had been abbreviating them with I (for "in") and O (for "out"). One of his first problems was to determine what sequence of in- and out-shuffles would be the most efficient in causing the top card of a deck to go to any desired position from the top. For example, suppose a magician, using a full deck, wishes to faro-shuffle the top card to the 15th position. Elmsley found experimentally that this could be done by the following sequence of faros: IIIO. This, he recognized at once, is also the way to write 14 in binary notation, and 14 is the number of cards above the desired position!

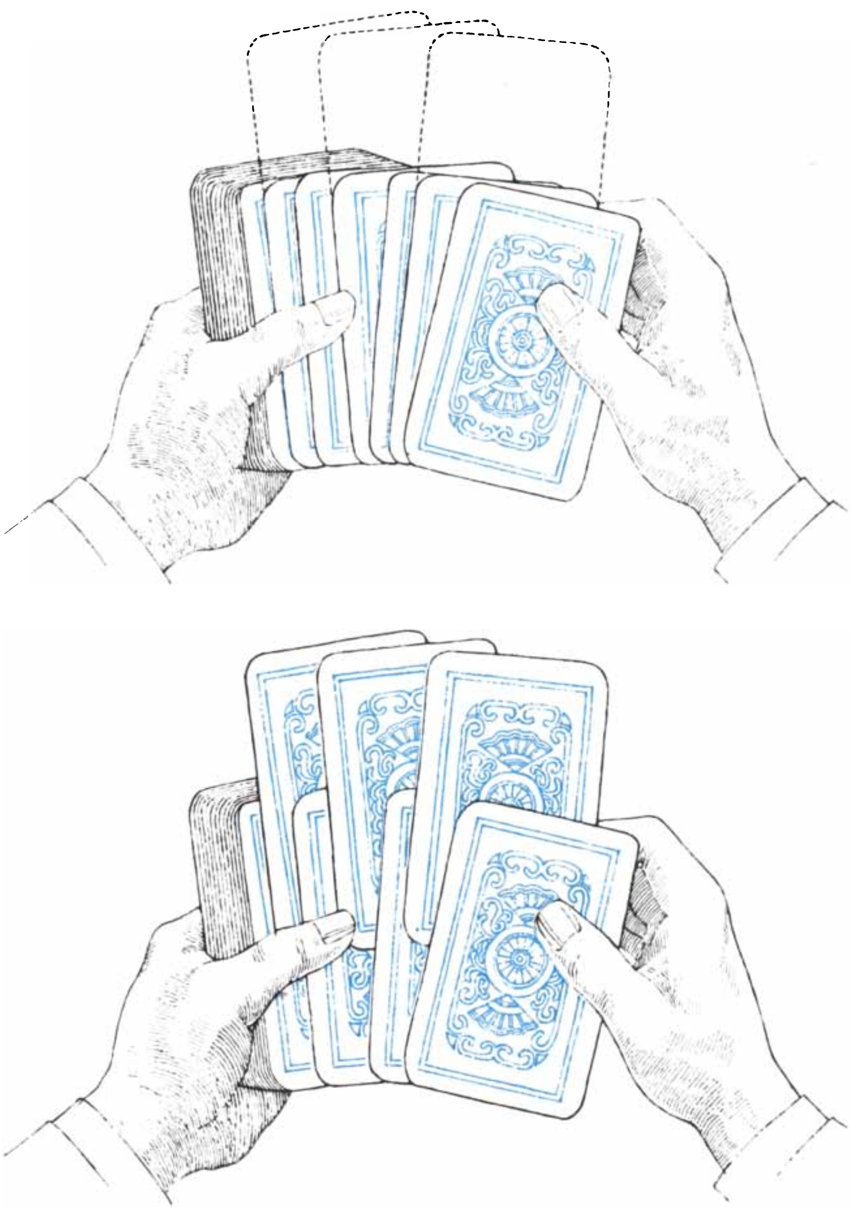
It was no coincidence. Regardless of the size of a deck, or whether it is odd or even, the following procedure always works. Subtract 1 from the position to which you want to bring the top card. Express the result as a binary number and you have the proper sequence of in- and out-shuffles to put the card there in the shortest possible time.

If the deck is even, there is an unexpected bonus. Whenever a faro is made, the downward shifts of cards in the top half are exactly mirrored by upward shifts of the bottom cards. While the card that is *n*th from the top goes to position *p* from the top, the card that is *n*th from the bottom goes to position *p* from the bottom. The same shuffle that puts the top card 15 down will simultaneously bring the bottom card 15 up. If a deck of 52 cards is arranged so that each card in the top half matches in value and color the card in the same position from the bottom, this matching is never destroyed by any number of faros, of either type. Many brilliant card effects are based on this mirroring principle.

The reader may enjoy testing Elmsley's formula by performing another time reversal, using in- and out-sorts to bring a card from any position, in any size of deck, to the top. Subtract 1 from the position number, write the result in binary form, then follow the sequence of binary digits *backward,* doing in- or out-sorts as indicated. In the previous example, to bring the 15th card to the top, write 14 as 1110. A sequence of one out-sort followed by three in-sorts puts the card on top. If the deck is even, the 15th card from the bottom simultaneously goes to the bottom of the deck.

The mirror principle does not apply to odd decks, but something even more astonishing obtains. It can best be understood by experimenting with a nine-card packet containing the ace, 2, 3, 4, 5, 6, 7, 8 and 9 of one suit. Arrange these cards in serial order, all face up, ace on top. Think of this as a cyclic order, the top and bottom cards joining like a closed chain. If you cut the packet to produce, say, the order 6, 7, 8, 9, 1, 2, 3, 4, 5, we shall call this the *same* cyclic order. The chart shows that a packet of nine cards returns to its original order after six sorts of either type. Now, however, you intersperse the sorts with as many cuts of the packet as you please. Cut one or more times, do a sort, cut some more times, do another sort, and so on until you complete the six sorts. Moreover, you can mix in- and out-sorts as you please. After the sixth sort examine the cards. They will be in the same cyclic order! This applies to any odd deck. Sorts of either type can be mixed with any number of cuts, and after the required number of sorts the original cyclic order is restored.

While the nine-card deck is being restored to its original state, it goes through five other states, each with its own cyclic order. The cyclic orders of these other states are also undisturbed by the cutting; they simply show up in different cyclic permutations, depending on which card is on top. Since each of the deck's six states has only nine differ-



Technique of the "reverse faro" shuffle

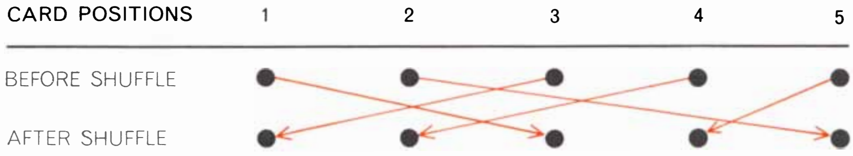


Diagram for a randomly patterned shuffle of five cards. It has a cycle of six shuffles

ent cyclic permutations, it follows that the total number of permutations of the nine cards that can be obtained by mixing cuts with sorts is no more than $6 \times 9 = 54$. This is only a small fraction of the $9! = 362{,}880$ possible permutations of nine cards.

Because sorts are time reversals of faros, all of this applies equally to the faro shuffling of odd decks. Solomon W. Golomb, in his paper on "Permutations by Cutting and Shuffling" (Technical Release 34–3, 1960, of the Jet Propulsion Laboratory of the California Institute of Technology), proved that by mixing cuts with in-shuffles or with out-shuffles an *even* deck could reach any one of its possible permutations. But for all *odd* decks of more than three cards only a small portion of the possible permutations are obtainable. Random cutting and faro shuffling can induce complete randomness in a deck of 52 cards because every one of the 52! possible permutations can be reached. But remove one card from the deck, leaving 51 cards, and no amount or mixture of faro shuffles and cuts will ever yield more than $8 \times 51 = 408$ permutations, out of the total of 51! possible permutations—a number of 67 digits.

Dai Vernon, one of the nation's top card magicians, has based an easy-to-do trick on this cyclic character of odd decks. Hand 20 cards to someone, and a joker. Ask him to shuffle the cards while your back is turned, insert the joker into the packet and remember the two cards the joker goes between. Turn around and take from him the packet of 21 cards, all face down. Do a reverse faro (either an in- or an out-sort, it makes no difference), then ask him to cut the packet. Repeat with another reverse faro, of either type, and let him cut again. Now spread the cards into a fan and hold the fan up so that the spectator can see the faces but you cannot. Ask him to remove the joker. Break the cards into two groups at the spot occupied by the joker, then put them together again the other way. In other words, you cut the packet at the point that was occupied by the joker. Do not call attention to this, however. To the audience it should look as if you merely put the cards together again as they were before the joker was removed.

You now hold 20 cards, an even number. Do two out-sorts and one in-sort. Put the packet on the table. Ask the spectator to name the two selected cards. Show the bottom card of the packet. It will be one of the cards. Turn over the top card of the packet. It will be the other card.

The faro is only one of many types of simple, strongly patterned shuffles that can be applied repeatedly to a deck with unusual results. Let us now generalize and define a "shuffle" as any transformation whatever, patterned or nonpatterned. We can specify the structure of the shuffle by writing a table such as the following one for a five-card shuffle:

1–3
2–5
3–1
4–2
5–4

The table shows that the first card goes to position 3, the second card to position 5, and so on. The same shuffle is diagrammed with arrows in the illustration above. There need be no pattern of any kind in the placement of these arrows. The pattern can be completely random, as if the cards were shaken in a barrel, then taken out one at a time to form a new deck.

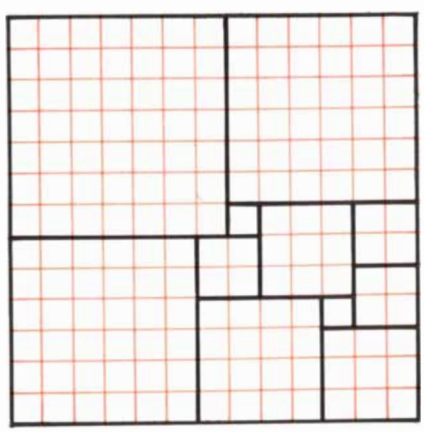
Assume that exactly the same shuffle, as specified by a table or diagram, is repeatedly applied to a deck of n cards. Will this eventually randomize the cards? No, it will not. Regardless of the shuffle pattern, the cards simply progress through a series of states, no two alike, until they return to their original order, then the cycle repeats. If the deck contains more than two cards, there is no shuffle that repeated will run through all possible permutations. Three cards, for instance, have 3!, or $1 \times 2 \times 3 = 6$, possible orderings. It is impossible to devise a shuffle that, if it is repeated, will require six steps to complete its cycle. The longest cycle possible is three steps.

This suggests a difficult but fascinating question. Imagine that a deck of 52 cards has been put inside a shuffling machine that keeps repeating exactly the same shuffle. You cannot see into the machine and so you have no notion of the shuffle pattern. Each time a shuffle is completed a bell rings. What is the smallest number of rings after which you can say with absolute certainty that the original order has returned at least once? Put another way: What is the longest cycle an iterated shuffle of 52 cards can have?

The question will be answered next month along with the answer to the following numerological quickie sent to me by Golomb. It is appropriate to give it this month because October is the month of Halloween. Can you show that Halloween and Christmas are equivalent holidays by proving that Oct. 31 = Dec. 25?

Last month's problem of cutting the order-13 square into 11 smaller squares is solved by the unique pattern shown in the illustration below. For readers interested in exploring higher-order squares, orders 14–17 have minimum patterns of 12 squares, orders 18–23 have minimum patterns of 13 squares, orders 24–29 have 14 squares, orders 30–39 and order 41 have 15 squares. (Order 40 apparently requires 16 squares.) These minimum values are from J. H. Conway's paper cited last month. The 15-square solution for order 41, Conway informs me, is unusually hard to find.

The best answer received to the problem of covering the maximum area of the order-70 square with nonoverlapping squares, from the set of 24 that have sides in serial order from 1 to 24, will be published after I have seen solutions from a sufficient number of readers.



Solution to the order-13 square problem

ELIMINATING INCLUSIONS

Modern techniques that remove harmful oxides from molten steel greatly improve steel quality. One method involves adding metallic elements. The newest is the vacuum degassing process.

by R. A. Walsh, Research Manager

Quality is an elusive term, and quality in steel is particularly so. While steel quality, in general, can easily be described in terms of satisfactory performance of the end product, a really accurate definition must include a detailed analysis of the entire steelmaking process. A quality steel, then, is the culmination of painstaking care and attention at every step in the process, from the molten steel to the product delivered to a customer's plant. The processing begins with the melting of a heat of steel. In the basic steel industry, this is accomplished in electric arc, basic oxygen, or open hearth furnaces. While each of these melting processes has its own individual characteristics, they have one thing in common, the presence of dissolved gases in the molten steel, notably hydrogen, nitrogen, and oxygen.

Hydrogen is not a problem of any general consequence in plain carbon steels, but it can be critical in large forging ingots where it can give rise to the defect known as flaking. Nitrogen may or may not be desirable depending upon the specific steel being melted. Oxygen is rarely regarded as beneficial, and the inexorable laws of thermodynamics dictate that it can be present in molten iron in amounts up to as much as 0.16 percent by weight, in commercial practice.

