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January 1959

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NUMBER ONE

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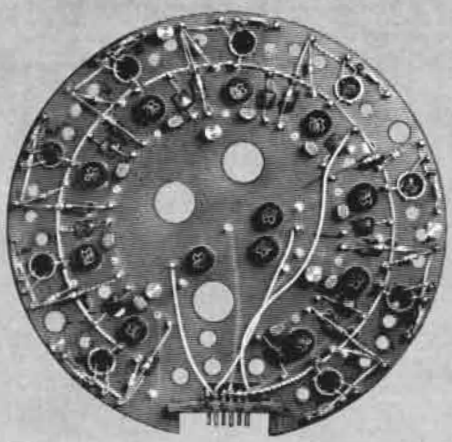

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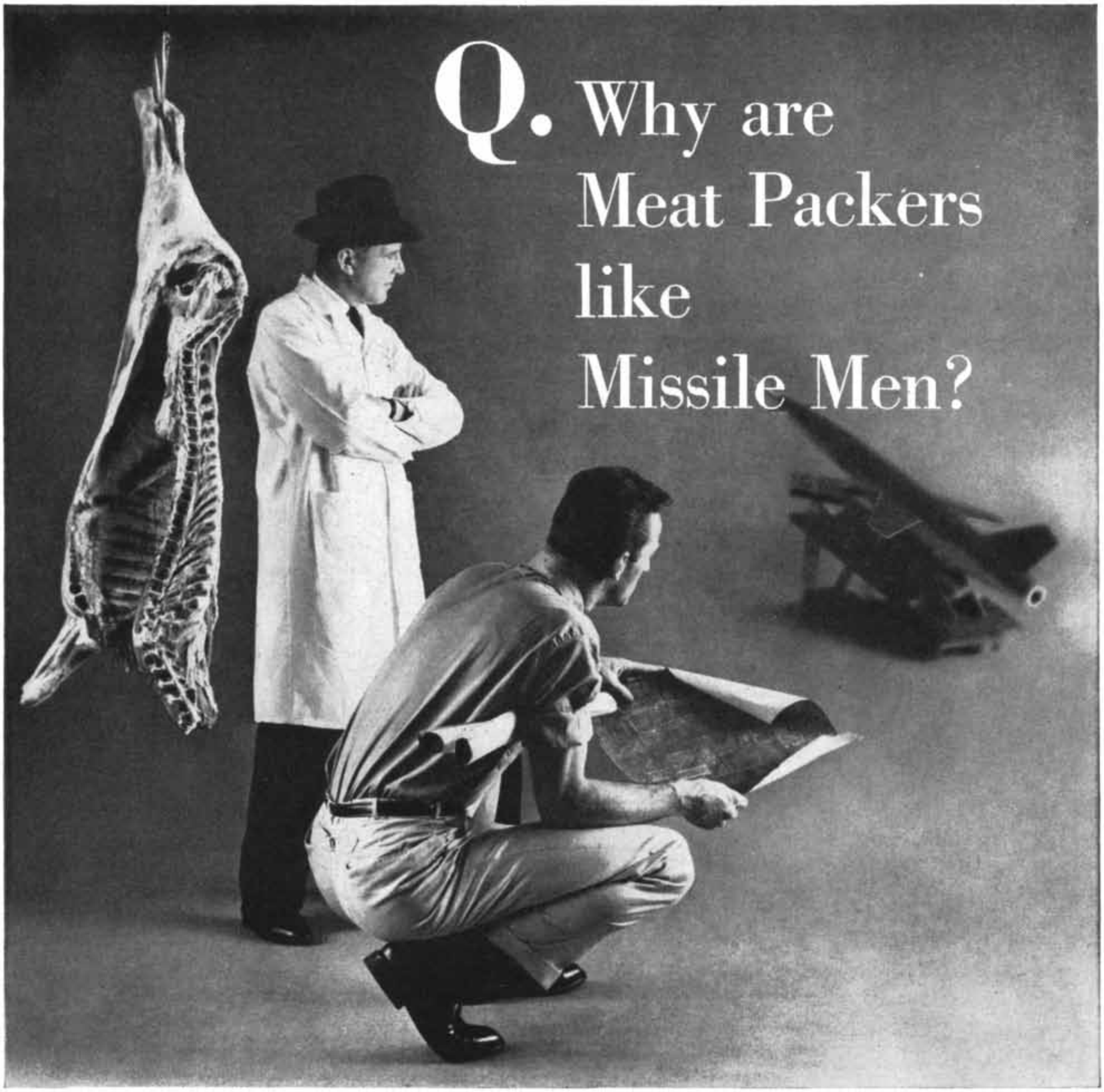

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ARTICLES

DEPARTMENTS

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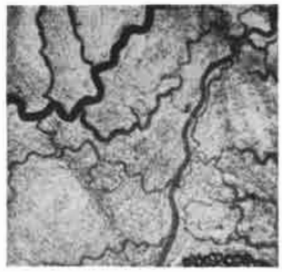

THE COVER

Enlarged 100 diameters in the photomicrograph on the cover are the tiny blood vessels in the mesentery of a rat (*see page 54*). The large vessel running from top right to bottom center is an arteriole; the somewhat larger vessel running from top center to left center is a venule.

THE ILLUSTRATIONS

Cover photograph by William Vandivert and Robert Waldeck

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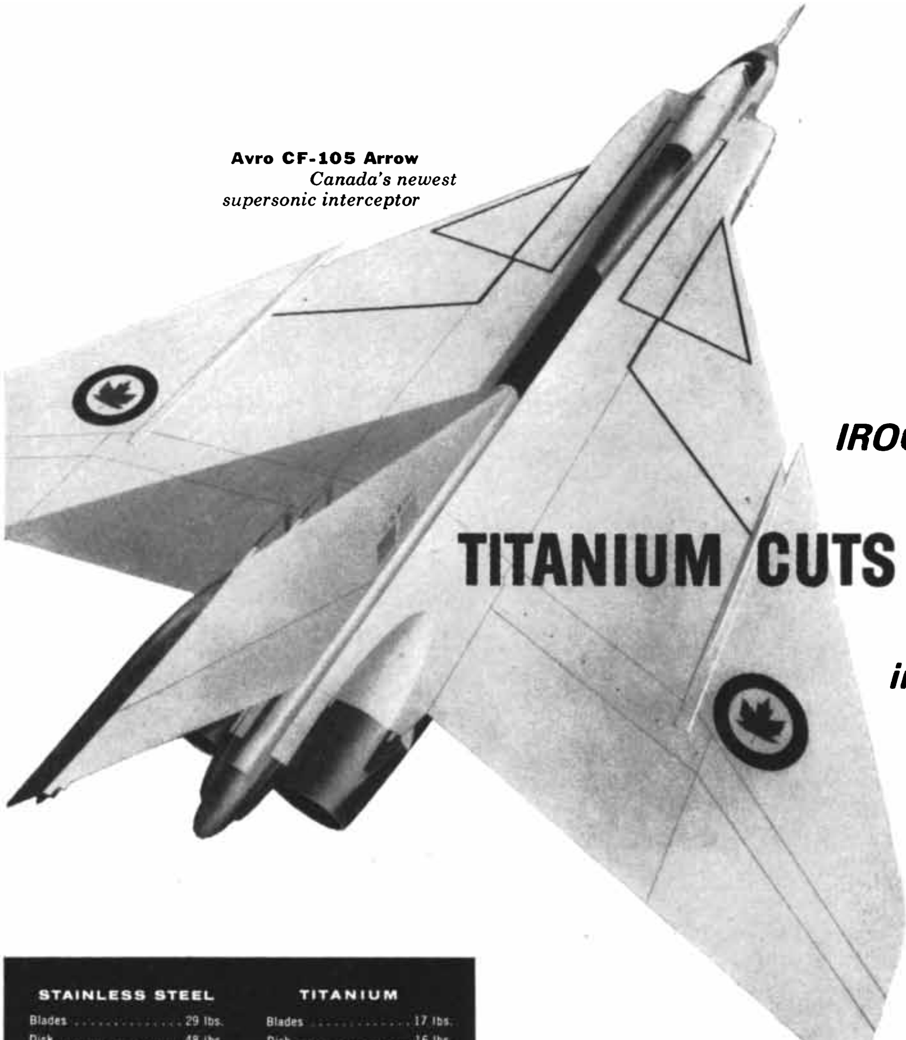

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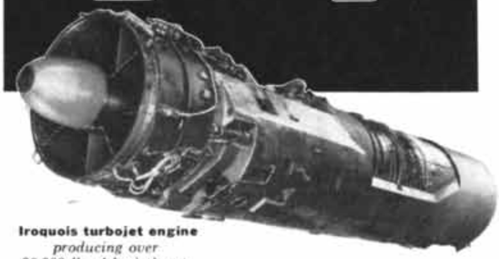
in compressor blade assemblies



Iroquois turbojet engine
producing over 20,000 lbs. (dry) thrust.

Twin Orenda-built Iroquois jet engines will speed the Avro Arrow through space at 20 miles per minute. In these advanced design turbojets, as in the aircraft structure itself, every pound of weight-saving becomes a vital consideration.

To Orenda designers, titanium's high strength-to-weight ratio proved a double bonanza. By using titanium in place of stainless steel for compressor blading, much lighter titanium disks could also be used. *Result: A total weight saving in the assembly of 57%* (see diagram). In addition, lighter structural members could be used, contributing further weight savings and improving performance.

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Many important industrial uses. Paper manufacturers use it to clarify the lake-size quantities of water they use in processing. Separan also separates solids from liquids in the clarification of coal-washery water and settles mud in the manufacture of alum. Industrial plant men long concerned with stream pollution problems are raving about the way Separan helps clear effluent waters. With Separan, industrial wastes can be economically removed from process water before it's returned to the stream, often saving valuable materials which would otherwise have been lost.

Dow "family of flocculants". At this time, there are two Separan products designated Separan NP10 and Separan NP20. Dow promises there will be more in the near future. Needs of various industries for specialized flocculants are spurring development of a complete line, designed to fit many industrial requirements.

Synthetic Gum:

New ally for food manufacturers

If mother was really as talented in the kitchen as legend insists, she did it pretty much on her own. Today's young wife has countless allies in the food industry and one of the stand-bys is Methocel®, as contained in prepared foods.

Used as a thickener, emulsifier, stabilizer and moisture retainer, it is colorless, odorless and tasteless. One common use is in canned fruit pie fillings where it provides consistent fluidity,

Filling makes the pie—and Methocel keeps the filling firm and consistent, hot or cold.

hot or cold. Its non-ionic quality means it is not affected by the natural acidity of fruit. Food men find Methocel invaluable in endless convenience items. As a redispersing agent in dehydrated fruits and vegetables, it provides a rehydrated product that smacks of original goodness. Methocel is good news for the food business—and has applications in an almost endless list of other fields . . . drugs, cosmetics, paint, leather and paper, to name a few.

Chelating Agents:

Poison antidote of the future?

Exciting possibilities in the medical field are beginning to emerge from research on chelating agents. Heretofore known as industrial chemicals, these ingenious compounds grasp metallic ions suspended in liquid in a claw-like hold, rendering them harmless.

Though still in the investigative stage, possible medical use of these metal-grabbing chemicals provides fascinating food for thought. Chelation, for example, could be used to counter calcium deposits on bones or to rid the body of poisonous lead accumulations. And it may offer virtually the only hope of an antidote for plutonium poisoning.

Effective medical use of the chelates is for the future, but industry is using them *today* in a hundred different ways. Whenever a manufacturing process is affected by impurities in water —and the instances are endless—the chelates come into their own. In making rubber, dyeing textiles, in cleaning scale from boilers and heat exchangers, the chelates do an important job cheaply and effectively. Dow chelating agents are sold as Versene®, Versenol® and Versenex*. They're worth investigating.

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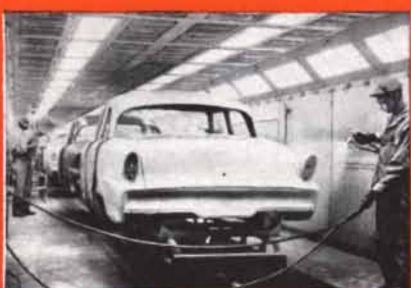
NEW AND NEWS WORTHY



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The vitally important missile industry is making widespread use of a new high-purity trichloroethylene developed by Dow especially for use in cleaning missile hardware. Minimum residue on the cleaned parts reduces the danger of misfiring.

Progress Report on

TWO NEW METHODS OF TUBULAR COMPONENTS PRODUCTION

Special metal-working techniques are being used by the Tapco Group to produce tubular members with distinct advantages for hundreds of aircraft, missile, and industrial applications. Two of these techniques, Metal Gathering and Flotrusion,* offer important solutions to designers and engineers with the problem of tubular parts production.

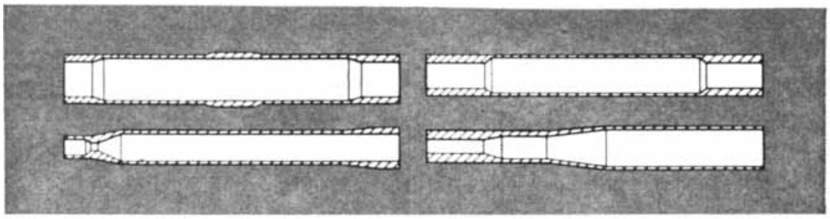

Figure 2—Flotrusion produces any desired variation in metal tubing, including those illustrated here.

METAL GATHERING

Using the Metal Gathering process, a portion of a metal tube is heated in a resistance unit, then "gathered" into a forged lump or mass at either or both ends of the tube. The heated end-mass can then be immediately extruded or forged to any desired rough configuration. After gathering or forging, any machining operation needed to finish the end is readily done right in the shops of the Tapco Group. Examples of tubing end-features produced by this process are illustrated in Figure 1.

Metal Gathering by the Tapco method offers several advantages: one-piece parts free from welds, brazing, or mechanical assembly; minimum machining for end features; no machining of tube interior to reduce wall thickness; better grain flow for greater strength and fatigue resistance; uniform heat-treatment because the whole part is formed from tubing; heavy sections are integral with tubing; no excess metal required, hence material cost is less; a rapid process for reproduction once tooling is established.

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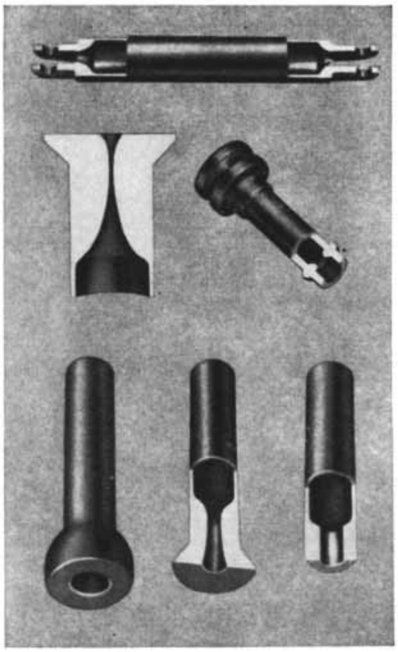

Figure 1—Typical end-features that are readily produced in tubing by the Tapco Group using the versatile, cost-saving Metal Gathering process.

The Tapco Metal Gathering process is readily applied to any metal, including steel, stainless steel, aluminum, titanium, and zirconium.

Designs are almost unlimited in size, complexity, and features. A broad range of tubing lengths, diameters, and wall thicknesses can be handled by the Metal Gathering process. Close tolerances can be supplied; grinding, polishing, or honing can be vastly reduced, and in some cases eliminated. One-piece parts replace multi-part assemblies. The process can also be used at various points along the length of the tubing.

FLOTRUSION

The Tapco Flotrusion process permits cold-drawing of tubing into various internal and external thicknesses, configurations, sizes, and shapes, shown in Figure 2. The process was developed to permit high-production rates of parts normally employing high-cost machining or polishing. Flotrusion can also be combined with the Tapco Metal Gathering process to produce an almost limitless variety of end-features, wall-thickness variations, and other features in tubing.

Tapco Flotrusion offers these advantages:

Heavy wall sections can be developed at one or both ends of cylindrical forms to provide for bearings, threads, or weldments,

Uniform wall thickness can be provided with smaller or larger diameters on the tube,

Surface finishes of excellent quality are standard, without expensive machining or polishing,

Burring and honing are not required,

Grain structure is improved, and additional heat-treatment can often be eliminated since cold-working improves tensile strength,

Tubing that has been heat-treated before Flotrusion gains added strength by cold-working,

Non-heat-treatable metals also gain strength by the cold-work effect of Flotrusion,

No excess material is required . . . Flotrusion requires only the exact volume of material that the finished part requires. Material cost is kept down.

All forgeable metals can be processed by Flotrusion . . . alloy and stainless steels, aluminum, titanium, zirconium, and others.

Tube diameters from 0.060″ to 10″ can be worked on present Flotrusion equipment at Tapco's completely-equipped plant. Lengths to 15 feet have been processed, but longer lengths and larger diameters are within the range of Tapco capabilities and facilities.

The configurations shown will give you ideas of how you can reduce the cost of tubular components by Metal Gathering or Flotrusion or a combination of the two. A 16-page design and data book on both processes will be sent to you on request.

TAPCO GROUP

Thompson Ramo Wooldridge Inc.

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LETTERS

Sirs:

The article by T. P. Bank on the Aleuts [SCIENTIFIC AMERICAN, November, 1958] was most interesting, and brought some coherence to a little known and little understood region and people. I'd like to know more.

Bank said that "it was not uncommon for Aleut hunters to rove the turbulent seas for hundreds of miles, paddling for days on end, resting seated erect in their skin boats when tired and lashing their small craft together to ride out storms. Russian explorers reported that Aleut hunters at sea 'blazed a trail' with whitened sea-lion bladders, weighted with long ropes and stone sea anchors, which they set afloat at intervals to mark the route home through the fog."

This was most amazing to me. The Aleutian Islands are noted for strong currents, strong riptides, dense summer fogs and truly ferocious winter gales. Any attempt to weather these elements today is foolish, and must have been more so with primitive boats. I know—in 1931 I boated in the eastern Aleutians with a rowboat, small power-dory, halibut-fishing boat, and a magnificent 30-foot motor-sailing pilot-boat, the *Picaroon of Seward.*

Might not the Russian stories of offshore Aleuts refer to interisland travel rather than to offshore hunting and fishing activities? The fish and game were close to shore! And did not the Aleuts

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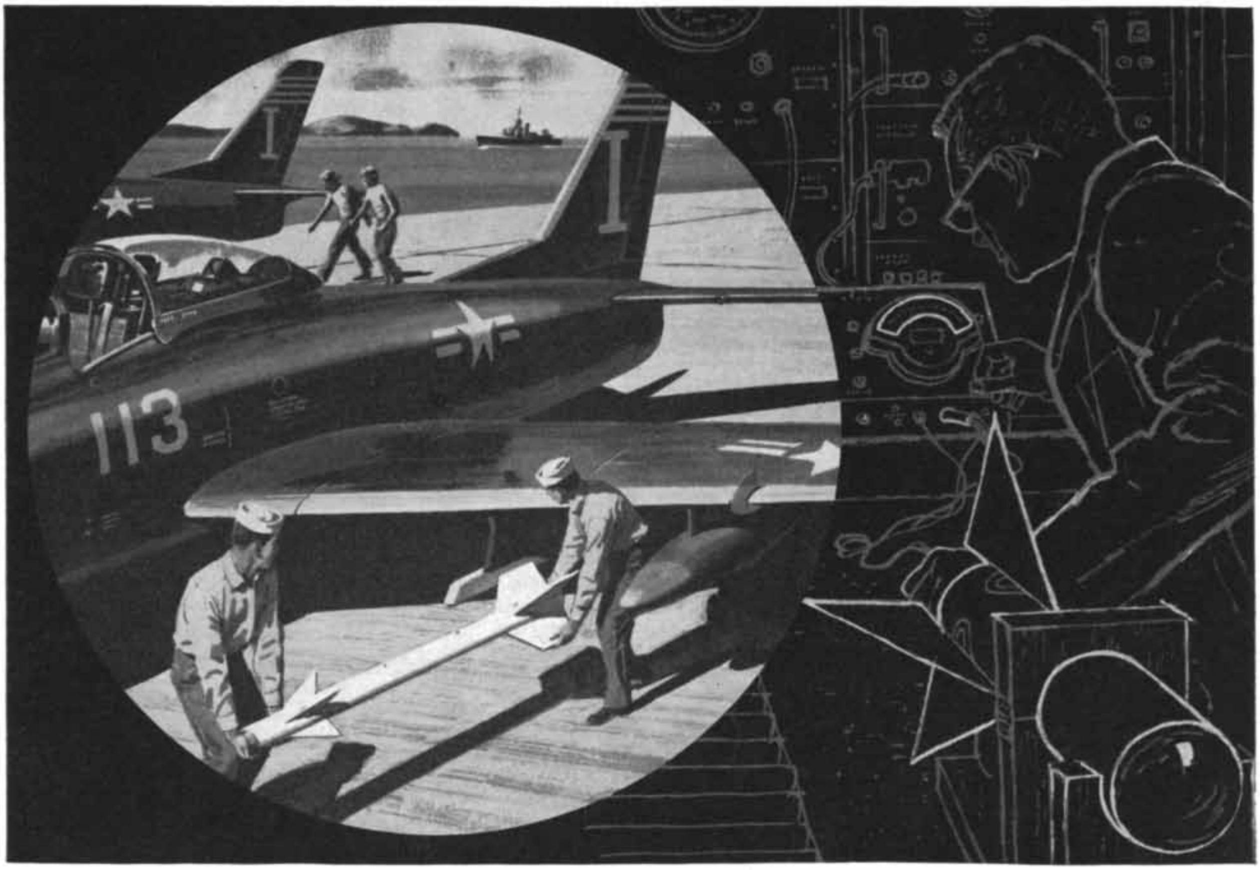

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probably lash their boats together to ride out a sudden storm, rather than for offshore travel?

Would not a floating buoy drift far in a short time in these waters, and thus be way off course and useless, if ever found? Could it be seen in dense fogs? Anchored floats are hard to keep anchored, and even harder to see when the waves and currents pull them low in the water, and even under. . . .

Bank's remarks about Ales Hrdlicka, his failure to keep accurate field notes of excavated skeletons, and his mistaken idea of replacement of dolichocephaly by brachycephaly, must have brought back nostalgic memories to many people who knew that dominating, opinionated, stumpy, grumpy man. "Hardlikker," as he was irreverently known to many, was about as far from scientific as it was possible to get at times, but the conservative stands he took for reasons other than objective caution often held some wild-eyed boys in check.

"Aleesh" was a personality, and must be understood to be interpreted. Science as well as life is made up of personalities. He smothered his many critics and detractors in a deluge of printed matter from his stronghold in the Smithsonian Institution. No one had time to call a halt before he was down the road making new announcements, and putting his pursuers farther and farther behind.

RAYMOND M. GILMORE

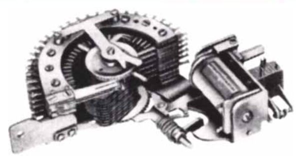
La Jolla, Calif.

Sirs:

As Dr. Gilmore correctly observes, boating in the Aleutians is often rather hazardous. Nonetheless my own experience in the Islands convinced me that the old-style Aleut *bidarkas* were safer than their modern counterparts—wooden dories and skiffs. Early explorers apparently agreed, for G. H. Langsdorff (1814) writes: "In my opinion, these *baidarkas* are the best means yet discovered by mankind to go from place to place, either upon the deepest or the shallowest water, in the quickest, easiest manner possible." The historian M. Sauer (1802), Steller (who was with Vitus Bering) and Captain James Cook also pay glowing tribute to their seaworthiness.

It is quite true that the Aleuts could usually catch all the food they needed close to shore, especially in summer. But in winter, according to reliable observers like Father I. Veniamenof, they frequently hunted sea mammals 20 or 30

How to keep track of 6,000,000 airplane seats



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miles out from shore. Long voyages became fairly commonplace in historical times, when the Russians sent brigades of Aleut hunters in their skin boats as far south as California and to the Kuriles. According to the Russian Tolstykh (translated by Waldemar Jochelson) and to E. L. Blaschke (1845), the Aleuts could paddle for 12 hours at a time.

Regarding the lashing of bidarkas together, it is true that this was primarily to ride out storms rather than an everyday practice. The use of bladder floats as markers at sea was noted by Captain Cook, Father Veniamenof and others. As I understand the manner in which they were used, it would make no difference if the floats drifted with the tides and currents. The Aleuts needed only a rough indication of the direction back to shore. If the markers drifted out to sea or parallel to the shore, they nevertheless would remain lined up with one another roughly as they had been placed in the water, and this was enough to guide the native voyagers.

Hrdlicka, although he may have been rough on some of his scientific colleagues, is still spoken of with awe bordering on reverence by many of the Aleuts. Despite his other faults he was a persistent and indefatigable collector in the field, and the picture of him standing in an Aleutian downpour—white celluloid collar and all—directing his assistants in their search for skeletons, made a lasting impression on the natives. They laughed at his name, which they couldn't pronounce, but they remembered it!

T. P. Bank

Ann Arbor, Mich.

Errata

In the chart on page 88 of the article "The Control of Sex" [Scientific American, November, 1958], two of the cells were incorrectly labeled. The cell second from the left at the bottom of the chart should be labeled "male," and the cell third from the left should be labeled "female."

In the top caption on page 69 of the article "The Contraction of Muscle," appearing in the same issue, the word "fiber" should be "fibril." The words "fibers" and "fiber" in the caption on page 72 of the same article should be "fibrils" and "fibril."

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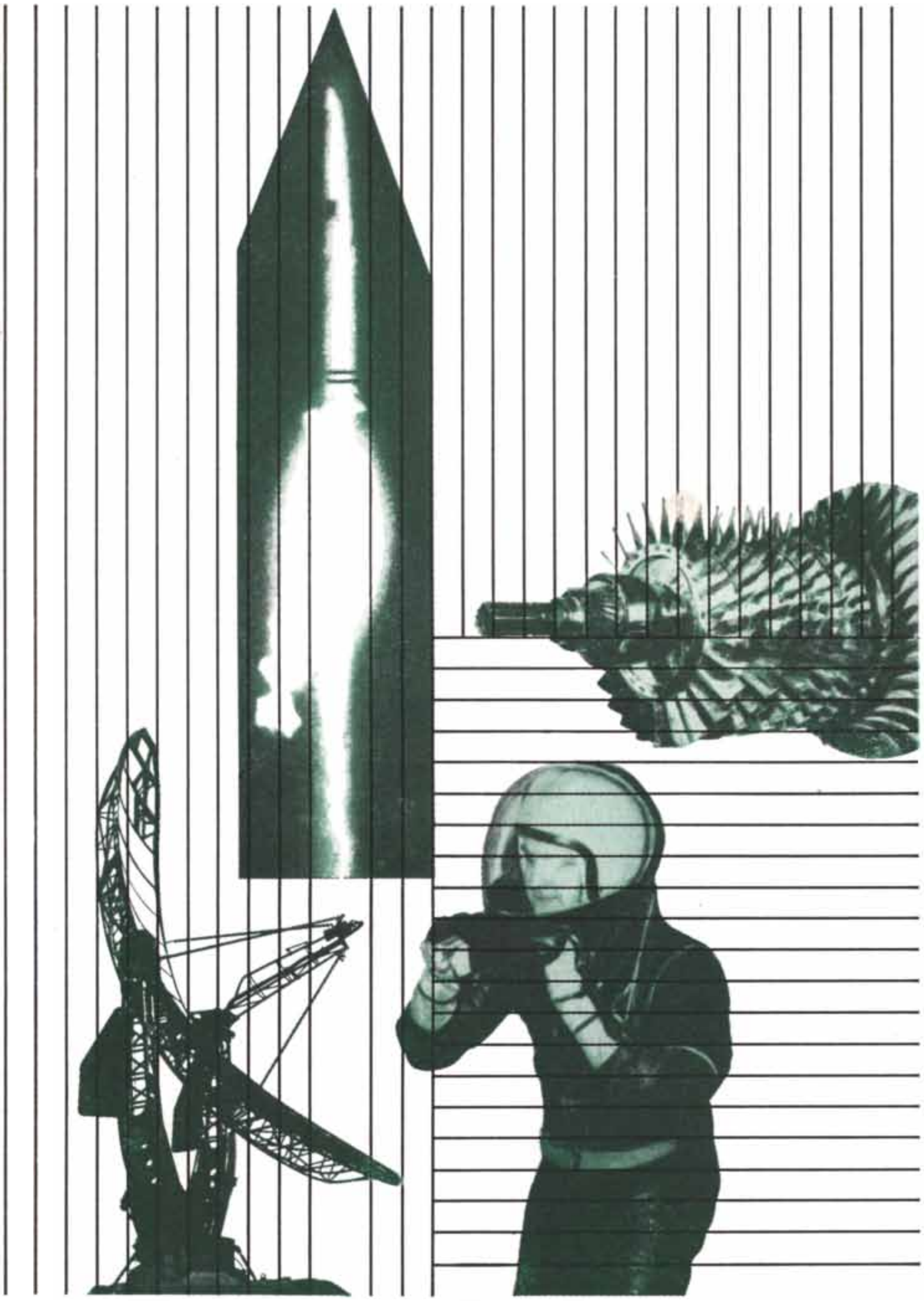

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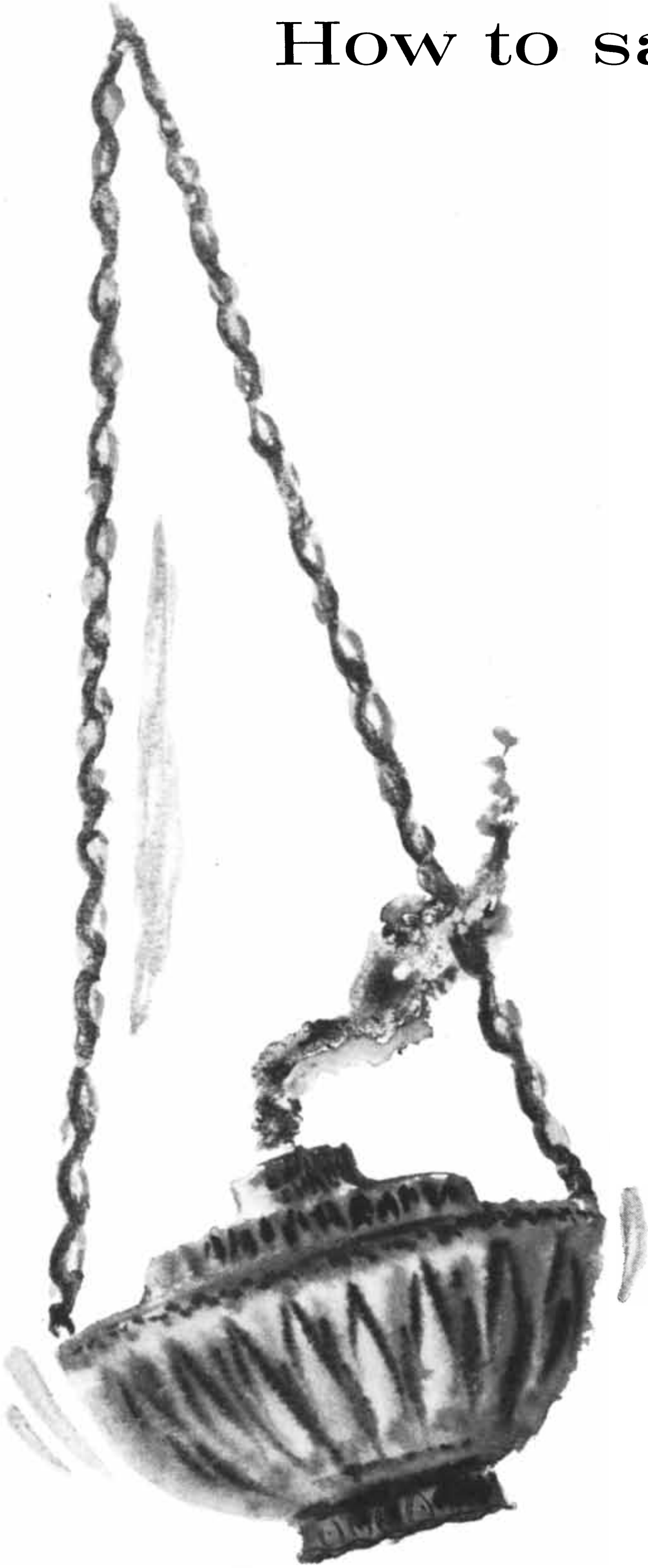
50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JANUARY, 1909: "On the last day of 1908 Wilbur Wright made a continuous flight at Auvours, France, of 76.5 miles in 2 hours 9 minutes 33 seconds, at a speed of 35.5 miles per hour. By this flight, which was made over a closed circuit, he broke all previous records, and thus won the Michelin prize of $4,000 cash and a $2,500 trophy. The French company that is selling Wright machines already has orders for 33 in hand. We are inclined to think that any advantages that the Voisin aeroplanes, flown by Farman and Delagrange, may have in the matter of inherent longitudinal stability are fully compensated by the greater lateral control secured in the Wright machine. Indeed, the Wrights frequently perform sensational evolutions, turning with their machines canted 30 degrees on a radius of perhaps not more than 60 or 70 yards. SCIENTIFIC AMERICAN believes that the machine of the future will be of the Wright type."

"The stupendous earthquake disaster in southern Italy and Sicily is probably, in respect of the lives and property destroyed, the greatest tragedy of its kind that has happened in the history of the world. At the present writing, it seems to be pretty certain that from 150,000 to 200,000 lives have been lost. The enormous loss of life is due to the circumstances; first, that the earthquake occurred in the early morning, when most of the population was within doors; second, that the earthquake was accompanied by a huge tidal wave which swept over the ruins of Messina and rolled for many miles inland; third, that the crippled and entombed survivors of this double disaster were caught, immediately afterwards, in a series of conflagrations."

"Sir James Dewar having succeeded, by the use of the radiometer, in detecting a gas pressure of a 50-millionth of an atmosphere, and having definitely detected by this means the helium produced in a few hours from about 100 milligrammes of radium bromide, has undertaken the direct measurement of



How to save 77 years

The boy Galileo sat in the sanctuary of Pisa's great cathedral, observing the movement of a lamp which had been set swinging by a sudden gusty draft. The chain by which it was suspended from the high ceiling was of such a length that the arcs decreased but slowly. Strange thing, though. No matter how far the pendulum swung, its movement consumed the same time. Galileo made a note of that. The year was 1581.

The old man sat at his writing desk, sixty years and a thousand disputes later, writing down a new theory. The regularity of a swinging pendulum might be combined with a spring mechanism to improve the unreliable clocks of that day. So Galileo scribbled on, and did nothing more about it. A number of years after his death Huygens took the notes and invented the pendulum clock. *Seventy-seven years had elapsed since the boy made the observation upon which it was based!*

The creative thinker today still need not have a specific use in mind when, by equation or formula, he branches off from the accepted to the hitherto unknown. The classic invention of this decade, the transistor, evolved in the Bell Telephone Laboratories as scientists sought a deeper understanding of semiconductors. On the other hand, another great invention, the feedback amplifier, came from the acutely creative mind of one Bell engineer faced with a specific problem.

Current Bell Laboratories activities—in such areas as data transmission, radar and submarine cable development—call for the coordinated efforts of all types of thinkers and all types of approaches. One type complements another.

Today, seventy-seven years would not have elapsed between the swinging lamp and the swinging clock pendulum—certainly not at Bell Labs, where ideas, though not rushed, are carefully advanced toward fruitful application in national defense, industry and communications. An important part of this harvest is the efficiency of America's telephone service, unequalled anywhere else in the world.

BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT the helium produced by radium. The apparatus employed consisted of a McLeod gauge in which no rubber joints were used. A steadily maintained helium increment was obtained of approximately .37 cubic millimeter per gramme of radium per day. This result agrees very closely with Rutherford's theoretical calculation, which gives about .3 cubic millimeter per day."

"There are in the United States over 250 firms engaged in the construction of automobiles, and it is estimated that over 52,000 cars have been sold during the year. Returns from the 29 states that have compulsory registration show that over 250,000 cars have been registered. Whereas the automobile business done in 1903 amounted to less than $8 million, the total for 1907 reached $105 million, and 1908 will show little, if any, falling off. The importation of foreign cars is rapidly decreasing. It is satisfactory to know that the tide has turned, and that American builders are sending their cars abroad in increasing numbers."

"Celestial photography in the wonderfully skillful and capable hands of Prof. E. E. Barnard of the Yerkes Observatory has given to astronomy fresh problems to be solved in the portrayal of the Morehouse comet, discovered by Prof. Morehouse on Sept. 1 last. Between Sept. 1 and 3, Prof. Barnard obtained 239 plates of the comet, which he believes is the most startling to have appeared since the application in astronomy of the sensitive photographic plate. What has made it especially remarkable has been the wonderful outbursts and transformations in its tail, which have changed its appearance with such force that after 24 hours it could scarcely be recognized as the same body. While the light-pressure theory explains the general behavior of comets' tails, it fails to give the cause of these sudden changes in brightness and direction."

SCIENTIFIC AMERICAN

JANUARY, 1859: "Eighteen Hundred and Fifty-nine! Why, it seems but yesterday that we ushered in, with due rejoicings and social joy, the year that, with his hoary cap upon his head, is, as we write, passing quietly but quickly away. The Atlantic cable has been laid, the Queen of Great Britain and the President of the United States are supposed

LOOK WHAT ELSE WE BUILD POWER BRAKES FOR!

The picture compares an automobile wheel with part of the massive landing gear and two of the eight giant wheels and brakes we build for the 450,000-lb. Boeing B-52 jet bomber, so vital to our national defense. When this intercontinental bomber makes a landing, it's like stopping 150 passenger cars going 60 mph! Since ordinary brakes and lining couldn't do this satisfactorily, we developed an extra powerful, segmented rotor brake and a special lining called Cerametalix® that withstands the extreme heat which is generated. We also build brakes and landing gears for many of the latest fighter and jet passenger planes.

If you have never experienced the nice feeling of ease and assurance that Bendix automobile power brakes give you, ask for a demonstration when you inspect the new 1959 cars.

Proof of power brake popularity is evident when you consider that 32 percent of 1958 car buyers ordered them. They cost very little compared to the pleasure they afford. We also make a model which can be quickly installed on your present car in case a new car is not in your plans this year.

Getting your brakes relined? Remember that Bendix makes the world's best brake lining—without qualification! That's why it's original equipment on more new vehicles than any other make. You will find it at quality-minded service places only. It's made by the same Bendix division that makes Cerametalix.

Of course, we also make power brakes for trucks, tractors, bulldozers and other heavy, off-the-road equipment. Even for bicycles.

Whatever your braking problem, we are sure we can help.

A thousand products **Bendix** AVIATION CORPORATION Fisher Bldg., Detroit 2, Mich. *a million ideas* to have exchanged salutations across Old Ocean's bed. It has ceased working; but it is, we are told, shortly to be again in working order. The Crystal Palace has been destroyed by fire. Photographic engraving has received a fresh impetus. The British Association have been talking about the strength of boilers. The civilized world of inventors have been busy on the steam-engine, improving mechanical devices, and saving fuel by every possible means. The *Adriatic* has been across the waters, and we hear a rumor that we are to see the *Great Eastern* next spring. Who shall therefore say that we have not progressed in the last year, or that we are not ever marching onward?"

"Aimé Bonpland died recently at Sao Borja, Brazil, at the age of eighty-five. In the early years he was the companion of Humboldt in his travels on this continent, and collected and classified upwards of six thousand plants then unknown. He was the friend of Napoleon I and the Empress Josephine, and is the person who advised the Emperor after his abdication at Fontainebleau to retire to Mexico and wait for a future opportunity of becoming again the lion of Europe. After the death of Josephine he returned to South America, and became a professor of natural history in Buenos Ayres. After many travels in the tropics, and imprisonment as a spy in Paraguay, from which he was released in 1829, he retired to Sao Borja, where, surrounded by rare botanical specimens and beauteous orange groves, he lived in tranquility and died in peace."

"We learn that there are 399,064 spindles and 12,234 looms at work in Lowell, Mass. There are 2,394,000 yards of cotton cloth made weekly, 44,000 yards of woolen cloth, and 25,000 yards of carpets. No less than 72 turbine wheels are required to drive the machinery of all the mills, besides several breast wheels; 61,617 gallons of sperm oil and 26,000 pounds of lard are consumed annually."

"Under the recent discoveries in photography by M. Niepce de St. Victor, of Paris, it is found that almost all soluble chemical substances are rendered available in the practice of the art. For example, if the paper be impregnated with nitrate of uranium, then exposed in the camera, and treated with a solution of red prussiate of potash, a beautiful red picture will be obtained; and if this be afterwards treated with sulphate of iron, a fine blue picture will be produced."

NYLON, "DACRON"*, "ORLON"*, "TEFLON"* and "SUPER CORDURA"*

How Du Pont Fibers Help Solve the Problems of Modern Industry

• Du Pont industrial fibers can be tailored to meet an immense range of product requirements. For example, special properties can be built into the man-made fibers, such as shrinkability, stretchability, fusibility, dimensional stability, crimp and curl. In addition, each type of fiber offers its own special advantages with regard to properties: Nylon fiber provides great toughness; "Dacron" polyester fiber—strength with low stretch; "Orlon" acrylic fiber—excellent weather resistance; "Teflon" TFE-fluorocarbon fiber—extreme resistance to corrosives; "Super Cordura" high tenacity rayon fiber—highest strength per dollar. Better semi-finished products are made from these fibers (yarns, fabrics, felts, batts, papers) and provide the starting point for a great variety of new applications. Designers are taking advantage of the strength and durability of Du Pont fibers to use them in many new ways, as shown by the interesting products pictured at right.

It will pay you to review the properties of these fibers and see how they fit in with your plans. Chances are that Du Pont fibers can make an important contribution to one of your products or processes. Du Pont's testing and research activities and experience offer you an authoritative source of assistance. Let us help you with your next materials problem.