As steel solidifies in an ingot mold, oxygen is rejected from solution. When this happens, bubbles of carbon monoxide may form and rise up through that portion of the ingot which is still liquid. Oxygen which does not react with carbon in this manner ultimately reacts with iron or other metallic elements in the steel to form liquid or solid oxides, generally termed inclusions. Some of these will rise through the liquid steel, forming a slag, but some inevitably are entrapped in the body of the ingot. In order to minimize the presence of oxide inclusions in the steel, metallic elements which have a great affinity for oxygen are usually added to the furnace or the ladle. Silicon and aluminum are prime examples. When added at the ladle or furnace stage, these elements quickly form oxides. The steel is molten and sufficient time is allowed for the oxides to levitate and thus escape from the melt. The oxygen which remains dissolved in the molten steel is thus lowered and the amount of oxide inclusions precipitating in the ingot when it solidifies is proportionately reduced. This can be expressed typically as:

$$Fe + \underline{2Al} + \underline{4O} \rightarrow FeO.Al_2O_3 \qquad (1)$$

which simply says that aluminum and oxygen dissolved in molten iron combine with each other to form hercynite. When more than one metallic deoxidizer is present, the situation becomes more complex. For instance, manganese and silicon together are capable of producing a lower oxygen level than either used alone. Other combinations such as silicon-aluminum or manganese-aluminum-silicon exhibit a similar trend. Not only is the dissolved oxygen content of the steel affected, but the chemistry and physical nature of the deoxidation products vary according to the specific deoxidizers used.

Another method of deoxidizing or degasifying steel is vacuum degassing. In this process, molten steel is exposed to a vacuum which favors the reaction:

$$\underline{C} + \underline{O} \rightarrow CO \qquad (2)$$

Reactions of the type represented by equation (1) are little affected by pressure, but in equation (2) the product of the reaction is carbon monoxide, a gas. For reaction (2)

$$\frac{a_c \times a_o}{Pco} = K, \qquad (3)$$

and at 1600°C, $K = 2.0 \times 10^{-3}$. If we have, say, an 0.2 percent C melt and have a partial pressure of CO of an atmosphere and assume for simplicity that activates equal weight percent, then

$$(\%0) = \frac{2.0 \times 10^{-3} \times 1}{0.2}$$
$$= 10^{-3}$$

But if we expose the same steel to a vacuum of say 76 microns Hg, then

$$(\%0) = \frac{2.0 \times 10^{-3} \times \frac{76 \times 10^{-3}}{760}}{0.2}$$
$$= 10^{-6}$$

Such extremely low oxygens are not attained in practice for a number of reasons; among them, melt-crucible reactions, ferrostatic pressure of the melt and factors associated with the nucleation of the CO bubble. The example illustrates clearly, however, the manner in which vacuum serves to promote deoxidation through the formation of CO.

Youngstown has recently installed a vacuum degassing unit as the latest step in a continuing search for better understanding of deoxidation phenomena, improved practice, and stringent control in production.

The work in eliminating inclusions is only a small part of the constant research going on 24 hours a day at Youngstown's research center. If you believe Youngstown can help you, call at your convenience. Or, write Department 251C6.

Youngstown Steel

THE YOUNGSTOWN SHEET AND TUBE COMPANY · YOUNGSTOWN, OHIO 44501

THE AMATEUR SCIENTIST

How to build a wind tunnel that achieves supersonic speeds with a vacuum system

Conducted by C. L. Stong

Wind tunnels for investigating supersonic flight can be built in a variety of ways. The purpose of such a tunnel is to provide a means of simulating the patterns made by the flow of air around an object moving faster than the speed of sound. A tunnel usually has five main elements: a chamber in which the model undergoing tests is supported; a device for accelerating the entering airstream; a device for suppressing turbulence in the airstream; a duct for disposing of turbulence downstream from the model, and one or more instruments for observing the behavior of the airstream around the model.

Each of these elements can be made in a number of different forms depending on the size of the model and the speed and altitude at which the object represented by the model is designed to fly. A supersonic wind tunnel for investigating the flight characteristics of a high-velocity bullet, for example, will necessarily differ from one designed for observing the reentry characteristics of a space vehicle; the bullet travels through relatively dense air at a speed of perhaps 2,000 miles per hour whereas the space vehicle flies more than eight times faster in the near vacuum of the upper atmosphere. Hence the problem of designing a supersonic wind tunnel consists largely of selecting components from among the many existing designs.

Gary S. Settles, a student at Maryville High School in Maryville, Tenn., spent most of his free time during the past two years selecting components and constructing a supersonic wind tunnel. The apparatus displays flow patterns around objects of interest to many amateurs, including small scale models of rockets. The models are available in most hobby stores. The project, which included a series of photographs of flow patterns made with the tunnel, won four prizes last year at the regional science fair. Settles writes:

"All supersonic wind tunnels share one characteristic: when they are in operation, they consume power at an astonishing rate. About 300 horsepower must be expended to maintain a flow of air at 1,500 miles per hour through a pipe only one inch square and two inches long. The air compressor of a continuous tunnel measuring nine inches square at the Aberdeen Proving Ground in Maryland absorbs the output of a 25,000-horsepower motor.

"A way out of this difficulty lies in the fact that energy from a source of limited capacity, such as an electric outlet in the home, can be stored in the form of compressed air and discharged intermittently. This principle is employed in 'blowdown,' or high-pressure, wind tunnels. Air is compressed in a tank during a comparatively long interval and discharged abruptly into the atmosphere at supersonic velocity. Conversely, energy can be stored by exhausting a tank to which air is abruptly admitted. The inflow reaches supersonic velocity if it enters through a duct of the proper design. In such 'indraft' tunnels the atmosphere acts as the high-pressure supply. The indraft tunnel has two advantages from the amateur's point of view. It is safer than the high-pressure type; a weak or faulty tank will simply collapse instead of exploding. Moreover, a vacuum system provides its own pressure regulation, whereas high-pressure systems require some form of such regulation.

"In view of these considerations I decided to construct a small tunnel of the indraft type for intermittent operation. Small tunnels operate well if they are made aerodynamically 'clean,' that is, if sharp turns are avoided and obstructions such as rough walls are eliminated in the duct through which the air flows. My tunnel consists of eight elements: a drier, a stilling chamber, a nozzle, a test section, a diffuser, a vacuum tank, a pumping system and a schlieren apparatus for photographing the flow of air around the model [*see upper illustration on page 122*].

"Air at atmospheric pressure enters the nozzle through the drier and stilling chamber, which are designed to remove moisture and to accelerate the flow smoothly. Specially shaped blocks in the nozzle first constrict the entering stream of air and then allow it to expand. In this arrangement the air is accelerated to the speed of sound at the point where the blocks constrict the channel to minimum area. Immediately downstream from this point the channel becomes larger. The air expands and so is further accelerated to supersonic velocity.

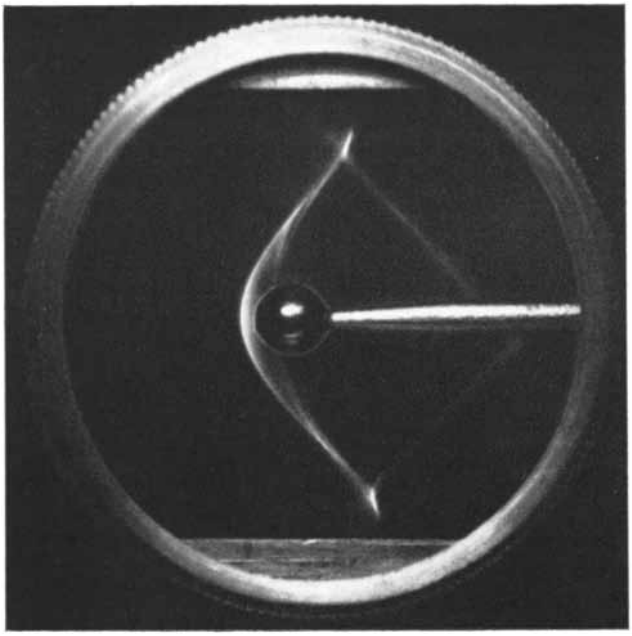
"After passing through the enlarged channel the stream flows through a duct of constant area. This is the test section, where models are mounted. From the test section the stream enters another channel known as the diffuser, which conducts the spent air away from the test section without distorting the flow pattern. A quick-acting valve between the diffuser and the tank seals off the system during pumpdown.

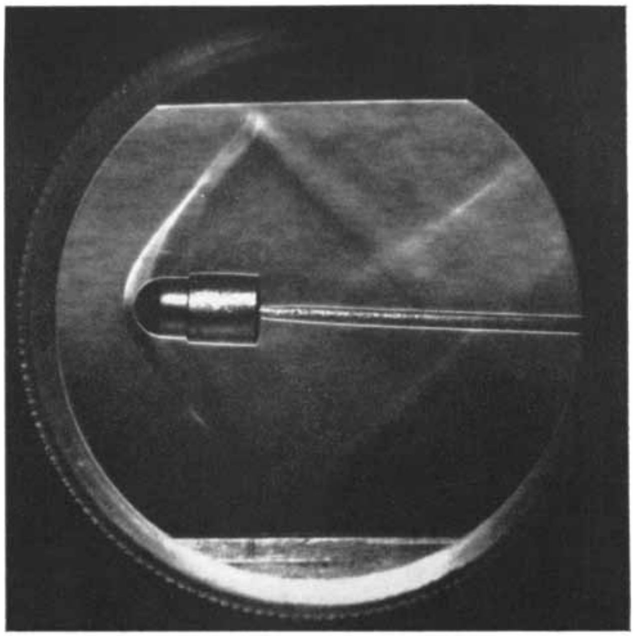
"The size of the installation is determined by its intended use as well as by the available space and power. My installation had to be portable because I wanted to enter it in the science fair. The power had to be taken from an ordinary 110-volt outlet fused for 15 amperes. This was adequate for operating a motor rated at 1/4 horsepower. In 30 minutes a motor of this size can store enough energy to operate a supersonic tunnel with an area of half a square inch for about three seconds at a stream velocity of 1,500 miles per hour. That is about twice the speed of sound. My apparatus is assembled in a table-like framework, supported by casters, that is 30 inches wide, 30 inches high and 48 inches long. It can be wheeled through most doors.

"The amount of energy that can be stored is determined by the size of the vacuum tank as well as by the capacity of the pumping system. The length of a test run varies directly with the size of the tank. New tanks are costly, but I found that those from discarded water heaters are both inexpensive and effective. They can be obtained from dealers in scrap metal. The price depends on the condition of the tank and the length of time it has been discarded.

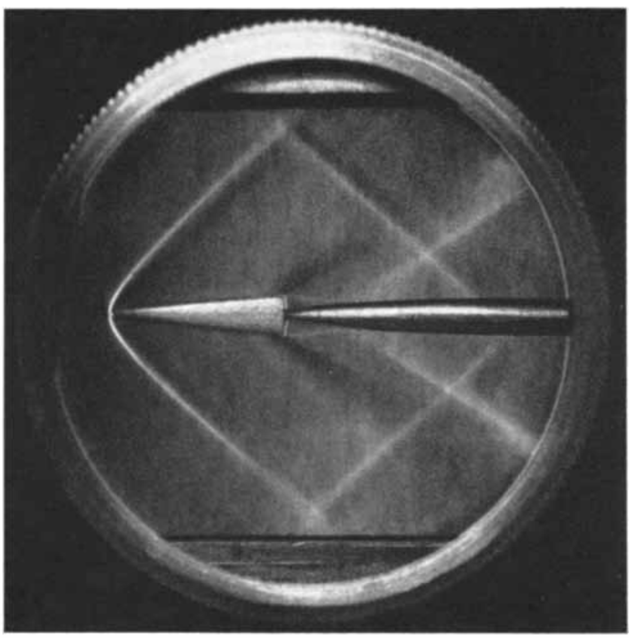
"Most of these tanks are designed to withstand a pressure of 150 pounds per square inch. The atmosphere exerts an inward pressure of only 15 pounds per square inch, so that even old water tanks are strong enough for wind tunnel purposes. I use three 30-gallon tanks that have a total volume of about 13 cubic feet. To connect the tanks I welded one-inch pipes directly into them. The tanks are stacked inside the framework and fastened in place with steel pipe straps. All joints in the plumbing system were welded and coated with a commercial gasket compound.

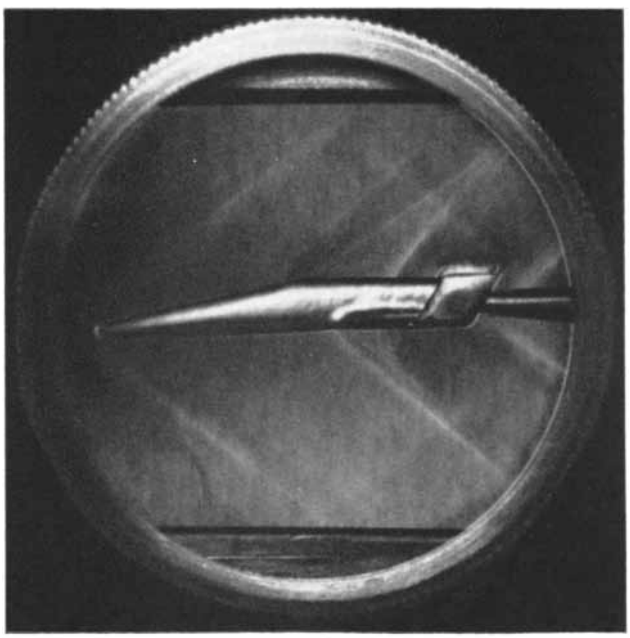
"The top of the framework consists of a sheet of 3/4-inch plywood on which the wind tunnel and the optical system are mounted. A lead-in pipe extends vertically through the platform and terminates in a quick-acting gate valve operated by a self-contained motor. The valve, a surplus item, was secured from the Surplus Center, 900 West 'O' Street, Lincoln, Neb. 68510. It is listed as item No. JX07 and priced at $4.25. The valve is vacuum-tight when closed. Although the motor is designed for direct current at 12 volts, I power it with alternating





Models in Gary S. Settles' wind tunnel: a sphere (left) *and a bullet* (right)





Patterns of supersonic airflow past a wedge (left) *and a winged body* (right) current from a variable-voltage transformer. For quick operation I use up to 60 volts.

"The intake side of the gate valve connects to the diffuser through a 90-degree pipe elbow. This arrangement makes it possible to mount the wind tunnel horizontally. The design of the diffuser depends on the shape and size of the test section. If the test section is rectangular, as it is in my apparatus, the diffuser must provide a smooth transition from the rectangular cross section at one end to the circular cross section at the other. The diffuser can be constructed by a variety of techniques. Mine was made by altering the shape of a pipe nipple that fitted the gate valve. A tapered bar of iron that matched the cross section of the test section was driven into the unthreaded end of the nipple after the nipple had been heated to redness with a blowtorch. A matching flange was welded to the rectangular opening of the diffuser. Four holes were drilled in the flange for attaching the assembly to the stilling chamber [*see lower illustration below*].

"The size of all components is determined by the cross-sectional area of the test section and by the maximum velocity of the airstream. In wind tunnel work velocity is expressed in the units called Mach numbers. The unit is 762 miles per hour, the speed of sound at sea level; it is named for the Austrian physicist Ernst Mach. Mach 1 is equal to the speed of sound, Mach 2 is equal to twice the speed of sound and so on.

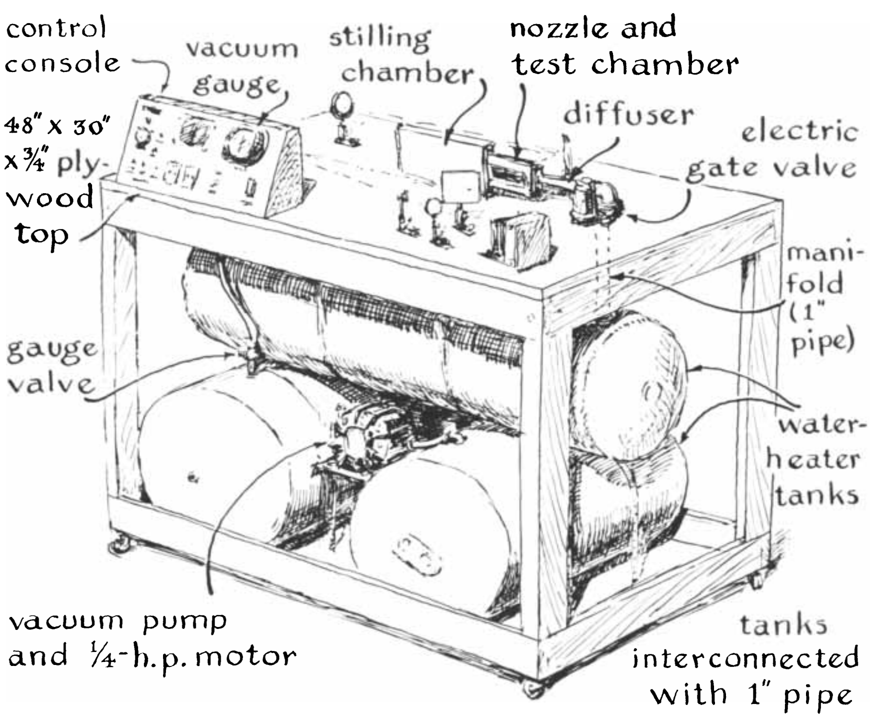
"In the case of an indraft tunnel the maximum velocity of the airstream is fixed by the contour of the nozzle. The walls leading from the upstream side of the nozzle curve inward, gradually reducing the area of the duct, and then diverge. Air that flows beyond the point of minimum area decreases in density much faster than its volume increases. For this reason the velocity increases as the air expands to fill the diverging portion of the duct and is independent of the difference between the upstream and the downstream pressure. A change in the downstream pressure merely alters the location in the duct at which supersonic flow changes to subsonic flow. Similarly, a change in the upstream pressure alters the pressure at which supersonic flow occurs. Neither of these changes affects the Mach number. Velocity can be changed only by altering the shape of the nozzle.

"The profile of my nozzle was supplied by R. W. Hensel of the Arnold Engineering Development Center in Tullahoma, Tenn. The dimensions of the profile are shown in the accompanying illustration [*bottom of opposite page*]. The nozzle develops an airstream velocity of Mach 2 when the tanks have been exhausted to a pressure of 38 centimeters of mercury or less. In small indraft tunnels the upper limit of velocity is about Mach 3, according to authorities with whom I have discussed the matter. The density of the air decreases with increasing Mach number. Above Mach 3 the air is too thin for observing flow patterns optically. Below Mach 2 it is difficult to maintain supersonic flow with a model of reasonable size.

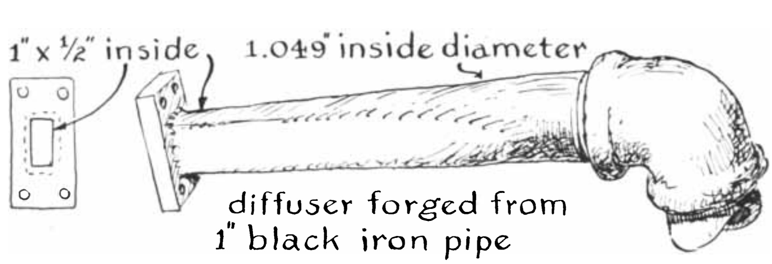
"The top and bottom of my nozzle and test section were made of a pair of aluminum blocks half an inch thick. The blocks were first clamped together. The profile was then cut in both blocks simultaneously by drawing a rattail file across the metal from front to back. The contour was checked periodically with a template cut from thin sheet metal. The filed surface was smoothed with successively finer grades of emery cloth and finally polished to a mirror-like finish with crocus cloth.

"One cannot take too much care at this point in the construction, because the performance of the tunnel will be no better than the accuracy with which the finished blocks conform to the specified profile. The blocks are assembled with the contoured edges facing each other to form a symmetrical duct and are fastened together by metal bezels, or frames, that also hold the plate glass walls. Flanges for bolting the unit between the diffuser and the stilling chamber were welded to the metal side walls that enclose the blocks.

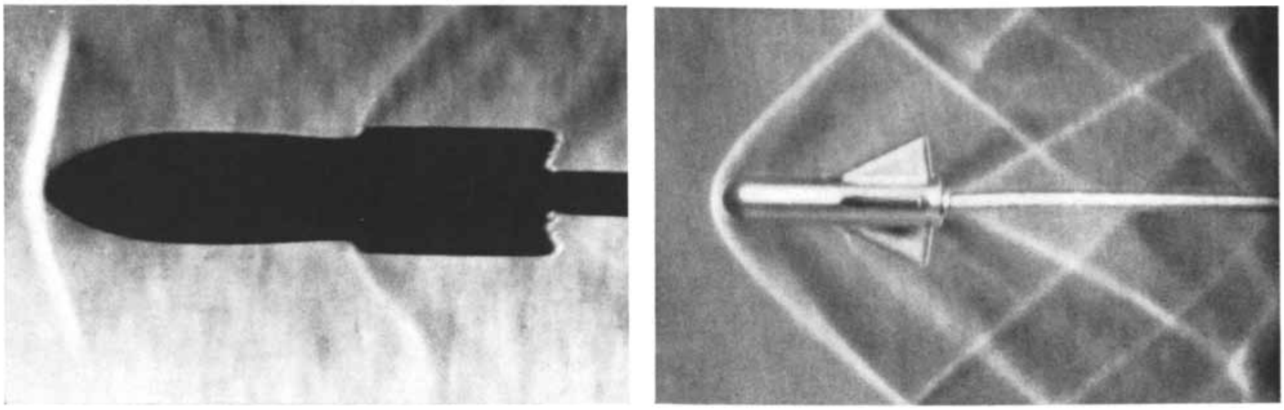
"Air enters the nozzle-block assembly through the stilling chamber, where turbulence is suppressed by 50-mesh wire cloth at each end of the cavity. Wire cloth for this purpose can be obtained



General view of Settles' apparatus



Construction of the diffuser

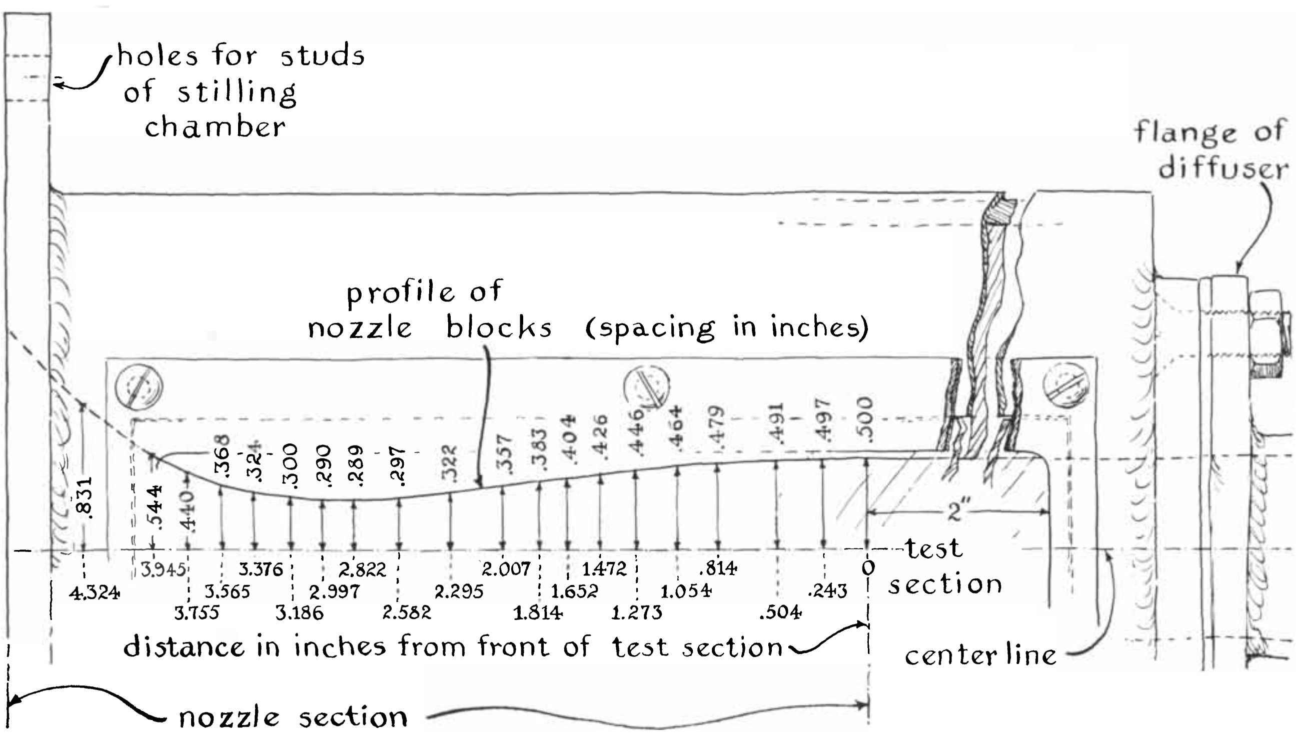


Schlieren photographs of models of a bomb (left) *and a missile* (right) *in the tunnel*

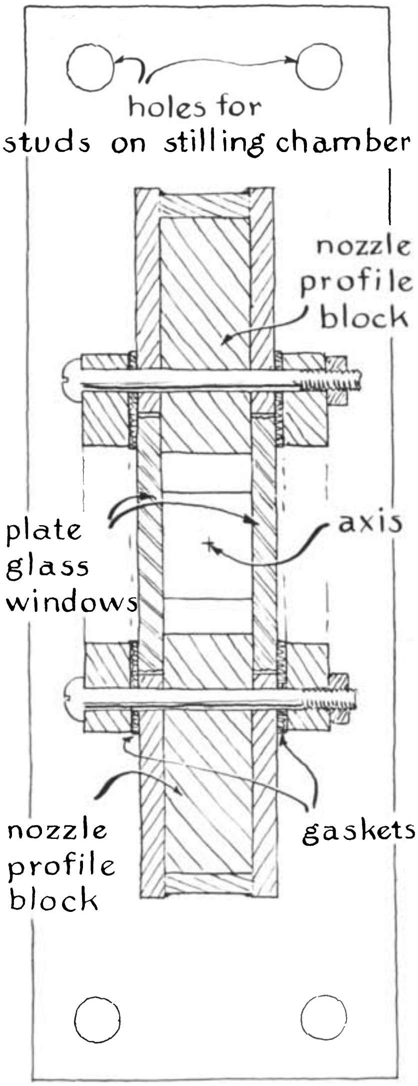
from the Cambridge Wire Cloth Co., Cambridge, Md. 21613. Air must be dried before it enters the stilling chamber or condensation will occur when heat is lost during expansion of the air. I dry the air by means of an apparatus consisting of a small motor-driven blower, a cardboard mailing tube packed with silica gel and a storage reservoir. My storage reservoir is a surplus weather balloon, obtainable from the Edmund Scientific Co., Barrington, N.J. 08007. The blower forces air through the mailing tube, where moisture is absorbed by the silica gel; the air then passes into the balloon for storage. A flange, cemented into an opening I made in the side of the balloon, connects to a duct through which the dry air flows to the stilling chamber. A gate valve I improvised from sheet metal closes the neck of the balloon after it has been filled.

"The stilling chamber can be made of wood. Fairing blocks should be inserted at the outlet end of the chamber to guide the air smoothly into the nozzle. Neither the curvature nor the finish of the blocks is critical, as it is in the nozzle-test-section assembly. My stilling chamber was made of 16-gauge sheet metal and faired with blocks of lightly sanded and varnished wood.

"The system does not impose a severe requirement on the vacuum pump. Any pump capable of reducing the pressure in the tanks to about 10 centimeters of mercury within a reasonable time, say 30 minutes, is adequate. Still lower pressures will increase the running time of the tunnel. It is possible to pump the tanks to a pressure of about one centimeter by using the compressor unit of an old electric refrigerator in reverse. Such compressors are available from dealers in refrigerators. Two or more units can be interconnected for reducing the time of pumpdown. I am now using an excellent and comparatively inexpensive pump that was obtained from the Groban Supply Company, 1139 Wabash Avenue South, Chicago, Ill. 60605. Designated model No. 480A, the unit is priced at $20. The price does not include a heavy-duty 1/4-



Profile of the nozzle section and the test section



End view of test section

horsepower motor, which is required for driving the unit. A check valve must be placed between the pump and the tank system to prevent air from leaking into the tanks when the pump is not operating.