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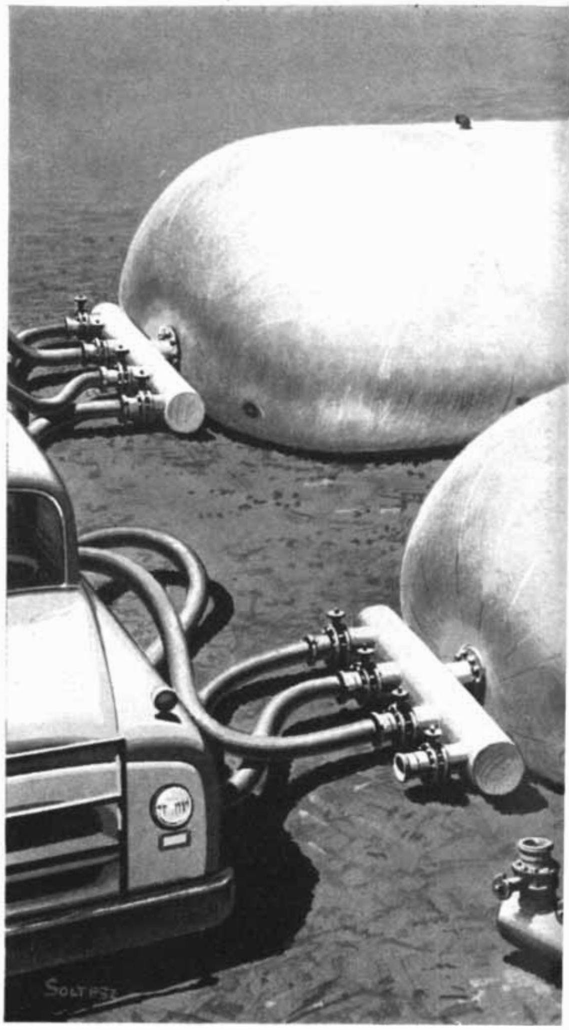
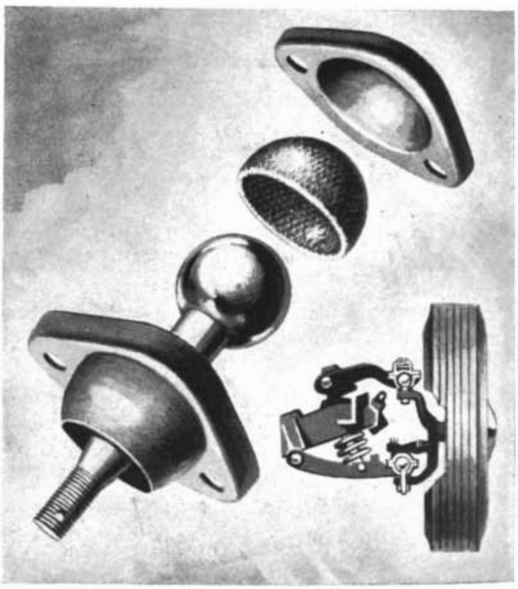
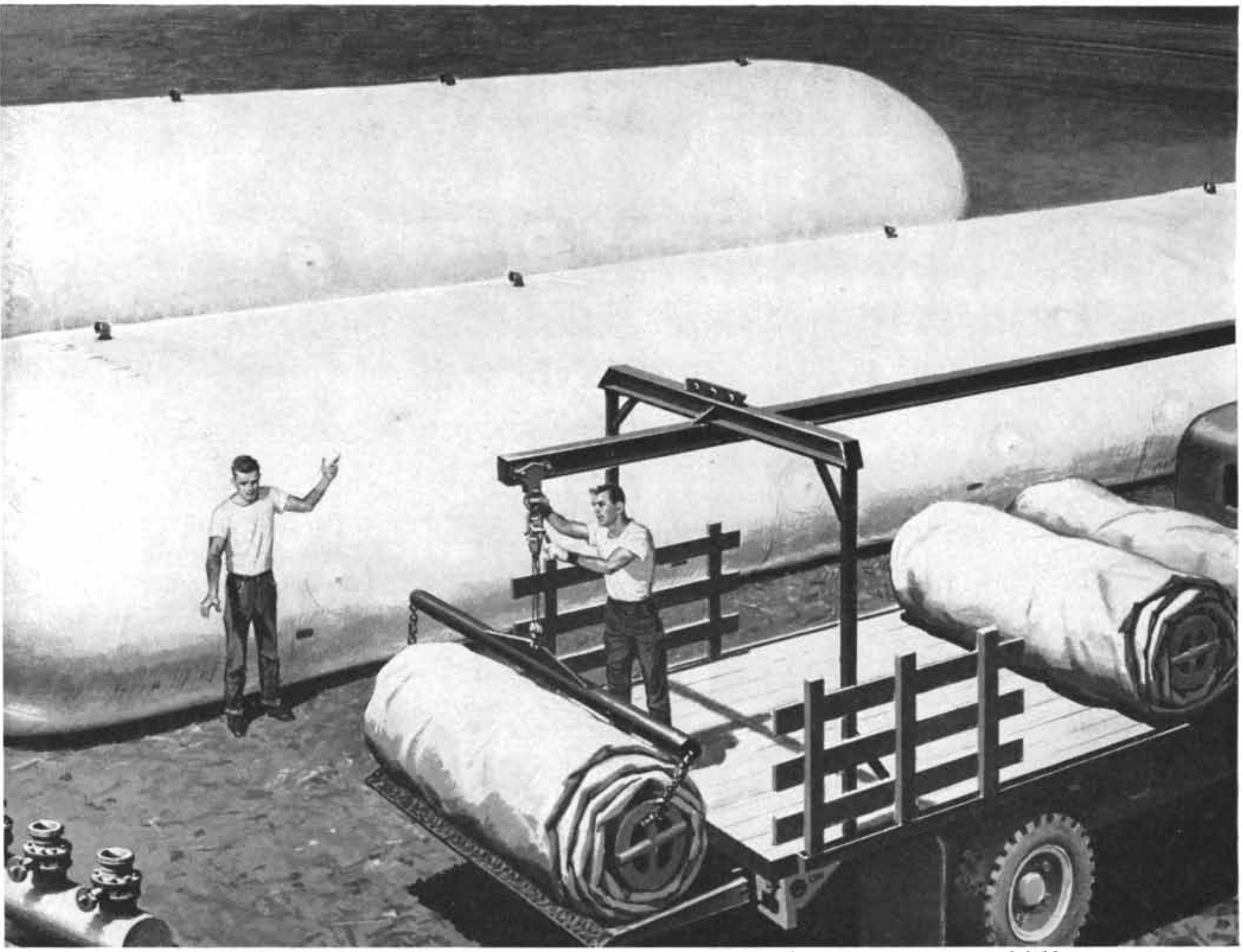


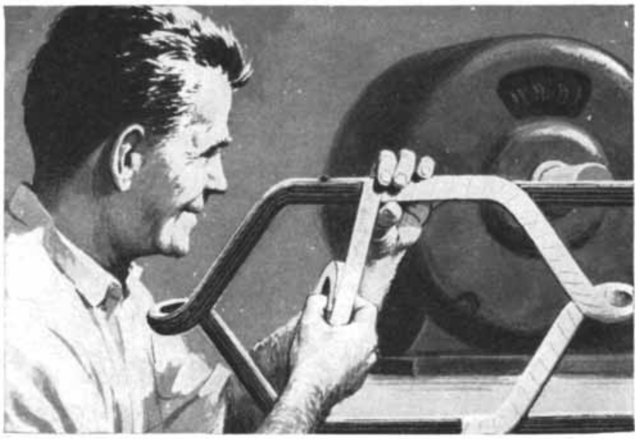


CHASSIS LUBRICATION may soon be a thing of the past for all automotive joints subject to high loads at low speeds. A new ball joint lined with a fabric of "Teflon" is designed for use in steering and suspension systems. The "Teflon" fibers provide an extremely low coefficient of friction. Substitution of the new "self-lubricated" ball joint can eliminate kingpin wear, high initial steering torque and slip-stick motion.



STORAGE TANKS CALLED "WHALES" because of their size and shape are made of nylon fabric coated with neoprene rubber. The nylon lends high tensile strength and light weight to the construction. Nylon is unaffected by grease, oil or moisture and will not rot in contact with soil. The tanks have a capacity of 15,000 gallons and, when empty and rolled up, are easily transported into rough country. Cost of transport to a remote oil field in one instance was $12.50, compared with $175 for moving a steel tank of the same capacity. The tanks can be rolled up into a package 8 feet long by 2½ feet in diameter. A small truck can carry about seven of these big tanks, and they are easily loaded by two men. The light weight of these storage tanks makes it possible to ship them by air.

INDUSTRIAL FIRE HOSE has always led a short, tortured life . . . dragged over rough floors through oil and chemicals, stored outdoors with the fabric outer jacket exposed to mildew damage. That's why hose manufacturers have switched to jackets of "Dacron". "Dacron" has high resistance to damage by abrasion, chemicals and mildew. The new hose has important *performance* advantages. **It** can be stored in half the space needed for conventional hose. **It's** only three-fourths the weight, too—so it handles easier and faster.



NON-WOVEN FABRICS are coming into their own with the availability of man-made fibers. High-grade electrical tapes are made of non-woven fabrics of "Dacron" polyester fiber. "Dacron" has great strength and will not absorb moisture. The non-woven tape stretches to give a secure, snug fit in coil winding. The result is neat appearance with up to one-third increase in dielectric strength.

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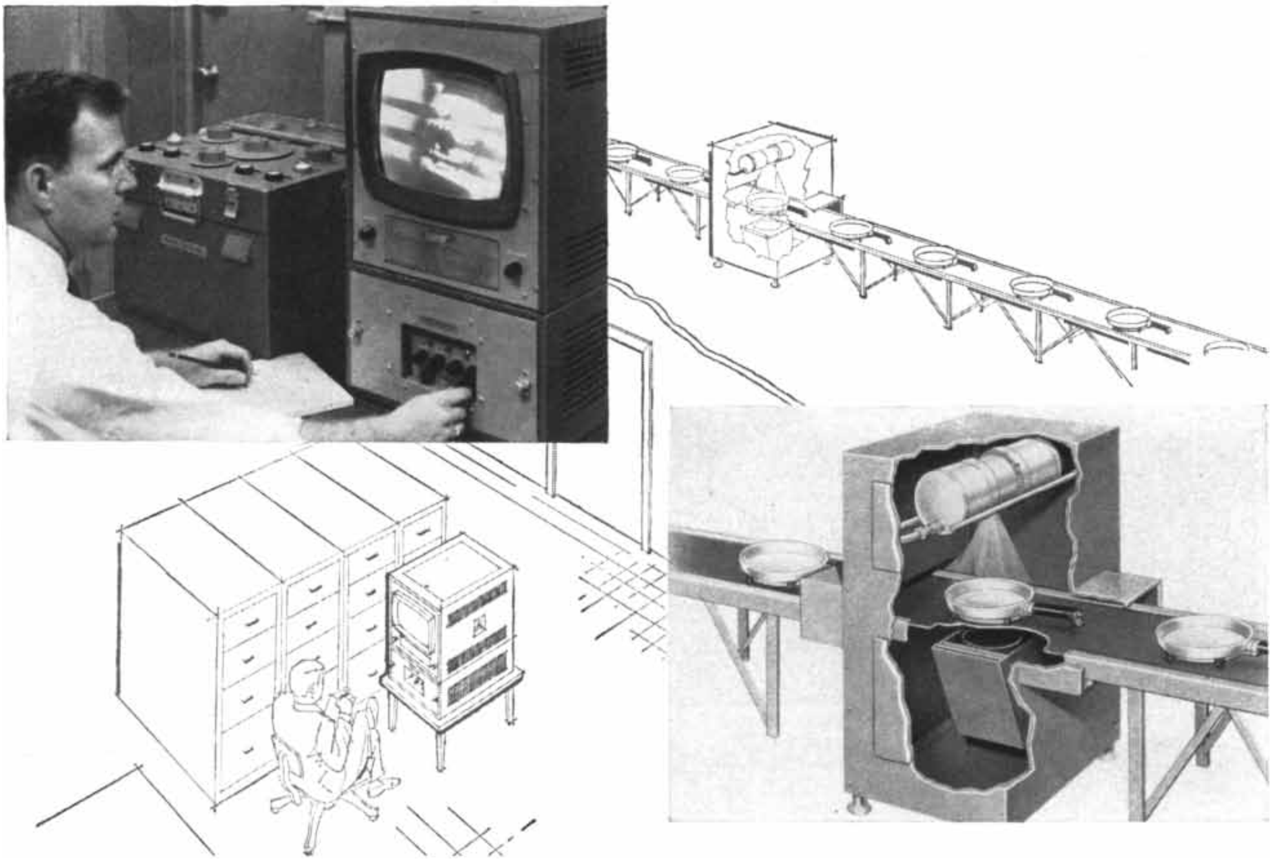
Now from G.E.—X-Ray inspection through closed-circuit television!

TVX

X-ray Image Intensification System



Permits viewing from remote locations...

A fabulous "first" from G.E.! TVX combines the speed of a fluoroscope, the flexibility and bright image of television. Allows continuous 100% inspection from any number of locations within 1400 feet of the monitor — in separate rooms, or even separate buildings.

The TVX monitor — designed to nest atop the control unit — has 12-in. picture tube, bright enough for easy viewing in normally lighted rooms. And should additional monitors be required for simultaneous viewing from multiple locations, any standard TV receiver will do.

Meanwhile, on the production line...

TVX camera picks up x-ray image of moving inspection line, covers a pickup field up to 6⅞-in. diameter. Image size can be varied electronically from ½ to 3 times that of the object, providing both magnification and image intensification.

Provides safety, too. Because the operator can be remote from the radiation area, any x-ray intensity needed for adequate penetration may be used. Power is furnished by a conventional x-ray generator.

TVX service is always promptly available from General Electric x-ray representatives in all major industrial areas.

For complete TVX specs and features data, see your G-E x-ray representative.
Or write General Electric X-Ray Department, Milwaukee 1, Wis., Rm. TT-14.

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THE AUTHORS

STUART MUDD ("The Staphylococcus Problem") recently succeeded Sir Macfarlane Burnet as president of the International Association of Microbiological Societies. He comes from Saint Louis, Mo., where his family has long been prominent in medical research and practice. After graduating from Princeton University with honors in biology, Mudd returned to Washington University in Saint Louis for his M.A. He then proceeded to Harvard University, where he was the first Medical School undergraduate ever to win the 100-year-old Boylston prize for medical research. Mudd acquired his M.D. in 1920, then spent several more years in biophysical research at Harvard and later at the Rockefeller Institute and the University of Pennsylvania, where since 1934 he has been professor of bacteriology.

JESSE L. GREENSTEIN ("Dying Stars") is an astronomer at the Mount Wilson and Palomar Observatories and, in addition, heads the astronomy department at the California Institute of Technology. A New Yorker, he graduated from Harvard College in 1929, took an M.A. at Harvard in 1930, then rode out four depression years as an operator in real estate and investments. In 1934 he returned to Harvard for his Ph.D. Subsequently he joined the staff of the University of Chicago's Yerkes Observatory, first as a National Research Fellow, then as associate professor. Greenstein has worked at Mount Wilson and Palomar and Cal Tech since 1949; for the past six years he has chaired the International Astronomical Union's commission on stellar spectra.

BENJAMIN W. ZWEIFACH ("The Microcirculation of the Blood") says that he is a "complete product of New York City's public-school system." Upon graduating from the College of the City of New York in 1931, at the height of the depression, he found himself jobless, and so decided to enroll for a year in the New York University Graduate School. There he came under the influence of Robert Chambers, a pioneer in the microsurgery of cells. Chambers's work on the permeability of cell membranes led Zweifach immediately into the study of how the cells are nourished by the blood capillaries. Zweifach took his Ph.D. in 1936, was a research fellow at Tufts University for two years, then returned

to N.Y.U., where (except for a period of a few years at the Cornell University Medical College) he has worked ever since.

R. E. PEIERLS ("The Atomic Nucleus") is a German-born British physicist who worked during the last two years of World War II at the Los Alamos Scientific Laboratory. Born in Berlin, he divided his training (according to the European custom) among several universities: Berlin, Munich, Leipzig (where he studied with Werner Heisenberg) and the Swiss Federal Institute of Technology in Zurich. In addition, he paid frequent visits to the Copenhagen laboratory of Niels Bohr; these, he says, "contributed more to my development than any other contacts." After several years as Wolfgang Pauli's assistant in Zurich, Peierls journeyed on a Rockefeller Fellowship to Rome, where he studied with Enrico Fermi, and also traveled to Cambridge to study under P. A. M. Dirac. Upon the advent of the National Socialist regime in Germany, Peierls decided to remain in England where, since 1937, he has been a professor at the University of Birmingham.

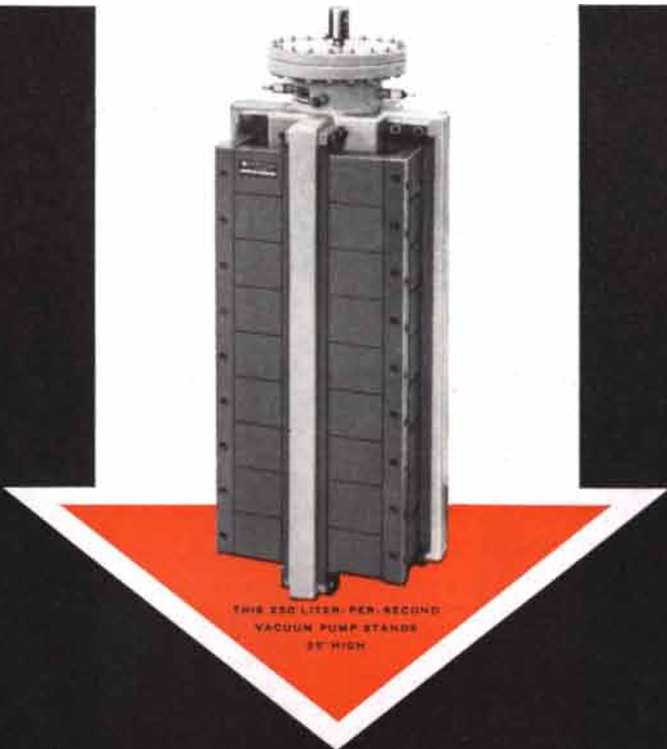
D. W. BRECK and J. V. SMITH ("Molecular Sieves") are a chemist and a mineralogist with, respectively, the Linde Company (a division of the Union Carbide & Carbon Corporation) and Pennsylvania State University. For several years they have collaborated in unraveling the complex structures of zeolites and other silicate sieves. Breck, a graduate of the University of New Hampshire, received his Ph.D. in 1951 from the Massachusetts Institute of Technology, where he held a U. S. Rubber Company Fellowship. Smith was born in England and holds a doctorate in physics from the University of Cambridge. He came to the U. S. in 1951 as a fellow at the Geophysical Laboratory of the Carnegie Institution of Washington. After returning to Cambridge for two years of teaching, he came to the U. S. again and took up his present post, where, with his colleagues, he is engaged in determining the history of minerals through the study of their chemical and physical properties.

A. J. ANDERSON and E. J. UNDERWOOD ("Trace-Element Deserts") are Australian specialists in plant and animal nutrition, respectively. Anderson, whose headquarters are in Canberra, directs the work of the plant industry division in Australia's Commonwealth Scientific and Industrial Research Organization; it was he who, early in his 20-year career

of research in that organization, discovered the vital need of Australia's pastures for molybdenum. Anderson, who holds the degree of Doctor of Science in Agriculture from the University of Western Australia, has twice visited and lectured in the U. S. In 1956 he received the Australian Medal of Agricultural Science. Underwood heads the University of Western Australia's Institute of Agriculture at Nedlands, Western Australia.

KNUT SCHMIDT-NIELSEN ("Salt Glands") has long studied the water metabolism of animals (see "The Desert Rat," by Knut and Bodil Schmidt-Nielsen; SCIENTIFIC AMERICAN, July, 1953). In addition to rats and sea-water-drinking birds, his recent subjects have included camels, whose physiology he studied in the Sahara Desert. Born in Norway, he studied at the University of Oslo, then went to Denmark to work at the University of Copenhagen under the well-known physiologist August Krogh (his wife and collaborator is Krogh's daughter). At Krogh's suggestion Schmidt-Nielsen augmented his training at the Carlsberg Laboratory, where he learned microchemical methods for the analysis of tiny samples of biological material. Since receiving the degree of Doctor of Philosophy at Copenhagen in 1946, he has worked at Swarthmore College, the University of Oslo, Stanford University, the University of Cincinnati and Duke University, where he is now professor in the department of zoology.

FAY-COOPER COLE ("A Witness at the Scopes Trial") retired in 1947 as chairman of the anthropology department at the University of Chicago—a post he had held for 19 years. Before joining the Chicago faculty he had spent another 19 years as an anthropological field worker for the Chicago Natural History Museum (then the Field Museum), in the Philippines, Borneo, the Malay Peninsula, Sumatra and Java. Cole, who is still professionally active, remains a research associate of that museum and in 1957 revisited his Southeast Asian haunts as representative of U. S. anthropology at the Ninth Pacific Science Congress in Bangkok. Cole graduated from Northwestern University in 1903 and did graduate work at the University of Chicago Medical School, the University of Berlin and Columbia University, where he received his Ph.D. He is the father of LaMont C. Cole, whose article "The Ecosphere" appeared in SCIENTIFIC AMERICAN for April, 1958.



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Introducing a whole new series of ion pumps that will develop absolutely clean vacuum, better than 10^{-9} mm Hg. They are available in pumping capacities of 100 and 250 liters/second. Larger sizes can be supplied on special order. They offer tremendous advantages in such applications as particle accelerators, space research chambers, fusion processes, mass spectrometers, electron microscopes, vacuum tube processing — whenever uncontaminated ultra-high vacuums are required.

HIGH CAPACITY — The VacIon High Vacuum Pump illustrated has a uniform pumping speed of over 250 liters/second for room air over the range of 10^{-4} to 10^{-9} mm Hg. Pumping speed for hydrogen is over 850 liters/sec.

RUGGED — No damage to the pump will occur if the system is accidently opened to atmospheric pressure.

ULTRA-HIGH VACUUMS — In ordinary applications, VacIon Pumps will produce vacuums of up to 10^{-10} mm Hg. Equal to space at approximately 120 miles above the earth.

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SIMPLE INSTALLATION — Complete units consist of a VacIon Pump, permanent magnet and power supply. A mechanical roughing pump is necessary only to bring the vacuum in the system down to about 10^{-2} mm Hg at which point the VacIon Pump starts operating. It will perform in any position.

LOW MAINTENANCE COSTS — If the pump becomes contaminated or at the end of its life, the internal elements can be easily removed and reconditioned or replaced.

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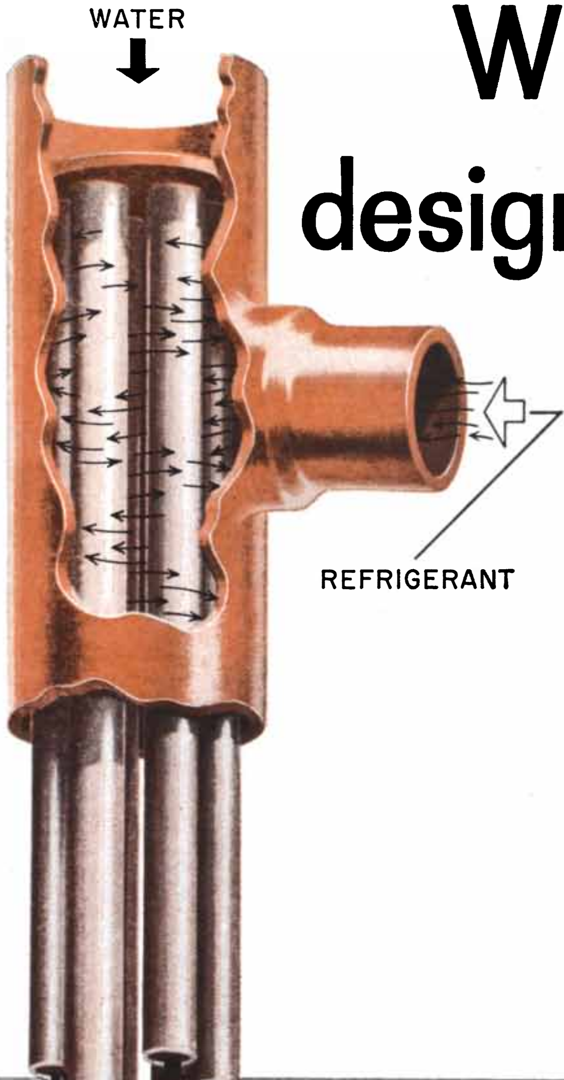
What are today's design possibilities?



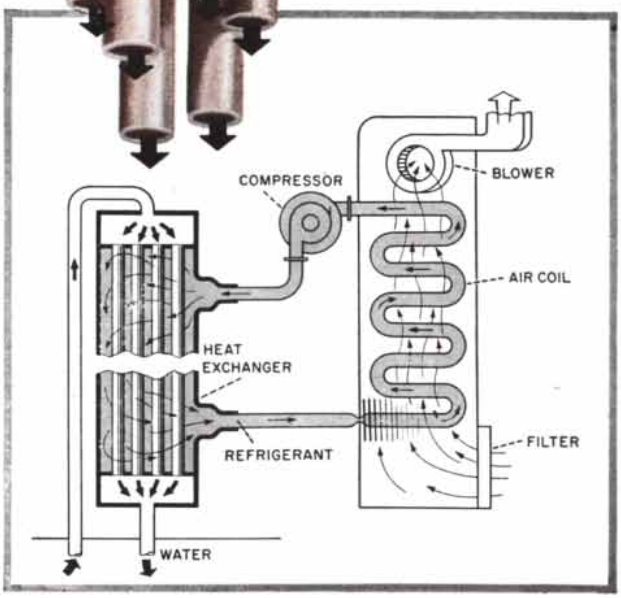
Design possibilities with the copper metals are as varied as these metals themselves. The forty-two industry standard alloys and the hundreds of special copper alloys offer combinations of electrical, thermal, chemical, structural, joining and finishing properties which are more valuable in this day of rigid performance specifications than ever before.

Today, most parts must meet several material requirements. Even a fastener, in addition to strength, may need corrosion resistant and high-finish properties. A supporting member may also have to conduct heat. Efficiency calls for materials versatility. And versatility calls for the copper metals. Although used since 7500 BC, copper is being re-examined as a new material with design possibilities that have scarcely been tapped. Here are some of the problems, and some of the properties that have special meaning at this time:

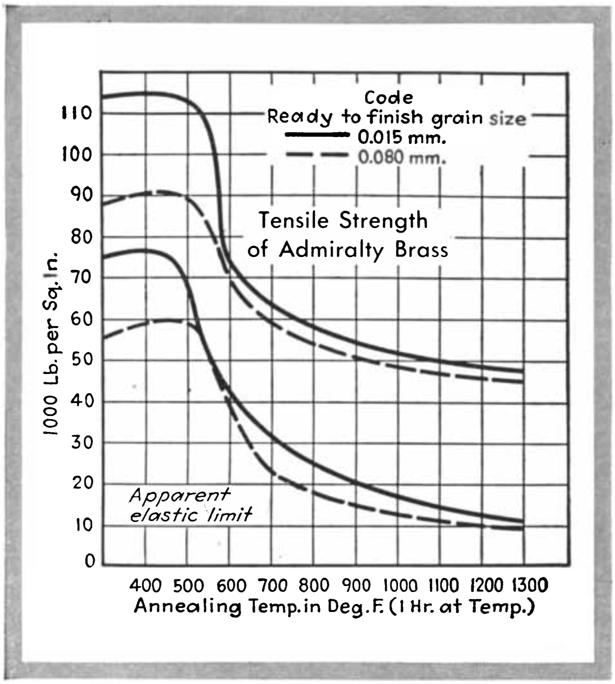
Design Problem — Heat pump condenser

The tube-in-tube condenser in a Typhoon Heat Pump must transfer heat between the ground water and the recirculating refrigerant. Corrosive sodium and sulphur compounds are dissolved in the ground water. The refrigerant, being highly volatile, must be confined in a leakproof system. The house air must be heated in winter and cooled in summer by passing over heat-transfer coils. The design requirements, then, include corrosion resistance, heat conductance and impermeability to the refrigerant. These requirements are met by three forms of copper. The ground water is contained in Admiralty Brass because of its excellent resistance to salt and sulphur corrosion. The refrigerant is contained in commercially-pure copper because of its density and the impermeability of its soldered joints. The air coil is a tinned copper fin soldered to a copper tube for maximum heat transfer at a realistic cost.

The good heat conductivity of copper and Admiralty Brass is, of course, important. But the conductivity of the metals themselves would be of little use if they did not also resist corrosion. The reason for this (besides durability) is because a heavy layer of corrosion products would severely reduce transfer efficiency.



TYPHOON HEAT PUMP CONDENSER SECTION (shown actual size). Heat exchange between ground water and refrigerant is accomplished in this unit. The corrosion resistance and high heat conductance of the copper metals used are vital to efficient operation. Drawing at bottom shows the complete cycles schematically.



EFFECT OF ANNEALING ON TENSILE STRENGTH and apparent elastic limit of admiralty-metal strip, previously cold-rolled 6 B. & S Nos. (50% reduction of area) from two different grain sizes, 0.015 and 0.080 mm. (0.040-in. stock).

As with any piping system, impact and tensile strengths of the groundwater tubing are also important. Slight shifts in the substrata can produce heavy stresses. Admiralty Brass, as manufactured for this tubing, develops a tensile strength of the order of 45,000 psi. Many copper alloys are even stronger. The high-zinc brasses, nickel silvers, beryllium copper, the silicon bronzes and the phosphor bronzes can be processed to provide tensile strengths of the order of 140,000 psi for hard-drawn wire. Strengths, of course, vary with temper. The graph above illustrates the range of strengths for Admiralty Brass.

Design Problem — Preheating for atomic reactor

The induction heating coils used in the Organic Moderated Reactor Experiment, a nuclear power project operated by Atomics International, a division of North American Aviation, Inc., for the Atomic Energy Commission, keep the organic moderating compound in a fluid state during reactor startup and shutdown. The necessary high temperatures are generated by eddy currents in the reactor tank. The design requirements for the coils were high electrical conductivity and good high-temperature characteristics. Oxygen-free, high-conductivity copper was the answer. Its freedom from impurities assures high conductivity and guards against high temperature oxidation and scaling.

Design Problem—Yours

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COPPER COILS being installed on the bottom of the main core vessel of the Organic Moderated Reactor Experiment.

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The picture above shows various combinations of coppers and brasses used decoratively in housewares.

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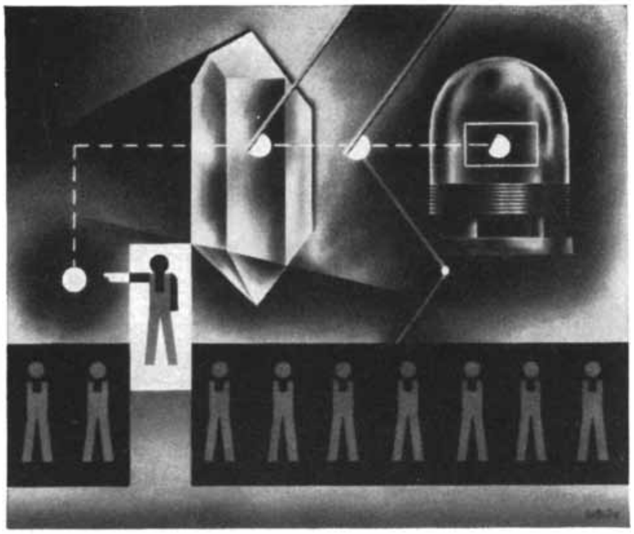

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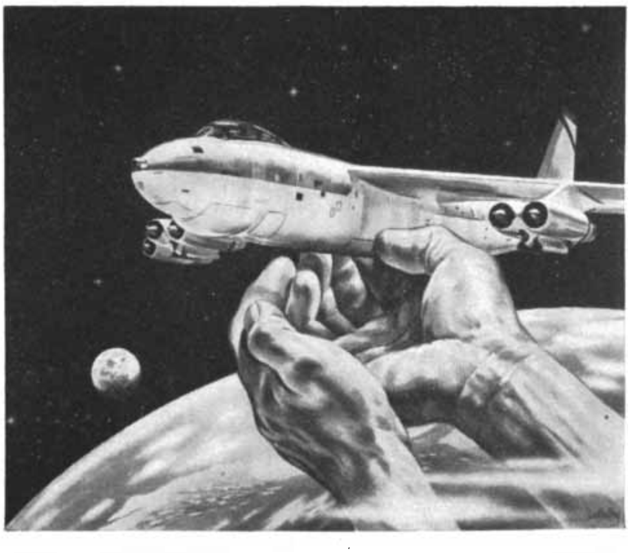

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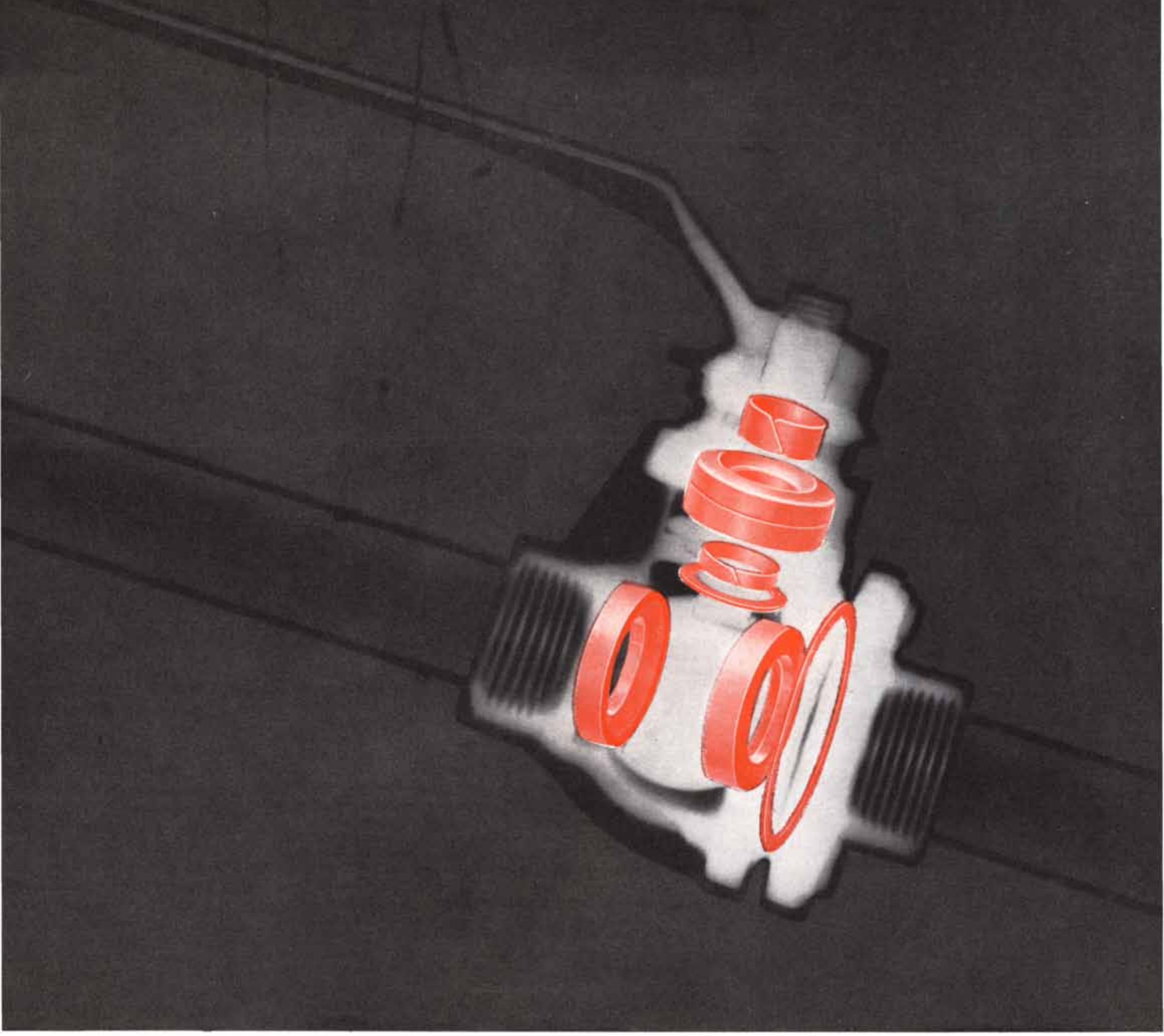

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The Staphylococcus Problem

A ubiquitous parasite has acquired resistance to antibiotics and is causing epidemics of purulent infection in hospitals. Control calls for renewed research and a return to aseptic and antiseptic routines

by Stuart Mudd

During the past two years the technology of modern medicine has been mobilizing to contend with a spreading prevalence of purulent infection in which that same technology has played an equivocal role. The prevalent infections manifest themselves in a variety of conditions, from abscesses and rashes to fatal blood poisoning and pneumonia. All the cases are traceable to certain strains of the familiar and ubiquitous staphylococcus. These strains are distinguished by their communicability and virulence, and by high resistance to antibiotics. They are, in fact, the product of selection by antibiotics; by bad luck, these resistant strains happen to carry the most harmful traits of their genus. The foci of prevalence are the hospitals, where antibiotics have been employed so extensively in recent years not only for treatment of diagnosed infection but also for prophylactic purposes, often with neglect of the standard routines of asepsis and antisepsis. This ironic turn of events has caught physicians ill prepared with alternatives to antibiotics. The emergence of the "miracle" drugs, the sulfonamides in the 1930s and the antibiotics in the 1940s, discouraged interest and support for the classical lines of bacteriological research just as they were reaching fruition with respect to staphylococcal infection.

Of course infection was the common hazard of hospital confinement throughout the centuries before the introduction of antiseptics and disinfectants in the last decades of the 19th century. The staphylococci, together with the pneumococci and streptococci, took the principal toll. These and some other less well-known microorganisms are "opportunist invaders." They are closely associated with man in his immediate environment but do not necessarily cause illness, unless they are given access to vulnerable tissue by breaks in the normal defenses of the body, or by general or local debility. Infections by pneumococci and streptococci had a high fatality rate. Staphylococci, on the other hand, often caused milder infections, and patients who contracted them spread the hospital strains abroad in the world. In 1852 a British physician named T. Hunt described the mid-19th-century prevalence of "carbuncles, boils, whitlows, pustules and superficial collections of purulent matter" as "the furunculoid epidemic." Leonard Colebrook, writing a century later about this "blackest period in all the history of hospital infection" attributes a large variety of illnesses to the staphylococci. His roll call—including post-operative infection; skin disease, eye infection and pneumonia in newborn infants; inflammation of the breast in nursing mothers; outbreaks of skin disease in the families of hospital-born infants—is uncomfortably suggestive of present experience.

For reasons in part historical and in part biological we know less today about the staphylococci than about the other opportunist invaders. The incidence and fatality of lobar pneumonia, caused by the pneumococci, inspired a brilliant series of investigations at the beginning of this century under the leadership of Rufus Cole, A. R. Dochez, Oswald T. Avery and Michael Heidelberger at the Hospital of the Rockefeller Institute in New York. These studies, still going forward, have led to a clear understanding of the many pneumococcal types and their interaction with the defensive humors and cells of their human and animal hosts. On the practical side, they yielded therapeutic horse serums and, later, diagnostic and therapeutic rabbit serums. These techniques did not, however, come into wide clinical use, for just at that time the era of chemotherapy began.

The hemolytic streptococci, as the agents of fatal post-operative and childbed infections, attracted the attention of the same group of investigators at the Rockefeller Institute. Another brilliant series of studies, carried on chiefly by Rebecca Lancefield, elucidated the chemistry of the many groups and types of streptococci and developed a wealth of information concerning the organization of these disease agents and the substances elaborated in their metabolism. From this knowledge came techniques for diagnosis and epidemiologic study. The work goes on in the effort to understand and prevent rheumatic fever and certain forms of kidney disease.

A solid foundation of knowledge about the natural history of the pneumococci and streptococci was thus at hand when the chemotherapeutic agents became available. Fortunately the combined action of the appropriate agent and the natural defensive mechanisms destroys these invaders effectively in the body. What is more, the pneumococci and streptococci have thus far manifested no great tendency to acquire resistance to sulfonamides or antibiotics.

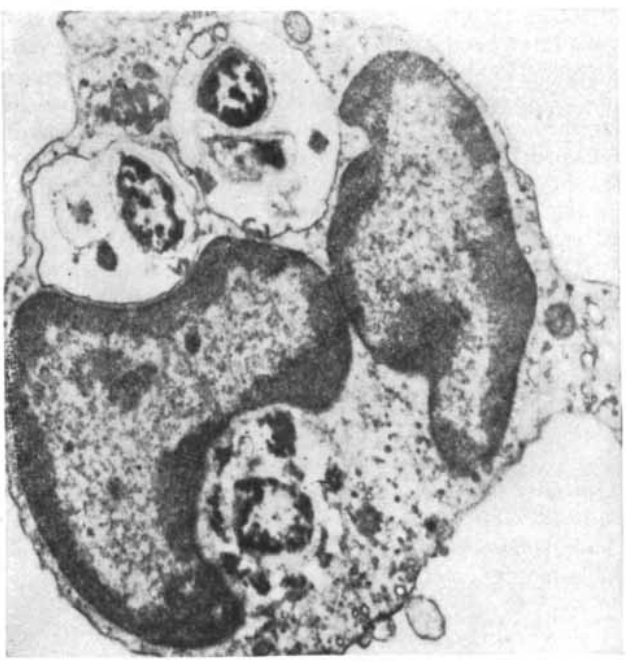
Through the first half of this century the dreaded pneumococci and streptococci quite overshadowed the importance of the staphylococci. No comparable concentration of resources and investigative effort was devoted to these microbes and the infections they cause. But with other opportunist invaders suppressed, staphylococcal infections now stand out in clearer relief. Infections and pneumonias caused by staphylococci in hospitals are now a major menace, particularly to the severely ill, to surgical patients and to newborn infants. There are already clear indications that the staphylococcal infections of hospitals are becoming problems of the community at large.

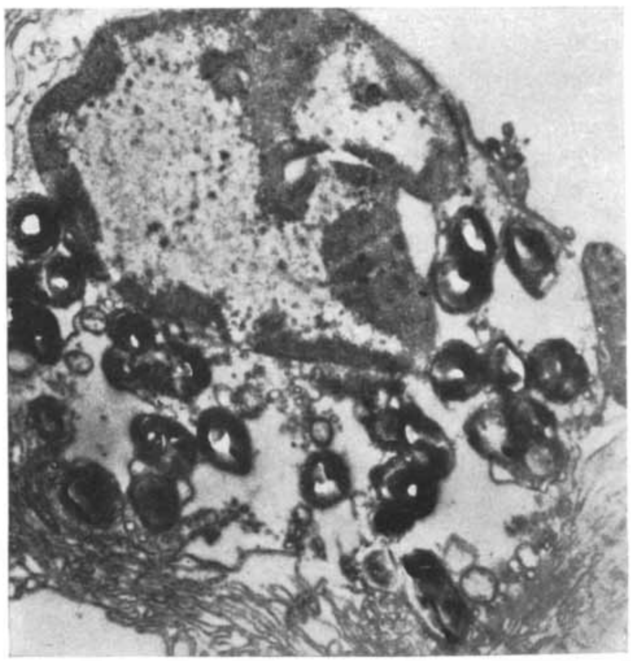
The situation is worsened by the capacity of the staphylococci to become resistant to the antibiotics used against them. The resistant strains have not only infected patients, but have colonized healthy members of the medical, nursing and housekeeping personnel, and lie latent in the dust, mattresses and blankets of the hospitals unless meticulous care is taken in all hospital procedures. The role of antibiotics in the selection of these strains can be seen in the chart at the top of the opposite page. When antibiotics were not widely used or where, as in a mental hospital, they are used only rarely, the resistant and disease-producing staphylococci may not be widespread among patients and staff members. But in hospitals where antibiotics are frequently used, the incidence of resistant organisms is high. The most meticulous and constant care is required to minimize infection by them. Some of the newer antibiotics have proven effective, but these rugged strains show amazing adaptability in acquiring resistance even to new antibiotics.