"The model is supported in the test section by a length of 16-gauge steel wire that is flattened at one end and pointed at the other. The flattened end is clamped between the flanges of the test-section and diffuser assemblies. The pointed end is heated and pushed into the tail of the plastic model.

"Although I have made a few models, I have relied mostly on the miniature plastic rockets and bombs that are found on scale-model aircraft. I have also used cones, spheres and wedges. In general, models should not occupy more than 15 percent of the cross-sectional area of the test section. In no case should they reduce the area to that of the nozzle constriction. The test section of the first tunnel I built measured only a quarter of an inch in width and half an inch in height. I had considerable difficulty finding models small enough to test. Large models block the airstream. Blockage seriously distorts the flow pattern around the model and results in the formation of shock waves upstream.

"Shock waves and other features of the flow pattern alter the density of the air and so change the amount by which a given volume of air can bend a ray of light. A similar effect causes stars to twinkle and explains why one can 'see' heat rising from a steam radiator or other hot objects. Advantage is taken of the effect to photograph patterns of airflow by the schlieren system [see "The Amateur Scientist," SCIENTIFIC AMERICAN, February, 1964].

"In this system divergent rays of light from a source of small area are made parallel by a spherical concave mirror. The parallel rays are then brought to focus by a similar mirror placed a few feet away. At the focal point half of the bundle of rays is blocked by an opaque object such as a knife-edge. If the column of air between the mirrors is of uniform density, the unobstructed rays will uniformly illuminate a screen placed beyond the knife-edge. If the density of the air is not uniform, some of the obstructed rays may be bent away from the knife-edge and will proceed directly to the screen, thus increasing the brightness of the screen in a certain area. Conversely, other rays that would normally fall on the screen may be deflected onto the knife-edge; this has the effect of reducing the brightness of the screen in certain areas. The net effect is the appearance on the screen of an image that represents variations in the density of the air.

"My schlieren system consists of the conventional light source, spherical mirrors and knife-edge and also of three plane first-surface mirrors, a lens and a camera equipped with a focal-plane shutter but no lens [*see lower illustration on page 126*]. The three plane mirrors are used for folding the light path so that the apparatus can be mounted on the tabletop. The light source is a 12-volt incandescent automobile lamp (GE 1133) equipped with a helical filament. The lamp is positioned so that the rays proceed from the side of the helix, forming a rectangular source.

"The spherical mirrors are three inches in diameter. I bought them from the Edmund Scientific Co. The catalogue number is 50,082. They are priced at $7.65 each. The knife-edge consists of a safety-razor blade supported by a fixture equipped with an adjustment screw for advancing the blade into the cone of light. The lens focuses the image of the test section on the photographic film.

"After the apparatus has been assembled in the approximate positions illustrated, the schlieren system must be aligned and focused. The small first-surface mirror is positioned to flood the first spherical mirror with light. The distance between the filament and the surface of this mirror is adjusted to exactly half the mirror's radius of curvature by sliding the mounting fixture. The correct distance has been determined when the rays reflected by the spherical mirror become parallel. A simple test for parallelism can be made by holding a piece of white cardboard in the reflected beam. The spot of light should not change in diameter when the screen is moved toward or away from the mirror.

"The parallel beam is then directed at a right angle through the test section by rotating the second first-surface mirror and is directed onto the second spherical mirror by similarly rotating the third first-surface mirror. These adjustments are checked by removing the lens and placing the eye where the lens was. The second spherical mirror should appear as a glowing disk resembling the full moon.

"The knife-edge is now advanced into the beam. If the knife-edge is too close to the spherical mirror, a straight shadow will move across the glowing disk in one direction when the blade is moved across the beam. If the blade is too far away from the mirror, the shadow will move in the opposite direction. When the blade is in the proper position, the disk will darken uniformly as the knife-edge is advanced. No moving shadow will be observed. The knife-edge is in the proper transverse adjustment when the brightness of the disk has been reduced to roughly half its maximum intensity. The lens is now replaced. Finally, a model is mounted in the test section and the position of the camera is adjusted until a sharp silhouette of the model appears on the ground glass.

"The controls of my tunnel are assembled on a small panel that contains a switch for operating the room light as well as the vacuum pump, schlieren light and gate valve. One quickly learns the positions of the various switches; this saves a lot of fumbling when the system is operated in a darkened room.

"Making a test run involves only a few basic operations. A model is installed in the test section and the system is pumped down. After the schlieren sys-

BASF is a city of chemistry. The main plant in Ludwigshafen, West Germany, consists of 1,500 individual units which employ more than 47,000 people. Of these, approximately 8,800 work exclusively in research. BASF's range of plastics is the most extensive in Europe today, and its production facilities for fiber raw materials are Europe's largest. In all, BASF offers over 5,000 products which are exported to 130 countries throughout the world. Among these are dyestuffs and auxiliaries, nitrogen fertilizers and pesticides, as well as numerous intermediates, basic chemicals, and even chemical plants and processes. In addition to the plants in Ludwigshafen and elsewhere in Germany, BASF also operates numerous manufacturing plants in Europe and Overseas. BASF extends to every corner of the world, and, drawing on its immense experience and scientific knowledge, takes progress with it wherever it goes.

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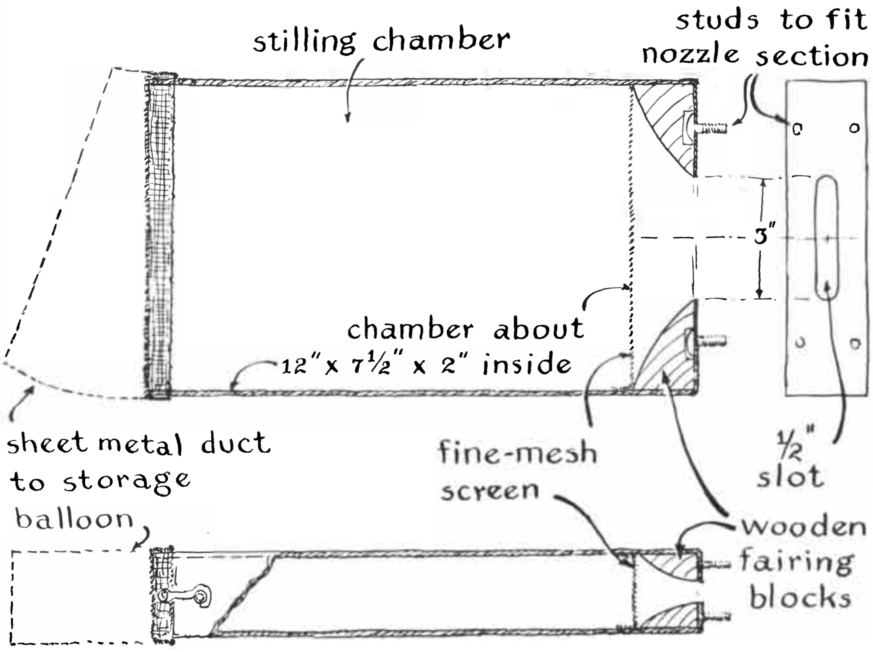
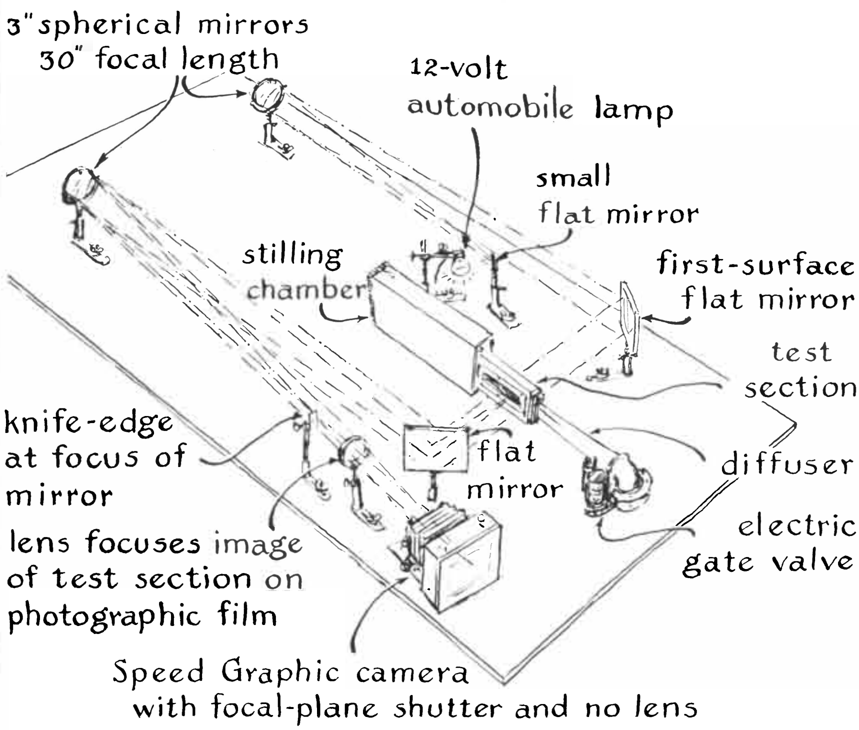
tem has been turned on and adjusted and the room has been darkened, the model is lighted obliquely from the front by a high-intensity lamp. (This step is not necessary if the experimenter does not mind having the model appear as a silhouette in photographs.) The gate valve is opened and a photograph is made during the two and a half seconds in which the tunnel is going supersonic. The film is developed and printed conventionally. Exposure time must be found by trial and error.

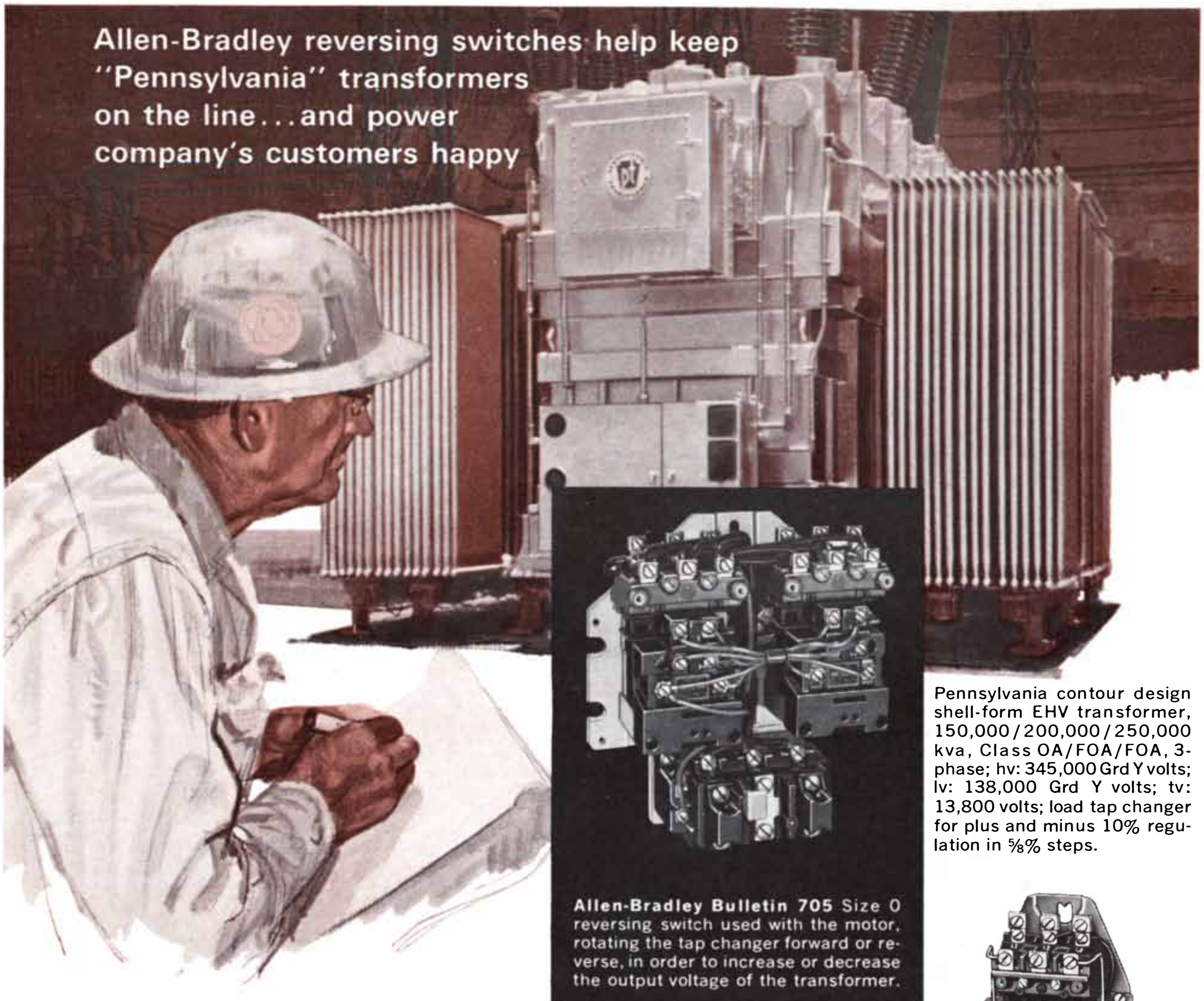
"I am now making a set of 20 manometers that will be connected to small ports distributed at various points in the vicinity of the model. These will indicate air pressure within the flow pattern and enable me to analyze in part the forces that arise from the flow."



Arrangement of the stilling chamber

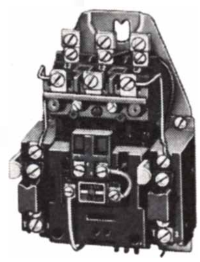


Details of the schlieren system



Pennsylvania contour design shell-form EHV transformer, 150,000/200,000/250,000 kva, Class OA/FOA/FOA, 3-phase; hv: 345,000 Grd Y volts; lv: 138,000 Grd Y volts; tv: 13,800 volts; load tap changer for plus and minus 10% regulation in $\frac{5}{8}$% steps.