The "hospital strains" were first recognized as epidemic in Australia, where staphylococci have been identified as to strain since 1949. Staphylococci are grouped according to the types of bacterial virus, or phage, that will attack them. There are four main groups of staphylococcal phages, each including many different types. The phages are highly selective with respect to the bacterial hosts they attack, but one strain of staphylococcus may be susceptible to attack by several phages of the same group. The pattern of susceptibility to phages provides a means of identifying particular strains of bacteria and tracing sources and pathways of epidemic infection. The patterns do not provide such certain identification of individual strains as, say, fingerprints provide in the case of men; rather they identify groups of strains which have traits in common.

The first staphylococci to emerge under the selection pressure of antibiotics tended to be susceptible to the so-called Group III phages. In the last few years, however, staphylococci susceptible to Group I phages have appeared even more commonly than those susceptible to Group III as "epidemic strains" resistant to antibiotics. Phyllis Rountree and B. M. Freeman of Sydney, Australia, have noted that most outbreaks of staphylococcal infection of newborn infants in that city since 1954 have been due to the strain of Group I, susceptible to the phage numbered 80. They also observed a subsequent increase in the incidence of this strain among patients hospitalized for generalized staphylococcal infection, indicating that the hospital strain has spread to the community.

Similar changes in the picture of staphylococcal disease have been observed in other areas. Staphylococci susceptible to phage 80 or its close relative 81 (lumped together in international shorthand as staphylococcus 80/81) have been implicated in outbreaks in Holland, Rumania, the United Kingdom and Canada, as well as in many parts of the U. S.





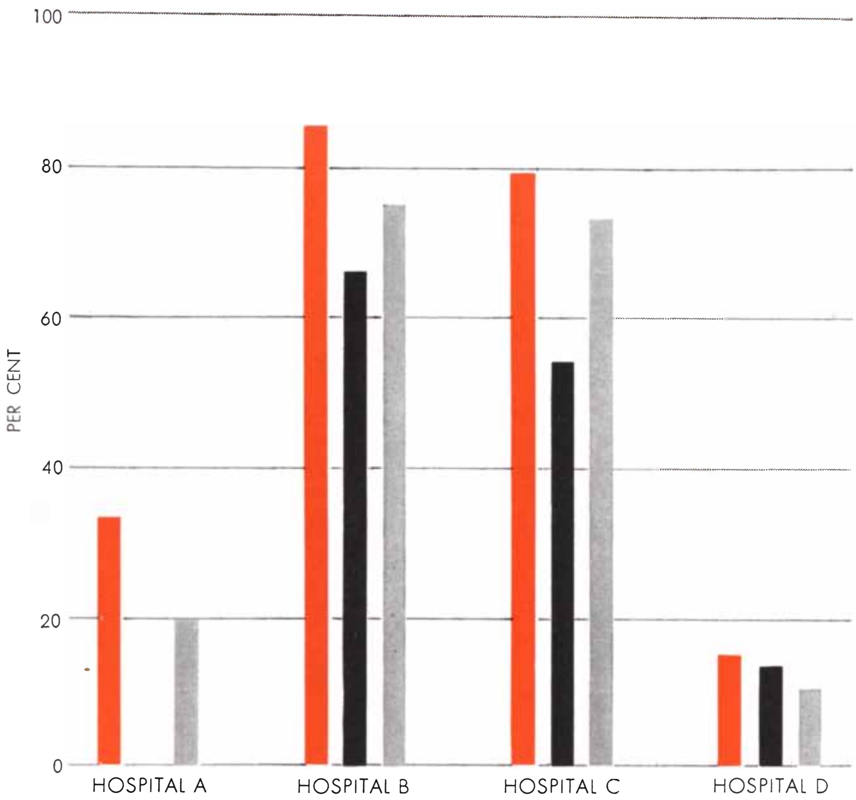
WHITE BLOOD CELLS defend the body against invading staphylococci by engulfing them. At left a cell has ingested three staphylococci which are disintegrating (*circular masses above and below gray, lobed nucleus*). The cell at right, however, is being destroyed by metabolic products of virulent staphylococci which survive after being engulfed. These electron micrographs, made by Joseph R. Goodman of the Veterans Administration Hospital in Long Beach, Calif., enlarge the two specimens about 13,000 diameters.

John E. Blair of the Hospital for Joint Diseases in New York City has typed staphylococci obtained from hospitals throughout the U. S. He reports: "Staphylococci of Type 80/81 have become widely disseminated in this country during the past three or four years, and are at present responsible for many, but by no means all, outbreaks of hospital-acquired infection." In a nationwide survey in the fall of 1957 he found that staphylococci that caused infections "were predominantly members of phage Group III or were of Type 80/81," and "a large proportion of the Group III strains and nearly all of Type 80/81 were resistant to penicillin, the tetracyclines and streptomycin.

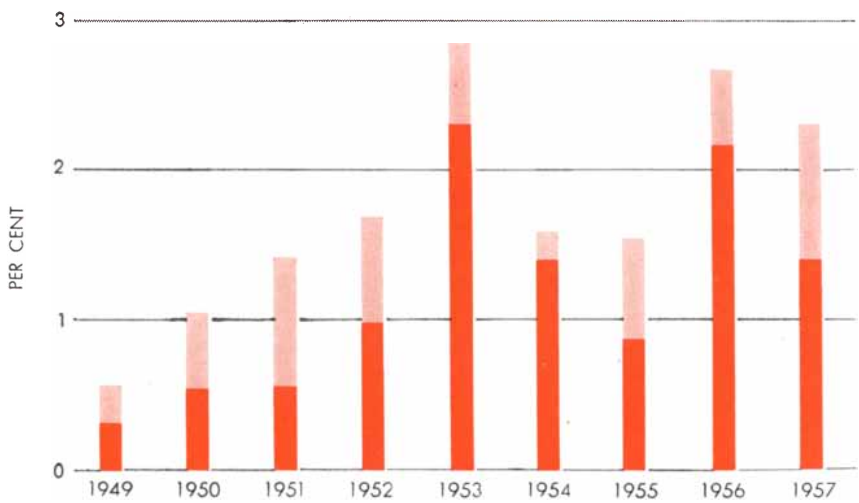
The invasion of hospitals and of communities at large by highly communicable, antibiotic-resistant staphylococci has brought vigorous response from major medical and scientific organizations. During the last year the American Public Health Association, the American Medical Association, the American Academy of Pediatrics, the U. S. Public Health Service, together with the National Academy of Sciences–National Research Council, have sponsored conferences on the problem. A number of state, county and municipal health departments have assigned health officers to the specific task of dealing with the trouble spots in their localities. More action is needed, however, in a great many more communities.

Investigators and clinicians who attended the conferences agreed that hospitals should use antibiotics with greater discrimination, especially when considered for prophylactic purposes, and return to the techniques of strict asepsis and vigorous antisepsis. These techniques are designed to minimize a patient's exposure to all microorganisms. In some hospitals such simple measures as wearing a double mask in the operating room or the bathing of infants with a hexachlorophene solution have helped to check the spread of staphylococci. The conferees have also urged the identification of dangerous carriers of staphylococci among apparently healthy members of the hospital staff, and the isolation of clinical cases.

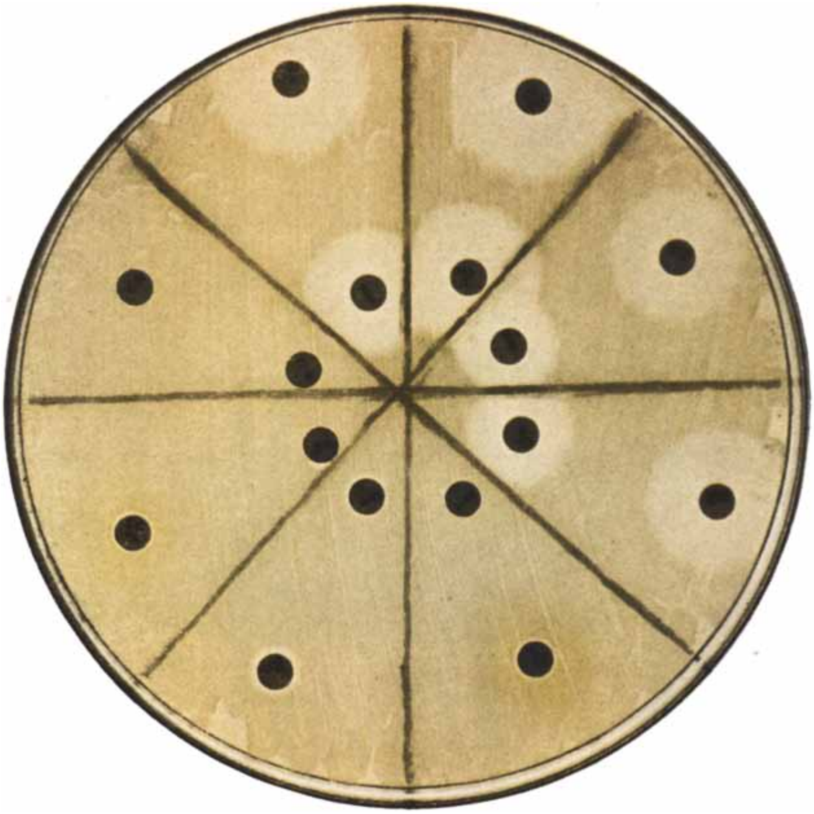
The vigorous application of aseptic and antiseptic techniques, however, can at best cut down the over-all infection rate; they will not eliminate the problem. Clearly a long-term fundamental and clinical research effort must be pushed to increase basic understanding of the staphylococcal organism in relationship to man. We must learn at least as much

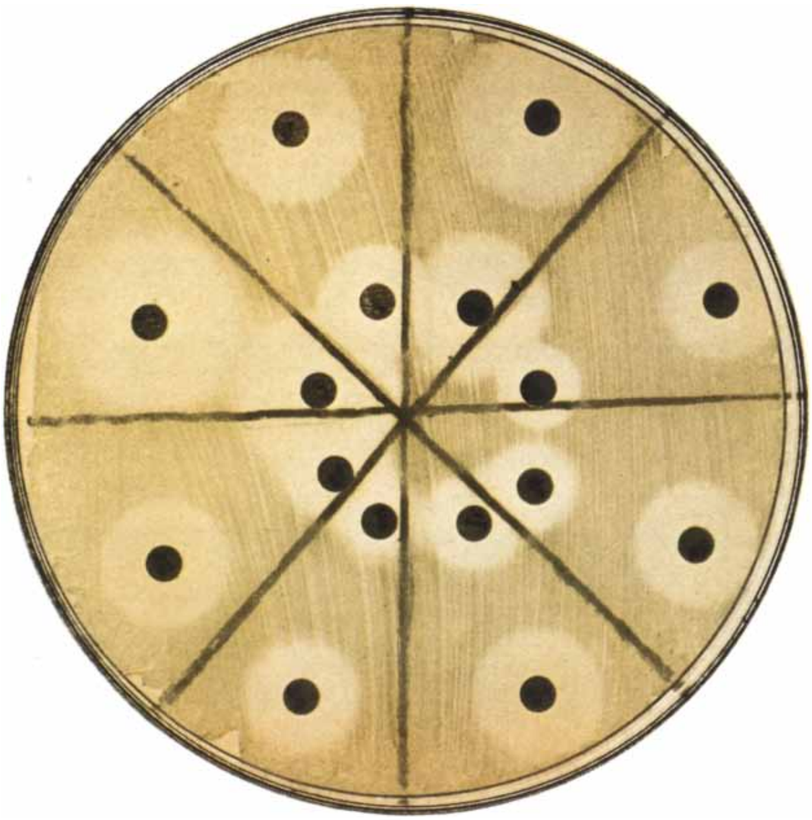


RISE OF RESISTANT STAPHYLOCOCCI parallels increasing use of antibiotics. In 1932-1948 at a general hospital (A) strains collected from patients included few of the Group III staphylococci (*gray bar*) and none resistant to the tetracyclines, which were not yet available. At two other hospitals which use much antibiotic therapy, strains collected in 1953-1954 (B) and in 1954-1955 (C) were largely resistant to both penicillin (*colored bar*) and the tetracyclines (*black bar*). The strains included many of Group III, in contrast to those from a mental hospital (D), where patients rarely receive antibiotics. This chart is adapted from a paper presented at the National Conference on Hospital-Acquired Staphylococcal Disease in September, 1958, by Vernon Knight, Arthur White and Thomas Hemmerly.



INFECTIONS IN SURGICAL WOUNDS have been increasing since 1949 at one hospital which averages over 1,000 operations per year. The incidence of staphylococcal infections (*dark color*) as well as of other types of infection (*light color*) decreased in 1954, when stringent efforts to prevent the spread of germs were introduced at the hospital. The chart is based on the data of Chester W. Howe of the Boston University School of Medicine.





VARIETIES OF ANTIBIOTICS are tested against a culture of staphylococci taken from a patient. Clear areas around a disk of antibiotic show that the antibiotic prevented growth of the bacteria. The first strain (*top*) is resistant to penicillin, the tetracyclines, chloromycetin and terramycin, but susceptible to four of the newer antibiotics. The second strain (*bottom*) is susceptible to all eight antibiotics at two concentrations. The pictures on these two pages were made in the laboratory of John E. Blair at the Hospital for Joint Diseases.

about the host-parasite relationship in staphylococcal disease as we know about pneumococcal and streptococcal infections.

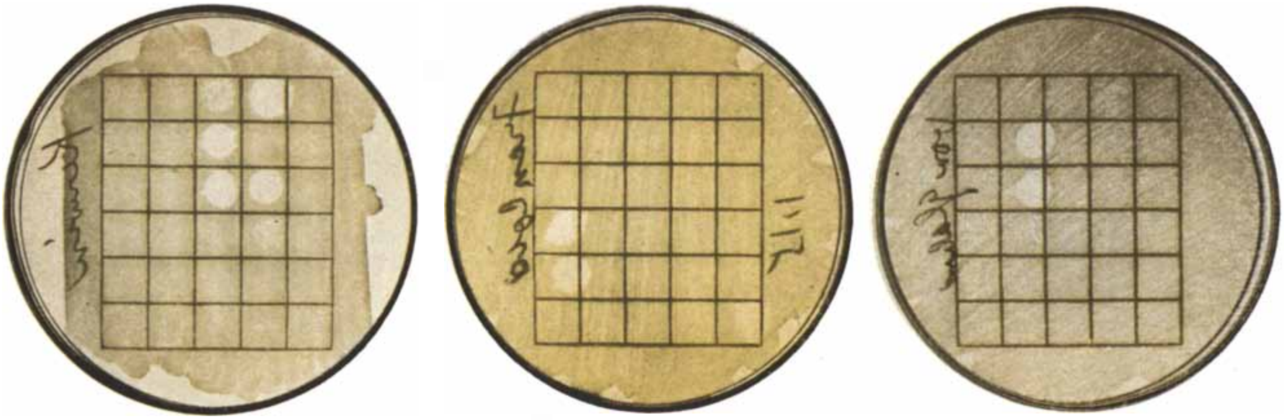
The modern conception of infectious diseases holds that infection is a special case of parasitism, an interaction between two biological systems, each constrained by the necessities of its own survival. To cause continuing infection in the human organism, bacteria must obviously be able to invade the body, to multiply in it, to produce substances which are in some way noxious to the system, and to ward off the host's defensive forces. The noxious substances or toxins elaborated by bacteria are many and varied.

The body, on the other hand, presents a complex array of defensive forces against parasitic invasion. They include a number of substances dissolved in body fluids, the lysozyme in tears and saliva, for example, and the "complement" and properdin factors carried in the blood. These substances act indiscriminately against many parasites. They vary in effectiveness with the general health of the body or with the nature of the injury. In general, however, the output of these substances is not stimulated in response to specific bacteria.

The white blood cells constitute a gendarmery which is always ready to repel parasitic invasion by engulfing the microscopic invaders and then digesting them. These cells are of two main sorts; the highly mobile, quickly responsive but somewhat vulnerable polymorphonuclear leucocytes, and the more rugged macrophages. Of themselves, however, the white cells are rather inefficient protectors. Their effectiveness is enormously enhanced by another type of defensive substance: the antibodies, which are evoked in specific response to invasion by particular parasites.

The antibodies, produced by the lymphoid tissues, are of two kinds. The antibacterial (or antiviral) antibodies combine with specific components of the bacterial (or virus) surface, producing a new surface about which the white cells can spread and so more readily engulf the parasite. These antibodies also reinforce the antibacterial action of the complement substances in the blood. The second type, the antitoxic antibodies, neutralizes the toxins chemically, without the intervention of the white blood cells. Antibodies of both types are so specific in their chemical architecture that they will combine only with the bacterial substances that elicit them.

The investigation of the pneumococci and streptococci yielded many leads to



PHAGE TYPING of staphylococci is performed by testing bacteria against various types of phage. In each culture dish a different strain is exposed to phages of Group I and IV (*first column, reading from left*), Group II (*second column*), Group III (*third and fourth columns*), and phages of miscellaneous type (*fifth column*). Whitish circles in cultures where bacteria did not grow identify the strains as susceptible to phage of Group III in the dish at left, Group I in center dish and Group II in the dish at right.

guide present efforts to amplify the body's defense against staphylococcal infection. In the prevention and therapy of pneumococcal infection, for example, we know that the antibacterial antibodies play the decisive role. These have the power to combine specifically with the carbohydrate capsules which enclose the parasite cells and thus prepare them for ingestion by the white cells. Injection of minute amounts of pure capsular material extracted from cultures of the invading strain evokes the production of the corresponding antibody. Similarly, the antibody specific to a protein on the surface of an important and virulent strain of streptococci provides protection against this parasite. In tuberculosis, resistance seems to depend on an increase in the capacity of the macrophages to destroy tubercle bacilli after they have been ingested. Vaccination with a living but harmless strain of tubercle bacilli, the B.C.G. strain, induces a self-limiting infection which confers immunity. The B.C.G. vaccine has now been administered to some 90 million persons around the world. Antitoxic antibodies confer immunity to diphtheria and tetanus. They can be evoked by inoculation with toxins that have been rendered harmless by treatment with formaldehyde; these "toxoids" carry unchanged their capacity to elicit the specific antibodies.

Are any of these procedures applicable to staphylococcal infection? Should we vaccinate with killed staphylococci, staphylococcal capsular substance, cell walls, or toxoid? Can we find among these alternatives an effective immunizing or therapeutic agent? We do not know enough about how the staphylococci inflict injury or how the body defends itself against them to proceed directly with vaccination or serum therapy. These organisms have become a serious challenge at a time when studies of immune relationships of infective bacteria have been allowed to lapse. Must we continue to rely, as at present, on antibiotics, with all the attendant difficulties and inadequacies? It goes without saying that major efforts are being devoted to countering the ever-changing sensitivity and resistance of staphylococci to antibiotics.

Staphylococci possess an extraordinary armamentarium of offensive factors. Disease-producing strains elaborate several different kinds of "hemolysins," substances capable of destroying the red blood cells; they also produce leucocidin, which injures the white blood cells, and hyaluronidase, an enzyme which can dissolve the intercellular cement of the tissues to aid the spread of the invaders. And most of the staphylococci currently causing infections produce penicillinase, an enzyme which destroys penicillin.

In addition, the strains harmful to man almost all produce substances called coagulases, which interact with the blood-clotting mechanism to coagulate plasma. One of these apparently acts upon prothrombin; another, bound to the surface of the staphylococcal cell, can react with fibrinogen to produce fibrin. There is evidence that the possession of coagulase makes it possible for these strains to grow in human serum and to survive inside rabbit white cells after being engulfed. Coagulase production thus provides a useful method for identifying potentially infectious strains, but we do not know as yet whether the presence of coagulase is significant in infection or merely incidental.

According to reports in the literature, staphylococci under certain conditions may have extracellular capsules. It is worth investigating to determine whether this capsular material might be used for immunization.

What can be done by the intelligent public to help in this situation? The hospitals are hard-pressed on many fronts. Diagnosis and treatment have been undergoing great and rapid elaboration, at a large increase in cost. Nurses and, in many hospitals, interns and residents are in short supply. In consequence of all this most hospitals now operate in the red. The return to meticulous asepsis and antisepsis and the many precautions essential to good housekeeping in hospitals are costly in time, effort and money. More adequate financial support by the public for its hospitals could be very helpful indeed.

Congress has appropriated $1 million for staphylococcal research through National Institutes of Health research grants, and with an appropriation of $325,000 for the current fiscal year the Public Health Service is expanding its services and investigations relating to staphylococcal disease at the Communicable Disease Center in Georgia. Our present ignorance in this significant area of medicine cannot, however, be dissipated in a few years by the work of a few investigators. Nor can we at this time predict the outcome of the extraordinary struggle for survival of a versatile microorganism against the efforts of an aroused medical profession. But sustained effort on a broad front will reap rewards measured in terms of deepening scientific insight and of increased security of health for everyone.

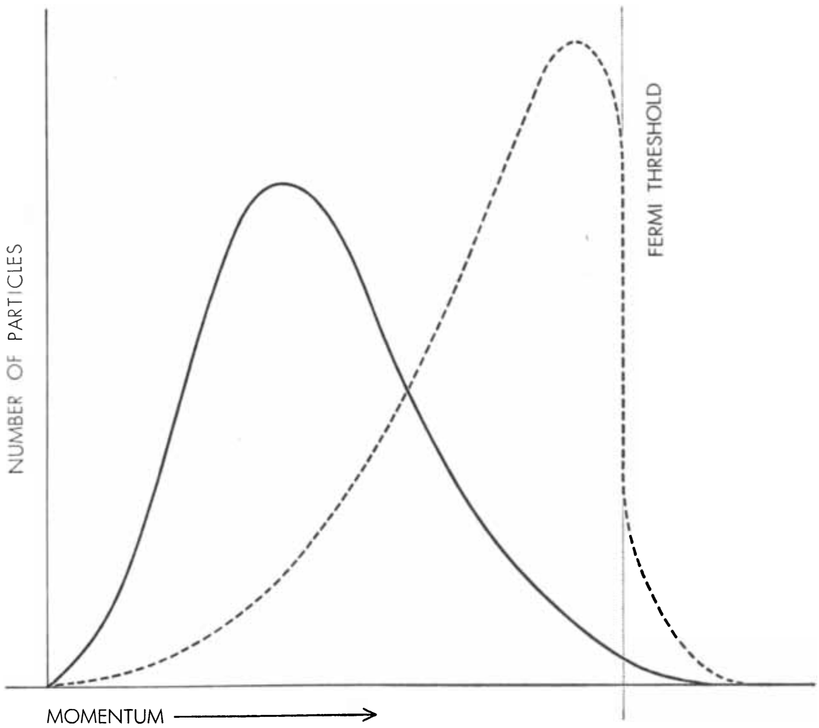
DYING STARS

The white dwarfs, with their thermonuclear fires long since extinguished, are cooling down to the temperature of space. They are a portent of the inexorable fate of all other stars

by Jesse L. Greenstein

Here and there among the tens of thousands of stars in the nearby regions of our galaxy are a few hundred whose fires have gone out. Once they burned as brilliantly as any we now see in the sky. Some had the "normal" size and brightness of the sun; some were giants, with many times the sun's diameter and brightness. Now these stars are approaching the end of the road. They have exhausted their fuel. The inward pull of gravity, no longer opposed by the outward push of pressure generated by heat within, has shrunk their diameters to a tiny fraction of stellar size, to that of the earth and even smaller, compressing their huge masses to unimaginable densities of many tons per cubic inch. In their fading light, detectable only by the instruments and techniques of modern astronomy, they are radiating the heat still left from the past out into the cold reaches of space

We call these stars "white dwarfs." They hold clues to many interesting questions of astrophysics. Until recently, however, much of what we "knew" about them was the fruit of theoretical speculation. They comprise some 3 per cent of all the stars in our galaxy and so must be rated a common type. Yet their luminosities are so low that only a few hundred have been tentatively identified and only 80 observed in any detail. Study of their color and the lines detectable in their spectra is yielding new insight into the synthesis of elements in younger stars. Their densities represent states of matter which we can hardly think of duplicating in terrestrial laboratories. But the white dwarfs have a more general significance. They are a portent. They show us that the laws of thermodynamics, which circumscribe events on the minuscule scale of our planet, hold also as the inexorable plan of the life history of the stars.



MOMENTUM OF PARTICLES in a "perfect" gas (*solid line*) follows the bell curve of random distribution. In a "degenerate" gas (*broken line*), the curve shows fewer low-momentum states available. Only the few particles above the Fermi threshold move at random.

An irreverent physicist once rephrased the laws of thermodynamics to read: (1) you can't win, (2) you can't even break even, (3) things are going to get worse before they get better and (4) who says things are going to get better?

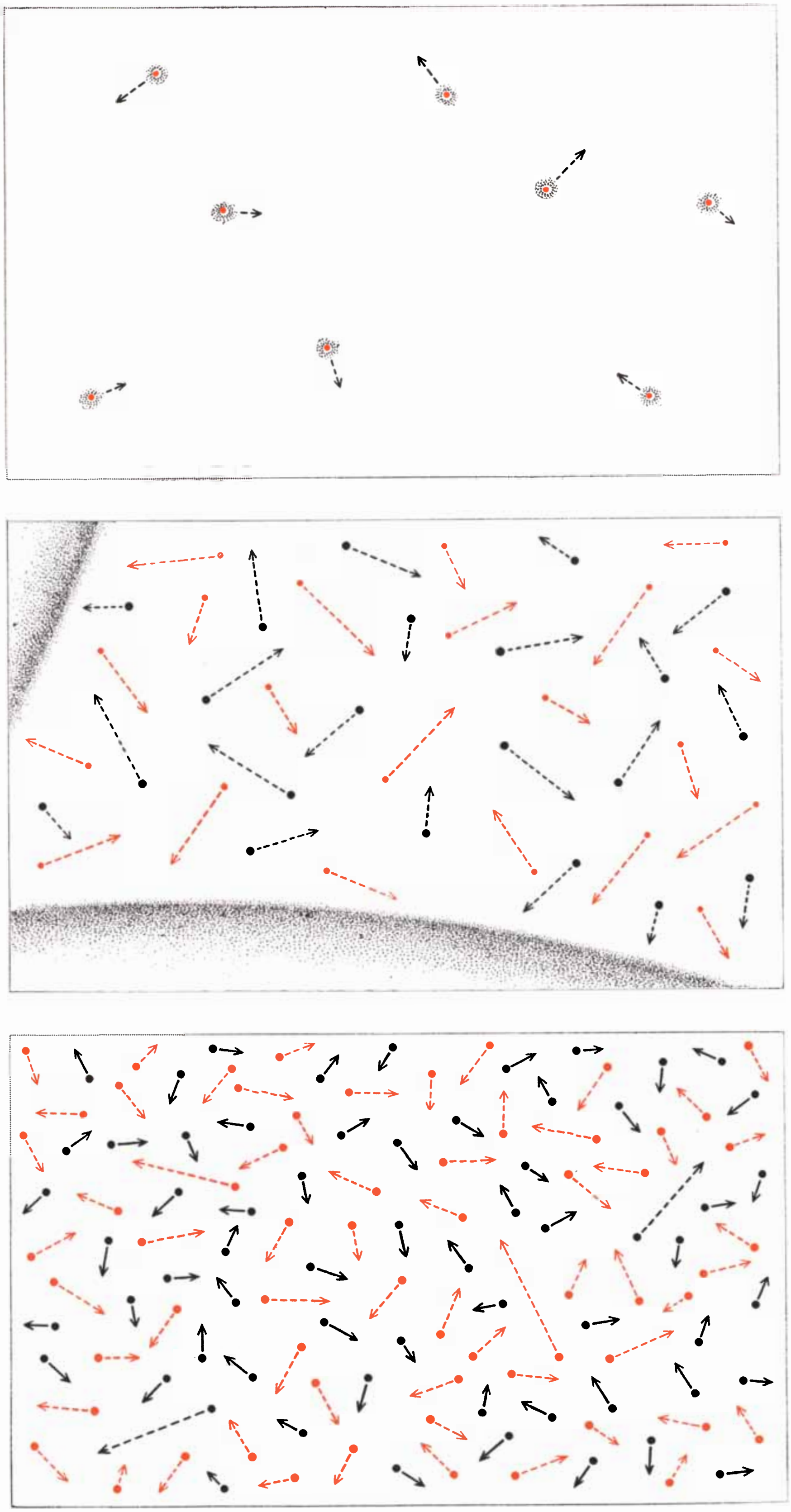
When it is applied to stellar processes, the first law reminds us that stars do not create energy, but only convert energy from one form to an equivalent quantity of another form; that is, they convert to radiant energy the energy contained in their gravitational potential and in that fraction of their mass which is consumed in thermonuclear reactions. They can never produce more energy than they start out with. In a steady-state star, with a stable balance between its gravitational contraction and the pressure generated by the heat within, the expenditure of thermonuclear energy can go on for a long time—10 billion years in the case of the sun.

But the second law reminds us that this cannot go on forever. A star can never recapture the energy it wastes into the sink of space; its life history is irreversible. As it uses up the hydrogen that comprises the bulk of its substance, the thermonuclear furnace begins to falter. Gravitational contraction restores the equilibrium, converting potential energy into thermal energy. But contraction raises the density of the star, and the new balance between gas pressure, heat transfer, energy production and radiation loss changes the internal structure. The star brightens, its outer envelope grows larger, and stellar "evolution" begins—earlier in the life of brighter stars, later in that of the fainter ones.

As the star enters the last phase of its existence it shrinks to the final, stable configuration of a white dwarf. The third and fourth laws of thermodynamics now assume increasing relevance to its condition. The third law says that the star will ultimately cool down to the temperature of space, and the fourth law declares that it will then no longer give forth light or heat. At this terminal point the white dwarf becomes a black dwarf. Since we could not observe black dwarfs, if there are any, we shall not now give further consideration to them. In any case a star persists as a white dwarf for billions of years. Its structure and condition in this phase is what interests us here.

Matter at white-dwarf density is strange to contemplate by celestial as well as terrestrial standards. A star like the sun has an average density of almost one gram per cubic centimeter, about the same as that of water. Astrophysicists nonetheless find it feasible to deal with the behavior of solar matter as if it were a gas, with its particles free to move about at random. At the high temperatures of the solar interior, hydrogen is 97 per cent ionized; the electrons of nearly all the hydrogen atoms are stripped from their nuclei (protons). This means that the bulky structure of the hydrogen atom, 10,000 times the diameter of its constituent particles, is obliterated. As a result a cubic centimeter of ordinary stellar material is largely empty space. The tiny protons and electrons are free to move in all directions and at all velocities, just as they would in a highly rarefied gas.

In a white dwarf, on the other hand, a mass on the order of the sun, equal to 332,000 earth masses, may be packed into a volume no larger than that of the earth, which has but one millionth the sun's volume. The density ascends to 1,000 kilograms per c.c.—more than 15 tons per cubic inch. Even after a white dwarf has cooled below the temperature needed for ionization, the atoms remain dissociated under the crushing pressure of gravity. The particles are not yet so tightly packed, however, that their vol-



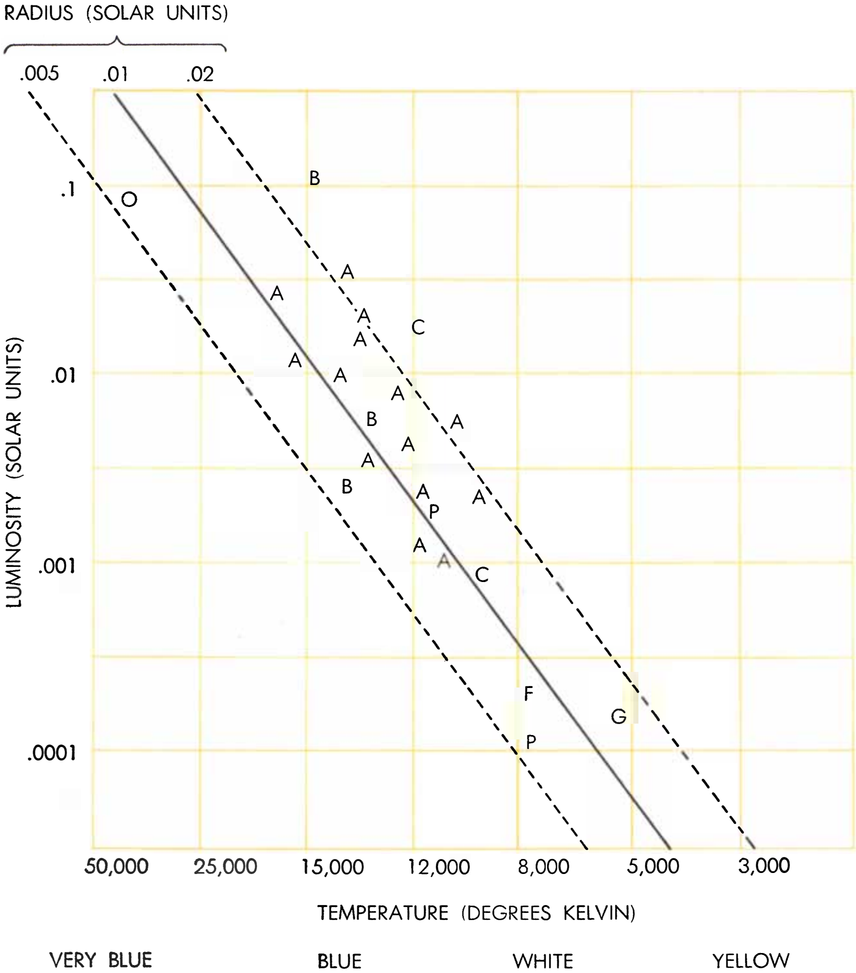
"DEGENERATE" GAS (*bottom*) is contrasted with "perfect" gases, made up of atoms (*top*) and ionized particles (*center*). Space available in gas of normal pressure permits random motion (*broken arrows*) to atoms. In an ionized gas, even at the density of a solid, the obliteration of the structures (*shadowed arcs*) of all but a few atoms opens up space to permit random motion of electrons (*black*) and nuclear particles (*color*). At the extreme density of a degenerate gas the energy states of most electrons are prescribed at low momenta (*solid arrows*). Only the nuclear particles and a few electrons move at random.

umes overlap; there is still empty space between them. But because each particle has only a small volume of space in which to move, its momentum as well as its position is prescribed. The exclusion principle of physics, which rules that no two particles can occupy the same energy state, rigidly specifies the coordinates and motion for all low-momentum states Since the electrons are the lighter particles, they have the lowest momenta and are frozen in space and velocity. Collisions cannot result in arbitrary changes of momentum, but can only kick the electrons into unoccupied states. A few electrons which attain velocities approaching that of light, above the so-called Fermi threshold, are still free to move, as are the nuclear particles [*see illustration on preceding page*]. The gas has entered the "degenerate" state.

We owe to Subrahmanyan Chandrasekhar of the Yerkes Observatory a beautifully complete theory of a self-gravitating degenerate sphere of gas. Strangely, according to the theory, the greater the mass of a white dwarf, the smaller its radius. This follows, however, from the degenerate-gas law, which predicts a gas pressure, for a given density, sufficient to counteract gravitational pressure only when the star is greatly collapsed. The inverse relationship of mass to radius is not affected, as it is in other stars, by temperature, luminosity or energy production. The mass and hence the radius of a white dwarf is fixed, in the theory, by the elemental composition of the star. For stars of each composition there is an upper limit of mass. Calculation from the theory shows, for example, that a white dwarf composed of hydrogen would have a maximum possible mass 5.5 times that of the sun. On the other hand, a white dwarf made up of heavier elements should have no more than one fourth this mass, or 1.4 solar masses. A more massive star must lose mass or suffer a catastrophe before it becomes a white dwarf. We have few reliable determinations of white-dwarf masses, but all such determinations lie well below the theoretical maximum of 1.4 solar masses. This is important confirmation for the deduction that these stars have exhausted their hydrogen, the principal thermonuclear fuel.

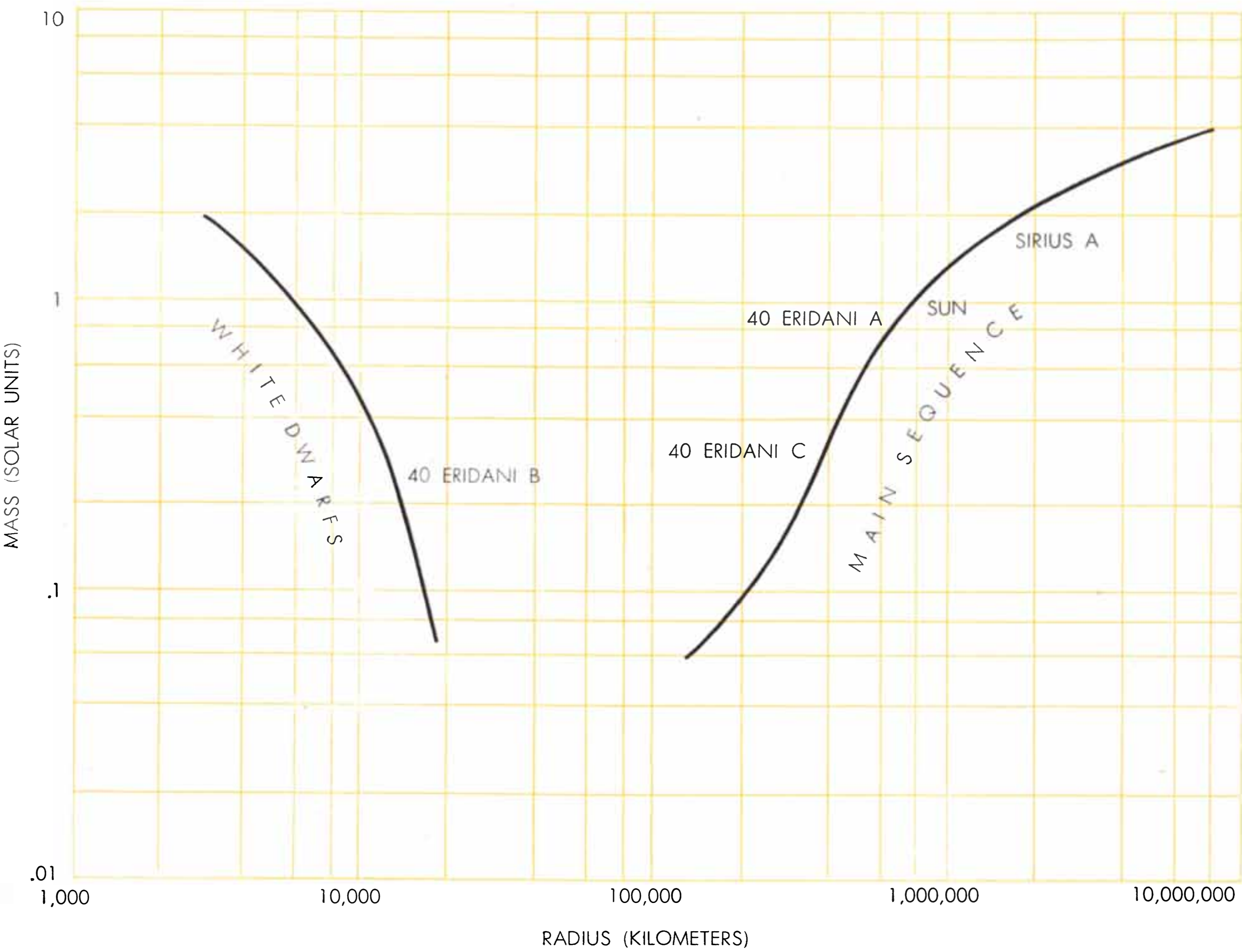
The theoretical picture of the white-dwarf star, extended by other investigators, makes it clear that it will always be difficult to test theory by observation. The dense degenerate mass of the star is surrounded by a sharply differentiated envelope about 65 miles deep; the material here is nondegenerate because of the lower pressure. Superposed on the envelope is the atmosphere of the star, which is only a few hundred feet deep. This is the only part of the star we can study spectrographically. What we observe in the spectra of normal stellar atmospheres, which are thousands of miles deep, tells us much about their surface temperature and composition, and also a good deal about their interior. The shrunken atmosphere of a white dwarf bears small relevance to the interior and can tell us little about it.

Evry Schatzman of the Institut d'Astrophysique in Paris has shown that white dwarfs cannot have the same composition at their surface as in their interior. In the absence of convection the gas stratifies under the intense gravitational field. The residual hydrogen is squeezed to the surface, while the helium and heavier elements gravitate to the center. Were it not for electrical forces, the electrons would tend to float on top. The electrical fields and nuclear forces set up by the stratification contract the star still further and so reduce the maximum possible mass to 1.25 solar masses.



RADIUS AND TEMPERATURE of white dwarfs show no correlation. Stars of various radii occur at all temperatures as indicated by the positions of the letters standing for various types. This is evidence that dwarf stars cool down without further gravitational contraction.

The fading light that carries off the heat remaining in their interiors has given us the location of several hundred possible white dwarfs. The brightest of them has a luminosity only .01 that of the sun; the faintest known dwarf has only .0001 solar luminosity, so faint that such stars cannot be observed at distances greater than 30 light-years. Their low luminosity, combined with our theoretical knowledge of their internal structure, provides convincing evidence that they have ceased transforming matter into energy. At their high densities thermonuclear reactions would go on at enormously high rates, even if temperatures were as low as 10 to 30 million degrees Kelvin. The reaction rate would be even further increased by the dense packing of the electrons, whose negative charges would partially nullify the mutual repulsion of the nuclei. The only possible explanation of their low lumi-



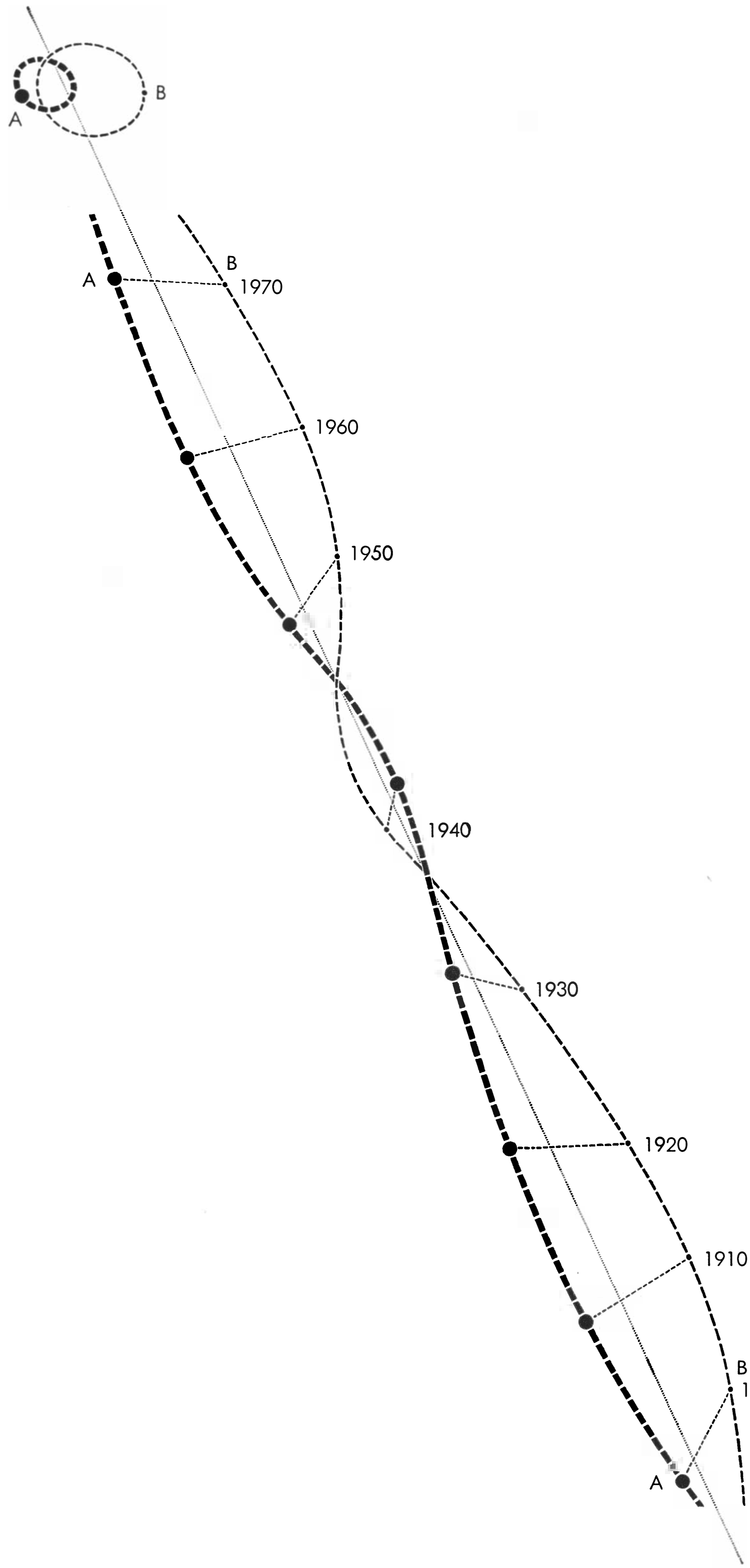
MASS AND RADIUS of white dwarfs show a correlation exactly opposite to that of normal "main sequence" stars (*curve at right*). The latter show increase of radius with increase of mass. White dwarfs, in contrast, have smaller radii at higher mass. The smallest dwarfs have masses which are larger than that of the sun, but these masses are compressed into volumes smaller than that of the earth.

nosity is that hydrogen must now comprise less than .00001 of the mass of a dwarf star. Reactions involving heavier elements—such as carbon, oxygen, nitrogen and neon—require higher temperatures than are likely to occur, though helium might react with these in large concentration at very high densities. However, another set of theoretical considerations argues against the possibility of any energy production at all. In a normal star the thermonuclear reaction-rate is regulated by feedback; with increase in temperature the star expands, and the reaction rate is damped. In a degenerate gas, on the other hand, pressure is unaffected by temperature. Local heating would bring higher temperature and an increase in the reaction rate. The star, in consequence, would explode. We must therefore conclude that the white dwarfs have substantially exhausted their nuclear-energy sources.

Because their luminosity is so low, it is difficult to obtain detailed information about other aspects of the dwarf stars from spectrographic analysis of their light. Only about 80 such stars have been studied in detail. With the light-gathering power of the 200-inch Hale telescope on Palomar Mountain I have observed 50 white-dwarf spectra at a larger scale than any obtained before.

Spectrographic analysis establishes with certainty that the white dwarfs are dwarfs indeed. The derivation of radius from the spectra is somewhat indirect, but it is reliable. Both from photoelectric analysis of the color of the light and study of the behavior of the absorption lines we can determine temperature. From apparent brightness and from independent measurement of distance, we establish the true luminosity. By combining temperature and luminosity, we determine radius. The results are impressively monotonous: the well-determined radii all lie between 3,000 and 10,000 miles. The constancy of dimension is in contrast to the range of size in normal stars, from .1 to 10 times the radius of the sun (430,000 miles) for "main sequence" stars [*see illustration on this page*], and on up to 10,000 times for red giants. The smallest white dwarf known has an estimated radius of only 2,800 miles, much smaller than the radius of the earth. This is close to the theoretical minimum for a star that has exhausted its hydrogen; the radius indicates a mass of 1.2 solar masses and a central density of 150 tons per cubic inch.

One of the most important theoretical predictions is fulfilled with the finding that there is no dependence of radius on surface temperature. The dwarfs we have observed range in temperature from 50,000 to 4,000 degrees K. The hottest is a blue-white star in the earliest phase of white-dwarf evolution; the coolest, a faint, reddish-white dwarf. As plotted in the illustration on the opposite page, stars of the same radius appear down the full range of temperature. Since their initial masses may vary, it is clear that they start with a small spread of radii at the upper left corner of the chart and cool off without further gravi-



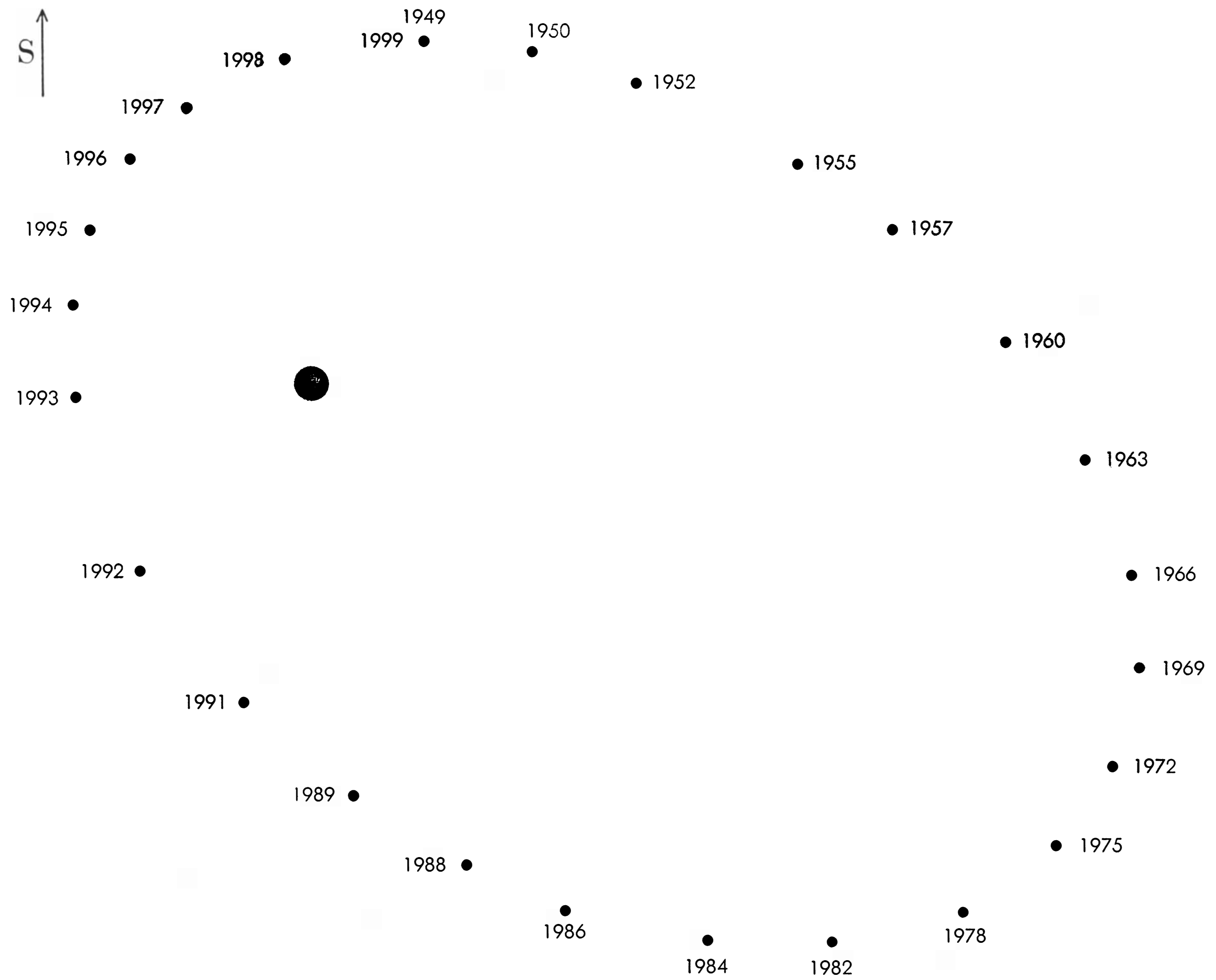
DOUBLE-STAR SYSTEM of Sirius is composed of one of the brightest stars in the sky (A) and a white-dwarf companion (B). Their orbits around the center of gravity of their system is shown at top. The motion of the two stars and of the center of gravity of their system with respect to the earth is indicated by the broken lines running diagonally up this diagram.

tational contraction downward and to the right in straight lines.

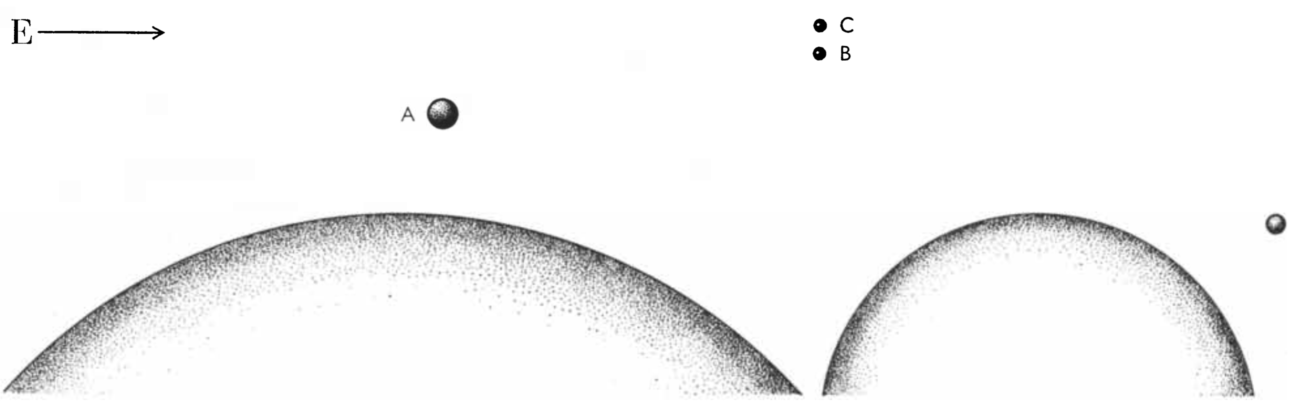
Unfortunately it is impossible to match these measurements of radius to equally reliable observational determinations of mass. Newton's laws can give the masses from observed orbital motion only in the case of those stars that are members of multiple systems. Three such dwarfs are known. For two of them, Sirius B and Procyon B, the masses are reliably established at 1 and .65 solar mass respectively. But their major companions, Sirius A and Procyon A, are so bright and so close that the spectrographic plate cannot register an uncontaminated picture of either of these two dwarfs. As a result it is still impossible to measure their radii.

The best-known white-dwarf member of a multiple system belongs to a three-star group: 40 Eridani. Here, fortunately, the distances between stars are wide enough so that good spectra can be obtained, and yet close enough for orbital motion to give reliable measurements of mass. From analysis of the spectrum, I have derived a radius of 6,500 miles, .016 of the solar radius; gravitational measurements establish the mass at .45 solar mass. Calculation from the theoretical mass-radius relationship yields a mass of .39 solar mass, satisfactorily close to observation. Thus, at least in the case of the single star that permits complete test by observation, the well-articulated theory of white dwarfs finds solid support.

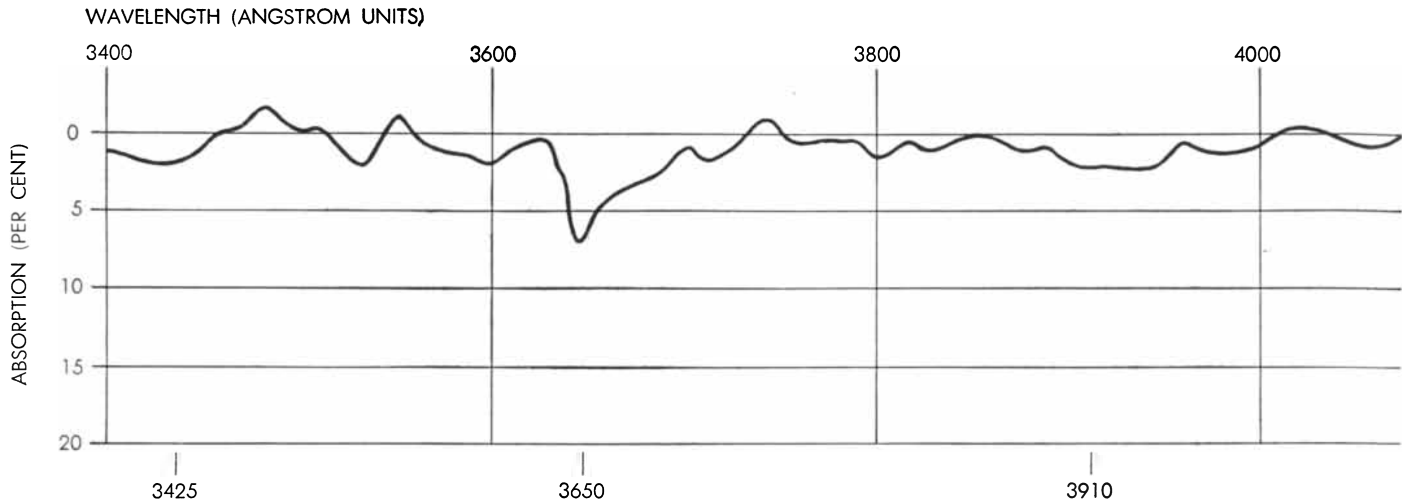
The spectra of the white dwarfs also confirm in a general way the theoretical prediction of their elemental composition. One type either shows no hydrogen lines at all, or has hydrogen lines which indicate the presence of relatively tiny residual quantities of hydrogen. Compared to the spectra of normal stars, in which hydrogen lines are universally strong, this anomaly would be enough to identify the dwarfs as a genus apart. The spectra of the commonest type of white dwarf (Type A), however, show only the residual hydrogen and no heavy elements. Here, apparently, gravitational forces have pulled all of the heavier elements, even helium, out of the atmosphere and squeezed the hydrogen to the surface. In dwarfs with surface temperatures below 8,000 degrees, the hydrogen lines vanish completely, and we see only a few lines due to metallic elements. Ross 640 is such a star [*see illustration on page 53*]; it is still hot enough to show hydrogen lines if any hydrogen were present. In general the spectra of white



DWARF STAR IN SIRIUS traces the orbit shown here with respect to the large primary star of this double-star system. The dates give the location of the dwarf in its orbit through the second half of this century. Its close approach to the primary star in recent years has made it impossible to secure spectrographic images uncontaminated by the light flooding from the 100-times brighter primary star. As the dwarf star approaches the apogee of its orbit during the next 20 years, it may be possible for astronomers to secure better spectra.



TRIPLE-STAR SYSTEM in constellation Eridanus is composed of a bright primary normal star (A), a faint late-type star (C) and a white dwarf (B), which appear in the relative positions, but not to the scale, indicated by the small spheres at the top of this diagram. The relative diameters of the three stars are shown across the bottom of diagram, star A (*at left*) having a radius .9 that of our sun; star C (*second from left*) having a radius .4 that of the sun; and the dwarf having a radius .017 that of the sun, or 7,000 miles.



ANOMALOUS SPECTRUM of a white dwarf shows no absorption lines, but does show diffuse bands of absorption at points not associated with any familiar elements or compounds. The spectrum has here been analyzed by a sensitive photoelectric device which meas-

dwarfs reflect little of the regular correlation between line characteristics and temperature found in normal stars. The varied compositions of their atmospheres therefore may be taken as evidence of their evolutionary history. From the spectrum of Ross 640 we can deduce that this star and other stars like it turned to synthesizing heavy elements from helium after exhausting their hydrogen. The redder and still fainter star called van Maanen 2 (VMa2) is the coolest so far subjected to detailed spectrographic analysis. Its peculiar spectrum [*see illustration on opposite page*] indicates that this star began as a metal-poor member of the long-lived, stable Population II family. Since its present low luminosity gives this star an age of four billion years in the white-dwarf phase alone, van Maanen 2 must have lived out its entire life as a brilliant star before the sun and the earth were formed. In a still fainter, cooler and more ancient star, no lines have yet been detected with certainty.

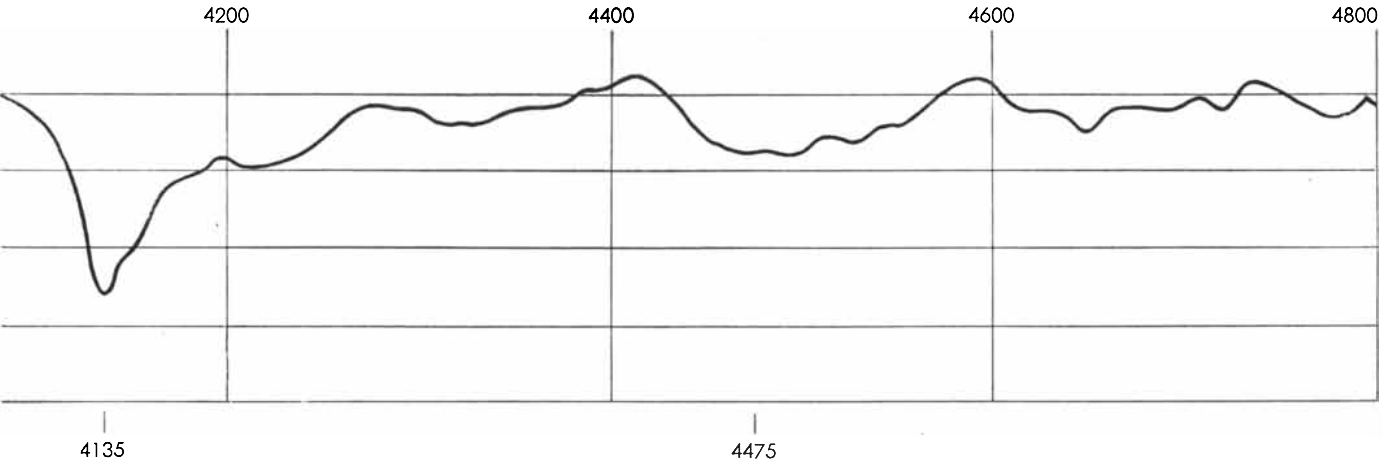
A spectrum without absorption lines might seem to be of academic interest to astrophysicists, who employ these lines as the tools of their trade. But we have spent many nights observing and many months of analysis to establish the real absence of lines in six white-dwarf spectra. Subjected to the most sensitive photoelectric inspection yet possible, the plates show no line, band or absorption depression as deep as 5 per cent. There are a number of possible explanations. Perhaps the most satisfactory will be found upon closer inspection of lines that do appear in other white-dwarf spectra. The extreme broadening and attenuation of the hydrogen lines in some spectra helps to make the complete disappearance of lines at very high pressure more understandable. Such broadening of lines is caused by random electric fields and by collisions between charged particles. In the van Maanen 2 spectrum Volker Weidemann of the Bundesanstalt in Braunschweig, who has been working with us on a grant from the Air Force Office of Scientific Research, has found lines of iron, magnesium and calcium broadened in a way that indicates a rate of particle collision 10,000 times that observed in the sun. He estimates a pressure of 2,000 atmospheres in this peculiar atmosphere—dense enough for some molecules to form. But though metal lines may be thus broadened, it is surprising that they should disappear entirely, as they do in the six spectra that show no lines at all.

To compound the mystery we have come upon several spectra with diffuse, shallow bands that cannot be related to any established laboratory spectral line; the photoelectric tracing of a plate made for one of these is shown at the top of these two pages. These bands may originate from molecules or unstable free radicals under unusual conditions of temperature and pressure. How atoms behave in the strange environment of the white-dwarf atmosphere is not yet known.

Our generation has seen at least one star arrive at the end of the evolutionary road and become a white dwarf. The recurrent nova, WZ Sagittae, which exploded in 1913, exploded again in 1946, brightening about 1,000 times. Its brightness is now about .01 that of the sun, and its spectrum resembles that of white dwarfs in everything but the presence of superposed emission lines. These lines are presumably due to the continued ejection of hot material. WZ Sagittae demonstrates one, though not the only, process by which stars may lose their mass and make the transition to the final stage in their history.

As living things live and die in countless ways, so stars have many possible evolutionary histories and deaths. When we have learned to read the spectra of white dwarfs better, we may see what paths they have traveled. Their faint light may give us evidence which will show what processes went on during ages past in their thermonuclear furnaces.

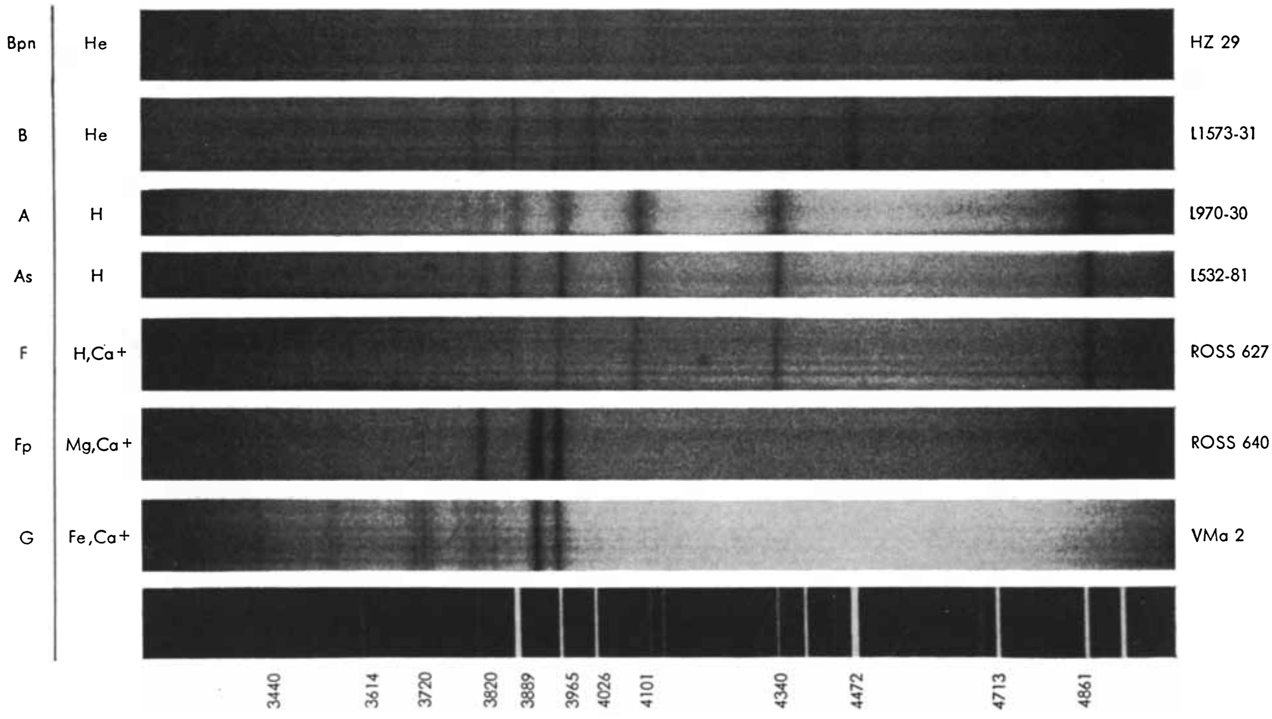
A white dwarf takes a long time dying. Its light bespeaks the slow leakage of heat from its interior down the temperature gradient set up by the conductive opacity of the degenerate gas. The thermal energy is contained only in the nondegenerate nuclei and the few electrons above the Fermi threshold. Though the initial temperature may be high, this thermal energy is all that is available throughout the entire dying stage. But as the star cools and its luminosity fades, the temperature gradient also declines. The dissipation of energy therewith slows down, and the time scale of evolution toward lower luminosity is greatly extended. According to Martin Schwarzschild of the Princeton Observatory, a white dwarf composed mainly of helium takes three billion years to cool from its initial blue-white stage down to a surface temperature of 7,000 degrees in the yellow-white stage. From yellow down to the 4,000 degrees of the faintest known red-white dwarf, it takes another five billion years. But 4,000 degrees is still red-hot. From red to infrared, the star will fade over fantastic spans of time, large compared to any present estimate of the age of our galaxy.



ures the density of the photographic plate from point to point. Only the deep absorption band at 4135 angstroms wavelength is visible to the eye on the spectrographic plate. The absorption bands may be due to presence of elements or free radicals under high pressure.

The fall in temperature brings the degenerate gas phase ever nearer to the surface. The nondegenerate electrons become scarcer and, at a very low temperature, even the nuclei become degenerate. When all the nuclear particles and electrons have occupied the lowest possible energy states, radiation ceases and the star becomes a giant "molecule." This is the end of the irreversible process of evolution—proof of the fourth law of thermodynamics. There are, however, no black dwarfs in our galaxy; it is as yet too young.

On the one-way track described here, all stars eventually fade to extinction. How will the sky look after our sun's evolution is complete, and our dead planets circulate about a dying star? In about seven billion years the sun will be a hot and very blue-white dwarf, too small to show a disk to the unaided eye on earth. The earth's temperature will be about 300 degrees below zero Fahrenheit. The sky at night will no longer be filled with stars, since star formation will have ended, and the high-luminosity stars that comprise our constellations will long ago have disappeared. Probably no star will be visible, except for an occasional faint, red normal main-sequence star that passes by chance near our dying system; such stars are so faint that their nuclear energy suffices for thousands of billions of years. Although the formerly bright stars will have become white dwarfs, they will all be too faint to be seen, and black night will reign supreme. Yet close to one of the faint red stars life might exist on other planets, in forms and for ages unimaginable to us.



DWARF STAR SPECTRA of various types (identified by initials at far left) show absorption lines for only a few elements (identified by initials in second column at left). The individual stars are identified by their code numbers at right. The spectrum at bottom is the reference spectrum of helium and hydrogen. Absorption lines of Type A dwarfs are characteristically diffuse and broadened.

The Microcirculation of the Blood

The primary purpose of the circulatory system is served by the microscopic vessels in which the blood flows from the arteries to the veins and thereby nourishes all the tissues of the body

by Benjamin W. Zweifach

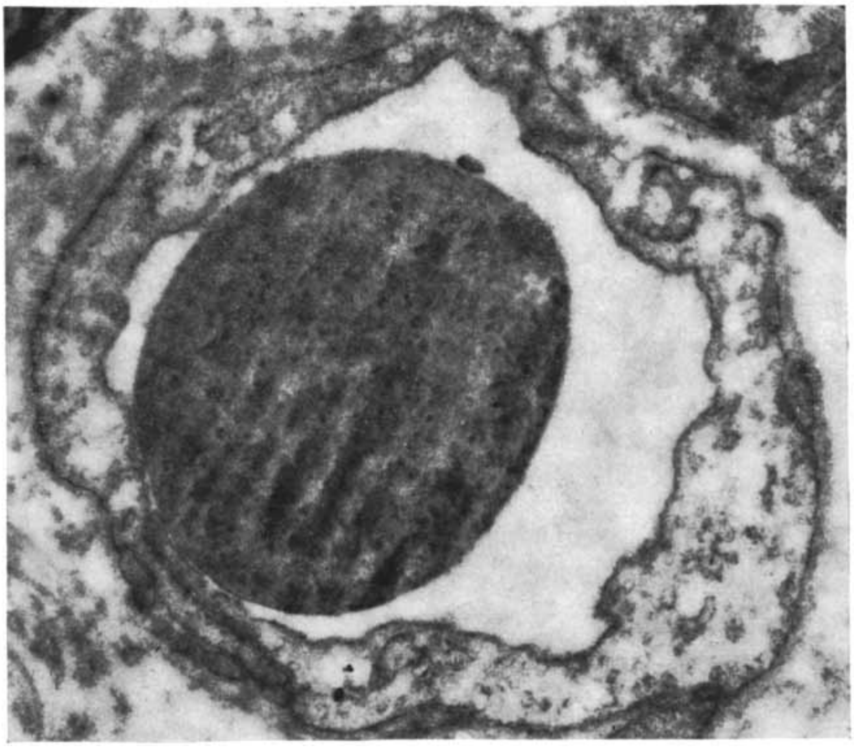
When we think of the circulatory system, the words that first occur to us are heart, artery and vein. We tend to forget the microscopic vessels in which the blood flows from the arteries to the veins. Yet it is the microcirculation which serves the primary purpose of the circulatory system: to convey to the cells of the body the substances needed for their metabolism and regulation, to carry away their products—in short, to maintain the environment in which the cells can exist and perform their interrelated tasks. From this point of view the heart and the larger blood vessels are merely secondary plumbing to convey blood to the microcirculation.

To be sure, the entire circulatory system is centered on the heart. The two chambers of the right side of the heart pump blood to the lungs, where it is oxygenated and returned to the chambers of the left side of the heart. Thence the blood is pumped into the aorta, which branches like a tree into smaller and smaller arteries. The smallest twigs of the arterial system are the arterioles, which are too small to be seen with the unaided eye. It is here that the microcirculation begins. The arterioles in turn branch into the capillaries, which are still smaller. From the capillaries the blood flows into the microscopic tributaries of the venous system: the venules. Then it departs from the microcirculation and is returned by the tree of the venous system to the chambers in the right side of the heart.

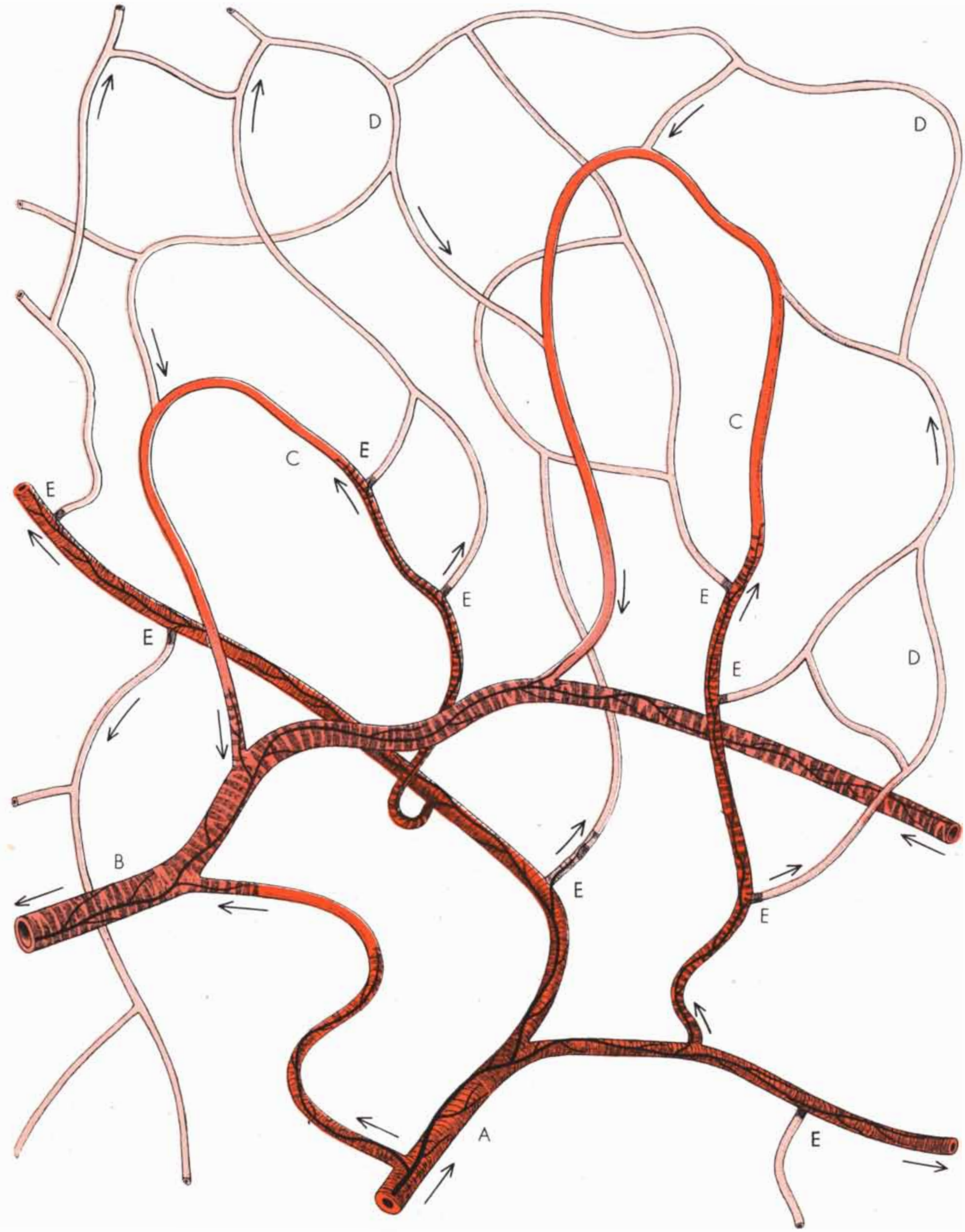
The vessels of the microcirculation permeate every tissue of the body; they are never more than .005 inch from any cell. The capillaries themselves are about .0007 inch in diameter. To give the reader an idea of what this dimension means, it would take one cubic centimeter of blood (about 14 drops) from five to seven hours to pass through a capillary. Yet so large is the number of capillaries in the human body that the heart can pump all the blood in the body (about 5,000 cubic centimeters in an adult) through them in a few minutes. The total length of the capillaries in the body is almost 60,000 miles. Taken together, the capillaries comprise the body's largest organ; their total bulk is more than twice that of the liver.

If all the capillaries were open at one time, they would contain all of the blood in the body. Obviously this does not happen under normal circumstances, whereby hangs the principal theme of this article. How is it that the flow of blood through the capillaries can be regulated so as to meet the varying needs of all the tissues, and yet not interfere with the efficiency of the circulatory system as a whole?

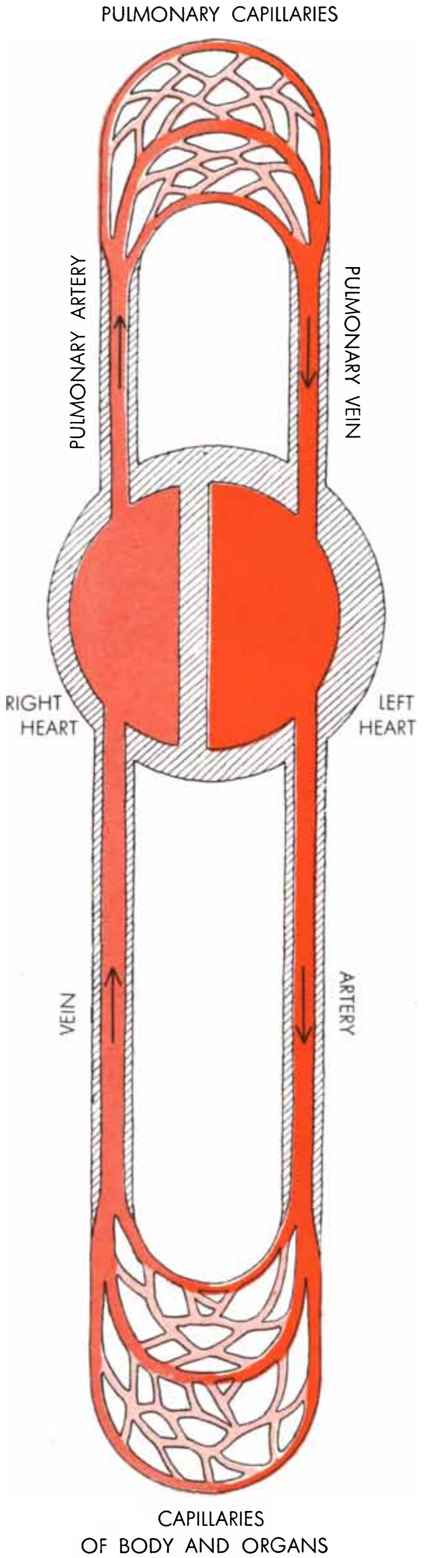
It was William Harvey, physician to Charles I of England, who first demonstrated that the blood flows continuously from the arterial system to the venous. In 1661, 33 years after Harvey had published his famous work *De Motu Cordis* (*Concerning the Motion of the Heart*), the Italian anatomist Marcello Malpighi



CAPILLARY from a cat's leg muscle is shown in cross section by this electron micrograph, which enlarges the structure some 20,000 diameters. The band running around the picture is the wall of the capillary. The large, dark object in the center is a single red blood cell. The micrograph was made by George D. Pappas and M. H. Ross of Columbia University.



TYPICAL CAPILLARY BED is depicted in this drawing. The blood flows into the bed through an arteriole (A) and out of it through a venule (B). Between the arteriole and the venule the blood passes through thoroughfare channels (C). From these channels it passes into the capillaries proper (D), which then return it to the channels. The arteriole and venule are wrapped with muscle cells; in the thoroughfare channels the muscle cells thin out. The capillaries proper have no muscle cells at all. The flow of blood from a thoroughfare channel into a capillary is regulated by a ring of muscle called a precapillary sphincter (E). The black lines on the surface of the arteriole, venule and thoroughfare channels are nerve fibers leading to muscle cells. At lower left, between the arteriole and venule, is a channel which in many tissues shunts blood directly from the arterial system to the venous when necessary.



CIRCULATORY SYSTEM is schematically outlined. The blood is pumped by the right heart through the pulmonary artery into the capillaries of the lungs. It returns from the lungs through the pulmonary vein to the left heart, which pumps it through the arteries to the capillaries of the internal organs and of the rest of the body. It finally returns to the right heart through the veins.

first observed through his crude microscope the fine conduits which link the two systems. These vessels were named capillaries after the Latin word *capillus*, meaning hair. Since Malpighi's time the capillaries have been intensively examined by a host of microscopists. Their work has established that not all the vessels in the network lying between the arterioles and the venules are the same. Indeed, we must regard the network as a system of interrelated parts. Hence it is preferable to think not of capillaries but of a functional unit called the capillary bed.

The capillary bed, unlike muscle or liver or kidney, cannot be removed from an experimental animal and studied as an intact unit outside the body of the animal. By their very nature the capillaries are interwoven with other tissues. It is possible, however, to examine the capillary bed in a living animal. For example, one can open the abdomen of an anesthetized rat and carefully expose a thin sheet of mesentery: the tissue that attaches the intestine to the wall of the abdominal cavity. In this transparent sheet the capillary bed is displayed in almost diagrammatic form.

The tube of a capillary is made of a single layer of flat cells resembling irregular stones fitted together in a smooth pavement. The wall of the tube is so thin that even when it is viewed edge-on at a magnification of 1,000 diameters it is visible only as a line. When the wall is magnified in the electron microscope, it may be seen that the wall is less than .0001 inch thick. This so-called endothelium not only forms the walls of the capillaries but also lines the larger blood vessels and the heart, so that all the blood in the body is contained in a single envelope.

In a large blood vessel the tube of endothelium is sheathed in fibrous tissue interwoven with muscle. The fibrous tissue imparts to the vessel a certain amount of elasticity. The muscle is of the "smooth" type, characterized by its ability to contract slowly and sustain its contraction. The muscle cells are long and tapered at both ends; they coil around the vessel. In the tiny arterioles, in fact, a single muscle cell may wrap around the vessel two or three times. When the muscle contracts, the bore of the vessel narrows; when the muscle relaxes, the bore widens.

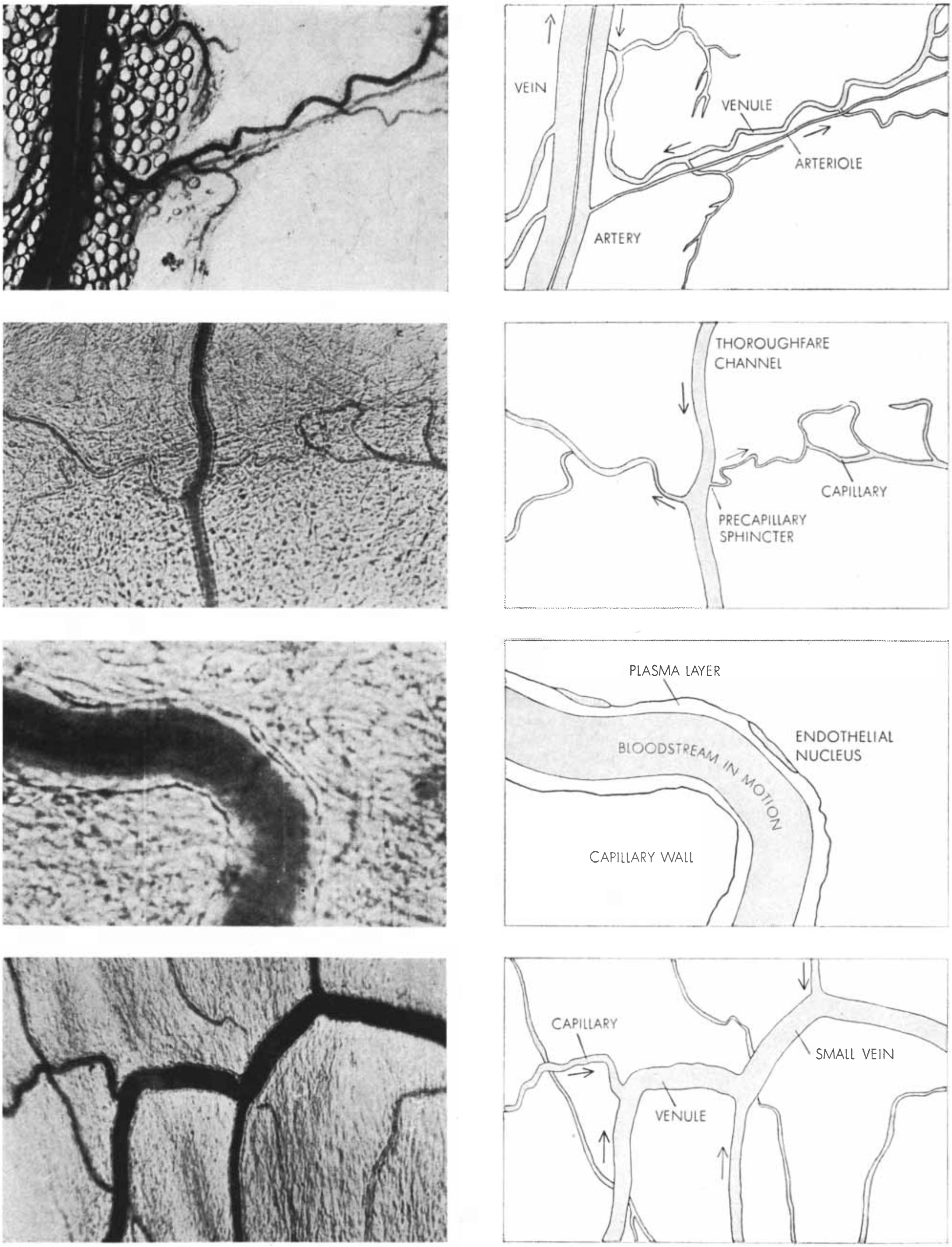
The muscular sheath of the larger blood vessels does not continue into the capillary bed. Yet as early as the latter part of the 19th-century experimental physiologists reported that the smallest blood vessels could change their diameter. Moreover, when the flow of blood through the capillary bed of a living animal is observed under the microscope, the pattern of flow constantly changes. At one moment blood flows through one part of the network; a few minutes later that part is shut off and blood flows through another part. In some capillaries the flow even reverses. Throughout this ebb and flow, however, blood passes steadily through certain thoroughfares of the capillary bed.