Allen-Bradley Bulletin 705 Size 0 reversing switch used with the motor, rotating the tap changer forward or reverse, in order to increase or decrease the output voltage of the transformer.



Allen-Bradley Bulletin 709 Size 1 starter. Four such starters are used on the transformer for operating pump motors.

■ Load tap changing equipment by Pennsylvania Transformer, a division of McGraw-Edison Company, has an established reputation for reliability—achieved by their taking infinite pains with every detail of design, manufacture, and assembly. Every part for every Pennsylvania load tap changer is individually checked against rigid standards—nothing is taken for granted. And, as a consequence, Pennsylvania Transformer has chosen A-B control because of its demonstrated dependability.

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BOOKS

A compendium of writing toward a discipline of international order

by Anatol Rapoport

THE STRATEGY OF WORLD ORDER: VOLUME I, TOWARD A THEORY OF WAR PREVENTION; VOLUME II, INTERNATIONAL LAW; VOLUME III, THE UNITED NATIONS; VOLUME IV, DISARMAMENT AND ECONOMIC DEVELOPMENT. Edited by Richard A. Falk and Saul H. Mendlovitz. World Law Fund ($10).

From the foreword to Volume I by Harold D. Lasswell and a statement by one of the editors (Mendlovitz) we learn that this collection is an outgrowth of a program to create an academic discipline centered on the subject stated in the title. The contributions are papers by some 80 authors from a dozen countries, and a selection of source materials such as the texts of treaties, debates in the United Nations, court decisions and so forth.

The articles themselves fall roughly into the following categories:

Descriptive and explanatory. Example: "United Nations Peace Force," by U Thant (Volume III).

Appraising. Example: "The Changing Effectiveness of General Assembly Resolutions," by Gabriella R. Lande (Volume III).

Programmatic. Example: "Towards a Warless World: One Legal Formula to Achieve Transition," by Falk and Mendlovitz (Volume II).

Strategic-analytic. Example: "Defence Against Ballistic Missiles," by Freeman J. Dyson (Volume IV).

Theoretical, philosophical, methodological and polemical. It is on such articles that my own appraisal of the volumes will be focused. I shall be concerned with theory, outlook and orientation, and with the philosophy underlying current discussions of war and peace, force and law, the struggle for power and world order. For this reason I shall not discuss Volume III, which is for the most part descriptive, or the various programs and proposals, except to say that I heartily endorse most of them. The fact that some are incompatible with others makes no difference; I would gladly settle for any one. I have found it convenient to review the remaining volumes in the reverse order.

First let us take up problems associated with disarmament. This topic is discussed mainly in Volume IV. When we think of problems, we tend to think of solutions. This is a habit we have acquired as participants in a technology-oriented civilization. For example, for some three centuries men have been seriously concerned with the problem of flight. Then a breakthrough occurred in the form of an operative heavier-than-air machine. Thereafter the general problem of flight broke up into numerous accessory problems.

In all the cases where such problems have been solved or are likely to be solved there have been (or are) men not only willing but also empowered to use the proffered solution, or at least to modify existing institutions in order to implement the solutions. That is to say, the solutions of the problems mentioned so far are recipes for manipulating materials (or men) to achieve more or less clearly perceived ends. Moreover, successful manipulation enhances the self-image, the prestige or the power of the manipulators. An effective new drug increases the prestige of the medical profession, to which its use is entrusted. New technology promotes the growth of the scientific-technological complex and in general rewards its members. Successful regulation of the economy enhances the power or the stability of the governments that achieve such regulation.

Problems of disarmament are of a different kind. The solution of these problems may well involve the discovery of techniques not of manipulation but of ways of persuasion. Thus before we institute a search for such techniques it would be good to know who is to be convinced of what and who is to do the convincing.

Consider the question "Does X [a major power] want disarmament?" This question may be in the same category as "Does an obese man want to be thin?" Both affirmative and negative answers to such a question can be reasonably defended, the affirmative on phenomenological grounds, the negative on operational ones (showing the failure of the man to take demonstrably effective measures to reduce his fat storage). Actually the problem is more complex. We can inquire into the reasons for the failure and so proceed again to the phenomenological level: the man "wants" to be thin but he is "unwilling" to take the necessary steps. Further attempts to analyze the meaning of "unwilling" will carry us either into unexplored territories of psychology or into metaphysical disputes about free will and determinism.

Complex as such problems are when individuals are involved, they are immeasurably more complex when the subject of "want" is "a major power." Replacing "major power" by its decision-makers (as is implied by the conventional definitions of "national interest") does not help matters much, because this identification bypasses the problem instead of solving it. We are therefore not in a position to ascribe phenomenological meaning to the "wants" of a major power: it is not a creature like us. Conceivably operational meanings can be constructed for

> **EDITOR'S NOTE**
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> With this issue of SCIENTIFIC AMERICAN the task of Book Editor is taken up by Philip Morrison, professor of physics at the Massachusetts Institute of Technology. Since the death of James R. Newman in May the reviews in this department (apart from the signed leading review) have continued to be his. Henceforward they will be written by Professor Morrison, who will also continue in his post at M.I.T.

what a major power "wants," but I have looked for them in vain in the literature of international relations. The assertions "the U.S. wants" and "the U.S.S.R. wants" are often tacitly taken in that literature to be analogous to "John wants."

Let us, for the sake of continuing the discussion, accept the anthropomorphized image of the major power. Let us further take at face value the official pronouncements of the major powers that they "favor" general and complete disarmament (see "Joint Statement of Agreed Principles for Disarmament Negotiations of the Soviet Union and the United States, Dated September 20, 1961" in Volume IV). The problem now seems to be *how* to create the conditions that would induce either or both sides to carry out what they favor. But we say "how" only by analogy with the problems that yield to manipulative solutions. In the context of disarmament, however, the question is *who* is to create the necessary conditions? The well-known accusations of obstructing disarmament, leveled by the agents of the U.S. and of the U.S.S.R. against each other, point up the impasse.

The impasse, in turn, points up the essentially nontechnical nature of the problem and accordingly the difficulty of dealing with it in an environment in which technical problems dominate the concerns of the ruling groups. The difficulty is revealed clearly in the contribution of P. M. S. Blackett ("Steps toward Disarmament"). Blackett takes the necessity of disarmament for granted and proposes a procedure with the view of effecting a compromise between Western and Soviet proposals of 1960. His argument duly takes into account the military establishments' concern regarding "security" (as the military understands it) during the process of disarmament. To this day I have not seen a refutation of these arguments in military terms, which leads me to agree with Blackett's conclusion. He writes: "If it is difficult to find legitimate military reasons for the vast number of U.S. nuclear weapons and delivery vehicles, it is clear that military arguments alone are not likely to be dominant in U.S. discussion of a possible drastic first step toward nuclear disarmament. This is widely admitted in the U.S., where the impediments to disarmament are being seen more and more as economic, political and emotional in origin rather than as based on operational military considerations."

On the other hand, Hedley Bull ("The Objectives of Arms Control" and "General and Comprehensive Disarmament") concentrates on questioning the arguments advanced for disarmament and for substantial arms control and even for the abolition of war. He does so by taking the arguments singly (usually in their extreme form) and showing that each of them is inadequate. Thus he easily refutes the notion that "arms races lead to war" by pointing out that there are other causes of war, for example clashing national interests. He examines the case for rigidly imposed arms control and finds it lacking, because the controls cannot be sufficiently comprehensive or reliable. To the moral arguments against war he replies: "War has its own ethic, its own distinguished apologists and its own place in the honour and esteem of many human societies, of which our present fears and interests cannot rob it."

A case for arms control is presented by Thomas C. Schelling ("Reciprocal Measures for Arms Stabilization"). In Schelling's view effective arms control depends not on formal agreements but on the antagonists' perception of mutual interests. It seems reasonable to suppose the present antagonists' mutual interest is to avoid a war in which both would suffer excessive damage. Accordingly there is a basis for "cooperation." The problem, as Schelling sees it, is to find forms of cooperation that do not depend on "mutual trust," "good faith" and so on, in short, on fundamental changes in the image each party has of the other as the enemy. Thus Schelling retains the basic premise of all military establishments, which is that the enemy is simply the enemy. He only questions the simplistic notion that whatever hurts the enemy necessarily benefits us and vice versa.

In particular, Schelling contends that the enemy's sense of security (say against a surprise attack) benefits us, since in our age of push-button warfare a jittery enemy is more dangerous than a composed one. Schelling's model is, then, essentially that of two scorpions in a bottle. To him the fundamental problem is how to avoid a situation in which each scorpion is impelled to sting "in self-defense."

The search for such areas of possible cooperation with the enemy, with the view of enhancing not only our security from unprovoked attack but also his, and consequently reducing the likelihood of a holocaust through miscalculation or misunderstanding, is the central idea in Schelling's conception of arms control. In his scheme communication with the enemy (which may be tacit but must be effective) is crucial. It is of course important that the enemy accept or at least understand this doctrine.

It is doubtful, however, to what extent Schelling's message can get across. In order to "read" his message the enemy must think within a similar conceptual framework—a framework in which his views and ours are symmetrical. One might expect that the enemy would eventually accept this framework, since its acceptance by us represents meeting the enemy, as it were, halfway. It represents a rejection of the crude cops-and-robbers image and the eschatology of final victory, which still pervades some sectors of American thought. Unfortunately the enemy seems to be thinking in a different framework, a definitely asymmetrical one in which he appears as a "peace-loving, nonaggressive" state. Those who see his defensive preparedness as a threat automatically appear to him as potential aggressors.

As an example, consider the antimissile missile. General Nikolai A. Talensky of the Russian general staff ("Antimissile Systems and Disarmament") calls the antimissile missile a purely defensive weapon. It is difficult to refute this characterization. If we assume, for the sake of argument, that the facts are as Talensky states them, such a weapon can be used *only* against enemy missiles. It is not inconsistent with Schelling's general orientation to argue that the weapon would be a destabilizing factor in the balance of deterrence; the essence of the balance is that each side remains vulnerable to a retaliatory attack. The antimissile missile reduces the vulnerability of one side and so may jeopardize the "balance." Such arguments against developing the antimissile missile are actually used in the U.S., and by no means only by "doves" but also by some staunch advocates of deterrence (see "Defence Against Ballistic Missiles," by Dyson, in which these arguments are briefly mentioned).

Now, Talensky is familiar with these arguments, and he replies as follows: "Who stands to gain and who is faced with 'serious difficulties' [by the upset of mutual deterrence]? Let us take two countries, one peaceable . . . and the other inclined to an aggressive policy. . . . It is obvious that the creation of an effective antimissile defense merely serves to build up the security of the peaceable, nonaggressive state. . . . A country not willing to abandon its aggressive policy will naturally not be too happy about such a state of affairs."

In order for Talensky to come to

terms with Schelling the general must either abandon his conviction that the U.S.S.R. is a "peaceable, nonaggressive state" or pursue the subtleties of "second-order and higher-order logics," in which the perceptions of intentions and even perceptions of perceptions of intentions are components of a deterrence model as important as the intentions themselves. Being a product of the Soviet system, and being in a position of influence very probably by virtue of his unswerving loyalty to it, Talensky can in all likelihood neither change his image of the U.S.S.R. as a "peaceable, nonaggressive state" nor follow Schelling's multistoried logic of mutual perceptions. The first option is closed to him on psychological grounds, the second on philosophical ones. (The dogma of dialectical materialism would surely regard phenomenological considerations as "idealism.")

Let us, however, assume that a breakthrough has been made and that both sides are convinced that the safe course to follow is to ensure the "stability" of the deterrence system. How is the "stability" of the system to be estimated? Not by putting it to a test. (God forbid!) There remains only argument by analogy, arguments based on the "logic of conflict," which supposedly guides "rational" antagonists aware of their individual and common interests. The logic of conflict is remarkably elusive, particularly the logic of conflicts in which the motives of the opponents are mixed. Schelling himself is well aware of the paradoxes and ambiguities that lurk in this logic and, perhaps for this reason, wisely refrains from labeling specific military policies as categorically "stable" or "unstable." He pleads for more "strategic analysis," presumably to develop methods that would enable the strategist to determine the degrees of stability of alternative weapons systems and postures. Significantly, however, he does not assume that weapons systems have any inherent, objective stability. Stability depends on what military specialists *think* about such systems. He writes:

"Whether we would like to see reconnaissance satellites banned or encouraged may depend, for example, on whether we think they will mainly provide targeting information to the initiator of war or mainly provide warning to a potential defender so that a potential attacker is the more deterred. Whether we like big missiles or not may depend on whether we believe, as so many believed a few years ago, the missiles would be simple and sturdy and hard to destroy in their underground sites, or believe, as so many fear now, that increased accuracies and yields make the present generation of missiles better for a first strike than for a second strike."

Schelling would agree, I assume, that what the enemy thinks is of equal importance. Apart from the question of what to do if the enemy does not think like us, is "stability" a proper term to apply if the "stability" of the system depends on what particular people think at a particular time? (Note the changes in thinking mentioned in Schelling's example.)

There are problems that have no solutions within a given framework of thought, as has been amply demonstrated in classical mathematics. Mixed-motive conflicts are by now the well-known additional examples of such problems. If "solutions" to these problems are to be found at all, the inadequate framework of thought in which they have no unambivalent solutions must be abandoned.

Lest I be misunderstood, let me say once more that it is not strategic analysis per se that spawns doctrines that appear bizarre to the nonmilitary mind (and perhaps also to many military minds). It is rather the recommendations made *to one party in a mixed-motive conflict* that expose the strategic framework of thought as inadequate. Such recommendations, if they are really recommendations (and not merely descriptions of the problem with all its ambivalence), must mask or de-emphasize the fact that many mixed-motive conflicts simply have no unambivalent solutions in the sense of specifying what is the best course to follow for *one* party to the conflict.

From this point of view Blackett's recommendations, which are made to *both* parties, offer more hope; at least the troublesome paradoxes of mixed-motive conflicts can be resolved in this context. (Schelling would say that his recommendations too could apply to both sides, but I suspect his framework of thought is far more removed from that of the Russians than Blackett's is.) Still, as we see from Blackett's remarks quoted above, his superior vantage point has its limitations. If military security is not the central issue in the arms race, the very relevance of military analysis becomes questionable.