If the capillaries have no muscles, how is the flow controlled? Some investigators suggested that although the endothelium of the capillaries was not true muscle, it could nonetheless contract. Indeed, it was demonstrated that in many lower animals blood vessels consisting only of endothelium contract and relax in a regular rhythm. However, contractile movements of this kind have not been observed in mammals.

Another explanation was advanced by Charles Rouget, a French histologist. He had discovered peculiar star-shaped cells, each of which was wrapped around a capillary, and he assumed that they were primitive muscle cells which opened and closed the capillaries. Many investigators agreed with him, among them the Danish physiologist August Krogh, who in 1920 won a Nobel prize for his work on the capillary system. It was not possible, however, to prove or disprove the contractile function of the Rouget cells by simple observation.

There the matter rested until methods were developed for performing microsurgical operations on single cells [see "Microsurgery," by M. J. Kopac; Scientific American, October, 1950]. Now it was possible to probe the cell with extremely fine needles, pipettes and electrodes. Microsurgery established that in mammals neither the capillary endothelium nor the Rouget cells could control the circulation by contraction. The endothelium did not contract when it was stimulated by a microneedle, or by the application with a micropipette of substances that cause larger blood vessels to contract. When one of the star-shaped Rouget cells was stimulated, it became thicker but did not occlude the capillary. When the same stimulus was applied to the recognizable muscle cell of an arteriole, on the other hand, the cell contracted and the arteriole was narrowed.

The microsurgical experiments established an even more significant fact: not



MESENTERY of a rat is photographed at various magnifications to show the characteristic structures of the microcirculation. The drawings at right label the structures. The magnification of the photomicrograph at top is 100 diameters; of the photomicrograph second from top, 200 diameters; of the third photomicrograph, 1,000 diameters; of the photomicrograph at bottom, 200 diameters.

all the vessels in the capillary bed entirely lack muscle. For example, if epinephrine, which causes larger blood vessels to contract, is injected into the capillary bed with a micropipette, some of the vessels in the bed become narrower. Even when no stimulating substances are added, the same vessels open and close with the ebb and flow of blood in the capillary bed. It is these vessels, moreover, through which the blood flows steadily from the arterial to the venous system.

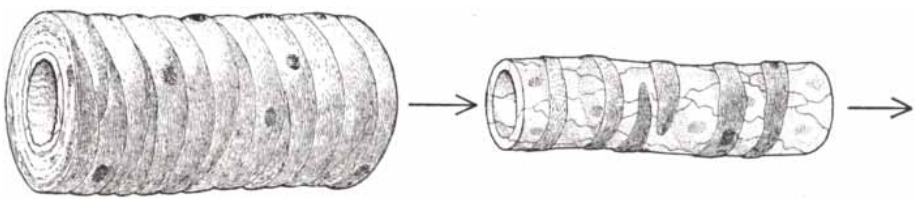
So the arterial system, with its muscular vessels, does not end at the capillary bed. The blood is continuously under muscular control as it flows into the venous system. To be sure, the muscle cells along the thoroughfare are sparsely distributed. As the arterial tree branches into the tissues the muscular sheath of the endothelium becomes thinner and thinner until in the smallest arterioles it is only one cell thick. In the thoroughfare channel of the capillary bed the muscle cells are spaced so far apart that the channel is almost indistinguishable from the true capillaries. The major portion of the capillary network arises as abrupt side branches of the thoroughfare channels, and at the point where each of the branches leaves a thoroughfare channel there is a prominent muscle structure: the muscle cells form a ring around the entrance to the capillary. It is this ring, or precapillary sphincter, which acts as a floodgate to control the flow of blood into the capillary network from the thoroughfare channel.

The muscular specialization of the circulatory system is illuminated by its embryonic development. In the early embryo the circulatory system is a network of endothelial tubes through which the primitive blood cells flow in an erratic fashion. The tubes are at first just large enough to pass the blood cells in single file. Attached to the outer wall of the tubes are numerous star-shaped cells which have wandered in from the surrounding tissue.

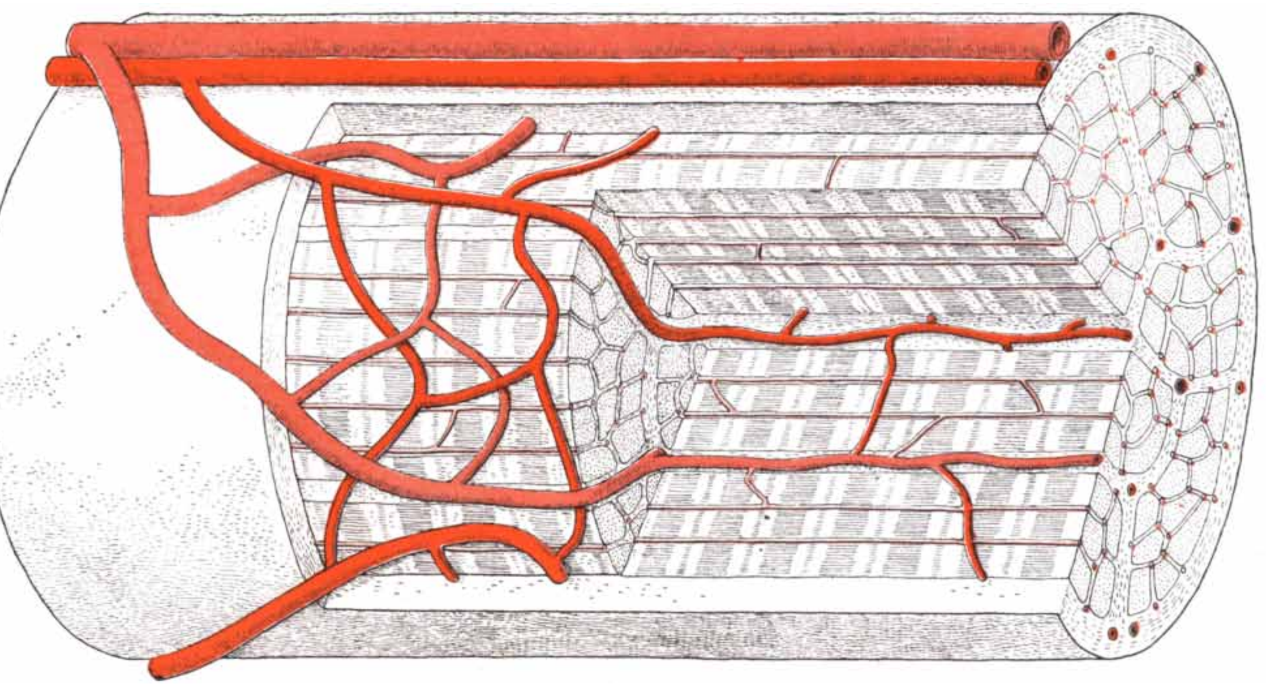
As the development of the embryo proceeds, those tubes through which the blood flows most rapidly are transformed into heavy-walled arteries and veins. In the process the star-shaped cells evolve through several stages into typical muscle cells. The outer reaches of the adult circulatory system possess a graded series of muscle-cell types, which are a direct representation of this developmental process. Thus the star-shaped cells of the capillary bed—the Rouget cells—are primitive muscle elements which have no contractile function.

From this point of view the capillary bed can be considered the immature part of the circulatory system. Like embryonic tissue, it has the capacity for growth, which it exhibits in response to injury. It also ages to some extent, and ultimately becomes less capable of dealing with the diversified demands of the tissue cells.

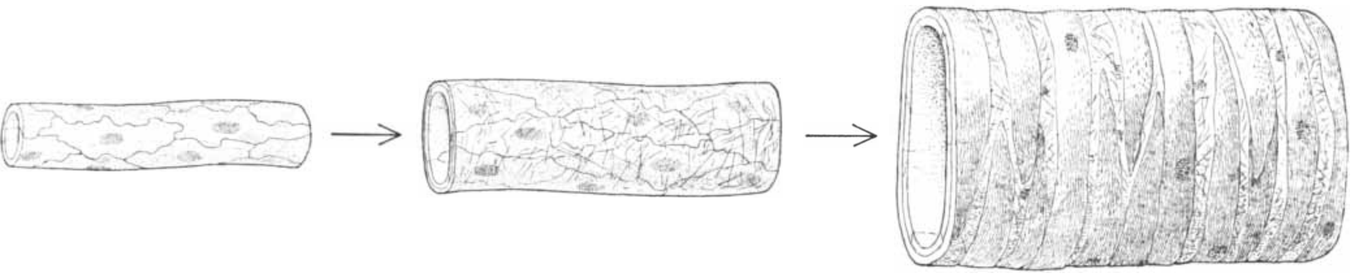
When we put these various facts together, we see the capillary bed not as a simple web of vessels between the arterial and venous systems, but as a



WALLS OF BLOOD VESSELS of various kinds reflect their various functions. The wall of an artery consists of a single layer of endothelial cells sheathed in several layers of muscle cells interwoven with fibrous tissue. The wall of an arteriole consists of a single layer of



MUSCLE FIBER is richly supplied with capillaries. Lying atop this dissected muscle fiber are two blood vessels, the smaller of which is an artery and the larger a vein. Most of the capillaries run parallel to the fibrils which make up the fiber. The vessels which cut across two or more capillaries are thoroughfare channels. The system is shown in cross section at the right end of the drawing.



endothelial cells sheathed in a single layer of muscle cells. The wall of a capillary consists only of a single layer of endothelial cells. The wall of a venule consists of endothelial cells sheathed in fibrous tissue. The wall of a vein consists of endothelial cells sheathed in fibrous tissue and a thin layer of muscle cells. Thus a layer of endothelial cells lines the entire circulatory system.

physiological unit with two specialized components. One component is the thoroughfare channel, into which blood flows from the arteriole. The other is the true capillaries, which form a secondary network connected to the thoroughfare channel. The precapillary sphincters along the channel open and close periodically, irrigating first one part of the capillary network, then another part. When the sphincters are closed, the blood is restricted to the thoroughfare channel in its movement toward the venous system.

The structure of the physiological unit varies from one tissue to another in accordance with the characteristic needs of the tissues. For example, striated muscle, which unlike the smooth muscle of the blood vessels and other organs contracts rapidly and is under voluntary control, requires over 10 times more blood when it is active than when it is at rest. To meet this wide range of needs each thoroughfare channel in striated muscle gives rise to as many as 20 or 30 true capillaries. Glandular tissues, on the other hand, require only a steady trickle of blood, and each of their thoroughfare channels may give rise to as few as one or two capillaries. In the skin, which shields the body from its outer environment, there are special shunts through which blood can pass directly from the arteries to the veins with minimum loss of heat. Still other tissues require specialized capillary beds. The capillary beds of all the tissues, however, have the same basic feature: a central channel whose muscle cells control the flow of blood into the true capillaries.

But what controls the muscle cells? To answer this question we must draw a distinction between the control of the larger blood vessels and the control of the microcirculation. The muscle cells of the arteries and veins are made to contract and relax by two agencies: (1) the nervous system and (2) chemical "messengers" in the blood. These influences not only cause the vessels to constrict and dilate but also keep the muscle cells in a state of partial contraction. This muscle "tone" maintains the elasticity of the vessels, which assists the heart in maintaining the blood pressure. The operation of the system as a whole is supervised by special regulatory centers in the brain, working in collaboration with sensory monitoring stations strategically located in important vessels.

In the capillary bed, on the other hand, the role of the nervous system is much less significant. Most of the muscle cells in the capillary bed have no direct nerve connections at all. A further circumstance sets the response of the microscopic vessels apart from that of the larger vessels. Whereas the muscle cells of the large vessels are isolated from the surrounding tissues in the thick walls of the vessels, the muscle cells of the arterioles and the thoroughfare channels are immersed in the environment of the very tissues which they supply with blood. This feature introduces another chemical regulatory mechanism: the continuous presence of substances liberated locally by the tissue cells. As a consequence the contraction and relaxation of muscle cells in the microcirculation are under the joint control of messenger substances in the blood and specific chemical products of tissue metabolism.

The chemical substances that influence the function of the blood-vessel muscle cells comprise a subtly orchestrated system which is still imperfectly understood. Among the more important messengers are those released into the bloodstream by the cortex of the adrenal gland. These corticosteroids are essential to all cells in the body, notably maintaining the cells' internal balance of water and salts. (They have also been used with spectacular results in the treatment of degenerative diseases such as arthritis.) When the corticosteroids are deficient or absent, the muscles of the blood vessels lose their tone and the circulation collapses.

Another substance of profound importance to the circulatory system is epinephrine, which is secreted by the core of the adrenal gland (as distinct from its cortex). Epinephrine is one of two principal members of a family of substances called amines; the other principal member is norepinephrine, which is released both by the adrenal gland and by the endings of nerves in the muscles. All the amines cause the contraction of the muscle cells of the blood vessels, with the exception of certain vessels such as the coronary arteries of the heart. Also liberated at the nerve endings is acetylcholine, the effect of which is directly opposite that of the amines: it causes muscle cells to relax.

Many workers have suggested that it is norepinephrine and acetylcholine which control the flow of blood through the small vessels. Our own work at the New York University–Bellevue Medical Center leads us to conclude that such an explanation is too simple. The mechanism could not by itself account for the behavior of the small vessels.

In our view the function of the muscle cells of the small vessels is regulated not only by substances that directly cause them to contract and relax, but also by other substances that simply modify the capacity of the cells to react to stimuli and do work. It is known that a wide variety of substances extracted from tissues cause the small vessels to dilate. We postulate that when the metabolism of tissue cells is accelerated, the cells produce substances of this sort. When such substances accumulate in the vicinity of a precapillary sphincter, they depress the capacity of its muscle cells to respond to stimuli. As a result the sphincter relaxes, and blood flows from the thoroughfare channel into the capillary which nourishes the tissue.

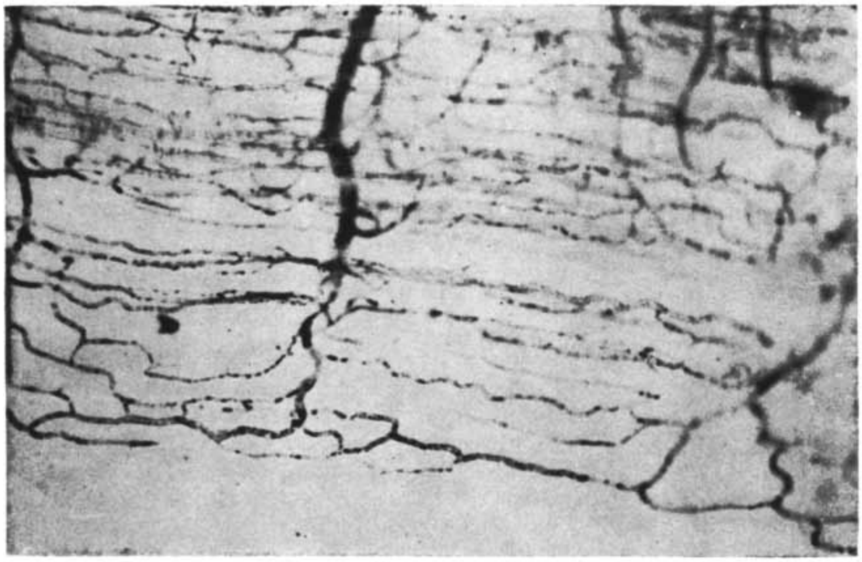
The reaction limits itself, because the blood flow increases to the point where it is sufficient to meet the nutritional requirements of the tissue cells. This leads to a gradual disappearance of the substances liberated by accelerated metabolism, and to a gradual lessening of the inhibition of the precapillary sphincter. As the muscle cells regain their tone, the sphincter shuts off the capillary.

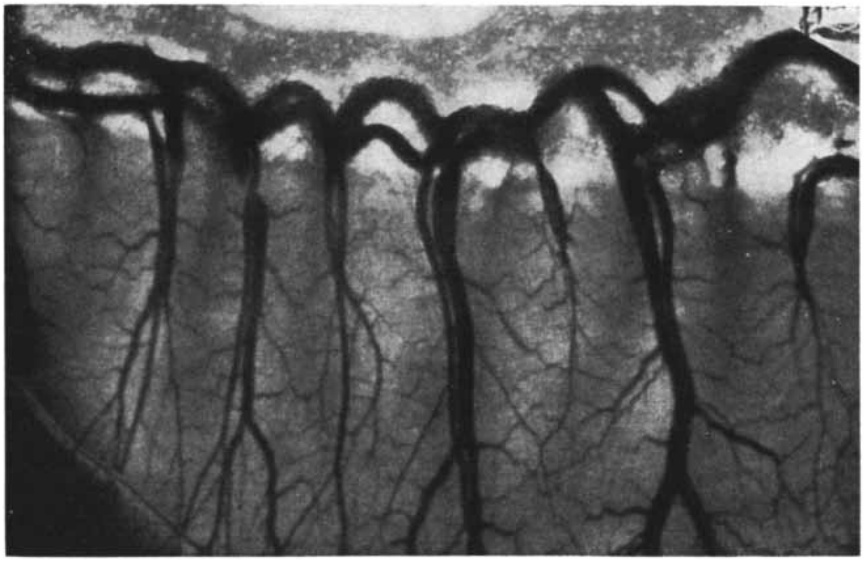
The muscle cells of the arterioles and the capillary bed are extraordinarily sensitive to chemical stimuli, so sensitive that they respond to as little as a hundredth of the amount of substance required to constrict or dilate a large blood vessel. This sensitivity is dramatically demonstrated by microsurgical experiments on the capillary bed of a living rat. As little as .000000001 gram (.001 microgram) of epinephrine, injected into the capillary bed by means of a micropipette, is sufficient to close its capillary sphincters completely. Such substances reduce the flow of blood through the capillary bed by an orderly sequence of events: first the precapillary sphincters are narrowed, then the thoroughfare channels, then the arterioles, and finally the venules. Substances that cause the blood vessels to dilate, such as acetylcholine, set in motion a similar sequence: first the precapillary sphincters are opened, then the thoroughfare channels, and so on. The sensitivity of the arterioles and the capillary bed to such stimuli contributes to their independent behavior. An amount of substance sufficient to cause dramatic changes in the microcirculation simply has no effect on the larger vessels.

The tone of the muscle cells of the microcirculation may well be maintained by norepinephrine continuously discharged from the nerve endings, and by the level of epinephrine circulating in the blood. Our work indicates that the tone is also influenced by the local release of sulfhydryl compounds, which are key substances in the regulation of the oxidations conducted by cells. Now epinephrine and norepinephrine lose their activity when they are oxidized. Thus the actual level of these substances in the vicinity of muscle cells is not only dependent on their formation but also on their removal or destruction. Sulfhydryl compounds have been found to reduce the rate at which epinephrine and norepinephrine are oxidized. In this way the local release of such compounds could regulate the tone of smooth muscle.

Recently it has been suggested that a role in the local control of the microcirculation is played by the so-called mast cells, large numbers of which adjoin the small blood vessels. Various investigators have shown that the mast cells release at least three substances that strongly affect blood vessels: histamine, serotonin and heparin. It has been proposed that these substances, working alone or in certain combinations, are local regulatory factors.

It must be borne in mind that, even though the control of the microcirculation is largely independent of the rest of the circulatory system, the small blood vessels depend upon the nervous controls of the larger blood vessels for the shifting of blood from one organ to another as it is needed. Obviously the nervous controls of the larger vessels and the chemical controls of the microcirculation must be linked in some fashion. Under normal circumstances tissues that are inactive are perfused with a minimal amount of blood to allow the flow to be diverted to the tissues that need it most. During shock and acute infections, on the other hand, the demands of the tissues may be so great that the circulatory system cannot meet them, and the circulation collapses. In such conditions the effect of substances released locally to relax the muscle cells of the capillary bed has superseded the efforts of the nervous system to restrict the blood flow by the release of substances such as norepinephrine. It is ironic that this primitive response, in striving to insure the survival of individual cells, frequently overtaxes the circulation and brings about the death of the organism.





CAPILLARY BEDS OF TWO TISSUES in a living rat are enlarged 200 diameters in these photomicrographs. At top is the capillary bed of a striated muscle; the capillaries run parallel to underlying muscle fibers. At bottom are capillaries in the surface of intestine.

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Between trademarks—which specify only commercial origin for merchandise otherwise named as to kind—and systematic but pedantic chemical names lies the convenient middle ground of trivial names (trivial: three roads, i.e., the fork where the people meet to chat, get it?). Some are trademarks abandoned by their owners, some are pronounceable combinations of letters from the systematic name, some are little amateur ads concocted by enthusiastic chemists who discovered the uses. (What does PAN mean? What does PAR mean?)

It has suddenly struck us that a few of the names neither cross-referenced in our catalog nor familiar to everybody gabbing at the crossroads, should be put in the hands of every chemist interested enough to ask. He gets them from Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y. (Division of Eastman Kodak Company). To use it the way we want him to, he must *also have a copy of Eastman Organic Chemicals, List No. 41, which gives the prices and package sizes for* all *the 3700 organics we stock.*

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X-ray film is getting better.

Our fastest kind used to be *Kodak Industrial X-ray Film, Type K.* Now we call it *Type KK.* The speed has gone up 50%. A 72-hour exposure becomes a 48-hour exposure. That's for something like a rudder post for a tanker. You get to sea a day sooner. Time is money. So they say. Same principle applies to uranium fuel elements. (To Cs^{137} gamma rays, ¾″ of uranium looks like 4″ of steel.) *Type KK* is a bit grainier than *Type K.* But it has higher contrast. The gain outweighs the loss. Up goes "radiographic sensitivity."* Radiographers can spot smaller voids.

Kodak Industrial X-ray Film, Type AA beats *KK* seven ways to Sunday for "radiographic sensitivity." It's some slower, though. As *Type A,* it used to be a lot slower. That was a little over a year ago. It was then the most widely used x-ray film in industry. Now it's more so. That sounds like tautology. Nevertheless, it makes us happy. With the higher speed, inherent contrast has gone up, not down. Grain's the same. This is remarkable.

They can just reduce exposure time. Even for thinner specimens than rudder posts, time is money. So it is said. Or they can cover more area at a single exposure. That's another way to save time. Or they can get their usual density with shorter processing. This likewise saves time.

Or they can take the same time and get more film density. Contrast and therefore "radiographic sensitivity" improve at higher density.

Or they can get through the specimen with less penetrating radiation. Softer radiation emphasizes density differences along ray paths of slightly different absorption. You want those differences.

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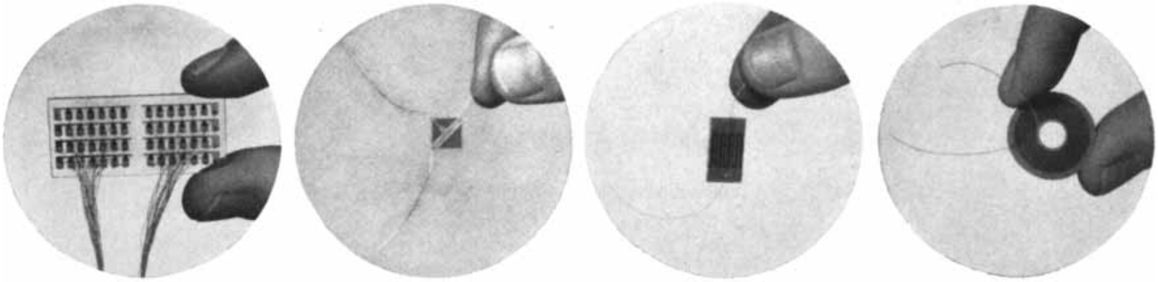
Kodak Industrial X-ray Film, Type M is for maximum detail and no rush, or else light specimens. *Kodak Industrial X-ray Film, Type F* goes with calcium tungstate screens. Their fluorescence in the visible intensifies the exposure. In a pinch that's sometimes all right.

Don't worry. You'd get the hang of it if you had to. Yes, even the radiography of plutonium hardware, where you're recording both endogenous and exogenous radiation. We'd give you what advice we could (but very little about plutonium). You'd write Eastman Kodak Company, X-ray Division, Rochester 4, N. Y.

But for goodness' sake, don't get physically involved before finding out about film badge dosimeters or placing yourself under the protection of someone who knows. For a free (literally) and easy smattering of that *subject and a bibliography of more substantial fare, ask for the brand-new pamphlet "Radiation Monitoring."*

*Don't trip. "Sensitivity" doesn't mean "speed" here.

They transduce



We make *Kodak Ektron Detectors* like these for transducing a visible or infrared pattern into electrical terms. The darker material is photoconductive lead sulfide or lead selenide; the electrodes (actually evaporated gold) appear grey here. Since we can lay down the photosensitive material in any configuration, enormous potentialities for inventiveness present themselves. Whether you seize them is entirely up to you. We offer a pamphlet, "Kodak Ektron Detectors." You get it by writing Eastman Kodak Company, Special Products Division, Rochester 4, N. Y. It describes what spectral sensitivities and time constants can be selected and very, very briefly summarizes the circuitry considerations—a little rough, perhaps, for persons with casual interest in this sort of thing. It does tell enough to place an order for breadboarding purposes or a request for quotation.

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

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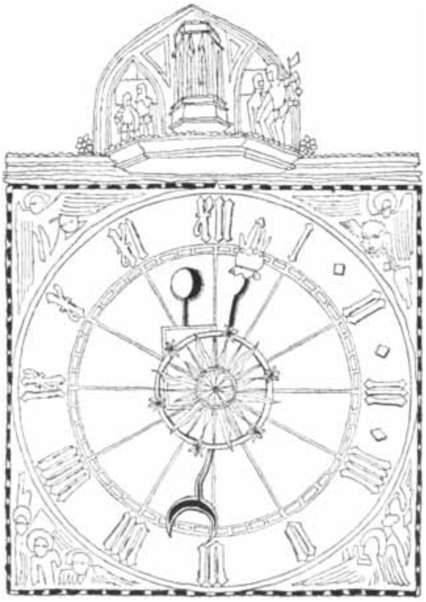


Awards

Two Hungarian-born scientists have received the Enrico Fermi and Atoms for Peace awards, each of which is larger than a Nobel prize. The Atomic Energy Commission bestowed the Fermi award (a medal and $50,000) on Eugene P. Wigner, who is Thomas D. Jones Professor of Mathematical Physics at Princeton University. Wigner, who was responsible for the design of the first atomic pile, was cited for his contribution to physics and reactor development.

The $75,000 Atoms for Peace award, financed by the Ford Motor Company, went to George Charles de Hevesy, professor at the Research Institute for Organic Chemistry in Stockholm. He was honored for his pioneer work on the use of isotopes as tracers in chemistry, biology and medicine.

Federal Science Support

Support for research and development will this year amount to almost 5 per cent of the Federal budget, according to the National Science Foundation's annual estimate. Federal expenditures for these purposes have been climbing steadily from $3,031 million in the fiscal year 1957 to $3,435 million in 1958, and to an estimated $3,732 million in 1959.

The pattern of spending has changed little from year to year. With the figures for the fiscal year 1958 almost complete, the report estimates that the Department of Defense and the Atomic Energy Commission disbursed 83 per cent of the total. Almost all the rest was spent by six agencies: the Department of Health, Education and Welfare; the Department of Agriculture; the National Advisory Committee for Aeronautics (now the National Aeronautics and Space Administration); the Department of the Interior; the National Science Foundation; and the Department of Commerce.

Roughly 65 per cent of the 1958 expenditures went for development; 35 per cent for research, including 8 per cent for basic research. The Government spent nearly $500 million, about 15 per cent of the total, via universities and associated research institutes and expended the balance about equally through its own laboratories and through industry. The physical sciences and engineering took 64 per cent; the life sciences, 32 per cent; the social sciences, 4 per cent.

Scientific Ambassadors

The Department of State has announced resumption of its scientific-attaché program, which it had abandoned in 1956. Two scientists will be dispatched to each of nine embassies: Bonn, London, Moscow, New Delhi, Paris, Rome, Stockholm, Tokyo and one South American capital, probably Rio de Janeiro. Their primary duties will be to advise U. S. ambassadors on scientific matters and to establish contacts with foreign scientists. They will also evaluate scientific research in the countries where they are stationed.

The State Department has had some difficulty in recruiting men for the jobs. In November, 1957, President Eisenhower proposed renewing the attaché program and also filling the post of State Department scientific advisor, which had been vacant since 1953. Two months later the post was filled by Wallace R. Brode, formerly associate director of the National Bureau of Standards. Since then Brode has spent much of his time persuading scientists to accept the two-year attaché appointments. In the first 10 months only six men had been hired.

Carbon 14 in Fallout

Linus Pauling of the California Institute of Technology has calculated that radioactive carbon 14 generated in the atmosphere by nuclear-weapons tests will ultimately do more biological damage than all of the fission products combined. Writing in *Science*, he states that at the present rate of testing a single year's output of C-14 will cause 55,000 children to be born with gross physical or mental defects, and will result in 170,000 stillbirths and 425,000 deaths of embryos and newborn babies. Says Pauling: "These numbers are about 17 times the numbers usually estimated as the probable effects of fallout fission products from one year of testing." In addition, Pauling reckons that C-14 will cause as much leukemia and bone cancer as fission products, including strontium 90.

The effects of C-14 had been discounted in earlier speculation on fallout. Two years ago Atomic Energy Commissioner Willard F. Libby estimated in *Science* that a small portion of the 10 grams of neutrons produced by a 20-kiloton fission weapon would react with atmospheric nitrogen to yield 1.05 kilograms of C-14. More recently Libby has estimated that the higher neutron flux from a thermonuclear weapon would yield 7.4 kilograms of C-14 per megaton of energy release.

Basing his present calculation on these estimates, Pauling predicts that most of the harm will come in the next generation. Because carbon is a universal constituent of cells, he points out, the radioactive effect of C-14 is not restricted to certain cells, as is the effect of radioactivity from the fission products.

Libby, meanwhile, has reported progress in a research effort aimed at minimizing the effects of strontium 90. In experiments performed in his off-hours at the Geophysical Laboratory of the Carnegie Institution of Washington, he has found that potassium fertilizers have a "possible effect" in reducing the amount of strontium that plants absorb. Libby estimates that as little as 30 pounds of potassium per acre could reduce the uptake of radioactive strontium by 40 per cent.

Perennial Wheat

After 35 years of experimentation U. S. Department of Agriculture plant breeders appear to be on the verge of developing a commercially valuable perennial wheat. A hybrid of wheat and certain tall wild grasses, the perennial yields grain for several years, resists insects and disease and provides year-round cover for the soil.

The quest for perennial wheat was started by W. J. Sando, now retired, who in 1923 crossed wheat with wheat grass and other species of the genus *Agropyron*. Among those who followed up his work was C. A. Suneson, a Department of Agriculture agronomist working in the California agricultural experiment station at Davis, Calif. He has evolved an especially promising perennial by backcrossing Sando's hybrids to spring wheat and intercrossing the progeny.

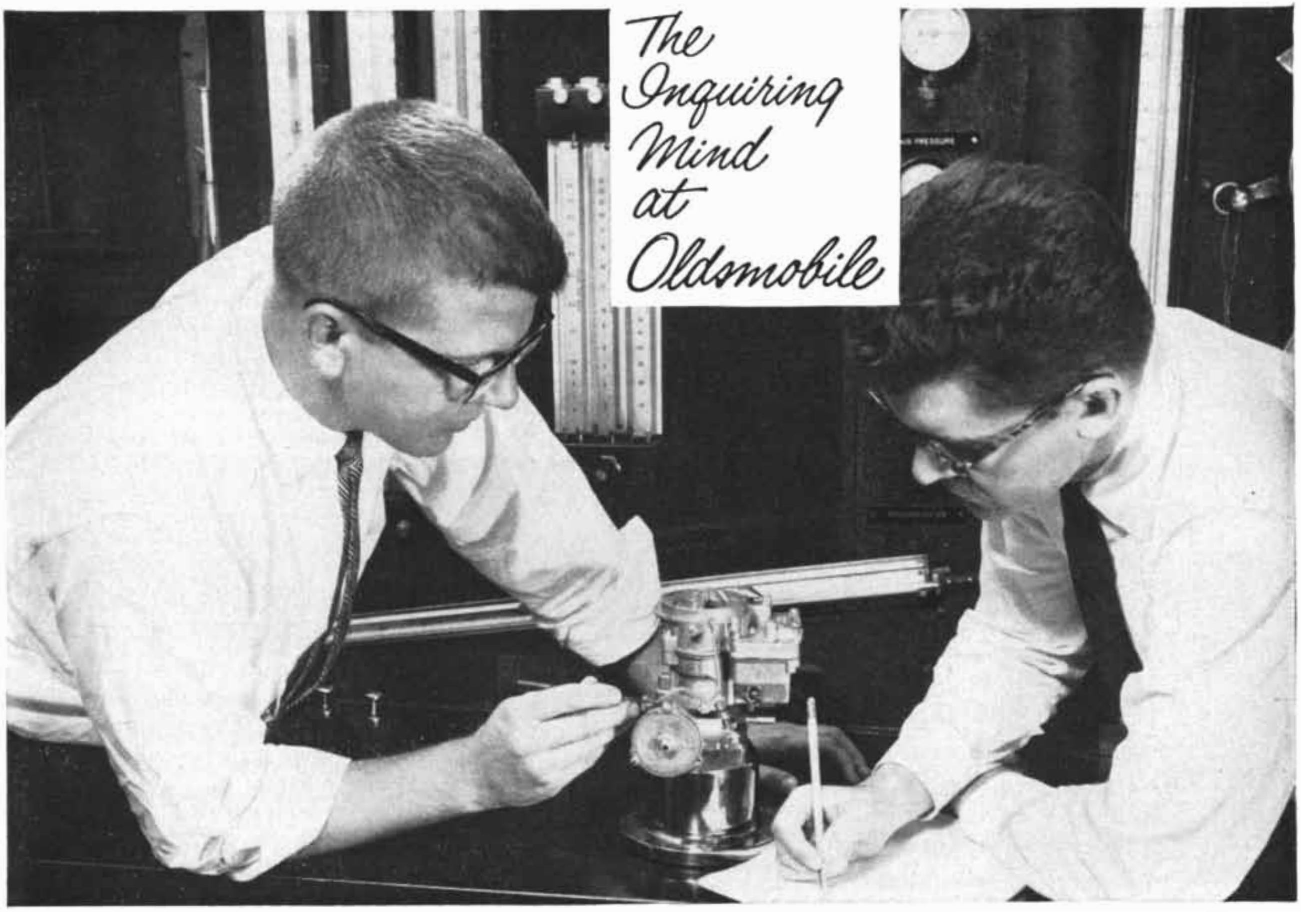
Suneson's plants live about four years and bear grain that is exceptionally rich in protein. They withstand drought and are highly resistant to smut, rust, mildew and other wheat diseases. Furthermore, they are not attacked by the Hessian fly and other insects that ravage wheat. There is, however, one drawback. While the yield of grain in the first year matches that of local wheats, it drops off by 40 per cent or more in the second year. But Suneson now believes he can keep the yield high throughout the lives of the plants if he can work out ways to fertilize them every year and to control weeds.

Electricity from Plasma

An electric generator called the plasma thermocouple, which converts heat directly into a substantial current, has been invented by five scientists at the Los Alamos Scientific Laboratory. A crude prototype has put out 350 watts at an efficiency of 5 per cent, the inventors report in *Journal of Applied Physics*. They expect that refinements will greatly improve the thermocouple's performance. Theoretically it could convert to electricity 30 per cent of the heat applied to it.

The plasma thermocouple differs little in principle from the bimetallic thermocouple that is widely used to measure temperatures. The bimetallic thermocouple consists of two pieces of dissimilar metals connected at both ends. When one connection is heated, a feeble current flows toward the cold connection [see "The Revival of Thermoelectricity," by Abram F. Joffe; SCIENTIFIC AMERICAN, November, 1958].

In the plasma thermocouple one of the metals is replaced with a vessel of liquid cesium. Contained in a vacuum, the cesium partly evaporates and dissociates



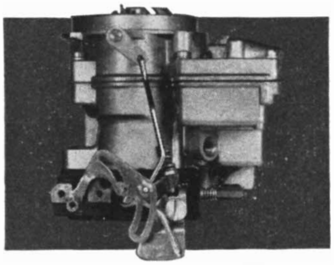
no. 6 OF A SERIES

TWO STEPS TO NEW FUEL ECONOMY

Unique Oldsmobile-developed two-stage automatic choke is a major step forward in improving automobile operating economy.

One of the important carburetor developments during the past few years was the automatic choke, a device that allows the automobile to be started in cold weather, and then keeps it running until the engine is sufficiently warmed up to sustain itself. Every automatic choke has two separate functions: 1) choking, which enriches the fuel-air mixture for starting, and 2) the idle speed control, which keeps the engine from stalling once it is started. In the past, and on all present carburetors except those used on the 1959 Oldsmobile, these two functions have operated simultaneously with the result that the engine ran on a rich mixture for the same length of time that the fast idle was "on". This resulted in excess fuel consumption.

With the introduction of the 1959 Oldsmobile, the two functions have been separated with a new and exclusive two-stage automatic choke developed by Oldsmobile engineers. An ingenious system of over-running levers allows the choke fly to open 75% sooner than previously required. The fast idle, however, remains "on" for the full warm-up period so the engine will not stall. This early elimination of the choking function represents a considerable fuel saving in cold weather when numerous short trips are made.



At Oldsmobile the Inquiring Mind is always at work, finding new and better ways to design, engineer and build finer automobiles for the most discriminating of buyers—the Oldsmobile owner. Discover the difference for yourself by visiting your local Oldsmobile Quality Dealer and taking a demonstration ride in a 1959 Oldsmobile.

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into a "plasma" of charged particles. These have a driving force 1,000 times greater than that of any solid metal, and for this reason the plasma thermocouple produces a much stronger current than the bimetallic thermocouple.

Cesium has been used because it can easily be kept liquid in an oil bath at 300 degrees centigrade, and because it is the most easily ionized of all the elements. Other elements which could be used in the generator include rubidium, potassium, sodium and lithium.

The inventors are G. M. Grover, William Ranken, D. J. Roehling and E. W. Salmi of Los Alamos and R. W. Pidd (a consultant) of the University of Michigan. All five have been working on Project Rover, which is concerned with nuclear rocket propulsion.

Paralytic Partnership

Severe outbreaks of paralytic poliomyelitis may be due not to the poliomyelitis virus alone but to a combination of two viruses. Experimental evidence that a group of the so-called Coxsackie viruses intensify the damage done by polio viruses is reported by Gilbert Dalldorf and Heribert Weigand of the New York State Department of Health.

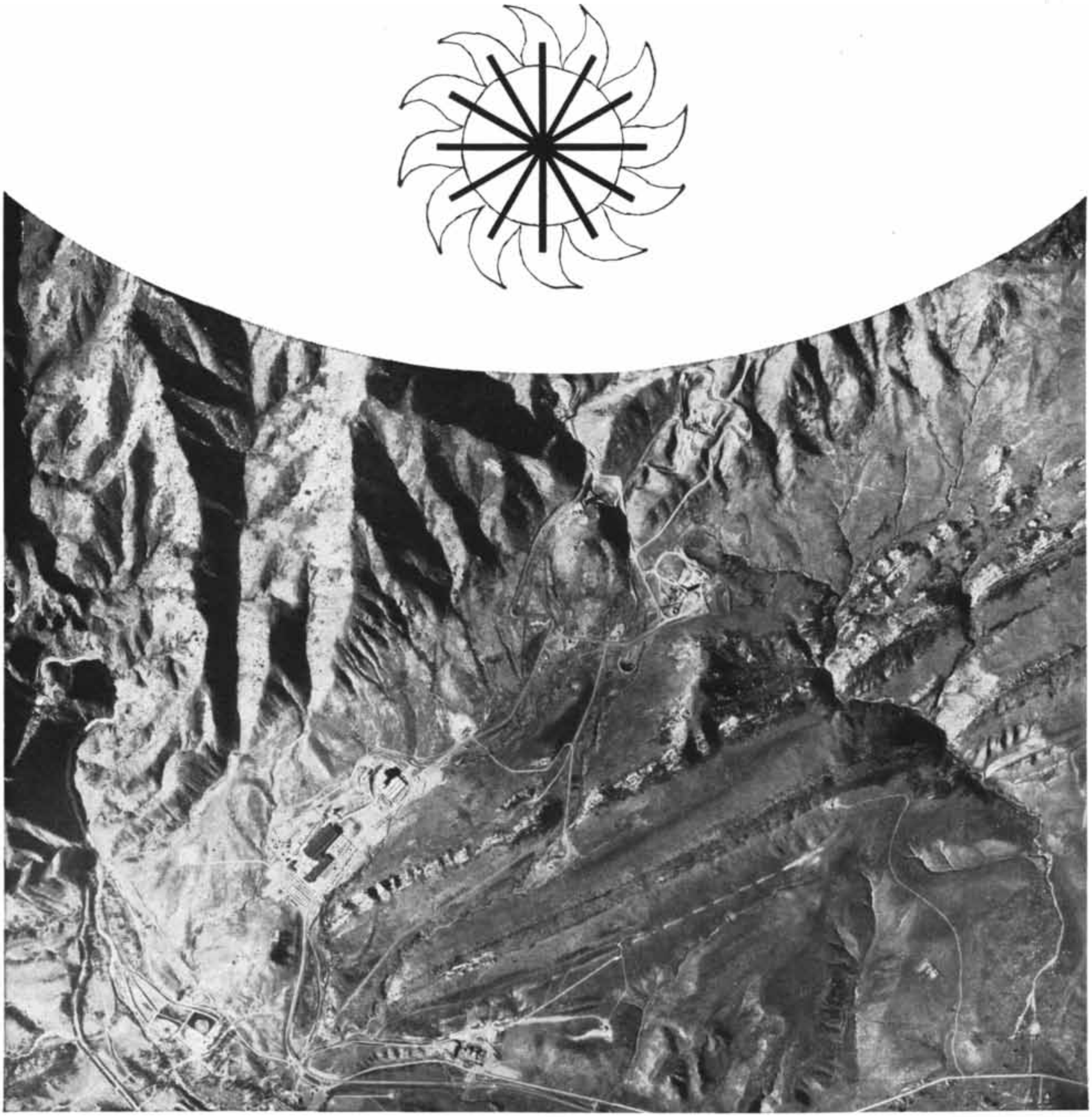
They inoculated young monkeys first with a weakened polio virus, then five days later with viruses of Coxsackie Group A. With few exceptions the animals became paralyzed. In contrast, animals that they had inoculated twice with the same virus were not seriously affected, although some developed minor lesions of the spinal cord.

Writing in *The Journal of Experimental Medicine*, Dalldorf and Weigand speculate whether paralytic poliomyelitis might not be the cumulative effect of repeated, though minor, virus infections, each of which destroys a number of motor cells. They point out that other investigators have observed that paralytic polio epidemics are frequently associated with widespread Coxsackie A infection. On the other hand, when Coxsackie viruses of Group B are prevalent, polio is seldom paralytic. Presumably this is because Coxsackie B and polio viruses somehow interfere and tend to cancel out. The different strains of polio virus interfere with one another in the same way.

Dalldorf and Weigand urge more study of the interrelationships of the polio, Coxsackie and other viruses that lodge in the intestinal tract. Many of the mysteries of polio epidemiology, they suggest, might be cleared up if medical workers knew more about how these


FRANK TINSLEY '58

There is nothing else like this under the sun. It is the Martin-Denver facility, birthplace of the Air Force TITAN. It is also this country's most advanced and fully integrated big-missile development center. Here, our most formidable weapon systems of tomorrow are being designed, built and tested—from the smallest component to the total system—within a single 7,000 acre complex. Every top military and scientific expert who has seen Martin-Denver from *within*, considers it one of our most valuable national resources.



viruses interact. Meanwhile, they advise, physicians should consider postponing vaccination for poliomyelitis when Coxsackie A infections are prevalent.

Deep-view Microscope

A new kind of microscope that makes it possible to see things like nerve networks in three dimensions has been invented by psychologist R. L. Gregory and physiologist P. E. K. Donaldson of the University of Cambridge. An ordinary microscope, because of its shallow depth of focus, reveals only a thin layer of the specimen. This can be a serious limitation when, for example, an investigator wants to view a tangle of fibers, Gregory and Donaldson point out in an article in the weekly journal *Nature*.

They made a crude prototype of a three-dimensional microscope by mounting a slide on one 50-cycle tuning fork and projecting the image on a screen mounted on another 50-cycle tuning fork. With both forks vibrating in phase, the slide thus was scanned in depth 50 times a second, and the image was projected faithfully on the screen.

At present the resolution and contrast of the new microscope leave much to be desired, and it seems to be useful only at relatively low magnifications—less than 100 diameters. But Gregory and Donaldson hope to improve the instrument by substituting a more precise oscillator for the tuning forks, and modulating the light so that all parts of the deep image appear equally bright.

Workhorse Accelerators

Two new atom-smashers, remarkable for the torrent of particles they will accelerate, will soon be built. The University of California Radiation Laboratory will break ground in May for an 88-inch cyclotron to cost $4,600,000. It will be small compared with the Laboratory's 184-inch cyclotron, and it will accelerate particles to only about one third the energy of those that stream from the big machine. The new cyclotron will, however, release an enormous flood of particles: some million billion per second, or 1,000 times as many as the 184-inch machine.

A new design feature first proposed by Donald Kerst is largely responsible for the new cyclotron's capacity. Spiral ridges radiating from the centers of the pole pieces will put wrinkles in the magnetic field. This effect makes it possible to accelerate particles with a steady, continuous current instead of the pulses used heretofore in large cyclotrons. The intense beam of particles that can be generated in this way will find many uses. In particular, it will permit physicists to produce considerably larger quantities of the artificial elements at the top of the periodic table.

The Argonne National Laboratory has drawn up plans for a proton synchrotron that will accelerate a thousand billion particles per second to energies of up to 12.5 billion electron volts. No other comparable machine produces nearly so intense a beam. The new synchrotron should prove valuable for making the short-lived "strange" particles that occur in cosmic rays and are believed to exist fleetingly in atomic nuclei.

Physicists studying the forces that bind atomic nuclei may also soon have a new tool to work with. Robert J. Van de Graaff of the Massachusetts Institute of Technology has devised a way of linking in tandem the accelerators that bear his name. Double Van de Graaff accelerators, which give particles two five-million-volt jolts, are now fairly common. But he now thinks it is practical to increase the accelerating stages to three or even four.

Soothing Bubbles

Engineers of a British firm have succeeded in quieting the sea by blowing bubbles through the water. Two lines of polyethylene piping submerged in Dover harbor release intermittent blasts of compressed air which break the rhythm of the waves. By creating a pattern of random turbulence, the bubbles reduce the height of big waves by at least 50 per cent.

The pipelines, each 300 yards long and anchored by junked steel rails, were recently installed by Pneumatic Breakwaters Ltd. of London. They protect ship berths, the train-ferry dock and the entrance to the inner harbor. A test pipeline had worked successfully for two years. Its lightweight plastic construction held up well despite the turbulence caused by ships that passed only 10 feet above it at low tide.

The air, supplied by six compressors on shore, is released in short blasts. These disrupt the rhythm of waves so that the energy of the waves themselves produces the quieting effect. Because the pneumatic breakwater can be installed anywhere without interfering with navigation, the company recommends it particularly for protecting offshore drilling rigs.

second in a series

THE MERGER

The legal act of merging two companies into one does not of itself change the sum total of their capabilities. Thus, today the competence of the Ramo-Wooldridge Division for the development of electronic systems for military and commercial applications is indistinguishable from that of its predecessor organization, The Ramo-Wooldridge Corporation, while the skills of the Thompson Products group of divisions in the design and large-scale production of precision devices also remain unchanged. Soon, however, effects of the merger will begin to appear. One early effect will be an important addition of manufacturing strength to Ramo-Wooldridge programs, several of which have passed out of development and are in the prototype or manufacturing phases. Conversely, the special skills of Ramo-Wooldridge scientists and engineers in certain fields can usefully supplement the services that the Thompson Products divisions offer to their customers.

The formation of Thompson Ramo Wooldridge Inc. is intended to provide an unusual capability for the development and production of the complex electronic and mechanical devices and systems required by today's expanding technology.

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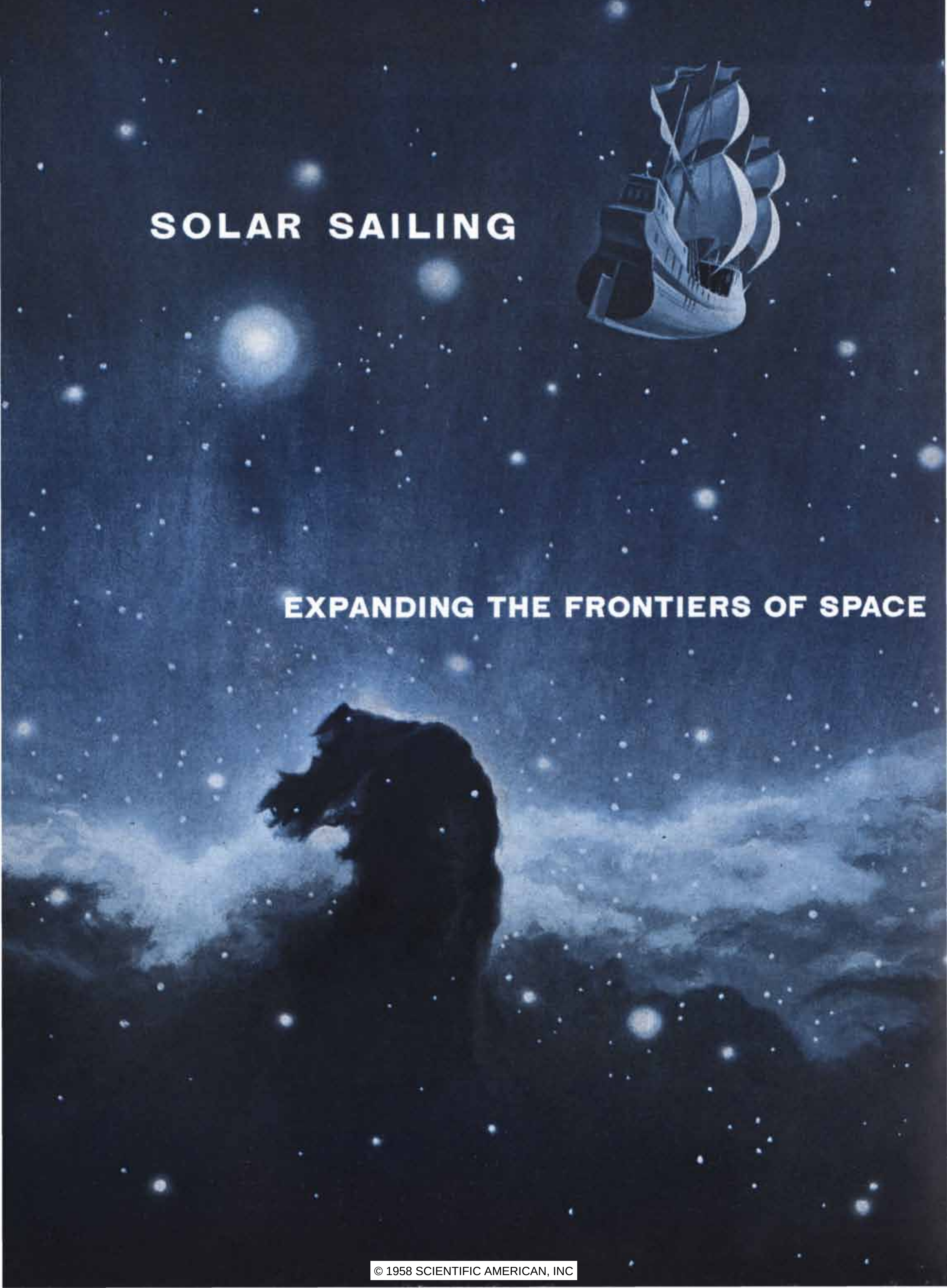
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THE ATOMIC NUCLEUS

How do physicists presently visualize it? Curiously, different approaches to the nucleus suggest different pictures, notably the liquid-drop model, the shell model and the optical model

by R. E. Peierls

Ever since 1930, when the discovery of the neutron made it plain that the nuclei of atoms were built of protons and neutrons, physicists have been trying to form a picture of the structure of the nucleus. The same task for the rest of the atom was completed in the first quarter of this century. We were able to understand in detail how the electrons move under the attraction of the nucleus, and how their motion is influenced by their mutual repulsion.

To achieve such an understanding requires three major steps: First, we must know the forces between the particles. Second, we need to know the mechanical laws which govern their motion under the influence of these forces. Third, we need in most cases a simplified picture, or model, from which to start. Once we have the first two ingredients, we could in principle write down a set of mathematical equations whose solutions would tell us all about the atom, or about the nucleus. In the simplest possible atoms, like that of hydrogen, in which there is only one electron, or in the simplest compound nuclei, like the deuteron, which contains only one proton and one neutron, such equations can be written down and solved without difficulty. However, for more complicated structures this head-on attack becomes much harder and soon exceeds the capacity even of modern electronic computers.

We are like men who encounter for the first time a complicated machine, and who try to analyze its operation. If we attempt, without any guidance, to puzzle out the interplay of all the parts of the machine, we should soon lose ourselves in a maze. Instead, we first try to ascertain the major features of the machine's operation. We then devise a model which resembles the real thing in these features, yet is simple enough to be analyzed. Then, of course, we must put in corrections for the complications which we have left out and check that they do not materially alter the picture.

In the study of the atom the first of the three steps hardly presented a problem. As soon as Ernest Rutherford had demonstrated that the atom consisted of a heavy, positively charged nucleus and of light, negatively charged electrons, it was taken for granted that the forces between them were the electric attraction of unlike charges, following the inverse-square law familiar to every student of physics. The major difficulty was the second step. It turned out that the basic mechanical principles of Isaac Newton, which applied to all "large" objects from the planets and the moon down to steam engines and watches, had to be revised in the atomic domain. To understand atoms we had to use the new ideas of the quantum theory, following the pioneer work of Niels Bohr, who adapted for this purpose the concept of the quantum of action which Max Planck had first found in the behavior of light. These new laws of mechanics were later formulated as the laws of "quantum mechanics," or "wave mechanics," which gave us complete command over the theory of the atom.

The third step, of finding a simplified model for discussing the atom, also proved relatively easy. In working out the possible orbits of a single electron under the attraction of a proton, as in the hydrogen atom, Bohr found that one could account for the behavior of a more complex atom by assuming that each of its electrons moved in such an orbit. The larger the number of electrons in an atom, however, the more distinct orbits they occupy; this is a consequence of the "exclusion principle" discovered by Wolfgang Pauli, which limits the number of electrons that can travel in a given orbit.

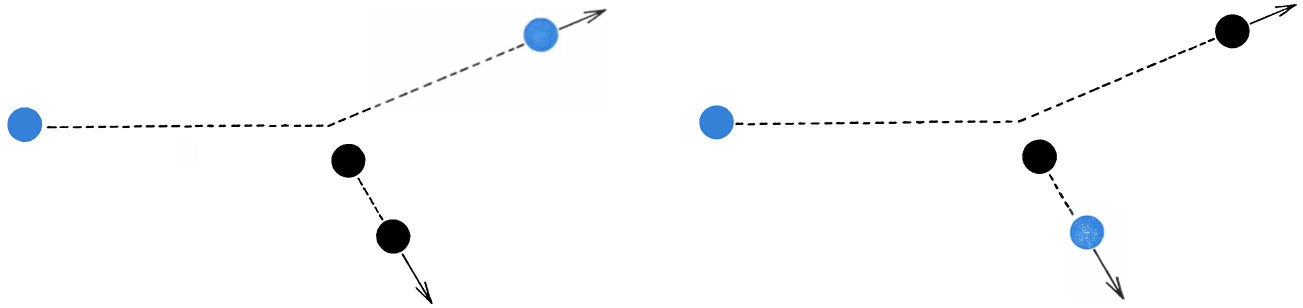
We must allow not only for the attraction of the electrons by the nucleus, but also for the repulsion of the electrons by one another. However, we simplify the nature of this repulsion by forgetting that it changes continuously as the electrons move around in their orbits, and treating it as a fixed field of force. In other words, we replace the repulsion due to a moving electron by that which we would obtain if the electron were spread out evenly over its orbit. This simplification can be justified by the fact that the repulsion acts over relatively long distances, so that each electron is at any time under the influence of several others. If we underestimate the effect of one of the electrons which may happen to be rather close to the one we are looking at, we are likely to overestimate the effect of another which happens to be rather far away.

This model of the atom is usually called the "shell model," because it is convenient to group together the electrons moving in orbits of similar size but of different shape and direction. Such a group of orbits is called a shell.

When the atomic nucleus first became an object of serious study, the nature of the difficulties was rather different. The general laws of dynamics did not seem to require further revision; the laws of quantum mechanics which had been discovered in atomic physics seemed quite adequate for the nuclear domain. Indeed, we have not yet found any evidence in the behavior of nuclei which would suggest that these laws might be in error. Thus the second step in our list presented no problem.

The Nuclear Forces

On the other hand the first step—the determination of the forces between the particles—proved to be a very difficult



CHARGE EXCHANGE in the nucleus is schematically depicted. When protons (*black balls*) are struck by fast neutrons (*red balls*), in half the cases (*left*) the neutron continues forward. In the other half (*right*), the proton exchanges its charge with the neutron.

problem. Even today, after some 25 years of intense study, we cannot claim to have a complete answer, but we have by now at least a fair knowledge of what the forces are like.

They cannot be electric in origin. The only electric charges found in the nucleus are the positive charges of the protons, and like charges repel each other; thus electric forces cannot be responsible for holding a nucleus together. Moreover, electric forces are much too weak. We know that the energy of attraction of two unlike charges (*i.e.*, the work we have to do to pull them apart) varies inversely as their distance. The attractive energy of an electron and a proton in the hydrogen atom is a few electron volts (ev), and since the diameter of the hydrogen atom is 20,000 times larger than that of the smallest nucleus we should expect electric energies in the nucleus to amount to some tens of thousands of electron volts. Actually the forces inside a nucleus run to many million electron volts (mev). It follows that nuclear forces are vastly stronger than electric forces.

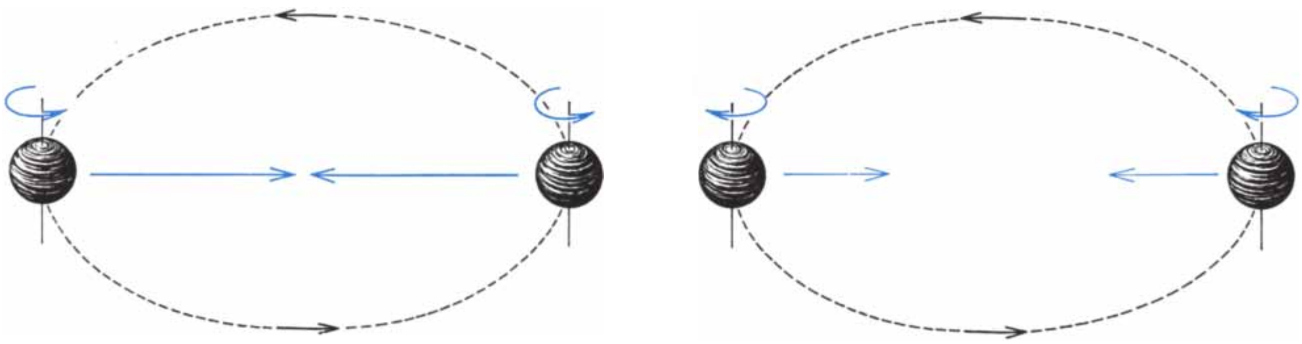
It is also clear that these strong forces act only over extremely short distances. The pioneer work of Rutherford on the passage of charged particles through matter showed that, even in encounters in which a charged particle approaches a nucleus to a distance of a few times the nuclear diameter, the only noticeable force is the electric one. We know today that nuclear forces between two particles are quite negligible if the distance between the particles is more than, say, four fermis. (The fermi, named for the late Enrico Fermi, is a convenient unit of distance for the nucleus. The diameter of a heavy nucleus is some 15 fermis; the diameter of the hydrogen atom, about 100,000 fermis.) It is not surprising, therefore, that earlier physicists did not meet nuclear forces in laboratory experiments. The only possible way of studying these forces is to observe the behavior of nuclei, or to bombard hydrogen or other nuclei with fast protons or neutrons under circumstances in which the effect of really close encounters can show up.

What makes this task harder is that the nature of nuclear forces, unlike the simple inverse-square law of electric or gravitational forces, is rather complicated. If the law of nuclear forces were simple, a few observations might suffice to guess its general form. But all simple guesses based on a few experiments have been disproved by later experiments. We are obliged to reconstruct the law of nuclear forces laboriously from the various pieces of evidence we can extract from the experiments.

Ultimately we hope to be able to derive the law of the forces from more basic principles, just as we can derive the inverse-square law of electric forces from the basic laws of electromagnetism. A beginning was made by the Japanese physicist Hideki Yukawa, who used the analogy with electromagnetic radiation to point out that nuclear forces must be related to a new form of radiation which could carry charged particles weighing a few hundred times more than the electron. His prediction was confirmed by the discovery of the so-called pi meson. His picture of the mechanism underlying the nuclear forces has been qualitatively confirmed by many observations, and has been a useful guide in our thinking about the forces. But it has not yet been possible to use his idea for a reliable and accurate derivation of the law of the forces because of the mathematical problems which stand in the way. We do not know today whether a correct solution of the equations embodying Yukawa's idea would yield the right forces, or whether there is something basically wrong with this approach. The difficulties arise chiefly from the greater strength of the nuclear forces, as compared to electric forces, which makes their mathematical analysis much more difficult.

Thus the best source of information about the forces still lies in direct experiments. These require collisions at high energies—much higher than the energies of particles inside ordinary nuclei. The reason for this is the wave aspect of particles, which is an essential feature of quantum mechanics. Slow particles are associated with waves of long wavelength, and collisions involving such slow particles do not provide much information about the finer features of the forces at work between them, just as in looking through a microscope at a dust particle with a diameter less than a wavelength of light we see only a general blur which does not reveal the shape or nature of the particle. To have particles of sufficiently short wavelength one must raise their energy to a few hundred mev. The most reliable information on nuclear forces has therefore become available only in the last few years, as a consequence of the development of accelerating machines which produce clean beams of protons, neutrons, or electrons with such energies. This need for high-energy beams is entirely similar to the situation in atomic physics, where detailed pictures of the structure of atoms require the use of X-ray or electron beams of several thousand ev—much greater than the energies of the electrons inside the atoms, whose wavelength is comparable to the atomic diameter. The complexity of the results has also made it necessary to call on the services of fast electronic computers for disentangling the observations.

I shall not attempt in this article to give anything like a complete specification of the nuclear forces, but shall stress only those features which are of impor-



SPIN-ORBIT FORCE arises from a relationship between spin and orbit. When two particles (*left*) spin in the same direction as that in which they move on an orbit, the force between them is strong. When they spin in opposite directions (*right*), force is weak.

tance for what follows. We have already noted that the forces must be strong and of short range. Since they hold the different particles together, they must on balance be attractive. At the same time they cannot be entirely attractive, since otherwise heavy nuclei would "collapse." By collapse we mean a state of affairs in which all the particles in a nucleus are so close together that each one is within the range of the attractive force of every other. In that case the attractive energy acting on each particle would grow with the total number of particles present, and the volume occupied by the whole nucleus would be the same no matter how many particles were in it. This is not found in reality. The energy per particle is roughly the same for all nuclei, light or heavy, and the volume of nuclei increases with the number of particles in them.

The Exchange Forces

This behavior, which indicates a limited attraction, is usually called "saturation" of the nuclear forces. There are two particularly plausible ideas to account for this saturation. One was suggested by the German physicist Werner Heisenberg, who was one of the founders of quantum mechanics. He postulated that at least part of the nuclear forces between a neutron and a proton involves an exchange of their position, so that after an encounter between them the neutron would tend to follow what had been the path of the proton, and vice versa. The exchange occurs readily only if the two move in very similar orbits, and, since the Pauli exclusion principle allows only a limited number of particles to follow the same orbit, such exchange forces would expose each particle to a strong attraction only from a few others. The bombardment of protons with fast neutrons confirmed this idea, because it showed that in most cases either the neutron or the proton tended to go forward with almost the same speed and direction with which the neutron had arrived. Since it is hard to deflect such fast particles from their path, this indicates that the incident neutron had continued almost in a straight line, but that in half the collisions it had changed its nature and become a proton, leaving a neutron behind.

However, the experiment also showed that only one half of the force was of the exchange type; the other half (corresponding to the neutrons still moving forward after collision) was an "ordinary" force. This is not enough to yield the required saturation, and some other factor must be involved. The second factor tending toward saturation is almost certainly a reversal of the direction of the nuclear forces at short distances, so that, as two particles approach each other, the attraction changes to repulsion. This concept of "repulsive cores" in the forces is familiar in the behavior of atoms. When atoms form chemical compounds, or liquid or solid substances, they are held together by attractive forces; but each atom has a fairly definite size, and when two atoms come into actual contact, their attraction changes into repulsion. We may liken this behavior to that of two rubber balls tied together with a rubber band. There is an attraction between the balls, but there is also a contact force which prevents the centers of the balls from approaching each other closer than one diameter. Shortly after the theoretical need for such a repulsive core in the nuclear forces had become clear, experiments on collisions between fast particles indeed showed direct evidence for these repulsive forces.

Among other features of the nucleus I should mention the "spin-orbit" force, that is, the dependence of the mutual interaction of two particles upon the direction of their orbit with respect to their spin. When the two particles spin on their axes in the same direction as that in which they revolve about each other, the attraction between them is stronger; when they spin in the opposite direction from that in which they revolve, the attraction is weaker. There is some evidence for such a spin-orbit force in experiments on nuclear collisions, but there is still some room for controversy in the interpretation of these experiments.

Our present knowledge of the nuclear forces, while still incomplete, is sufficient to discuss the behavior of nuclei and the collisions between them. At this point we meet the need for the third step in our general program, namely a simple model in terms of which we may approach the dynamical problem of the motion of the 16 particles in the oxygen nucleus, or the 208 particles in the most stable lead nucleus.

Models of the Nucleus

The selection of a suitable model is not at all straightforward. Not that there is a shortage of suggestions. In fact the trouble in the recent past has been a surfeit of different models, each of them successful in explaining the behavior of nuclei in some situations, and each in apparent contradiction with other successful models or with our ideas about nuclear forces. In the past few years great progress has been made in bringing some order into this confusion and in understanding the justification for each of the models in the domain to which it is properly applied. I shall attempt to explain briefly some of the ideas behind these developments.

The most obvious idea was to use the shell model, which had been so successful in dealing with the atom. In fact, the first attempts to set up such a shell model were made even before the discovery of the neutron, when it was believed that nuclei were made of protons and electrons. A shell model with the wrong constituents cannot have much success in accounting for the facts, but in those days rather few facts were known, so such models were able to survive for some time.

After the discovery of the neutron, attempts to formulate a nuclear shell-model were renewed. This involved the idea of orbits (or quantum states) for the protons and neutrons, in which each of them was pictured as moving independently under the influence of some force which represented the average effect of the others, as in the case of the electrons in the atom. It did not seem possible, however, to choose groups of orbits of the right kind, so that the number of similar orbits which formed a shell could accommodate just the right number of neutrons and protons to account for the exceptional stability of nuclei with certain numbers ("magic numbers") of neutrons or protons.

The same idea was applied to the collision of neutrons with nuclei. According to the shell model, the impinging neutron should travel through the nucleus on its own orbit, as through some field of force, and individual encounters with the particles constituting the target nucleus ought to be rare and unimportant. Hence the neutron should in most cases emerge with the same speed as that with which it entered, and only rarely should it get trapped. The details of the process should not depend critically on the speed of the neutron.

Observations of such collisions, initiated by Fermi in Rome, gave a completely different picture. Most of the neutrons that interacted with a nucleus were trapped, their excess energy being radiated in the form of gamma rays. Moreover, the chance of the neutron being affected by the nucleus depended very critically on its energy. One found a large number of resonances, *i.e.*, sharply selected energies, for which a neutron was sure to be picked up by the nucleus. For each target nucleus there are many such resonances, the energy difference between them being often as low as 100 ev, an exceedingly small difference on the nuclear scale.

These resonances turned out to be exceedingly sharp, and on the uncertainty principle of quantum mechanics a sharply defined energy is associated with a long time. So it follows that once a neutron gets into a nucleus in conditions of resonance it must stay there a long time —much longer than it would take it to cross a region the size of a nucleus.

The Liquid-Drop Model

The way to resolve these apparent contradictions was pointed out by Bohr. He recognized that it was not right to think of a neutron as passing just through a general field of force, since the nucleus is densely packed with particles which each exert strong forces on the extra neutron as well as on each other. Instead of comparing the process with the passage of a comet through the solar system, as was appropriate for the passage of an electron through an atom, we should liken it to the entry of a golf ball into a space already fairly densely filled with similar balls. The result will be a complicated motion of all the balls, and the energy of motion of the extra one will rapidly get shared with the others.

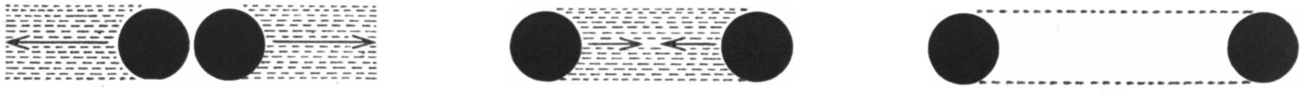
The dynamical problem is now that of a true many-body motion, and we have vastly more possibilities of varying the details of the motion of all the particles. This means that the rules of quantum mechanics will give us far more states of motion, and these are responsible for the greatly increased number of resonances. We also see the reason for the long stay of the neutron in the nucleus, because when the energy of motion is shared among many particles, none of them can attain enough speed to escape from the general attraction. It must take a long time before by chance one of them collects enough of the available energy to get away. In our picture of the golf balls this will actually never happen, because in the meantime too much of the energy will have been dissipated in friction. In the nuclear case the analogue of friction is the loss of energy by gamma radiation, and this is responsible for the events in which the neutron gets trapped. But it is less effective than in the case of the golf balls, and some neutrons do get out again.

The physicist does not invoke here the similarity with a system of golf balls, which is not quite close enough, but he is reminded of a very similar situation which arises when a water molecule hits a drop of water, and for this reason Bohr's model is often called the "liquid-drop model."

The liquid-drop model met with considerable success, and was able to explain many detailed features of nuclear reactions. At this time it seemed evident that the whole earlier idea of the shell model, which pictures the particles as moving independently, was doomed to failure, in view of the high density of the nucleus and the strong forces a particle was bound to experience in many encounters with others during the course of its motion. Most physicists then regarded the whole idea of a shell model as misconceived, but some, whether out of a stubborn refusal to accept the arguments against the model, or out of a deeper intuitive insight which convinced them that somehow one might be able to get around the argument, continued to look at the behavior of nuclei in their normal states in terms of shells.

The Shell Model Again

It soon became evident that there was overwhelming evidence in favor of such a shell picture, and the final success came when Maria G. Mayer of the University of Chicago and J. D. H. Jensen of Heidelberg independently noticed that the facts fitted amazingly well with a slightly modified shell model. The new feature was that when a particle spins in the direction in which it moves about the center of the nucleus, its orbit is different from the orbit of a particle spinning in the opposite direction. When this idea was put forward, it was not known that the force between two particles depends on the relative orientation of spin and orbit. Today the idea appears entirely natural. With this refinement, such a mass of data about the behavior of nuclei could be explained that there remained no doubt as to the essential



NUCLEAR FORCES are dependent on the distance between particles. If the particles are very close, they repel each other (*left*). If they are a certain distance apart, they attract each other (*center*). If they are farther apart, they have little effect on each other (*right*).

correctness of the shell model [see "The Structure of the Nucleus," by Maria G. Mayer; SCIENTIFIC AMERICAN, March, 1951].

But what of the argument that the mutual disturbance of the particles in their orbits must be so strong that the shell model could not possibly be right? Coupled with this puzzle was the question of how one should work out the orbits of the particles from the basic forces between them. So far the orbits had merely been chosen in such a way as to fit the data as well as possible; it was also desirable to understand the origin of the orbits.

These questions are finding their answers in a series of investigations initiated by Keith A. Brueckner, now at the University of Pennsylvania, and extended by many others. There are two main ingredients to this work. The first is to take into account the effect of the exclusion principle. This says that only two neutrons and two protons can move in exactly the same orbit. In the normal state of a nucleus all orbits of low energy are occupied by four such particles, and it is very difficult for them to disturb one another's motion. To deflect a particle from its orbit it must be thrown into another one, but all the other orbits of low energy are already occupied. To throw it into an orbit in which the energy of motion is higher is difficult unless the other partner in the encounter can give up energy, *i.e.*, go itself into a motion with lower energy, which is in turn impossible because all the suitable orbits are occupied. Such a behavior is familiar among the electrons of metals, which are hard to deflect from their orbits for the same reason; this is why many metals are good conductors of electricity.

The exclusion principle would provide a plausible justification for the shell model if it were not for the repulsive core of the nuclear forces. The repulsive force between two particles that are quite close to each other is so strong that it is impossible in a head-on collision for one particle to pass through the other. Thus in spite of the exclusion principle the particles are bound to be somewhat deflected from their orbits.

This brings in the second ingredient of the Brueckner approach. One looks carefully at the encounter between two particles which are influenced by such a short-range repulsion and sees that the deflection from their paths does not depend so much on how strong the repulsion is (provided it is strong enough), but on the distance over which it operates. If this distance, *i.e.*, the core diameter, is small enough, the resulting disturbance will be small, since the particles only have to take slight "evasive action" to get past each other. Now the core diameter of the nuclear forces is small compared to the mean distance between particles in the nucleus, and we may therefore hope that the disturbance caused by the repulsion is weak. But to describe the encounter correctly we must be able to solve the problem of the collision of two particles correctly, even in the presence of the repulsive force. This, fortunately, is a problem that can be solved.

Whereas in the atom we assumed that each particle moves under the influence of the average force of all the others, the nuclear problem may be simplified by assuming that the collision of *two* particles takes place while they both move under the influence of the average force of all the others. A mathematical treatment embodying these ideas has made it possible for the first time to calculate the binding energy, and other properties, of a nucleus from the forces that had been derived from the study of two-particle collisions, without further *ad hoc* hypotheses.

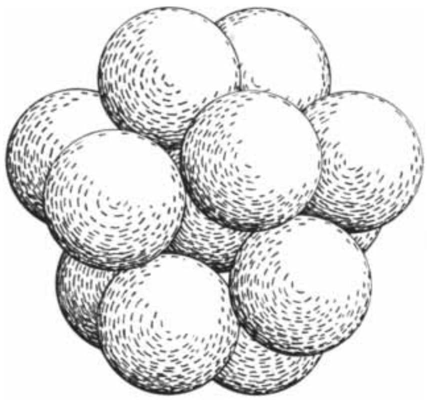
These ideas do not invalidate the argument of Bohr concerning the impact of an additional particle on a nucleus. Here we are concerned with a particle that has a good deal of spare energy, namely the energy required to remove the particle from a nucleus once the particle has got trapped in it. Thus the particle can easily exchange energy with the other constituents of the nucleus without violating the exclusion principle.

But this problem, too, has more than one side to it. In the study of the neutron resonances which were mentioned earlier, and in the similar collisions of protons with nuclei, it was found that not all the resonances were of the same strength. For a given neutron speed there were some nuclei that showed particularly strong resonances, or conversely, for any one nucleus there were some regions of neutron speed in which the resonances were particularly pronounced. Such regions are called "giant resonances."

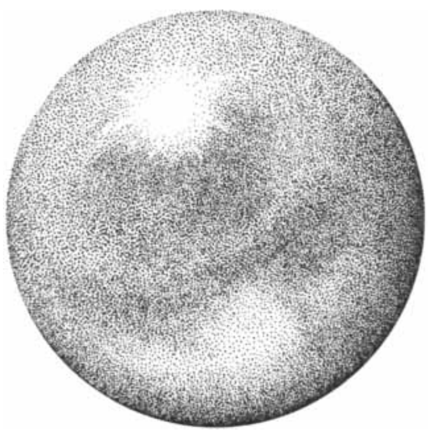
The Optical Model

These results were linked by Victor F. Weisskopf of the Massachusetts Institute of Technology to an "optical model" of the nucleus in which we go back to the picture of the particle moving by itself through a field of force. To this picture, however, we add the possibility

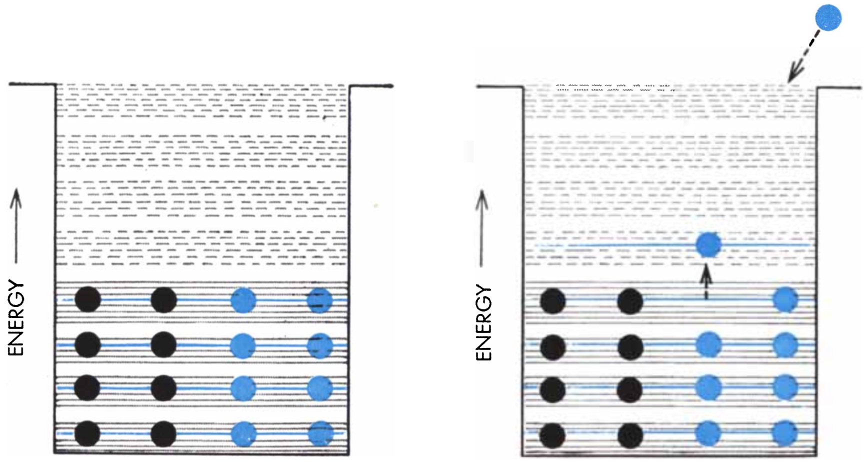
SHELL MODEL of the nucleus is represented by a potential "well" in which the groups of horizontal lines indicate orbits that can be occupied by particles in the nucleus. The groups of solid gray lines indicate orbits of lower energy; the groups of broken gray lines represent orbits of higher energy.



LIQUID-DROP MODEL may also be represented as a collection of golf balls. When another particle, or golf ball, enters the nucleus, the motion of all the balls is disturbed.



OPTICAL MODEL pictures the nucleus as a somewhat cloudy crystal ball. The cloudiness represents the tendency of bombarding neutrons to be absorbed by the nucleus.

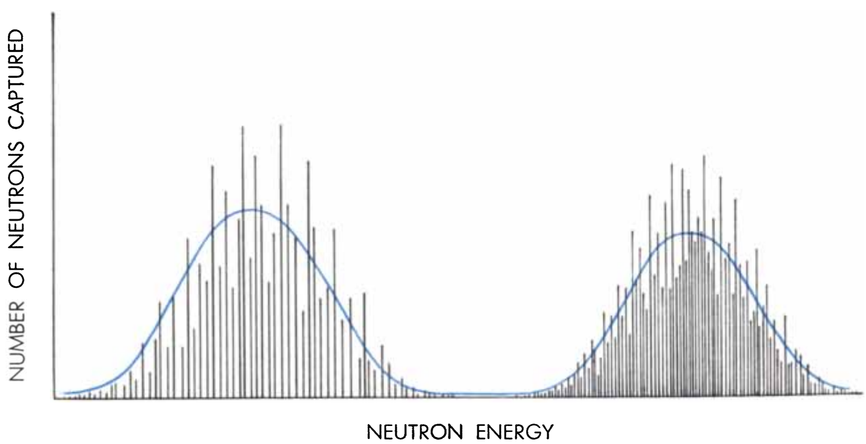


LOW-ENERGY ORBITS in the shell model of the nucleus may each be occupied by only two neutrons (*colored balls*) and two protons (*black balls*). In the normal state of affairs (*left*) the low-energy orbits are filled; the particles cannot gain or lose energy, and thus cannot change their orbits. A bombarding particle (*upper right*) has energy to spare; thus it can exchange energy with a particle in nucleus and move it to orbit of higher energy.

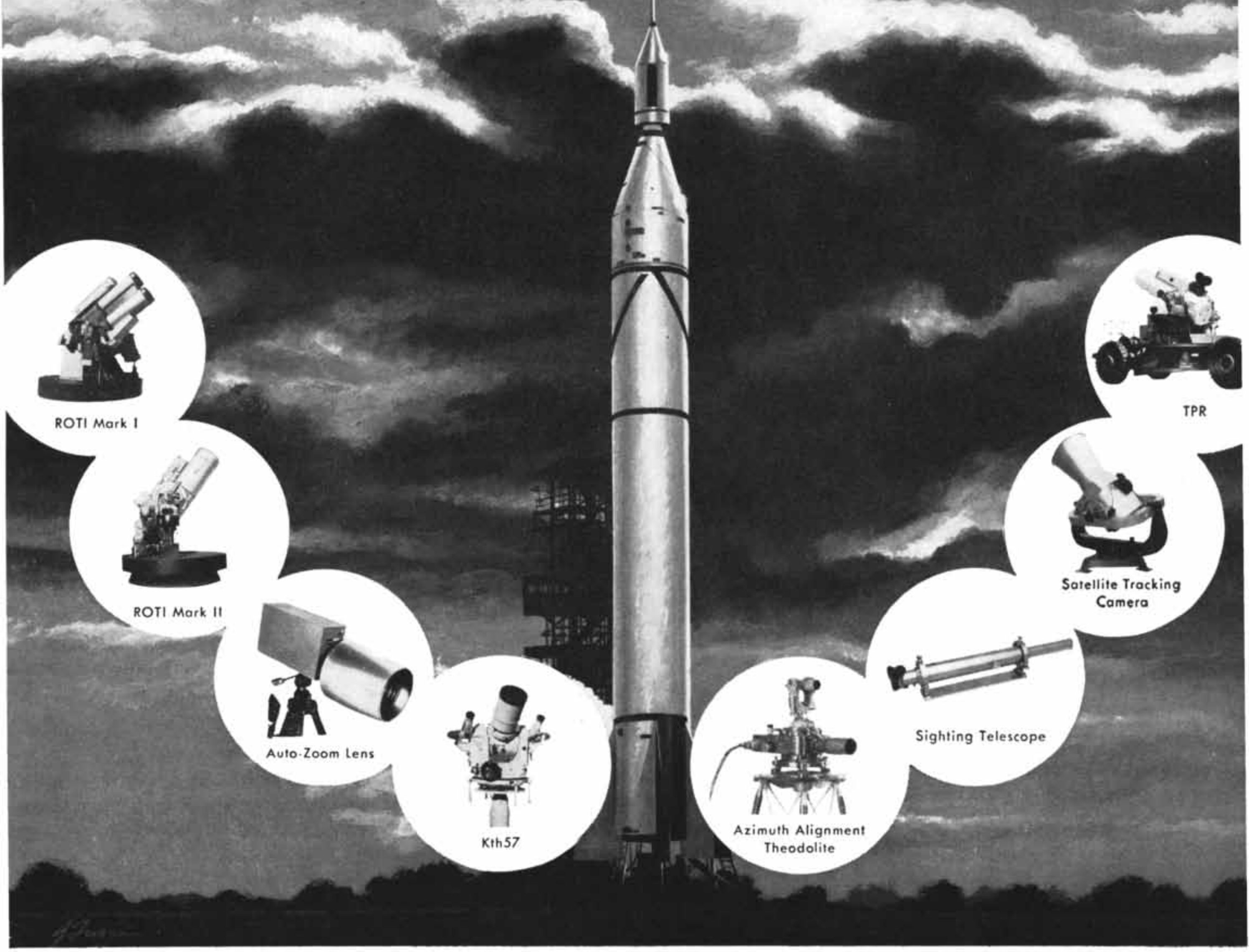
of the particle being absorbed, *i.e.*, lost from the beam of bombarding neutrons [see "A Model of the Nucleus," by Victor F. Weisskopf and E. P. Rosenbaum; SCIENTIFIC AMERICAN, December, 1955]. How can we understand the success of this picture of independent particle motion in view of the Bohr argument?

The answer to this question has been given in essence by Weisskopf. It may be expressed by considering the time sequence of events. To be sure, the bombarding particle is likely to be disturbed from its path by collisions, but this will take a little time. So for a short time it will penetrate into the nucleus on a regular orbit, and this initial period is important for determining whether it will actually get deep inside or be turned back at the surface. Now, to recall once again the uncertainty principle, we know that in talking about a short time interval we must not try to specify the energy too accurately. We should therefore think not of neutrons with a well-defined energy, but of a beam of neutrons varying in energy by an amount that is greater the shorter the time in which they are likely to be involved in collisions inside the nucleus. Experiments often make use of such mixed beams, if the experimenter does not take trouble to select the neutron energies accurately. If we have data with accurate energy selection we should lump together the observations over a suitable range of energies.

Then we do not see the sharp resonances any more because there will al-



GIANT RESONANCES of a typical nucleus are indicated by the colored curve. Each of the vertical lines represents an ordinary resonance. The height of each line denotes the number of bombarding neutrons at that energy which are trapped within the nucleus, or which emerge from the nucleus with only part of their original energy. Giant resonances are observed when nucleus is bombarded with particles of lower energy and lower resolution.



P-E optical range instrumentation provides vital missile data

checks behavior from production through flight

Engineers must *see* what is happening to a missile at every stage of its life. And Perkin-Elmer optical range instruments help them see . . . on the production line where stable platforms are aligned by P-E theodolites . . . at the launching site where P-E instruments first lay the missile for flight and then record vital data about its ascent . . . downrange where P-E tracking instruments let observers watch – and learn from – its meteoric journey across the skies.

Data grows more complex as the state of the art advances and the demands upon optical range instrumentation multiply. That calls for a high order of creative engineering. The number of P-E instruments in the missile program today demonstrates the emphasis that Perkin-Elmer places on this singular talent.