If recommendations given to one party in a mixed-motive conflict tend to be misleading, and if recommendations given to both or all parties cannot be implemented (because the antagonists do not share the same conceptual frameworks or cannot make joint decisions), what remains? Admittedly little in the way of "solving" problems of disarmament and thereby establishing a sound basis for world order. Some, however, persist in pursuing the analysis of this problem. They speak not to decision-makers but to the world at large. Their aim is not to advise the power-wielders on what to do but to enlighten people about the situation they are in. The methods, the assumptions and the conclusions of these writers differ, but their stances are similar. They are detached, not by any means in the sense of not caring but in the sense of viewing the situation as an issue with which humanity as a whole is confronted, a perspective that is invariably lost as soon as the analyst becomes an adjunct to the military establishment of one side. (The strategists also claim "detachment," but not in the sense in which I have just used the term.)

I shall cite one example of detached analysis, namely the lucid paper by Klaus Knorr ("Supranational versus International Models for General and Complete Disarmament"), who undertakes a comparison between two views of disarmament. The supranational view favors the transfer of major weapons to a world agency (to be used for peace-keeping purposes). The international view favors total elimination of major weapons through voluntary agreement. Knorr presents the case for both views, pursuing the ideological underpinnings of each. This analysis in turn brings out some most important problems likely to arise in a disarmed world, the foremost among them being an immediate pressure for a redistribution of wealth between the advanced and the underdeveloped regions. Thus the disarmament problem emerges in perspective, which in the context of purely strategic analysis remains obfuscated.

Knorr's "detachment" is not neutral. He frankly favors one method (the international) over the other. Nor is Knorr a visionary; he is frankly pessimistic about the present prospects for the realization of either program. I call his analysis detached because it is not coupled with a prescription for a policy to be implemented by "decision-makers." Such stances are often dubbed unrealistic, but they may be the most realistic after all. There seems to be no one at the helm of a major power today who is receptive to any advice except on how to get the most and get away with it.

Is there no one, then, who might profit from a reasoned analysis of the dynamics of the power struggle in the

sense of doing something on behalf of world order? There may be, if the lines separating "us" from "them" are redrawn. To the extent that people begin to realize there are common human interests that are subverted and jeopardized by the manipulators of genocidal weapons systems and their strategic advisers, a realignment may take place.

The main theme of these four volumes is not, however, disarmament but the nature of international systems and international law. Volume II contains the material most directly relevant to this theme. The principal issue joined is the antithesis between two philosophies of law.

One way of thinking about law is to assume some principles from which existing laws derive, be it "natural law" or the commandments of a supreme being. Existing statutes and other formal manifestations of law are in this view assumed to be attempts to realize such principles. The existing laws need not, for this reason, be assumed to be just or immutable. Indeed, the justice or validity of statutes can be questioned precisely because the ideal law is assumed to be known, and the existing laws can be compared with that source. The opposite view holds that laws come about through custom and practice, the formalized statutes being the expressed recognition of the practice.

The validity of the pragmatic concept of law can be demonstrated by historical instances, in the evolution of common law, for example, by the relations that can be established between codified law and prior existing practices. The pragmatic concept is also in accord with the positivist, operational point of view, with which the contemporary philosophy of science is often associated.

The idealistic concept is not, however, without its justification. It can be pointed out, for instance, that certain codes are not formalizations of existing practices but rather projections of envisioned future arrangements to be lived up to. Our Constitution can be so interpreted, and so can the Covenant of the League of Nations and the United Nations Charter. Robert M. Hutchins argues eloquently to this effect ("Constitutional Foundations for World Order," Volume I).

Thus it seems that both the "leading" and the "following" features of law must be recognized. This dual view of the nature of law has a bearing on the role of international law as it is seen by contemporary jurists.

Another difference in views on law, in many ways related to the one mentioned above, concerns the very definition of law. One view, the "command theory," holds that to have the force of law at all a ruling must be clearly enforceable. To quote Roger Fisher ("Bringing Law to Bear on Governments"): "If a court declared that Doe must pay Roe a stated amount, the sheriff and the marshal stood ready to enforce the judgment with the full power of the state."

According to this precept it is doubtful that there exists anything like international law, since the sheriff and the marshal are conspicuously absent. However, the view of law as "enforceable command," Fisher argues, is too narrow. There are reasons in addition to the existence of organized force that impel people and institutions to obey laws. In particular, governments as a rule obey their own laws, even though there is no sheriff to put a government in jail. These are clearly instances of voluntary compliance, although it is not hard to discern indirectly compelling forces that bring it about, namely the danger of consequences (such as retaliatory action by citizens and loss of respect for law) that governments wish to avoid.

Fisher goes on to argue that the absence of enforcing agencies with absolute enforcing power need not be an impediment to the establishment of international law: "Before a government decides to break a rule of international law, it must consider the possible reaction of other states. It is not only the immediate reaction of the states most affected by the breach that is relevant; the effect on what may be called world public opinion must also be considered. Thus, should the United States consider resumption of espionage flights over the Soviet Union in violation of Soviet and international law, an intelligent decision could not ignore three factors external to the government: (1) political criticism within the United States; (2) the possibility of direct retaliation by the Soviet Union; and (3) the likelihood of an adverse reaction among our allies and the uncommitted nations. These considerations are analogous to those which an individual must weigh before deciding to disregard domestic law." In other words, compliance with the law can be based on enlightened self-interest as well as the presence of a superior force.

Stanley Hoffmann ("International Systems and International Law") evaluates the status and the prospects of international law in less optimistic tones. He views international law as an aspect of international politics. This is saying a great deal in the light of the distinction made between law and politics by Morton A. Kaplan and Nicholas deB. Katzenbach ("Law in the International Community"). Without implying that law and politics are ever separated in practice, these authors nevertheless find it useful to cite the definition of law as "that in which an impartial judge objectively applies a pre-established rule to decide a controversy," and of politics as "that in which the stronger influence or interest regulates the social distribution of values."

Of course, to say that law derives from politics is not to identify the two. Still, an appreciation of the intimate connection between law and politics raises serious doubts concerning expectations that international law may grow out of the enlightened self-interest of states. Such expectations may be reasonable if the "international community" is indeed a community of well-defined entities called states, each accepting at least the existence of others and adjusting the pursuit of its interests (assumed to be in some way "legitimate" by explicit or tacit consensus) to the realities of limited competition. Indeed, there have been situations of this kind, which Hoffmann calls "stable systems"; for example, Europe between the Peace of Westphalia and the French Revolution, and Europe between the Congress of Vienna and World War I. But there are other phases of the international system, which Hoffmann calls "revolutionary," in which stable norms of conduct cannot develop, because not only is there no framework of concepts shared by the comprising units but also even the "units" of the system are only fuzzily defined. At times the very existence of these ambivalent units (their "legitimacy") is perceived by contending power blocs as a life-and-death issue. The periods preceding the Peace of Westphalia, the Napoleonic Wars and the present era are, in Hoffmann's view, examples of revolutionary phases of this kind. The revolutionary phase may portend the end of the system itself, in which case it may be irrelevant to speak of the system's regulatory mechanisms.

Contemporary law, Hoffmann says, reflects the radical changes in the international system that have become manifest in recent decades. (I take it that under "law" he includes law-in-action, not just the covenant of international law embodied, say, in the UN Charter.) Contemporary law reflects the heterogeneity of the structure of the world (varying degrees of "statehood"); the asymmetry of domestic regimes (for example the sharply divergent views of

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"democratic" and "totalitarian" states with regard to secrecy); the forces that cut across the units (for example the opposition between the nuclear "haves" and "have-nots"), and the contradictions in the relations among the units (although treaties have been extended to entirely new fields—labor, human rights and so on—the agreements themselves are weak). Thus international law, according to Hoffmann, hovers between the "obsolete" (the old balance-of-power idea) and the "premature" (utopian) conceptions.

Edward McWhinney ("Soviet and Western International Law and the Cold War in the Era of Bipolarity") strikes what he conceives, I assume, to be a more optimistic note. Reviewing the development of the coexistence line in the U.S.S.R., he leads up to what he evidently views as the crucial test of the doctrine: the Cuban crisis of 1962. The resolution of the crisis, in McWhinney's view, marks the emergence of "inter-bloc international law." This law is conceived as a tacit acceptance by both sides of the "rules of the game" and as a reflection of the Russian preference for bilateral agreements over a supranational authority.

Viewed in this way international law becomes indistinguishable from Schelling's cooperation between enemies on the basis of perceived common interests. In other words, all the aspects of law that relate it somehow to a recognition of interests higher than those of the actors in question are in this view removed from the concept of international law. That is the pragmatic position carried to its logical conclusion with regard to international law.

A quotation from Oliver Wendell Holmes, Jr., at the head of McWhinney's paper has been frequently cited as a succinct statement of the pragmatic philosophy of law: "The prophecies of what the courts will do in fact, and nothing more pretentious, are what I mean by the law." We must observe that Holmes at least refers to the courts in connection with law. It seems that in McWhinney's, and perhaps in Schelling's, conception of world order the quotation should be amended to read "The prophecies of what the litigants will do, and nothing more pretentious, are what we mean by the law." I would question the relevance of this notion to the concept of world order.

Volume I in *The Strategy of World Order* purports to be concerned with theories of war prevention, but the material in it is too diffuse to be so described. Nor does it serve well as an introductory volume. For example, Section 1 is entitled "The Problem, the Plan, and Some Preliminary Considerations." The subtitle promises the beginning of a systematic treatment of a large and complex subject. The only problem of which there is talk in this section to warrant the use of the definite article is what to do about the prospect of being blown to kingdom come. We have all been worrying about this problem for 20 years, and stating it has become more a ritual than a substantive formulation.

The plan mentioned in the title of the section is not discernible. The referents of "some preliminary considerations" are equally vague. Surely neither "Pacem in Terris, Part IV" (Pope John XXIII) nor the pleas for "Constitutional Foundations for World Order" (Hutchins) and for a "Universal Law for Mankind" (Quincy Wright) are in the nature of "preliminary considerations." One is left with the impression that the subtitle was chosen because it is a good opening title. So it is, but the contents of the section are not suited to it.

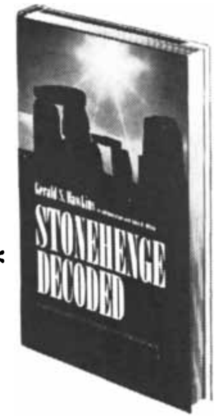
Several of the papers included in Volume I might have been subsumed under the title "A Vision of a World Order." This topic, together with some of the papers on methodological and philosophical matters related to the study of international relations, war and peace ("Analysis of the Causes of Wars," by Wright, and "The Level-of-Analysis Problem in International Relations," by J. David Singer), as well as the papers on world economic development now in Volume IV (for example "International Aid for Underdeveloped Countries," by P. N. Rosenstein-Rodan, and "The United Nations Development Decade," by U Thant), would have made a suitable last volume, devoted to a projected view of the future. The materials dealing with the present and the imminent could then have been suitably organized in three volumes, namely "I: Strategy and Military Technology" (not "Disarmament," because many of the papers dealing with weaponry do not touch on the problem of disarmament at all, except perhaps to dismiss it), "II: The International System and International Law" and "III: Institutions." Their contents would be respectively much the same as the present contents of Volume IV (minus economic development), Volume II and Volume III. In this way the papers now included in Volume I, which clearly do not belong in a possible Volume IV, could be distributed among the other three volumes. As an example, "The Arms Race and Some of Its Hazards," by Herman Kahn, clearly belongs with "Strategy and Military Technology," as does Albert Wohlstetter's "Technology, Prediction, and Disorder." Section 3 of the present Volume I, entitled "The Nature of International Society," could go into Volume II (which already contains some very good treatments of this topic such as Hoffmann's "International Systems and International Law," discussed above).

I feel justified in making these unsolicited suggestions for reorganizing the material, because the material is said to have been prepared to stimulate a new academic discipline. It therefore seems proper to deal with the problem of organizing the teaching materials for the discipline so as to bring the fundamental problems into focus. The materials in *The Strategy of World Order* are for the most part well chosen. Some of them, it is true, are rapidly becoming obsolete, and some were obsolete at the time of their original appearance. Obsolescence, whether due to rapidly developing events or to encrusted habits of thought, should not, however, be a reason for excluding materials from a collection of this kind. How people think or thought about world order, whether their thinking is profound or shallow, cosmopolitan or parochial, lucid or muddled, tradition-bound or original, is in itself an important factor in the shaping of world order or in impediments to it. Although I found some of the papers appalling as samples of contempory thinking on international relations, I would nevertheless urge that they or even worse examples be included as required reading in courses of the proposed discipline—in the role of case histories, as it were. Such, for instance, are some papers (which the interested reader can identify for himself) that are mainly restatements of the conventional wisdom of the cold war. They remind one of Wagnerian opera. In the *Ring of the Nibelungs* there are interminable retellings of the history of the world, which begins with the theft of the Rheingold by a wicked dwarf and continues through the trials and tribulations of Wotan as he tries various schemes to reestablish world order. In modern versions of this saga we read and reread accounts of the trials and tribulations of our country cast in Wotan's role. It is tedious but instructive to read these accounts as primary sources in which the self-image of American officialdom and its academic adjunct stands revealed.

Other examples of this kind readily

About Stonehenge Decoded—

a bestselling book reviewers are calling "as fascinating an archaeological detective story as our time has seen."*

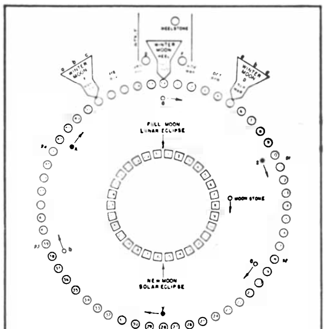


"Stonehenge is unique. In all the world there is nothing quite like the gaunt ruin which Henry James said 'stands as lonely in history as it does on the great plain.' What purpose did it serve? Was it a city of the dead? A Druid place of horrid sacrifice? A temple of the sun? A market? What was it . . . and when?"