ROTI (Recording Optical Tracking Instrument) Mark I — Twin telescopes equipped with cameras track and record flight data on missiles and airborne objects.

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Azimuth Alignment Auto-Theodolite — Short, intermediate and long range models align inertial guidance systems at assembly and at the missile launching site.

Sighting Telescope — Combines wide field of view and high magnification for quick target acquisition.

SATRACK (Satellite Tracking Camera) — Employs P-E aspheric optical systems. High light-gathering power, wide field of view will enable camera to photograph IGY satellites.

Auto-Zoom* Lens — Extends versatility and range of standard closed circuit TV cameras. Permits remotely controlled wide-angle or closeup observation of action, target or instruments.

An interesting booklet, "Optical Tracking Instruments," describes these and other P-E instruments for the Space Age more fully. Write for it.

*T.M.

ENGINEERING AND OPTICAL DIVISION

Perkin-Elmer *Corporation*

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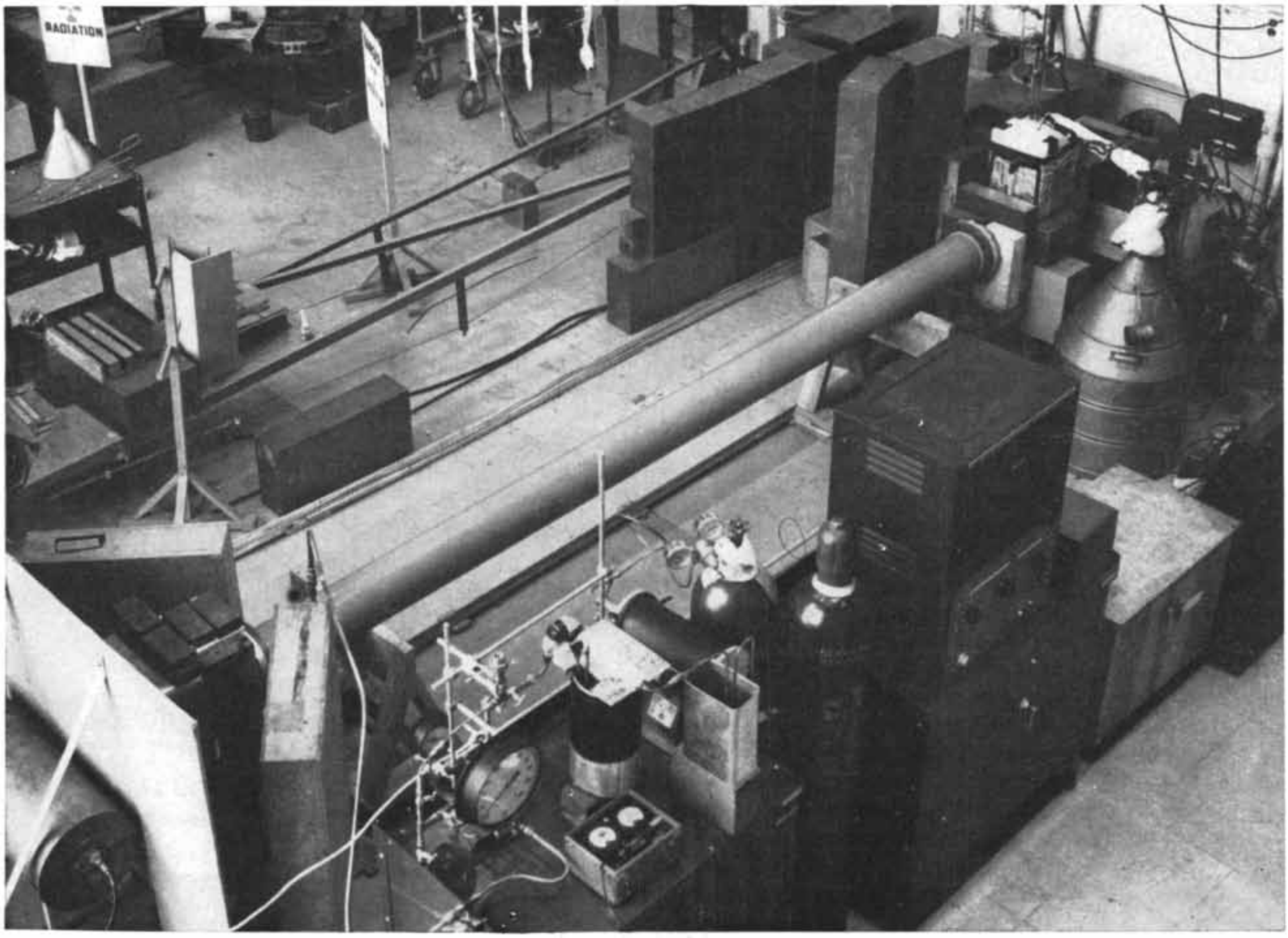


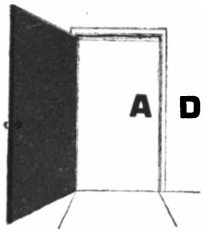
OXYGEN NUCLEI ARE BOMBARDED with neutrons in this apparatus at the Brookhaven National Laboratory. The neutrons are produced by the Brookhaven nuclear reactor, the concrete shield of which is visible at right. The oxygen atoms are contained in the long tank in the middle of the picture. The neutrons which are not absorbed are counted in the shorter tank at lower left.

ways be many of them within the energy range we use. The result we get in this way will reflect the number and strength of the resonances within the selected range. But we may now think of these results also as determined by the first short time interval of the event, and as the neutron pursues a regular orbit during this short time interval the results now should reflect the behavior of such regular orbits. This therefore leads us directly to the picture of the optical model, which has neutrons traveling in regular orbits. The absorption which was allowed for in Weisskopf's optical model merely reflects the fact that the particles do not stay on such a regular orbit forever, but are sooner or later removed from it by collisions with other particles.

The strength of this absorption is thus related to the rate at which collisions occur inside the nucleus. If they are very frequent, so that the particle covers only a small fraction of the nuclear diameter before it hits something, the "giant resonances," which correspond to the orbits of a single particle, will become weaker and more diffuse. The fact that they are found to be pronounced and distinct shows that the particle has a fair chance of completing at least one revolution in its orbit. In this respect we see that the extreme form of Bohr's liquid-drop model, or our simple picture of golf balls, exaggerates the situation. But we have succeeded in reconciling Bohr's explanation of the many sharp resonances in terms of the many-body aspects of the problem, with the superimposed structure of giant resonances, which characterize the early stages of the process.

It remains to account for the quantitative features of the optical model—and in particular for the long time a particle can stay in its orbit before being thrown out of it by a close encounter with another particle—in terms of the basic forces. A promising attack on this problem is now under way. The workers engaged in it include G. E. Brown in the author's group at the University of Birmingham. In particular, the low rate of collisions is seen to be linked again with the effect of the exclusion principle. We have seen that this cuts down the rate of collisions in a normal nucleus drastically. In the impact problems where there is more energy to spare, the collisions are more frequent, because there are more orbits available that are not already occupied, but the prohibition is still partly effective and the collision rate is still a good deal less than that suggested by the picture of golf balls, for which all quantum effects, including the exclusion principle, are of no importance.

A picture thus emerges in which the various, apparently contradictory, models of the nucleus are seen as consistent parts of a whole, each appropriate for answering certain questions about the behavior of nuclei. There are problems for which yet other models have to be used, including the important "collective model" developed by Aage Bohr and B. Mottelson of Copenhagen, but it would exceed the scope of this article to describe them and show how they fit into the story.

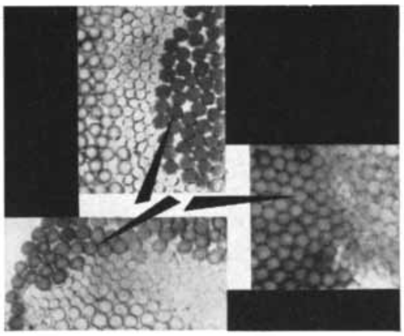


A DOOR IS OPENED... TO A NEW NYLON FROM FIBER RESEARCH

We're new to the textile business . . . at least the fiber end of it. But for some years Allied has concentrated on textile chemicals, and we've some reputation for our dyes, processing chemicals and finishing agents. So we took our chemical experience into fibers.

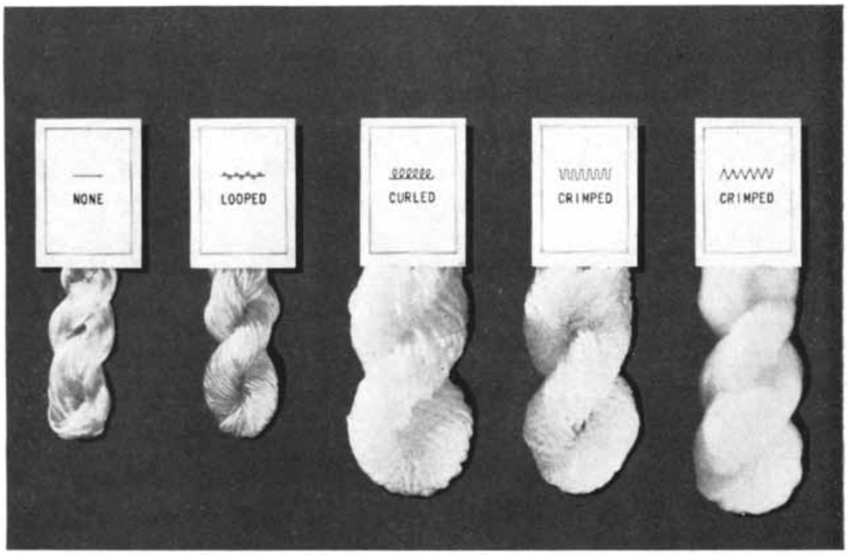
Allied turned to synthetic fibers as a new area for product achievement about ten years ago. Researchers worked on an important member of the polyamide family which had remained unexploited, nylon 6, and developed specific processes to improve its molecular architecture.

At the same time, they were meticulous about the purity of the starting material, epsilon-caprolactam monomer. So meticulous that it is the purest anywhere in the world. Color, for example, is specified at a maximum of 25 on an APHA standard; we usually bring it in at 3, and cannot detect color without instruments. The narrow range of alkalinity is such that it cannot be measured on a conventional pH meter. And the principal impurity, specified at a maximum of 25 parts per million, is normally analyzed at 5 p.p.m.



Dyeability. Dark areas show dye penetrating CAPROLAN carpet staple in contrast to surface-tinting conventional nylon (light areas). Both nylons were dyed together in the same bath.

Purity shows up in a fiber as whiteness and uniformity. But the creative process is rarely easy, and a lot of sweat, tears and caprolactam went into this project. The result is what our sales manager, with customary modesty, describes as "the first truly new nylon in 20 years." We call it CAPROLAN.



***Texturized filament CAPROLAN yarn.** Each skein is 60 yards of the same weight. Note how texturizing processes offer versatility of style and design.*

So it's new. But how *good* is it—and what's it good *for?*

Well, CAPROLAN is good for (actually better, of course) everything conventional nylon fiber is good for—carpeting, upholstery, outerwear, marine cordage, safety belts and many industrial uses. (If you should ever need an industrial sling—some people do, you know—CAPROLAN's tensile strength is such that you can make one with a breaking strength of 195,000 pounds.)

A lot of CAPROLAN is going into tire cord, too, where its resistance to heat, fatigue and shock makes driving safer. And cordage manufacturers are making CAPROLAN marine hawsers of 7-inch circumference that outperform 8-inch lines of conventional nylon.

But the use which best highlights the capabilities of CAPROLAN lies in the sphere of textiles. So here, unsuccessfully resisting the temptation to point out it makes a darn good yarn, we'll talk about two of its paramount virtues—dyeability and texturizing.

Dyeability. This new nylon, being a white white, gives truer colors. It has a marked affinity for virtually every class of dyestuff, and its "deep-dye" characteristic permits dyes to penetrate deep into the fiber itself instead of being merely deposited on the surface.

Texturizing. In filament yarns, a door is opened to fabric engineering and design. Due to their parallel arrangement of filaments, CAPROLAN heavy yarns are especially compliant to the newer texturizing processes (often called "bulking"). One of our statistically minded engineers has estimated that 45,759 completely new and different yarns are possible, depending on variations in denier and bulking processes.

WE'D LIKE TO TELL YOU MORE of the outstanding performance characteristics of CAPROLAN—and in greater detail. Why not write us, indicating your interest in carpeting, upholstery, cordage, tires or whatever, and telling us what you can about your proposed use of this new nylon. Address: Allied Chemical Corporation, Dept. 19-S, 61 Broadway, New York 6, N. Y.

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BASIC TO AMERICA'S PROGRESS

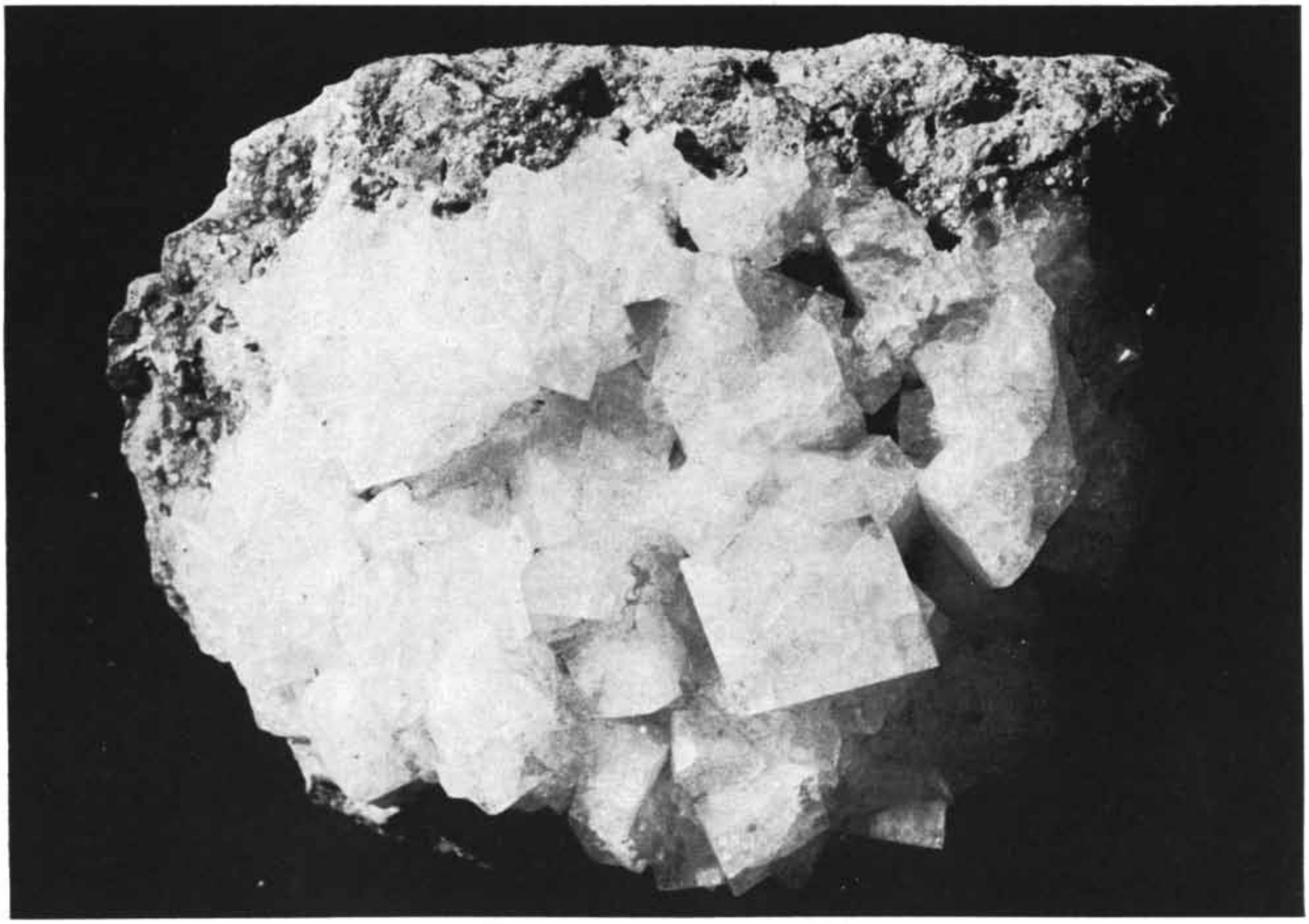
MOLECULAR SIEVES

The zeolite minerals, whose crystals contain a myriad of minute pores, have made possible a new branch of chemical technology. They can perform precise separations of very similar molecules

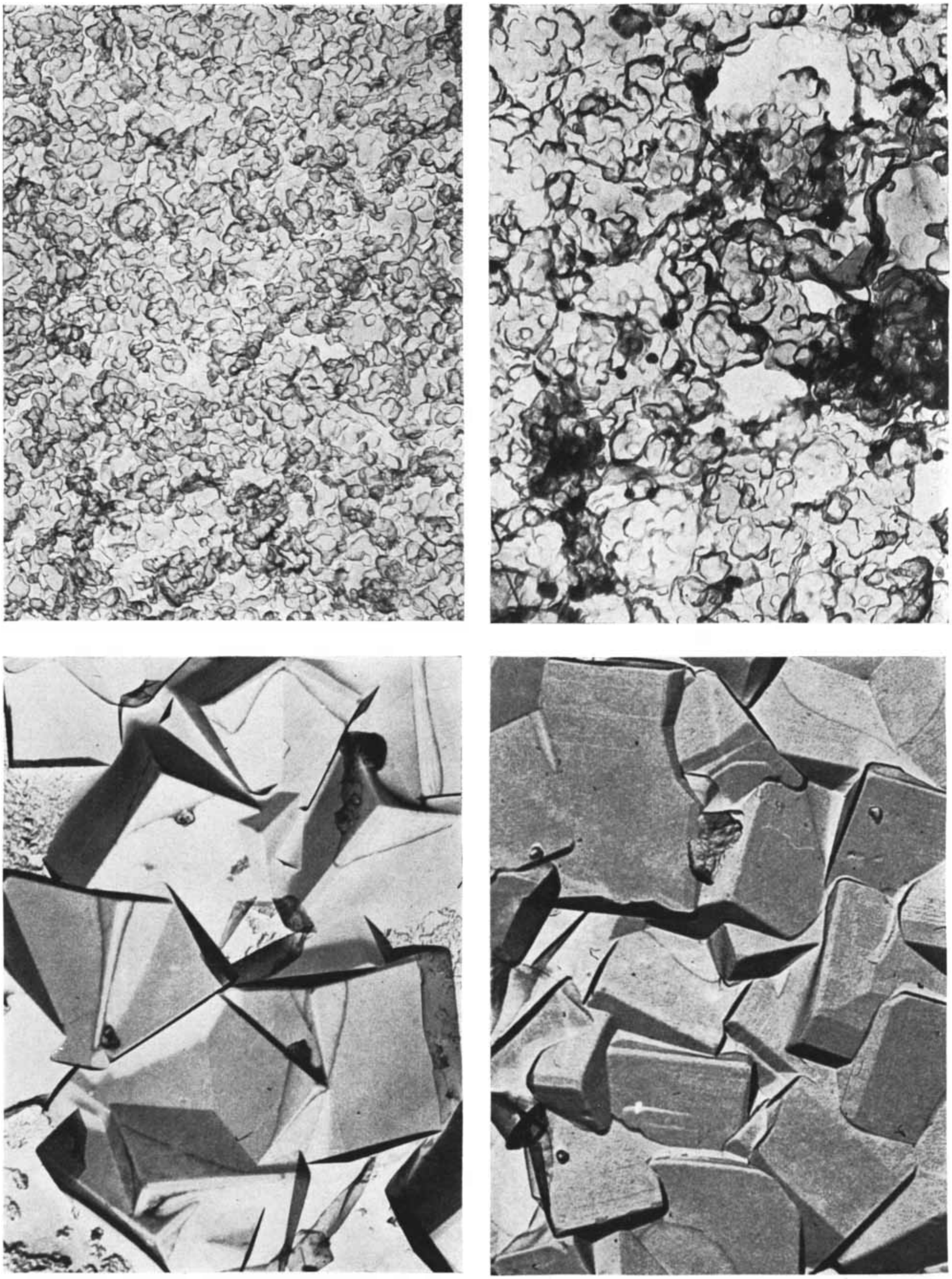
by D. W. Breck and J. V. Smith

An amateur mineralogist, probing a cavity in a volcanic outcrop, will occasionally come upon a gleaming white cluster of prismatic, rhombohedral or needle-like crystals. Tapped loose from their black basaltic matrix and examined at leisure, they display some unusual properties. When one of these crystals is heated gently in a test tube, it will give off water vapor, but unlike most other water-bearing crystals it will not disintegrate in the process. When it cools, it will adsorb water to replace that which it has lost. When such a crystal is heated to a higher temperature in a flame, it will sometimes seem to melt and boil simultaneously as it fuses into a bubbly glass. These crystals are zeolites (from the Greek *zeo*, meaning to boil, and *lithos*, meaning stone). The unique molecular structure which explains their peculiar behavior is now making itself useful in a new branch of chemical technology.

The Swedish mineralogist Baron Cronstedt gave these "boiling stones" their name some two centuries ago. Mineralogists later distinguished some 40 kinds of zeolites, each with its own crystal structure. Analysis showed that all of



NATURAL ZEOLITE CRYSTALS are found in the crevices and cavities of volcanic rocks. Shown here are the rhombohedral crystals of chabazite, one of the commonest of these rare minerals. Some other varieties of zeolites have prismatic or needle-like crystals.



SYNTHETIC ZEOLITE CRYSTALS can now be grown in the laboratory. This series of electron micrographs (magnification 30,000 diameters) shows the growth of "Type A" zeolite crystals. The process begins with an amorphous mass of silica-aluminum-sodium gel (*upper left*) and ends with a dense mass of cubical crystals (*lower right*) averaging about .001 millimeter on a side.

them are complex silicates containing aluminum and one or more other metallic elements: usually sodium, potassium or calcium. However, zeolites of the same crystalline form frequently differed in chemical composition. Three specimens—each with the same proportion of silicon, aluminum and oxygen—might contain sodium in one case, calcium in another and both in a third. Chemists were able to explain these puzzling variations when they found that zeolites could exchange electrically charged atoms (*i.e.*, ions) with other substances. For example, when they soaked a sodium-bearing zeolite in a solution of calcium chloride, the sodium and calcium ions gradually changed places and the crystal became a calcium-bearing zeolite. Manufacturers of water-softening equipment have for many years taken advantage of this property by using amorphous (noncrystalline) zeolites to remove the calcium ions which make water hard.

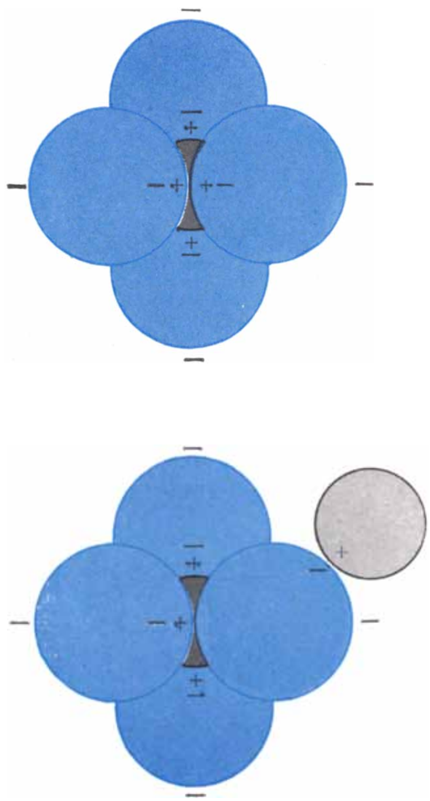
Though ion exchange accounted for the varying composition of some zeolites, it did not explain their mysterious ability to lose and gain water. Indeed, it provided a mystery of its own. Feldspars, which are common minerals of much the same composition as zeolites, do not exchange ions and do not contain water. Crystals of other substances which do contain water normally disintegrate when the water is driven off by heating. A number of investigators suggested that the properties of zeolites could be explained on the assumption that these crystals possessed a porous structure. X-ray diffraction studies in the early 1930s confirmed this hypothesis. The diffraction patterns of several zeolites showed that each crystal contains a precisely arrayed network of minute cavities linked by apertures. The water molecules and exchangeable ions lie in the cavities, not in the crystal framework, and can pass through the apertures. This arrangement makes possible reversible dehydration and ion exchange.

The fundamental "building block" of any zeolite crystal is a tetrahedron of four oxygen ions surrounding a smaller silicon or aluminum ion. Each of the oxygen ions has two negative charges; each silicon ion has four positive charges; each aluminum ion, three. A silicon thus takes on a "half-interest" in the eight charges of the four oxygens which surround it. Each oxygen retains one negative charge which enables it to combine with another silicon or aluminum ion and extend the crystal lattice in all directions. The aluminum ion, with one less positive charge than the silicon, can only satisfy three negative charges of the four oxygens which surround it. To produce a stable crystal structure it must have the help of another positively charged ion. This is the function of the exchangeable ions. A sodium or potassium ion can make up the charge deficit of one aluminum ion; a calcium ion, with two charges, will neutralize two aluminums. The exchangeable ions attach themselves loosely to the oxygens at the corners of the tetrahedra.

The structure of most crystals extends uniformly in all directions without leaving empty spaces. In zeolites, however, the framework of silicon-oxygen and aluminum-oxygen tetrahedra forms a structure which is honeycombed with relatively large cavities. The shape and size of the cavities depend on the variety of zeolite. For example, in chabazite, which is one of the commonest zeolites, six silicon and aluminum ions, with their associated oxygens, form a tight hexagon. Two of these hexagons face each other to form a flattish prism. Eight prisms linked together partially enclose a roughly football-shaped cavity whose longest diameter is about 11 angstrom units (one angstrom unit is a hundred millionths of a centimeter). Each cavity connects with six adjacent cavities through apertures about 3.9 angstroms in diameter [*see illustration on next page*].

Feldspars, which are commonly found in association with zeolites, are built of the same silicon-oxygen and aluminum-oxygen tetrahedra. In volcanic rocks both minerals evidently originated in hot, water-bearing lavas. After most of the minerals in the lava had crystallized out as feldspar, the zeolites formed in the dilute solution which remained. Unlike the feldspars, they crystallized in such a way as to leave room for part of the excess water within their cavities. A cubic inch of chabazite contains about 5×10^{21} cavities, each filled with 24 molecules of water, along with four calcium ions.

If the myriad pores of a zeolite crystal are emptied of water by heating, it can adsorb other molecules like a sponge. Chemists investigating this phenomenon in the 1920s noticed that zeolites adsorbed some substances but not others. J. W. McBain of Stanford University seems to have been the first to speak of zeolites as "molecular sieves," thus suggesting that they could be used to separate one kind of molecule from another. Zeolites, in fact, resemble a "jungle gym" through which small children (*i.e.*, small molecules) can move easily while larger

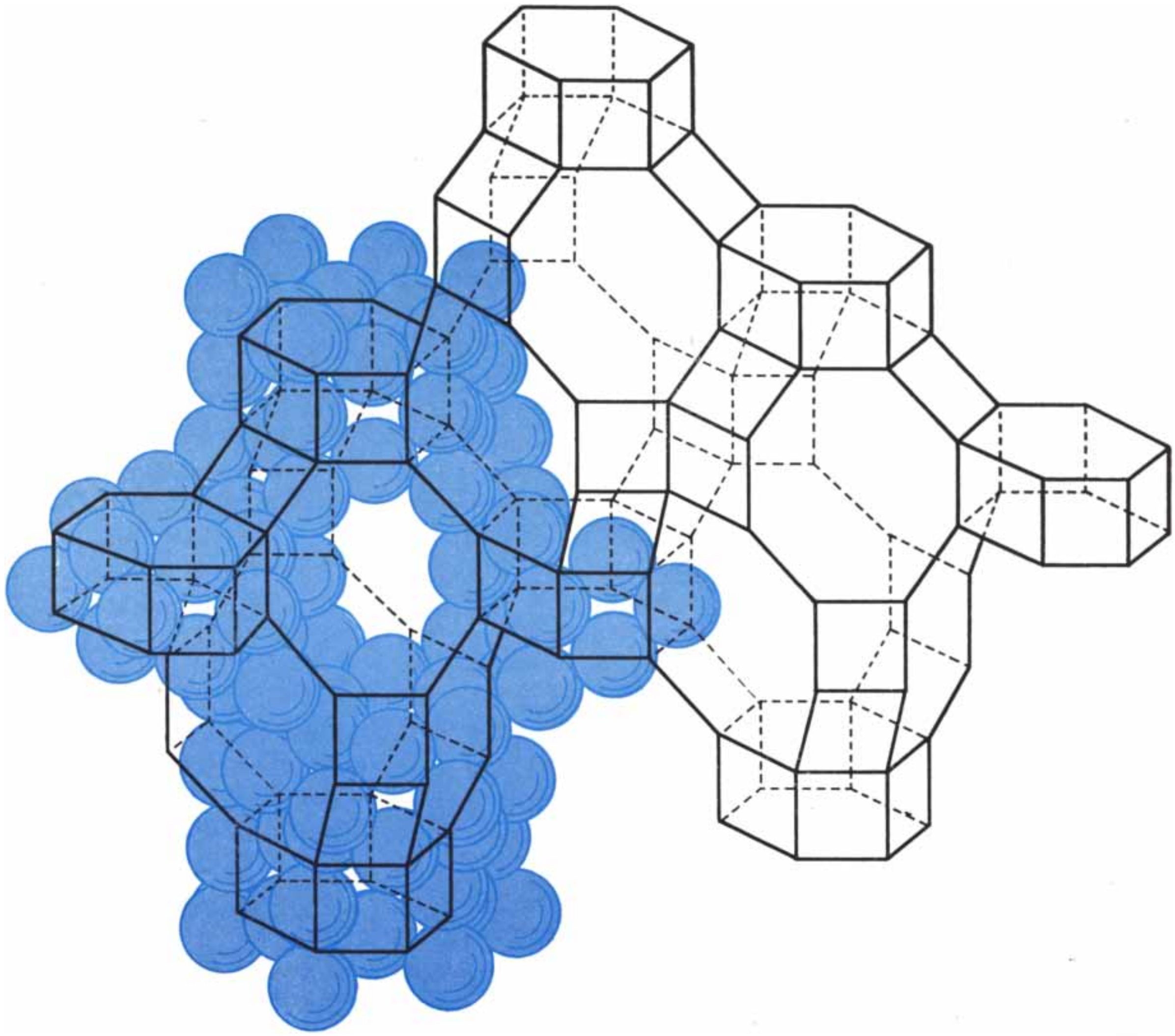


"BUILDING BLOCKS" of all zeolites are tetrahedra of four oxygen ions (*color*) surrounding a silicon or aluminum ion (*dark gray*). Silicon ion (*in upper drawing*) has four positive charges, which cancel half the charge on each oxygen. The remaining charge on each oxygen ion combines with another silicon or aluminum. Aluminum ion (*in lower drawing*) has only three positive charges; the deficit must be made up by another positive ion, *e.g.*, sodium (*light gray*).

children can move only with difficulty or not at all. For example, water molecules easily pass into a chabazite crystal but the larger molecules of propane must remain outside.

In 1938 R. M. Barrer, now of Imperial College in London, undertook a lengthy study of zeolite molecular sieves. His investigations led the Linde Company to inquire whether zeolites could be used to separate atmospheric gases. In 1948 a group of Linde researchers, including one of us (Breck) set out to answer this question.

We first had to secure an adequate supply of zeolites. The rarity of natural zeolite crystals compelled us to seek ways to produce our sieves artificially. Some types of zeolites had been grown in the laboratory, but the crystals invariably had small cavities and small apertures. We found that these unsatisfactory results stemmed from the use of relatively insoluble ingredients which necessitated growing the crystals at high



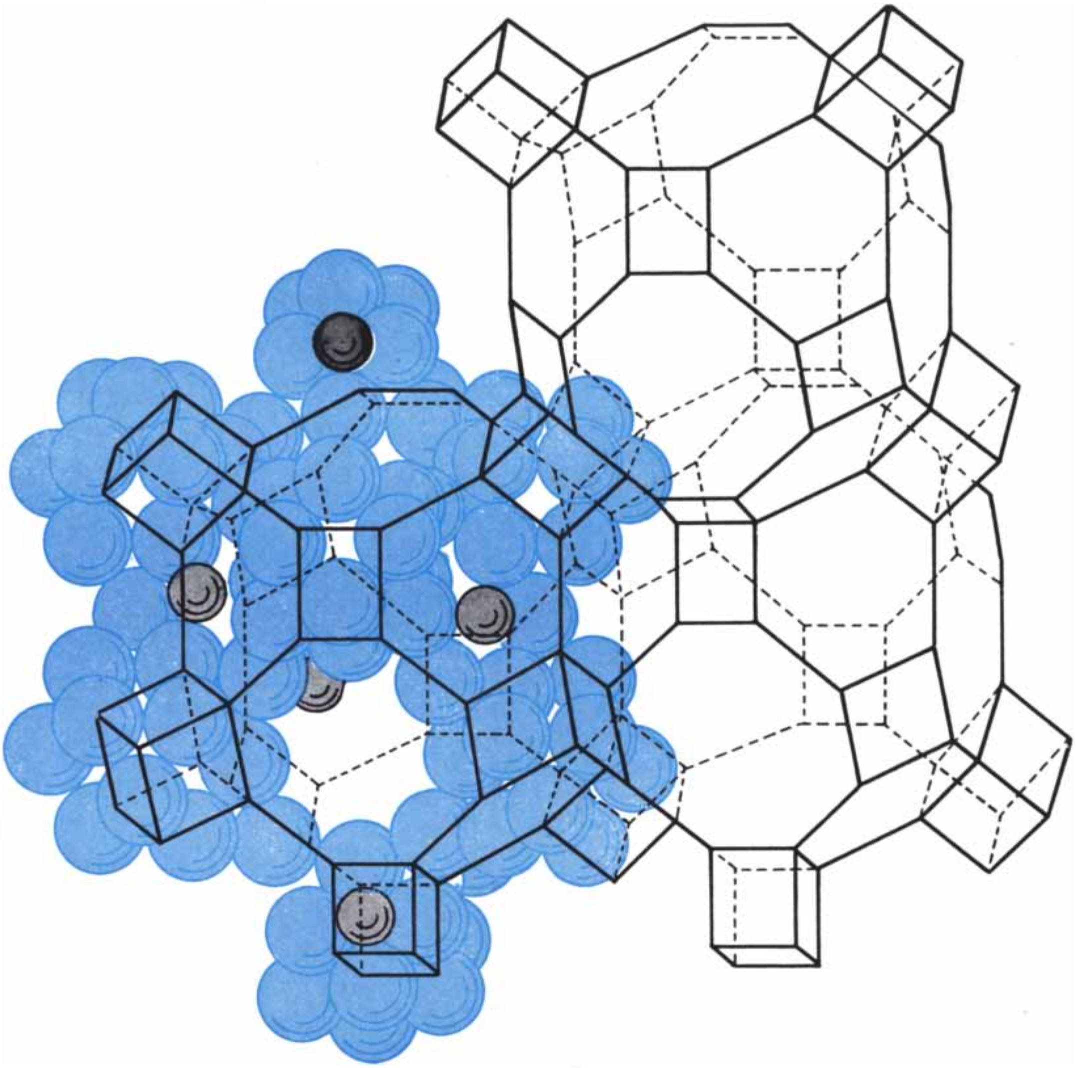
MOLECULAR STRUCTURE OF ZEOLITES reveals the cavities which account for their peculiar properties. Silicon and aluminum ions (*not shown*) occupy the corners of the frameworks depicted schematically in black; they are surrounded by oxygen ions (*colored spheres*). Each unit of the framework contains one large cavity which is connected to adjacent cavities through apertures.

temperatures. By using more soluble starting materials (a mixture of sodium and aluminum oxides and freshly prepared silica gel) we were able to hold down the temperature and produce crystals with a high adsorptive capacity. At first we grew them in a sort of pressure cooker; more recently we have obtained good yields at atmospheric pressure.

By 1952 we had produced nearly a dozen types of synthetic zeolites. Some were analogues of natural crystals; others were entirely new varieties, including a most useful new sieve we call Type A. This synthetic zeolite has pores of a high capacity, and apertures that can be adjusted to perform many useful separations. Moreover, it withstands temperatures as high as 700 degrees centigrade—hot enough to melt aluminum. The roughly spherical cavities, some 11 angstroms in diameter, each have a volume of about 925 cubic angstroms. Together they account for about half the volume of a crystal [*see illustration on opposite page*]. The crystals themselves are about 1,000th of a millimeter across. We can grow them larger, but the smaller crystals seem to sieve quite as efficiently as the large ones.

The "mesh" of a zeolite sieve of course depends not on the volume of the cavities but on the diameter of the apertures which connect them. The apertures of sodium-bearing Type A have a diameter of 3.5 angstroms. One might expect that molecules more than 3.5 A. in diameter would be unable to enter the crystals, but the reality is not quite so simple. We find, for example, that ethane molecules, with a diameter of 4 A., readily pass through the 3.5-A. apertures at normal temperatures; propane molecules, 4.9 A. in diameter, do not. The reason becomes clear enough when we recall that atoms are not rigid bodies. They more nearly resemble pulsating rubber balls. The pulsations of both the aperture atoms and the incoming molecules combine to make the effective diameter of the aperture considerably larger than its "free" diameter of 3.5 A. Moreover, the kinetic energy of the incoming molecules helps them to "shoulder their way" through the opening. We have found in general that at ordinary temperatures molecules up to .5 A. wider than the free diameter of the aperture can pass through it easily. Larger molecules enter the crystal with greater and greater difficulty; molecules 1 A. wider cannot enter at all.

Because heat so directly affects the behavior of molecules, the regulation of temperature gives us precise control over the sieving properties of a zeolite. Molecules that are no wider than the free diameter of the apertures enter the

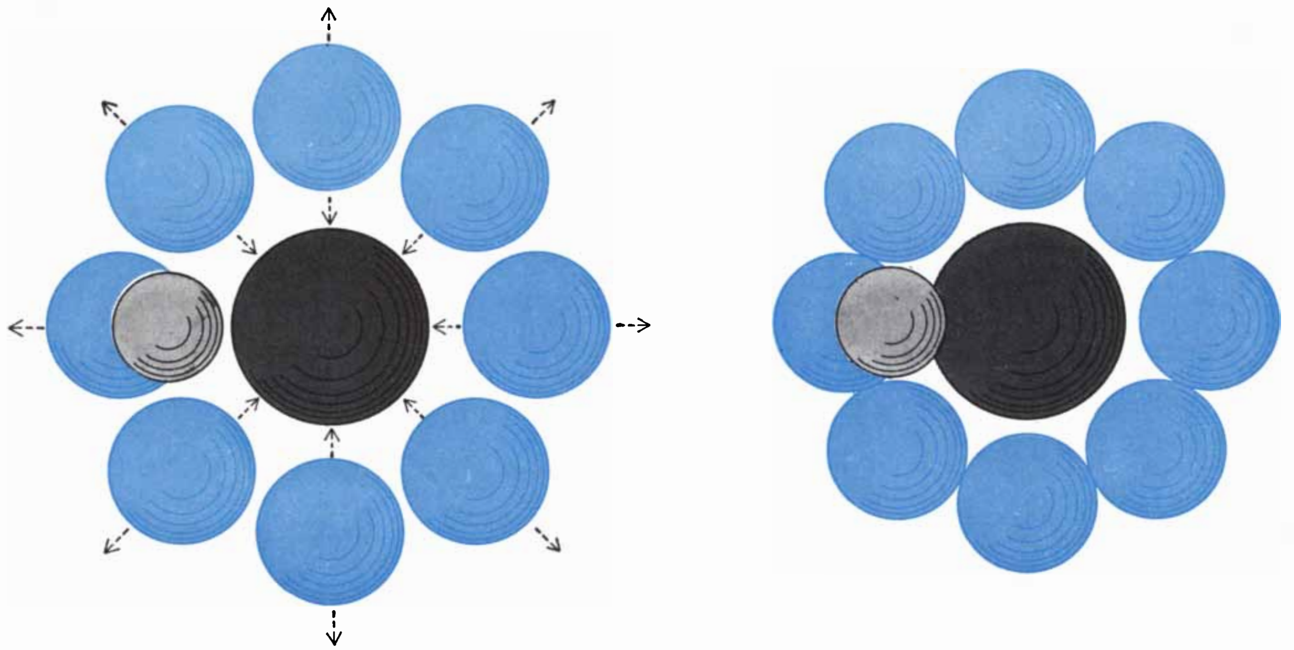


The diameter of the apertures determines the sieving properties of a particular zeolite. Chabazite (*left*), a natural zeolite whose crystal structure was determined at Pennsylvania State University, has apertures about 3.9 angstrom units in diameter. Apertures of "Type A," a synthetic zeolite (*right*), are only about 3.5 A. in diameter, due to sodium ions (*gray*) which partially block them.

crystals more readily at lower temperatures. Somewhat larger bodies, however, behave peculiarly as the temperature drops. Argon, for example, shows an increasing rate of adsorption down to --150 degrees C., but below this temperature the rate falls sharply. Nitrogen shows a similar drop at —120 C. Oxygen, by contrast, is freely adsorbed even below —200 C. Evidently the effective diameter of the apertures depends partly on the temperature. Chilling a crystal damps the vibrations of its atoms and "shrinks" the effective diameter of the apertures to something approaching their free diameter. Cold also cuts down the kinetic energy of the gas molecules. The oxygen molecule, only .1 A. wider than the apertures, can still pass through freely (except, perhaps, at temperatures close to absolute zero). The larger argon atom does not have enough energy below —150 C. to squeeze through. The nitrogen molecule, still larger, finds the squeeze even more difficult, and is blocked below —120 C. [*see top illustration on next page*]. If we fill a zeolite crystal with argon or nitrogen and cool it to —200 C., the gas will be trapped in the crystal.

We can alter the "mesh" of our sieve not only by changing its temperature but also by introducing different ions into it. In the sodium-bearing Type A zeolite, 12 sodium ions are associated with every cavity. Four of them take positions in or near the apertures and partially block them. Since there are six apertures and only four blocking ions, it might seem that two apertures would be unobstructed. But since each aperture serves two cavities, eight ions are available for every six apertures; the free diameter of the apertures is thus reduced to 3.5 A. If we soak the sodium-bearing crystal in calcium chloride solution, a single calcium ion replaces each pair of sodium ions. With only four ions now available for six apertures, two apertures will be unobstructed, and their diameter will increase to 4.2 A. We need not replace all 12 of the sodium ions in each cavity. For some as yet unknown reason the calcium ions first replace the blocking sodium ions. Thus we find that heptane, which cannot enter the sodium form of a Type A zeolite, begins to be adsorbed rapidly when only a third of the sodium ions have been replaced.