With these words, Gerald S. Hawkins begins the account of his dramatic evidence that ancient England's "Druid temple" was actually a sophisticated, brilliantly conceived astronomical observatory . . . a Neolithic computer designed and used by three different groups of people over a 400-year period beginning about 1900 B.C. STONEHENGE DECODED is the full story of how a twentieth-century astronomer — and sixty seconds of computer time — solved one of the great puzzles of the ancient world.

Dr. Hawkins, a professor of astronomy at Boston University and astronomer at the Smithsonian Astrophysical Observatory, first became interested in Stonehenge a dozen years ago, while working at a nearby missile-testing base just north of the ancient monument. Challenged by the known astronomical fact that the main axis of Stonehenge is aligned to the midsummer sunrise, he returned to Stonehenge in 1961 to photograph the phenomenon for himself. Immediately he became aware of questions which the massive stones themselves seemed to pose:

* **Why had the midsummer sunrise alignment been so beautifully and precisely established?**
* **Why were the great archways so astonishingly narrow, restricting the observer's view as sighting instruments do?**
* **Most important, if the monument's original purpose had merely been to mark the midsummer solstice, why had the many other stones — the many other precise alignments and controlled vistas — been so painstakingly erected?**



Stonehenge computer; schematic plan.

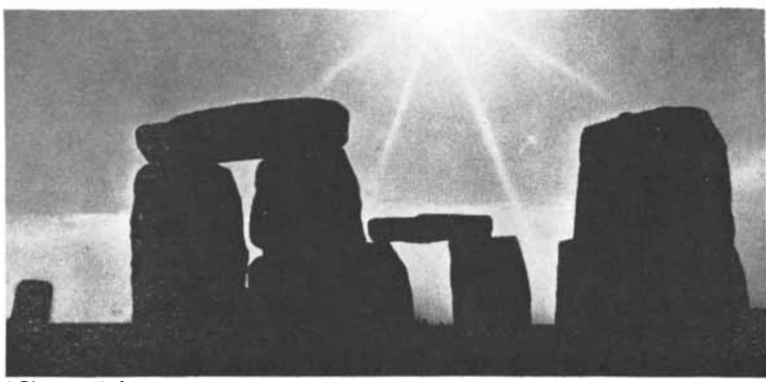
How the computer was used

"I felt that my field of observation was being tightly controlled, as by sighting instruments . . ." Dr. Hawkins speculated on the possibility that Stonehenge might have other solar alignments — and immediately realized that to answer this question would require a great volume of trial-and-error work well suited to computer analysis. He and his programmers gave the computer specific pertinent information about the positions of the stones at Stonehenge and the stars, planets, and other bodies of the sky. In his words, "it was as if [we] told the machine to stand at each of the selected points, look across each of the other points to the horizon, and each time report what spot of the sky it saw." The task took the computer less than a minute. The results were astonishing.

The dramatic facts were these: Each significant stone aligns with at least one other to point to some extreme position of the sun or moon. The mysterious circle of 56 "Aubrey" holes that ring the arches was probably used as an eclipse predicter. Stonehenge was an astronomical observatory and a good one. In fact, Dr. Hawkins believes, Stonehenge astronomy was so sophisticated that its Stone Age astronomers had apparently observed a phenomenon which had escaped modern astronomers: that eclipses of the moon occur in 56-year cycles.

Stonehenge Decoded

The full story of how these facts were uncovered, and what their significance may be, is told in STONEHENGE DECODED. The *Smithsonian Astrophysical Observatory News* calls it "a fascinating, explosive chapter [in] the 3500-year-old story." In addition to describing the astronomic discoveries, Dr. Hawkins, with Dr. John B. White, his collaborator, fills you in on the fascinating mythology that has grown up around Stonehenge, and on the remarkable techniques used in its construction. For, as archaeologists know, the building of Stonehenge, with huge stones carried across 100 miles of land and sea, was in itself a miraculous feat of construction. The book is indexed and illustrated with more than twenty brilliant photographs and endpaper maps of Stonehenge. It is a volume every reader of *Scientific American* will want to read and own. For this reason, it is being offered on a special trial basis. Send the coupon for your copy now. If you are not completely fascinated by STONEHENGE DECODED, simply return the book within two weeks and owe nothing.



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suggest themselves; for instance, the *reductio ad absurdum* of power politics by strategic analysts mesmerized by the intricacies of the balance of terror and nuclear blackmail. The classical theorists of international relations, I feel, should share the responsibility for these caricatures, since the balance of terror is merely an up-to-date version of the balance-of-power dogma.

It is important to make all these materials available to future students of international relations. It is also important to preserve a proper focus. The editors did have a focus in mind, namely the ideas embodied in Grenville Clark and Louis B. Sohn's *World Peace through World Law,* to which frequent references are made throughout the collection. The editors state in the preface that *World Peace through World Law* was selected as "a model... of what an alternative international system might be like."

There is no question that a comparison of what might be with what we have is thought-provoking. Casting the whole immense tragedy of our century in terms of obstacles to an orderly arrangement of human affairs does not, however, come to grips with one of the most fundamental issues: the relevance of the categories in which human beings think.

The very title of the collection detracts from this issue. *The Strategy of World Order* is not a good title, because of the connotations of the word "strategy," which in this context may be seriously misleading. The basic idea in the concept of strategy is the contingent nature of the choices of alternatives. A strategic decision is one that involves *provisional* decisions: I shall do this; the outcomes may be *A*, *B* or *C*. If outcome *A* obtains, then I shall do that next; if *B* obtains, then this, and so on.

Seen in this way, the term "strategy" in the title gives the impression that at least proposed *contingent* plans of action exist, aimed at achieving a state of affairs conceived as world order. The materials do not justify this expectation. The discussions that revolve around strategic problems are (with a few exceptions) those concerned with weaponry, deterrence and the like. Serious discussions of world order center for the most part on the examination of *conditions* (not clearly realizable contingent plans of action) that may or may not be a help or a hindrance in the establishment of world order.

Cannot, then, strategic thinking (that is, providential intelligence) be *enlisted* in the service of constructing a world order? Does not a denial of this possibility amount to abandoning hope that rationality can be used constructively to solve vital problems with which humanity is confronted? The answer to this question has already been suggested. It is not enough to design a strategy; someone must use it. For example, Charles E. Osgood's scheme for reducing tensions ("Reciprocal Initiative") is clearly a strategy: it specifies decisions contingent on previous decisions. The strategy, however, has not been tried. Or perhaps a start was made at trying it but events put a stop to the experiment. Was this not merely a stroke of misfortune, that President Kennedy was assassinated and that President Johnson staked the fate of humanity on holding on to South Vietnam? I do not think so. I do not think that any of the political leaders who are now in power or are likely to come to power soon are able to think persistently, imaginatively and with providential intelligence in the context of international relations, except when they think in the traditional terms of the struggle for power. Nor are they likely to pay more than fleeting attention to people who think creatively about world order as the antithesis of the struggle for power, regulated or not.

Bull represents the mentality of the power realist when he says: "The promotion of international security is a matter of preserving and extending something with which we are familiar, rather than of manufacturing, out of nothing, some novel device." It is not the political leaders' "fault" that they have never learned to restructure their thinking in the context of international politics, for example by bringing common human values to the forefront of political goals. There have been hardly any precedents. Besides, our leaders would not have achieved political prominence had they not oriented themselves primarily toward a struggle for power.

A discipline that seeks to educate the young in thinking about world order in new ways should not concentrate on imparting strategic techniques. Such techniques could be developed only in the process of experience in using them, but the people who would have to use them are not in a position to acquire such experience. The educational task is not one of training but of enlightenment. Before we think of designing strategies for world order we must gain a better understanding of where we find ourselves in history and how we got here. In the process of this enlight-

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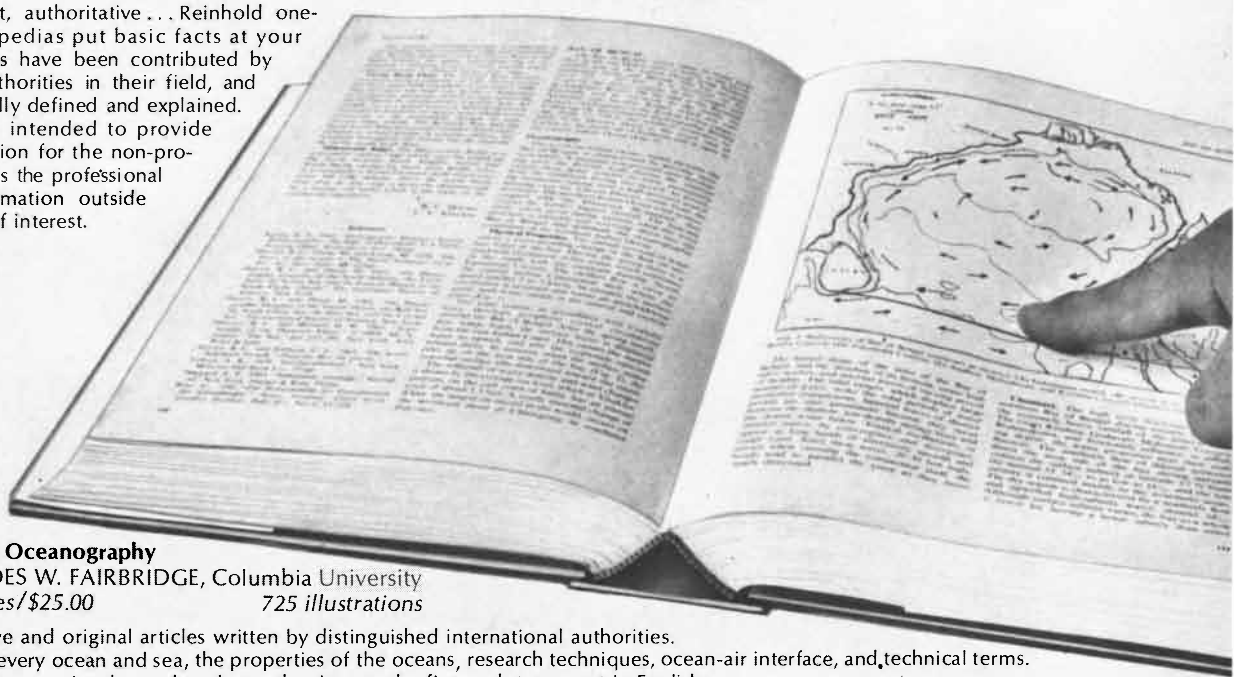

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enment we may learn, for instance, that all the world orders designed by the power elites failed. The order based on the Peace of Westphalia failed because it could not survive the rise of a revolutionary middle class. The world order based on the Congress of Vienna failed because it could not cope with nationalist movements and because in it the military was promoted to a position of tremendous political influence. The world order designed during World War II was never born, because it was based on the supposed community of interest of the Big Five. Two of the five failed to perceive this community of interest, and one turned out to be a phantom.

Political history, seen in the proper perspective, is not the only (nor even, perhaps, the most important) source of insight into the nature of our predicament. The global-economic point of view (see "The Concept of World Interest," by Kenneth E. Boulding, Volume IV) also provides a valuable antidote to the conventional view of "international relations" and to the military strategists' refined taxonomies of Pandora's zoo.

A biologist might have contributed even more to what I think ought to be the principal aim of the discipline envisioned by the editors. Ecology, for example, turns our attention toward a system that may be of vastly greater importance to the future of our species than the "international system." We keep thinking up ways to prevent ourselves from destroying ourselves with the infernal machines we created in order to safeguard our power (to destroy ourselves). And all the time our survival as a species may depend not on power at all, nor even on a "wise use of power," nor on the exercise of justice, nor on the compatibility of ideologies. Rather it may depend on laws of biological balance, which remain equally indifferent to power, to sophisticated strategies, to justice and to ideologies. The day of reckoning may come not with a big bang but with a disclosure of our biological bankruptcy.

In short, what is needed is a reexamination of man's prospects of survival made precarious by delusions of omnipotence. As a corollary, what is needed is a dethronement of power as a primary human goal. Once this idea takes root future generations may be increasingly moved to withhold loyalty from all contemporary power elites. (Perhaps I should make clear that by the contemporary power elites I do not necessarily mean groups that derive their power from privilege, as has been the case traditionally. I mean rather the groups that are oriented toward the struggle for power and that achieve influence by virtue of their inherent or professionally acquired competence in conducting such struggles.) The hope that the power-oriented elites will lose the allegiance of the populations they control is not unrealistic: all previous power elites have suffered similar fates and have disappeared. I am fairly certain that the next revolution in the sequence will occur. I am only not certain that, when it does occur, it will not be too late to think of any kind of world order.

Short Reviews

An Assessment of Quality in Graduate Education, by Allan M. Cartter. American Council on Education ($3). Questionnaires usually give the impression of naïveté or even insensitivity, but if you want to play the popular game of ranking your peers they work beautifully. Presented in this book are the rankings of university graduate faculties and their Ph.D. programs as compiled from the answers of 1,000 department chairmen in 30 academic fields, plus 3,000 scholars in these fields, many of them young people less than 10 years beyond their Ph.D. Checks of various kinds were applied to the data, all clearly and cheerfully reported here, and a strikingly consistent pattern appears. One such check is the following: By mistake Harvard University and two other strong places were included in a list sent out for rating by men in a field where none of the three schools had graduate departments. All three were quite correctly reported in the data as falling below the minimum quality for granting the doctorate. The effect of time on reputation is small in the data; the senior men and the chairmen agree quite closely with the junior scholars, and known changes of personnel in the past five years are clearly reflected in the rankings.

Everyone knows by now that the University of California at Berkeley leads the list, if all 30 fields are given equal weight. Harvard, perhaps trying harder in a less benign climate, is second. There is no dark horse at all in the first 10 or 12 places, either overall or for most fields. A few outsiders catch the eye: Bryn Mawr in classics, the University of Delaware in chemical engineering and the Polytechnic Institute of Brooklyn in electrical engineering. Less of a surprise are the University of Iowa in psychology and the University of Arizona in anthropology. Each of the

largest 10 cities can claim an overall high-ranking graduate school, with the exception of the nation's capital. Economists assigned the lowest average marks to their colleagues, civil engineers the highest. Physiology gave the smallest fraction of *A*'s, astronomy the largest. Out of 4,000 respondents only one chauvinist went so far as to rate his own department distinguished and all the others unfit to grant the Ph.D.

The actual questions were brief and wholly subjective. The respondent was asked to rate the faculty of the listed department as distinguished, strong and the like, and the program for the Ph.D. as extremely attractive, attractive and so on down the line. All the institutions that in recent decades have granted more than 10 Ph.D.'s a year were listed; in all, 106 places were on the lists. Points were given (five for the top), the "grades" were computed and the super-dean's list was prepared. The book contains the 60 lists, a clear account of the methods and their testing, a closer look at a few fields and various comparisons with other measures of educational quality. The data were collected in 1964.

No doubt the book is entertaining and full of curious facts for those who have anything to do with graduate study. It is not very important to have data showing that the Ivy League, the big California schools and the Big Ten are our best universities. It is of lasting value, however, for counselors and policy-makers to see the detailed lists, field by field, of the other places that received a grade. There is the bite and the hope.

PERCENTAGE BASEBALL, by Earnshaw Cook in collaboration with Wendell R. Garner. The M.I.T. Press ($9.95). There are two poles of explanation: the causal and the statistical. Even for atoms they seem to create a dilemma. Applied to the affairs of men, they always look irreconcilable. A metallurgist and a psychologist from Baltimore here successfully apply statistical analysis to the singular events of the national pastime. Baseball, with its wealth of data, its explicit rules, its staccato repetitiveness, is wholly suited to these tools. Cook and Garner have even uncovered a kind of Ohm's law, describing the complex playing out of the game on offense by a certain scoring index. They show quite convincingly from a detailed study of 750,000 times at bat that the probability of scoring a run, for one confrontation of batter against pitcher, is a linear function of a simple product. The two factors of this product are the probability of the batter's advancing somehow to first base multiplied by the mean number of bases he gains on a hit. On this basis the authors examine teams, players and tactics. They show that the hit-and-run play is a powerful way to improve results but that the sacrifice and the intentional walk are generally useless. On the subject of defense they make clear that relief pitchers ought to *start* games, always to be taken out for pinch hitters in a couple of innings. They propose other unorthodox tactics.

They also consider, rather briefly, the physical problems of play. The official ball almost certainly became more elastic in 1920, when Babe Ruth began modern long-ball play. The height of the pitcher's mound—probably introduced for reasons of drainage—is the determining feature of the pitcher's art. The ball is not homogeneous, yet its eccentricity of mass is not (openly) controlled.

The most interesting feature of the book is an account of the interplay of chance and cause. The World Series are so short, and played between teams so nearly equal, that their results and even their duration are nearly pure chance. Batters obviously differ in skill, but most of their slumps and streaks cannot be distinguished from randomness. Mickey Mantle's good and bad years agree with chance. The greatest hitters were, Cook and Garner say, Ty Cobb, Ruth and Ted Williams; the correlation between scoring indexes and general informed judgment is excellent. Nonetheless, the contrast between the run of sheer probability and the overheated effort to understand causally the inner reason for each loss, each "streak," each day-by-day fluctuation is incontrovertible. Most real events of the game are simply too complex to interpret and ought in all reason to be handled with statistics, that is, patiently. It would be interesting to know how many cold-eyed gamblers exist who take advantage of this fact to beat not the averages but their fellow fans, for example by always betting on the unfavored World Series team.

The book is easier reading for a baseball fan than for a mathematician. It is amateur—and charming—operations research, told in the sportswriter's mock-elevated style, with tongue-in-cheek verse. The mathematical notation is typographically ugly, since subscripts are not used, and conventions such as the function argument and the definition of mean number are disregarded. Cook and Garner use only the classical

theory of probability for means, regression, fluctuations and so on. The next step is clearly game theory. If batters never bunt, what will that do to infield play and hence to base hits? Such subtleties lie in the future of analysis.

Enrico Fermi once remarked that a general was judged great when he had won five or six battles in a row. If battles are fought at nearly even odds, this would happen to about one general in 50 or 100. Among the hundreds of World War II generals we called several great. This book shows Fermi to be right for World Series teams and managers. For real war the argument is less convincing. Statistics seem to work for baseball; they might work for battles; they certainly do not work nowadays for wars. There the rules keep changing and events are few. World War III will surely not be a doubleheader. Let the analysts rejoice in baseball.

INTELLIGENT LIFE IN THE UNIVERSE, by I. S. Shklovskii and Carl Sagan. Holden-Day Inc. ($8.95). In 1963 the most original of modern Russian astronomers, I. S. Shklovskii, published a semipopular book on the prospects for our eventual knowledge of reasoning beings somewhere near a distant star. Carl Sagan, an imaginative young American astronomer (one of the few men of that profession to have adorned the faculty of a medical school), saw Shklovskii's book. He was stimulated to augment it and to see it through translation. Shklovskii was delighted, writing "the prey comes to the hunter." This is their joint effort, a distant dialogue. Sagan keeps the last word, marking his material with a pair of deltas. It is a lighthearted, wide-ranging and penetrating book. The canonical subject matter of the new quasi-discipline is found here. The Russian version was called *Universe, Life, Mind;* that, in fact, is a telegraphic table of contents. The first portion is an outline of the facts relevant to an estimate that our galaxy holds hundreds of millions of earthlike planets near sunlike stars. The second section outlines the circumstances that might surround the origin and evolution of life on those earths. The final section discusses the rise of civilization, definable as the ability somehow to signal across the vacant interstellar spaces, and conjectures in a controlled and plausible way on the nature of the signals, the distance to our nearest possible correspondents and the anticryptography of the messages. Some of the statistical arguments in this section are presented so well, and require so little technical mathematical background, that they should open such ways of thinking to many nonmathematical readers. Add the anomalies of the motions of the moons of Mars (Shklovskii argues they *might* even be the hollow spaceships of a dead Martian society), the trial of a con man who purported to ride with saucerians and its theological implications, and the imaginings of Freeman J. Dyson and N. S. Kardashev (who envision societies disposing of the energy not only of suns but also of entire galaxies) and you have a most readable and quite complete example of the new genre of this protoscience, so close to the edge of fiction and yet so plainly potential fact. Excellent illustrations, through both microscope and telescope, as well as clear graphs and diagrams.

INTRODUCTION TO ELECTRONICS: FOR STUDENTS OF BIOLOGY, CHEMISTRY AND MEDICINE, by Vincent A. Suprynowicz. Addison-Wesley Publishing Company, Inc. ($12.50). Black boxes (gray and beige ones too) with their enigmatic lights and ranks of knobs and toggles now take the places on laboratory benches once occupied by brass cylinders and smoked paper. Electronics, that subtle blend of physics, electrical engineering and art, is nowadays the tool of the investigator in every discipline that measures. The speed of electrons, the ease of electrical energy transfer and the extravagant nonlinearities of response that determine the nature of electronic circuits give to all science its instruments.

There are many people who every day measure the concentration of hydrogen ions, the form of brain waves and the energy of alpha particles who are not very sure of how their particular black boxes work. Some patient, knowing, skilled young man, the boss of a shop in a place where other young men of skill work, has to supply, repair, explain or build their scientific tools. If you ever want to lift that lid, or to talk sensibly to the expert who builds circuits for you, you need to have mastered a book such as this one. Here are accounts, in clear physical language, with many graphs and some algebra, of matters such as the Schmitt trigger, the clamp and the emitter-follower. They are described and analyzed at a working level. Practical concerns such as shielding and power supply are not neglected.

The classic guide to the world of electronics on a level below the professional is the *Radio Amateurs' Handbook. Introduction to Electronics* is

clearer, more complete and more teacherly than the *Handbook*. It lacks, however, the rich concreteness of the *Handbook;* one probably cannot expect to design or troubleshoot from *Introduction to Electronics* alone. What is unmatched is Suprynowicz' choice of subject matter. It is much wider than the communications-centered *Handbook*, and it includes the kind of material that people who measure electronically need daily. The circuit builder needs tools, just as the instrument maker does. The micrometer calipers of the electronics shop is the oscilloscope. Several are described, ending with the elegant Tektronix 545. Such a modern scope is not merely the display tube but also a boxful of clever circuits to start the sweep when it is wanted, to the split microsecond, to magnify any part of the curve for close inspection and to match the response to the signal.

As the complete title of the book suggests, much of it deals with bioelectronic gear. There is at least one physicist, however, who will keep the book on his shelf. One small complaint: Like every other book of its kind, it lags a couple of years behind the marketplace —it has not yet been thoroughly transistorized.

MARINE BOTANY: AN INTRODUCTION, by E. Yale Dawson. Holt, Rinehart and Winston ($9.95). About all the different kinds of plants in the sea, from bacteria to the giant kelp. Not a mere guide to species but a unified discussion of whys and whats. The author emphasizes plants that like seaweeds adhere to the bottom, but plankton and the others are here too. A disarming photograph of the balding author collecting deep underwater in shirt and slacks is Figure 1. Toward the end of the book you can see women drying nori in Japan. Such cheerful touches are merely occasional in a serious and comprehensive text. The language is filled with jargon; scales are rarely found in the illustrations, although they vary from electron micrographs to pictures of seaweed 30 meters long. The present growth of interest in the sea, in future sources of food and in the origins of life all reinforce the value of this lively and somewhat eccentric textbook. Dawson rather irately censures Darwin for a neglect of plants in coral-reef building!

THE POWER OF MOVEMENT IN PLANTS, by Charles Darwin, assisted by Francis Darwin. Da Capo Press ($9.75). A well-made, handsome facsimile of the chunky Victorian volume (1881). The

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

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

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

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

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

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

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

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

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

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CONTRIBUTIONS ARE INCOME TAX DEDUCTIBLE SA10-6 wavering millimeter-per-hour motions of the tips of all growing plants (300-odd species) are plotted out with Darwin's patient, simple, penetrating technique. He shellacked a glass fiber to the tiny tip and lined up its end by sighting through a glass plate against a black mark on a stick in the ground. A dot of India ink on the glass and the graph is built up, magnified 30 or 40 times. He proves here that the bending effect of light on grass seedlings diffuses down from the tip of the seedling to its base. This effect, and Darwin's brilliant choice of experimental material, became the basis for the modern work on plant hormones. The book is more or less a journal of repeated, similar experiments. Even Darwin says: "No one ... need read all the details." They are rather dull. Nonetheless, the sharp look it provides at the style of work of one of the great experimenters makes the volume worthy of general notice.

ARCHAEOLOGY: HORIZONS NEW AND OLD. The American Philosophical Society ($1). A symposium report by seven learned scholars, most of them writers of clarity and elegance, who sum up postwar progress and problems in all fields of archaeology, from the Stone Age to Greece and the New World. This special journal issue amounts to a slender paperback book of the highest quality. One small nugget from this rich mine: There is a building boom in the little country town called Thebes, between Athens and Delphi. The contractors sinking narrow shafts for footings to concrete buildings have come down at many points onto the walls and floors of a "large and splendidly decorated palace of the Mycenaean period. This can be none other than the House of Kadmos," where Oedipus ruled happily for a space of time. The myths of Greece have meaty kernels of truth. The booklet is unfortunately available only at libraries or by mail.

RADIOACTIVE PHARMACEUTICALS, edited by G. A. Andrews and H. N. Wagner, Jr. United States Atomic Energy Commission ($5). A medical symposium report (1965) on a powerful diagnostic scheme that makes possible quantitative studies of metabolic change and flow in the patient. Drugs enter the bloodstream or some special organ and can be followed as they move along because they contain gamma-ray-emitting isotopes. The gamma rays, acting like an interior X-ray source, are detected outside the body with special scanning "telescopes," displaying their counts on television-like screens. Views of gross anatomy are not the aim but rather such subtleties as the volume of normal blood supply within the lung. This volume treats of the drugs themselves and their radioactivity; the instrumentation was the topic of 1962 and 1963 conferences. Patently hazardous if wrongly made or used, even though they are supremely perishable, these new diagnostic tools raise problems of marketplace and ethics that are honestly and interestingly discussed. A specialist's work but worth browsing for anyone.

NIMRUD AND ITS REMAINS, by M. E. L. Mallowan. Dodd, Mead & Company ($60). Two luxurious volumes and a folder of plans (they even smell good) detailing the excavation of the military capital of Assyria. A narrative of 14 years' work, outlining a clever plan of the dig and displaying a treasure-house of art. Fortress design, ivory carving, writing on beeswax—all are here from the days of the Prophets.

DOROTHEA LANGE, with an introductory essay by George P. Elliott. The Museum of Modern Art ($6.95). Miss Lange was one of the first photographers to "team with a social analyst," making her art a statement of a social problem. Organized, focused, loving, her photographs timelessly record ourselves. Two of these beautiful and eloquent images are a deserted tenant shack under the featureless sky of Texas, tractor-plowed furrows running to its very walls ("Tractored Out," 1938), and a dozen Egyptian peasant women in long black robes, baskets on their heads, against a row of spreading palms ("Procession Bearing Food to the Dead," 1963).

Notes

THE EARTHLY VENUS, by Pierre-Louis Moreau de Maupertuis, with an introduction by George Boas. Johnson Reprint Corporation ($8.50). A fluent translation of the famous essay (1753) by the first of the French Newtonians, in which he argues for the inheritance of traits from both parents by a competitive contribution of many discrete germs, and very nearly for the origin of species by natural selection.

CALCULUS: PART I, by Edwin E. Moise. Addison-Wesley Publishing Company, Inc. ($8.95). An introductory calculus book with the usual scope but an unusual pedagogy: heuristic, informal and yet fully mathematical.

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