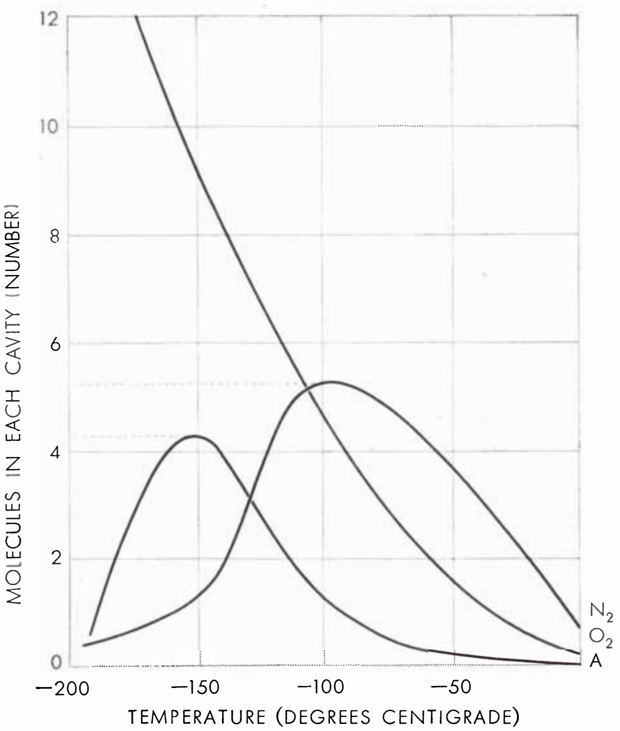
Ion exchange and temperature, working separately or together, can adjust the mesh of a molecular sieve to the needs of a particular separation problem. A good example of the practical application of this principle is the use of the calcium variety of zeolite A to upgrade gasoline. As it comes from the refinery, gasoline consists of a mixture of hydrocarbons, some of which ignite more readily than



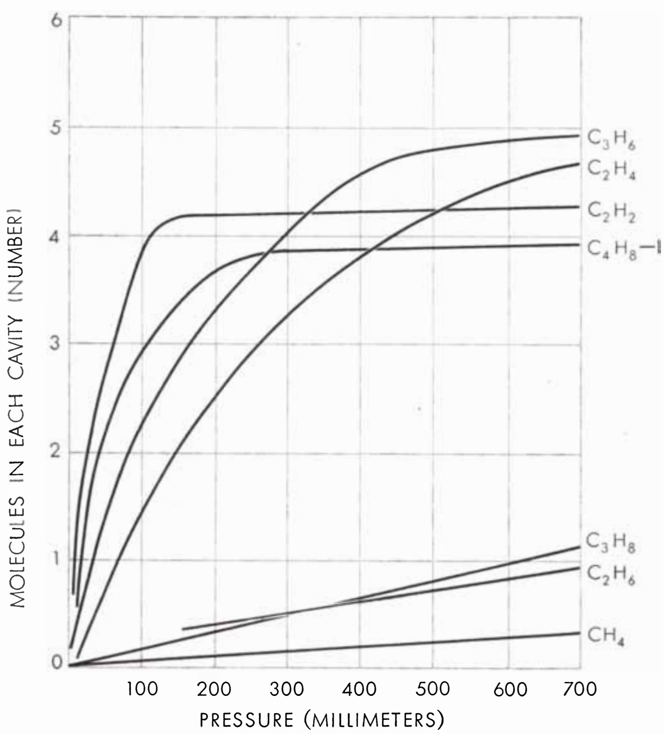
EFFECT OF TEMPERATURE on zeolite apertures is shown schematically. At 0 degrees centigrade (*left*) the oxygen (*color*) and sodium (*light gray*) ions which form the aperture pulsate rapidly (*arrows*). Nitrogen molecule (*dark gray*) can enter even though sodium ion partly blocks the way. At —150 degrees C. (*right*) the pulsations are damped and nitrogen molecule cannot enter.

others. Hydrocarbons whose carbon atoms are arranged in straight chains (for example, normal octane) tend to ignite prematurely, producing a "knock" which cuts the efficiency of the engine and may even damage it. Hydrocarbons with a branching structure (for example, iso-octane) burn less explosively and thus have a higher anti-knock or "octane" rating. Since the other physical and chemical properties of octane and iso-octane are almost identical, they cannot easily be separated by conventional methods such as distillation.

The sodium form of a Type A zeolite will not sieve octane from iso-octane, since neither molecule can enter its narrow apertures. The calcium form, however, separates the two without difficulty. The long, slender molecules of normal octane slip easily into the crys-



ADSORPTION OF GASES by zeolites normally increases at lower temperatures, as shown by curve for oxygen. Adsorption of nitrogen and argon drops off at —100 and —150 degrees C. due to "squeeze" shown at the top of this page. Below these temperatures, gas already in cavities is trapped (*broken lines*).



ADSORPTION OF HYDROCARBONS by zeolites is much greater for "unsaturated" hydrocarbons whose molecules contain double or triple bonds. From top to bottom the curves show adsorption (at 150 degrees C.) of propylene, ethylene, acetylene and iso-butylene (unsaturated) and propane, ethane and methane (saturated).

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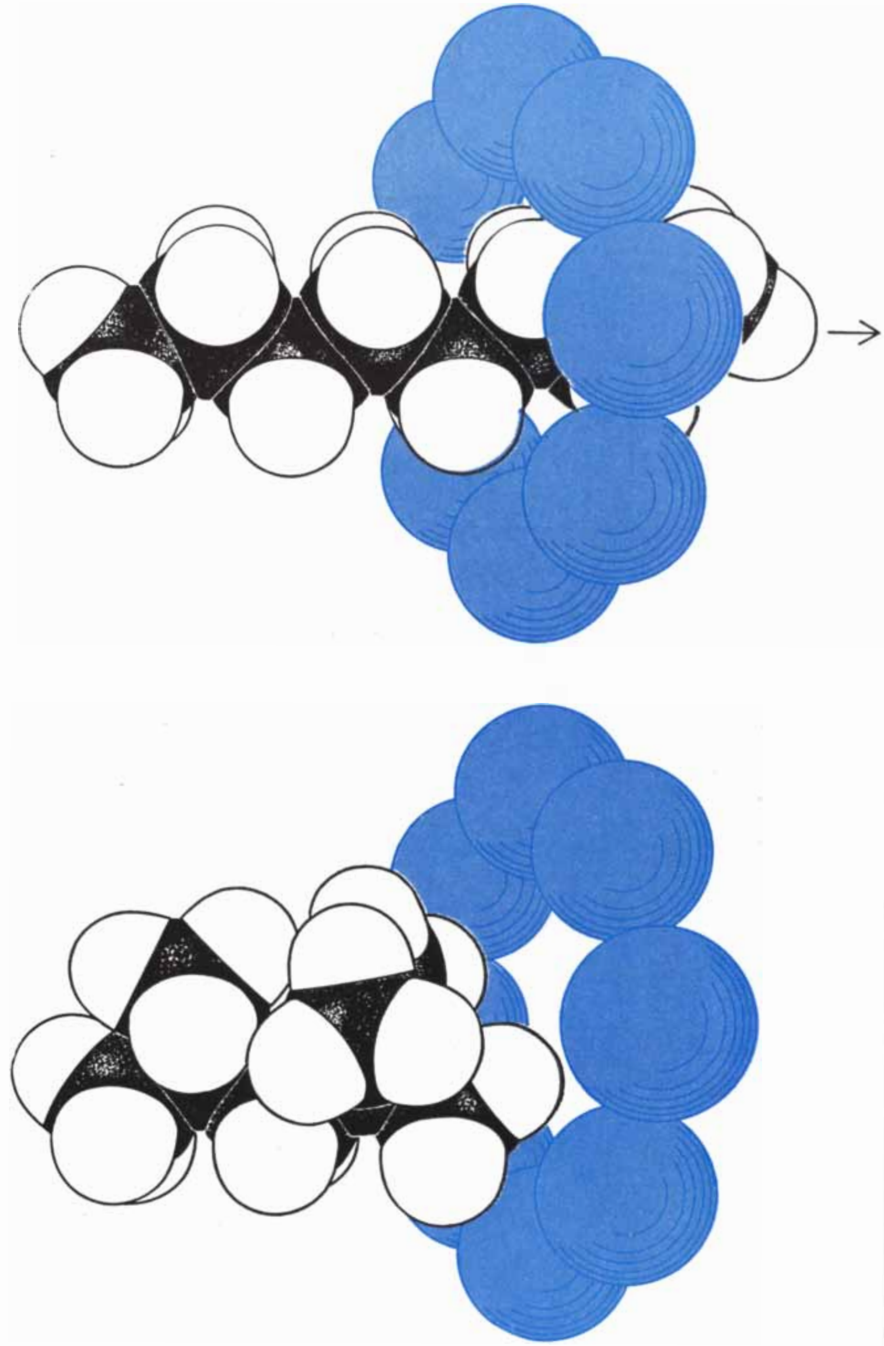


ZEOLITE SIEVE SEPARATES normal octane and iso-octane, two constituents of gasoline. Blue spheres indicate apertures of "Type A" zeolite; the sodium ions which partly block the apertures have been replaced by calcium ions (*not shown*) which do not. Straight-chain molecule of normal octane (*left*) can pass through the aperture; branching molecule of iso-octane (*right*) cannot. Except for iso-octane's higher "anti-knock" rating, the two compounds have almost identical properties, and are thus very hard to separate by ordinary methods.

tals, while the wider, branching molecules of iso-octane cannot [*see illustration above*]. Eventually, of course, the crystals become saturated with normal octane, but they can be quickly regenerated by a stream of hot gas.

Zeolite molecular sieves can not only separate molecules of different sizes; they can also segregate molecules of the same size but different electrical properties. The crystals have a particularly strong affinity for water molecules, and will adsorb them in preference to any other substance. The structure of the water molecule is asymmetrical: the two positively charged hydrogen atoms are both attached to the same side of the negatively charged oxygen atom. This "polar" structure gives the molecule a partial positive charge on one side and a partial negative charge on the other,

though the molecule as a whole is electrically neutral. These partial charges and similar charges on the inner surfaces of the zeolite cavities attract one another. So strong is the attraction that zeolite crystals will retain all their water at temperatures well above the boiling point, and can scavenge small residues of water at even higher temperatures. Zeolites are so avid for water that they can reduce the proportion of water in a gas or liquid to as low as four parts per million. This provides the basis for a highly efficient drying technique which is already being applied commercially by chemical processors to handle large quantities of natural gas at low temperature. Even small quantities of water combine with the hydrocarbons of natural gas to form hydrates which can freeze and clog pipes.

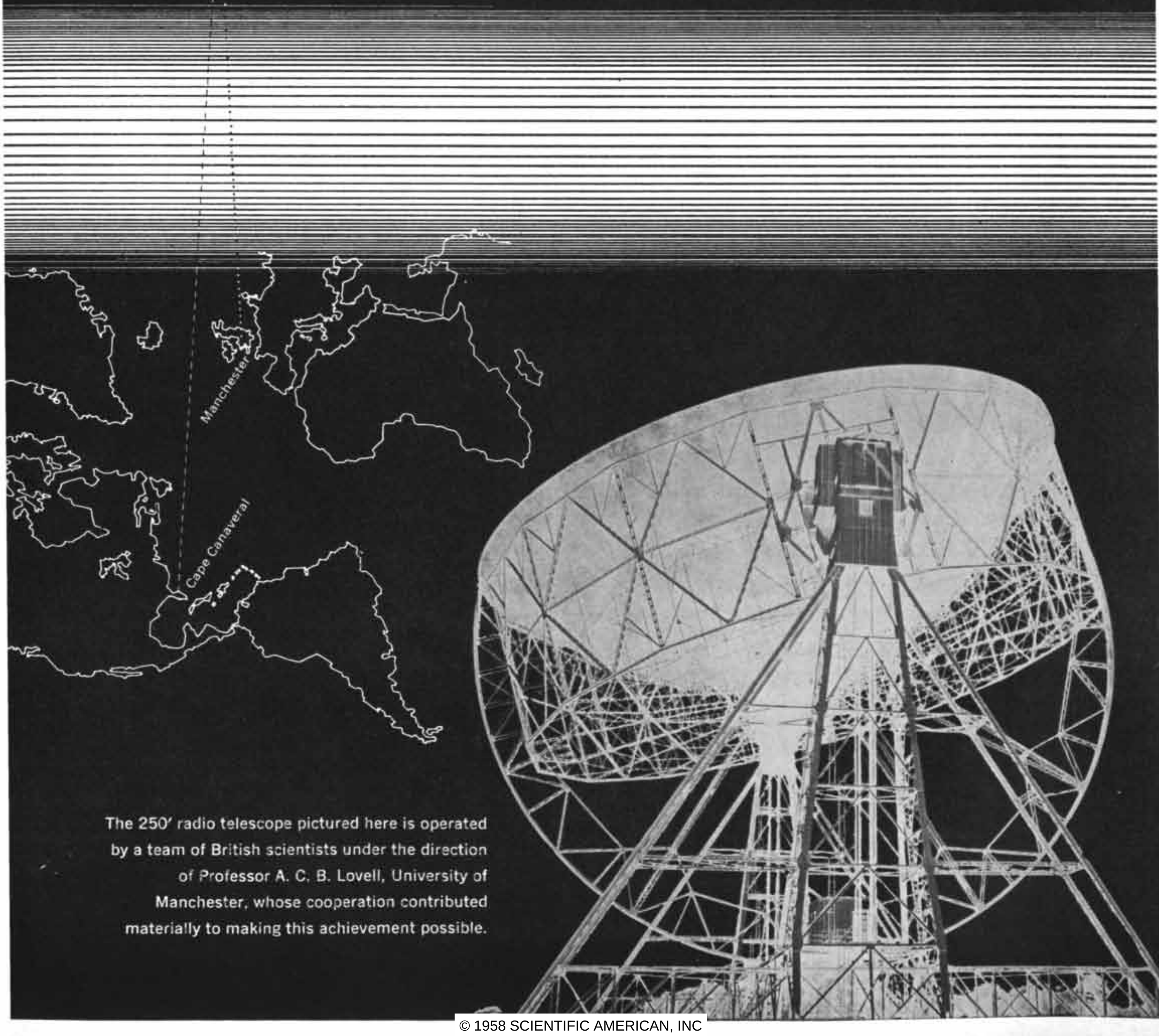
Along with their preference for water, zeolites display a somewhat similar preference for certain types of hydrocarbons. We have found that unsaturated hydrocarbons, in which some carbon atoms are joined by double or triple chemical bonds (for example, ethylene) are more "at home" in zeolites than saturated hydrocarbons which contain only single bonds (for example, ethane). Ethane and ethylene differ little in their physical properties, and their molecules are about the same size. Yet if we pass a mixture containing equal parts of the two substances through a bed of Type A zeolite (either the sodium or the calcium form), 80 per cent of the molecules that enter the crystals will be ethylene. Zeolites prefer unsaturated hydrocarbons because the molecules of these substances contain loosely bound electrons which give them polar characteristics resembling those of water molecules.

By choosing appropriate species of zeolites, matching their ionic content to the needs of a particular separation problem and juggling the temperature of the operation, we are developing a variety of new industrial sieving techniques. For example, we can now employ zeolites as "carriers" for certain catalysts which were previously unusable because of their high volatility. By trapping these substances in zeolites, we can use them to facilitate chemical reactions without losing them in the process. Zeolite adsorption may prove to be a safe method of disposing of radioactive wastes and ensuring that they do not contaminate water supplies or vegetation. But even if zeolites had no practical use whatever, they would fascinate the investigator because of the elegance of their unique molecular architecture.

MAN'S FIRST SPACE COMMUNICATION STATION

On 12 October 1958, an historic event took place. A group of Space Technology Laboratories' engineers at Cape Canaveral, Florida, transmitted radio signals far out into space to the NASA/Air Force Pioneer space probe vehicle. The tiny receiver and transmitter in the Pioneer relayed these same signals to the Space Technology Laboratories' group at Manchester University, England. • This significant experiment promises, like those earlier achievements of Morse, Bell, and Marconi, to pave the way for the use of space vehicles to relay information to and from points on earth. One day the entire world will view televised events as they happen. • Future experiments of this kind will undoubtedly assist mankind in his search to understand, use, and benefit from his knowledge of space phenomena. • Scientists and engineers whose interests and abilities enable them to contribute to these developments are invited to join our technical staff.

Space Technology Laboratories, Inc. P.O. BOX 95001, LOS ANGELES 45, CALIFORNIA



The 250′ radio telescope pictured here is operated by a team of British scientists under the direction of Professor A. C. B. Lovell, University of Manchester, whose cooperation contributed materially to making this achievement possible.

Trace-Element Deserts

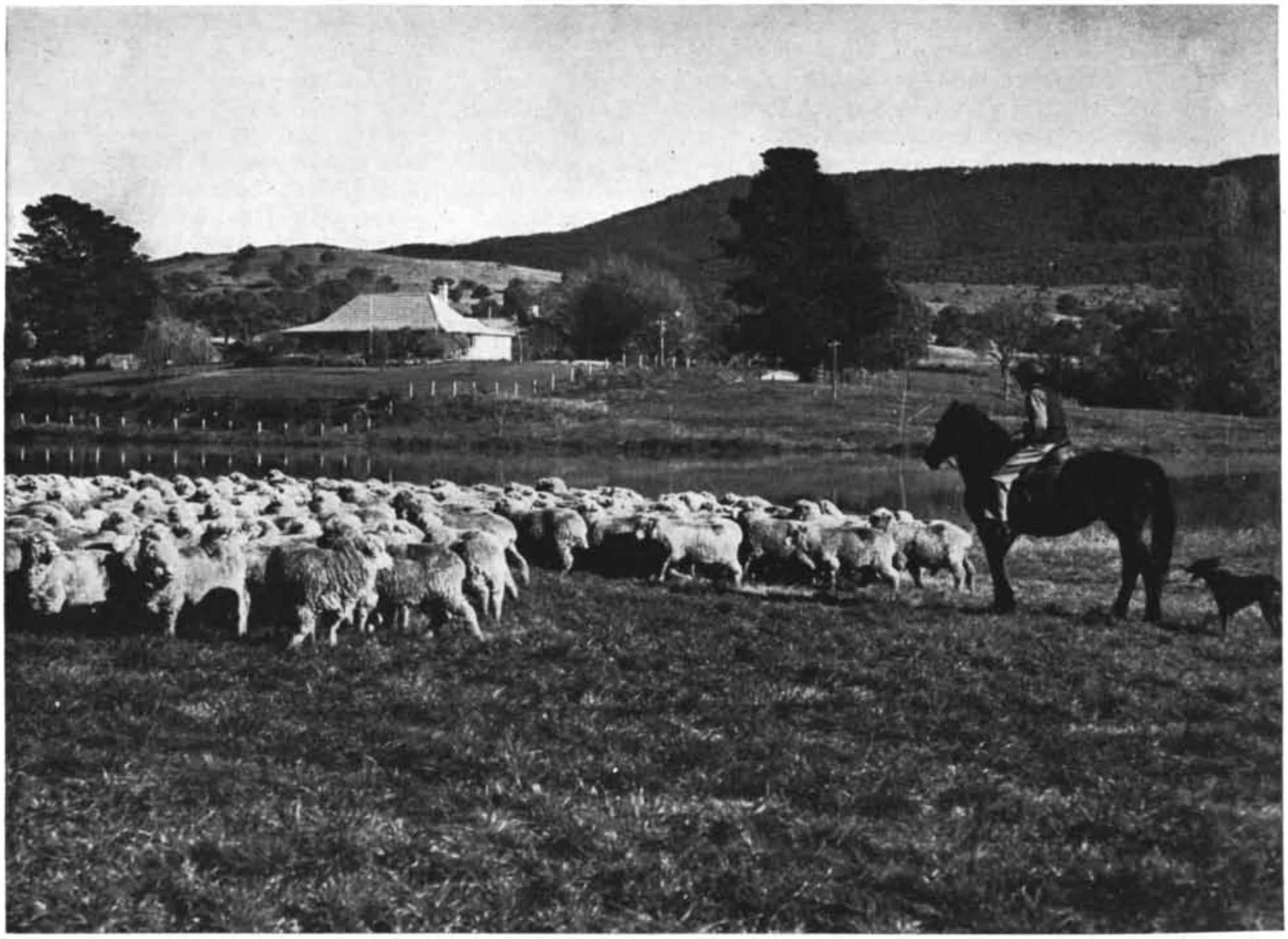
Throughout the world potential farmland goes to waste for the lack of elements required in traces by plants and animals. By rectifying such deficiencies, Australia hopes to reclaim some 300 million acres

by A. J. Anderson and E. J. Underwood

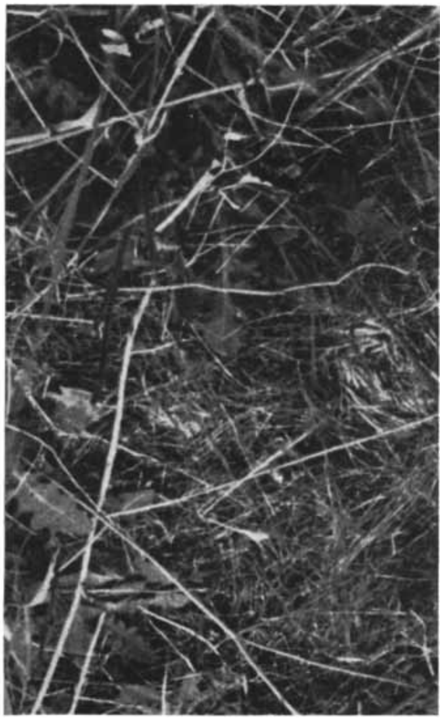
Until recently South Australia's Ninety Mile Desert was a scrubby wasteland of heath and eucalyptus thickets. Today its six million once worthless acres are being swiftly transformed into bounteous pastureland. The "Desert," which formerly supported one sheep per 20 acres, can now sustain 40 times that number. Indeed, the Desert—in name, at any rate—is no more: its prosperous new residents have rechristened it Coonalpyn Downs.

The new fertility of Coonalpyn Downs was not obtained by expensive irrigation or clearance projects. Like much of the world's unproductive land, it suffered from an ailment subtler than lack of water. Recent investigations have made it possible to diagnose a large group of deficiencies of soil, plants and animals. The infertility of the soil at Coonalpyn Downs was found to arise from the absence of an almost infinitesimal sprinkling of zinc and copper.

In the context of biology, zinc and copper are numbered among the "trace elements," that is, elements that com-



RECLAIMED DESERT in eastern Australia was once infertile from lack of molybdenum, which plants require in order to fix nitrogen from the air. Shown here are sheep being mustered for shearing on the reclaimed Southern Tablelands near Canberra.



RECLAMATION of Australia's Southern Tablelands is illustrated in this series of photographs. At left is shown a still-infertile portion of the Tablelands, which the reader may compare to the reclaimed area illustrated on the preceding page. The middle photograph shows

prise so small a part of the substance of an animal or plant that chemists of an earlier time, unable to measure them exactly, could state only that they had found a trace of them. Trace amounts of 20 to 30 elements occur in living matter. Some of the elements may be present by accident Others—we cannot yet be sure how many—are indispensable to higher organisms. Most of them apparently contribute to the catalytic activity of particular enzymes in the chains of molecular events that constitute the processes of life. The trace elements, along with the vitamins, are often called "micronutrients."

The study of trace elements promises rich rewards for the agriculture of the future. The world's food-producing capacity is already sorely taxed by the explosive multiplication of the human species. Yet it seems likely that hundreds of millions of acres are now kept from productivity by nothing more than the easily remedied lack of trace elements. The reclamation of Coonalpyn Downs is today being repeated in many parts of Australia; tomorrow the same methods may be ameliorating trace-element deficiencies in other underdeveloped regions of our planet.

The trace elements now recognized as essential to plant life are seven in number: iron, manganese, copper, zinc, molybdenum, boron and chlorine. Higher forms of animal life also need seven: the first five listed above plus cobalt and iodine. As research proceeds, these lists will doubtless grow. There is already suggestive, if not conclusive, evidence that plants need cobalt, sodium and vanadium, and that animals require selenium, bromine, barium and strontium.

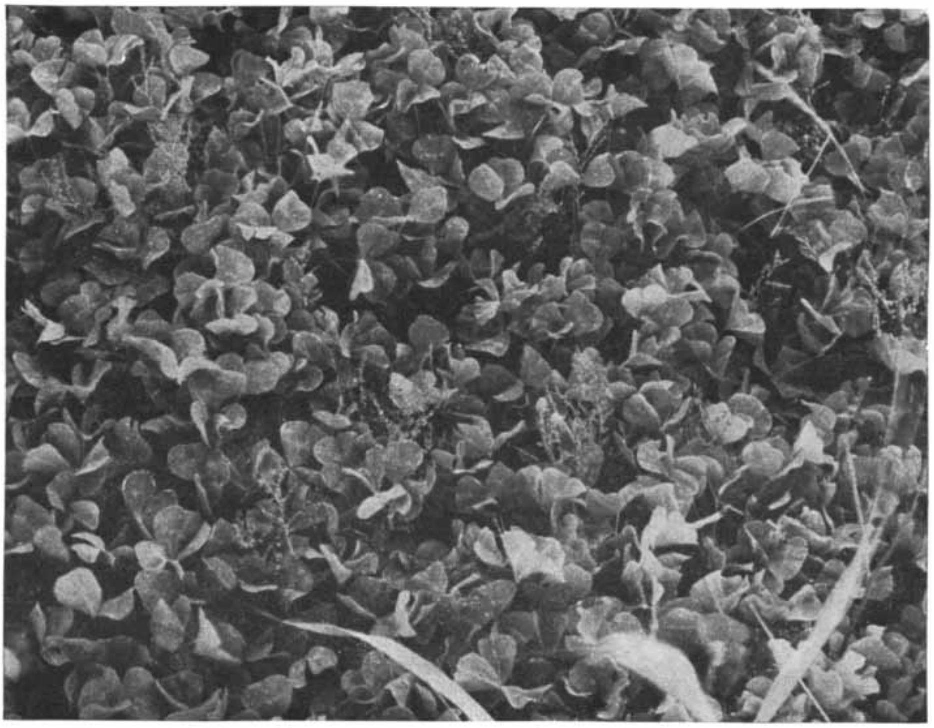
The need of the human body for certain trace elements has been known for some 100 years. Nineteenth-century French physicians found that iron therapy remedied the "green sickness" (anemia) of adolescent girls; the French investigator Eusebe Gris ascertained that plants grown in a medium free of iron were yellow and stunted. The careful observations of A. Chatin, another French worker, disclosed the connection between goiter and lack of environmental iodine. Thus iron and iodine were the first trace elements to be identified. Many years passed, however, before investigators traced these elements to the metabolic system: oxidative enzymes in the case of iron, and the thyroid hormone thyroxine in the case of iodine.

Not until this century was it known that organisms require trace elements other than iron and iodine. As early as 1860 the German workers W. Knop and J. von Sachs were able to raise green plants in artificial media without soil or organic matter of any kind. By supplying measured amounts of apparently pure mineral salts and water, they and their successors sought to determine the exact chemical requirements of plant life. The need for trace elements went unnoticed, because they were unwittingly supplied in the form of unobserved contaminants of the salts.

Experiments of this kind were conducted for more than half a century before the "pure" mineral salts were observed to contain trace elements. Without these hidden elements the plants could not have lived. While the trace elements had escaped detection by chemists, they were easily found and utilized by the plants growing in culture solution.

Animal experiments similarly overlooked the trace elements, which contaminated not only the mineral content of "pure" diets, but were also present in the crude vitamin supplements which the animals needed for growth. After it was recognized that trace elements might be essential to life, new techniques were developed which made it possible to control their content in both plant and animal nutrients. The present list of vital elements is the work of the past 35 years. New methods of purifying the diet of experimental animals, developed particularly at the University of Wisconsin, showed that mammals require copper, manganese and zinc. The

the continuing infertility of this land when sown to clover and treated with fertilizers



(but no trace elements). At right the same land has received molybdenum as well as fertilizers. An ounce of molybdenum per acre amply insures the clover's health and nitrogen-fixing ability.

latest addition to the list of elements needed by plants is chlorine, which is acquired largely from the air—a discovery made possible by a new technique, developed at the University of California, for eliminating trace elements from experimental atmospheres.

In our country—Australia—more than 400 million acres of adequately watered land lie undeveloped, much of it for lack of the trace elements required by farm crops and animals. To appreciate the significance of this fact for Australia, one must compare the enormous figure of 400 million acres with our 22 million acres of cropland, 27 million acres of forest and 28 million acres of improved pasture. Suppose that we eliminate 25 per cent of the 400 million acres as unsuitable for agriculture or needed for urban development. That still leaves 300 million acres of potentially useful land—more than four times the present acreage! This area may ultimately be of enormous importance not only to Australia but to a world hard-pressed for food. Of course most of the land needs the benefit of routine agricultural measures, such as treatment with superphosphate and the planting of nitrogen-accumulating legumes. But the fact remains that much of it would have to remain forever in the category of "inherently infertile" land unless it is treated with a tiny but vital dose of trace elements.

Copper, zinc and molybdenum are the elements that cropland and pasture most often lack. Copper and cobalt are those most generally needed for the health and productivity of sheep and cattle. At Coonalpyn Downs the sowing of seven pounds per acre of zinc sulfate and seven pounds of copper sulfate made the difference between infertility and fertility. More recently workers of the Western Australia Department of Agriculture have found that traces of zinc and copper, together with superphosphate, provide the key to the development of the three-million-acre Esperance Plain, near the southwest corner of the continent. This area now bears nothing but harsh native scrub; agriculturists have always thought it worthless despite its adequate rainfall. Very likely the entire region will soon contribute to Australia's food-producing capacity.

While copper and zinc deficiencies occur in southern and western Australia, the eastern part of the continent suffers mostly from a lack of molybdenum. About a third of the so-called podsolic soils in eastern Australia is more or less deficient in the metal. The podsolic soils stretch for 1,000 miles along the east coast, reaching more than 150 miles inland into Victoria, New South Wales and Queensland. They also cover much of the island of Tasmania. The whole of the podsolic belt receives more than 20 inches of rainfall per year, and most of it can be sown to pasture if treated with a molybdenum-superphosphate fertilizer. This is rapidly being done.

The lack of molybdenum in Australian soils was discovered only in 1942. It works in an unusual way on the affected plants. Symptoms of molybdenum deficiency were observed in plants in the laboratory before any attempt was made to diagnose the infertility of podsolic soils. But the laboratory symptoms were quite unlike those observed in the plants of podsolic pastures. The first clue to what was wrong with the pastures was gained when they were found to respond well to treatment with wood-ash, lime or other alkaline matter. At first it was thought that the lime aided pasture growth by counteracting phosphate fixation in the soil. Experiments disproved this theory, however, and the search continued. Finally it was observed that clover grown on the podsolic soils responded spectacularly to molybdenum. Now it has been discovered that plants of many species all over the world grow faster in soils to which molybdenum has been added.

But why did the molybdenum-deficient pasture plants not resemble those grown in the laboratory? The reason is that the lack of molybdenum in the soil interfered with the ability of the pasture plants to fix nitrogen from the air, but was not severe enough to induce the symptoms obtained in the laboratory. The laboratory plants, on the other hand, received nitrogen in their well-balanced diet, and did not exhibit the symptoms of nitrogen deficiency. Thus the pasture plants were stunted by lack of nitrogen, and did not show the other symptoms of molybdenum deficiency. The laboratory plants were afflicted only with the other symptoms. To appreciate the importance of this fact, one must realize that clover is especially valued for its capacity to enrich the soil with nitrogen. A small dose of molybdenum restored its dark-green color and normal growth, just as if the pasture had been heavily dressed with a nitrogen fertilizer.

Remarkably little molybdenum is needed to correct its deficiency in the soil. On some soils even one sixteenth of an ounce per acre is sufficient to effect a

COMMONWEALTH OF AUSTRALIA has been scene of pioneer efforts to amend trace-element deficiencies, which occur in the areas hatched in color. Areas A and B (*black hatching*) are, respectively, the zinc- and copper-deficient Ninety Mile Desert (now Coonalpyn Downs) and a similar area, the Esperance Plain. The broken colored lines define areas of equal average rainfall per

clear-cut response in clover plants. The normal commercial application for pasture is of the order of one ounce per acre. This homeopathic dose, by far the smallest in trace-element therapy, is known to be effective for at least 10 years.

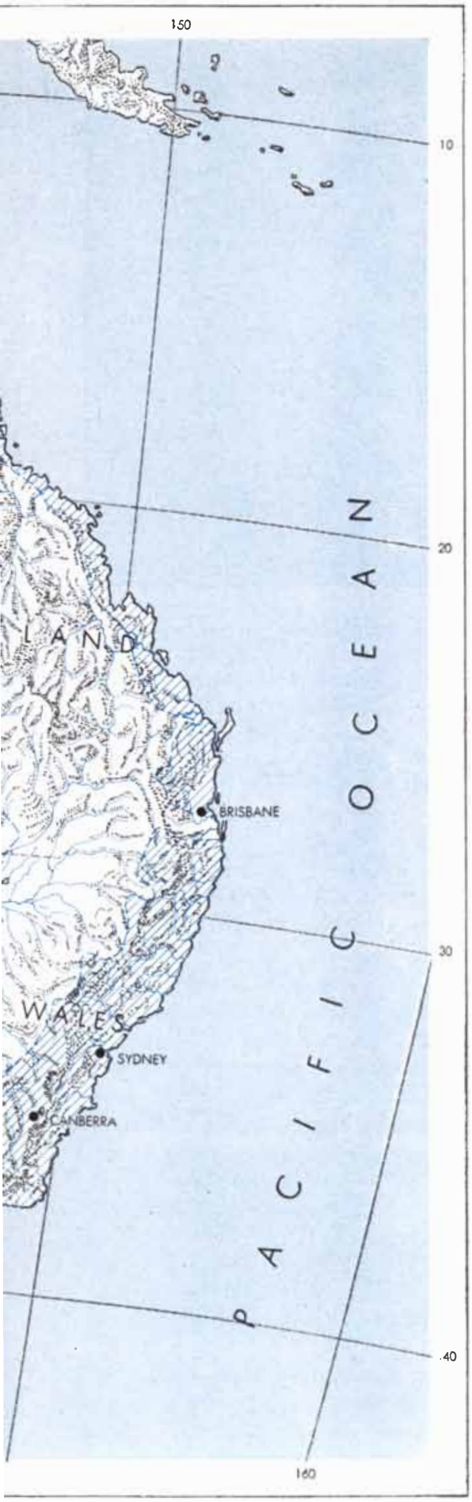
Some trace-element deficiencies affect plants, some affect animals and some affect both. Even where pasture growth is poor from lack of zinc or manganese, the sparse herbage will contain enough of these elements to meet the needs of livestock grazing on it. Naturally the livestock will benefit greatly from treatment of their pasturage with zinc and manganese. But the benefit to them will lie in the increase of herbage, not in the increase of zinc and manganese. It is otherwise in the case of cobalt or copper. Pasture plants can apparently thrive with no cobalt at all, yet a lack of this element is deadly to sheep and cattle. Both plants and animals require copper.

When sheep suffer a deficiency of copper, their wool often loses its crimp and takes on a stringy or steely appearance. Such sheep are poor wool producers, and their product brings much less in the market than normal wool. Extensive areas exist where wool production and quality are thus affected. Fortunately the condition is easily remedied, either by feeding the land five pounds per acre of copper (in the form of "copperized" superphosphate) or by providing the stock with copper-treated salt licks.

In some parts of Australia, notably the south and west, the copper deficiency is more serious. Here the breeding performance of ewes as well as the quality of wool is likely to suffer. Lambs may be stillborn, or they may be born with a curious wobbly gait and die soon afterward. It has been found that lambs which are dropped by copper-deficient ewes have malformed brains and spinal cords. The condition is completely prevented by the addition of copper to the pasturage, by salt licks or by drenching the pregnant ewes with a solution of a copper salt.

Calves born on such land rarely suffer from symptoms as severe as those observed in lambs. But cows often have a strange malady, locally known as "falling disease" because the afflicted animals suddenly drop dead in the fields. These cows have died of heart failure. Prolonged copper deficiency has so weakened their heart muscles that any momentary stress can kill them. This disease, too, can be prevented. We should add that in all cases the copper not only prevents the specific ailment but markedly improves the over-all health and productivity of the flock or herd.

Some parts of southern Australia have suffered from a deficiency of both copper and cobalt so severe that sheep and cattle could not survive unless they were regularly transferred to a healthier area. This problem has also been solved, with the result that several hundred thousand acres of well-nigh valueless land have



year. Deficient areas total about 400 million acres, three fourths of which (three times the now productive area) may be reclaimed.

COBALT-DEFICIENT SHEEP (*number 38*) **is compared to healthy sheep** (*number 37*) **in an experiment performed by H. A. Keener at the University of New Hampshire. Cobalt deficiency, identified in the U. S., Britain and Australia, can be remedied by dosage (for sheep) of one tenth of a milligram per day. The cobalt is needed for synthesis of vitamin B-12 by microorganisms in gut.**

been transformed into thriving communities. It has recently been found that the cobalt requirements of a ruminant stem from a unique symbiosis of the animal and the vitamin-producing microorganisms in its gut. For this reason the cobalt deficiency and its cure merit special attention.

The fact that cobalt is essential to life was first discovered in 1935 by Australian workers. Their observation emerged from the study of a peculiar and highly localized disease. In some parts of southern and western Australia, animals from seemingly healthy pastures weakened and died, apparently of starvation. New Zealand also suffered from this disease: workers there attributed it to deficiency of iron, having observed that the malady did not affect animals dosed with crude iron compounds.

This explanation did not satisfy students of the problem in western Australia. The effect of various iron compounds seemed unrelated to their iron content; moreover, the doses needed were suspiciously large. Perhaps, these workers thought, the effectiveness of the compounds was due not to iron but to some other element. Accordingly they fractionated one of the compounds and tested its constituent elements separately. It at once became clear that cobalt was the effective substance. Soil from the sick pastures and from the livers of diseased animals were found to be abnormally low in cobalt. An exceedingly small amount of cobalt is needed by ruminants: less than a tenth of their copper requirement. A sheep needs only a tenth of a milligram of cobalt per day; cattle must have five to 10 times as much. A single ounce of cobalt will sustain nearly 800 sheep or 80 cattle for a year!

While this investigation was proceeding, investigators in southern Australia, working on a similar disease of sheep, arrived independently at the same discovery. These workers found that cobalt is ineffective if injected with a needle; it must be taken by mouth. To obviate the need for repeated oral doses, they invented an ingenious cobalt "bullet"—four to five grams of cobalt oxide mixed with clay and baked into a small, heavy slug. Placed in the sheep's throat with a special gun, the bullet lodges in the upper alimentary canal, where it yields a steady supply of cobalt. One bullet lasts for months, and sometimes for years. It is possible that this novel technique can be used with other trace elements.

New interest in cobalt was aroused 10 years ago by the discovery in England and the U. S. that the element appears in the molecule of vitamin B-12. Within three years workers at Cornell University and in Australia had demonstrated that vitamin B-12 injections swiftly secured the remission of cobalt deficiency symptoms. Ruminants, they found, derive their natural supply of the vitamin entirely from the microorganisms in their gut. The microorganisms must have a steady supply of cobalt for their synthesis of the vitamin. It would be more accurate to call cobalt deficiency a nutritional disease of the microorganisms, rather than of their animal host.

Many chemical reactions in plants and animals are now known to require the presence of a trace element. But it is difficult to connect these reactions in cells and tissues with the outward symptoms of trace-element deficiency. Boron deficiency, for example, profoundly inhibits the growth of plants. Yet we know

THIS IS GLASS

A BULLETIN OF PRACTICAL NEW IDEAS FROM CORNING

POPPER THAT'S A STOPPER

It has been pointed out to us that every day the world survives, fewer are the chances that anything is the most, the biggest, the only, or the first.

But this corn popper *is a first*—to the best of our knowledge.

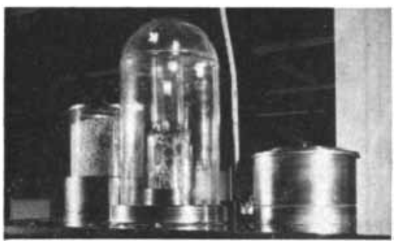
This machine pops corn with *hot* air—and all the action takes place *before your eyes*.

But that's putting the cart before the horse, because it was quite a number of moons ago when the designers at Electri-Cooker Division of General Foods were at the idea-developing stage.

They wanted a *new* way of popping corn. And they wanted to boost sales by having all the popping parts *visible*.

So, they developed a way of turning kernels into a fluffy delight with a *blast* of hot (about 200° F.) air. Then they turned to Corning.

And Corning in turn came up with a number of key components made from a PYREX brand glass. Included are a 17-inch display dome, 13-inch lamp chimney, and an 8-inch chamber for storing unpopped corn.



Why a PYREX brand glass? Because you can use it at elevated temperatures without worrying about thermal shock. (For example, PYREX brand glass No. 7740 has a linear coefficient of expansion of 32.5×10^{-7} in./in. between 0° and 300° C.)

Also, you can see through glass (an obvious but still extremely useful feature).

And glass is so easy to keep clean, there's no place for dirt to lodge in its *smooth* surface. Glass No. 7740 also is resistant to the attacks of most acids and alkalies and stands up well under distilled water.

You can find machines dispensing corn popped by hot air at Woolworth's, Grant's, Kresge's, McCrory's, Newberry's and Sears Roebuck & Company. You can find *glass* answers to one of your materials or component problems by coming to Corning.

You can get a head start by perusing "This Is Glass," a 64-page, well-illustrated primer. And/or ask for Bulletin B-83, a detailing of mechanical, thermal, electrical, and chemical properties for three of Corning's most popular types of glass. Use the coupon.

PURITY—KEY TO FUSED SILICA'S VERSATILITY

What material would you pick if you had the problem of accurate spectrum *transmission*, growing *high-purity* crystals, or building a component that would *not* darken under radiation?

The answer: Corning's 100% Fused Silica, an extremely versatile material that will handle these, as well as many other, specialized tasks. And the key to this material's versatility is its *extreme* purity.

Capacity to stand up to high temperatures, coupled with optical properties that yield excellent schlieren or shadowgraph quality, makes fused silica a natural for installation in wind tunnels for designing supersonic aircraft and missiles.

Optical purity and a high softening point (1585° C.) make Corning's 100% Fused Silica useful in wind tunnel windows.

Fused Silica also is used in ultrasonic delay lines, being well suited for handling delays ranging from 10 to 16,000 microseconds. More: You'll find this material possessed of high electrical breakdown resistance, low dielectric loss, and low expansion. And it is permeable to helium.

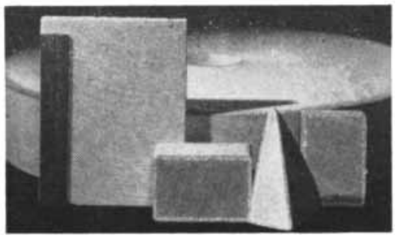
Uses (other than ultrasonic delay lines and windows for wind tunnels) include the following: windows for high-temperature applications, windows for hot cells, and the optical components for ultraviolet instruments.

All the facts are now available in spec sheet form. Check the coupon.

NEW—CELLULAR CERAMICS

Now, for the first time, from Corning's Cercor process, you can get thin-walled cellular ceramics.

These cellular ceramics are lightweight, resist oxidation, and have an extremely high surface area. Here is a sampling of Cercor products.



The material used to make these objects has 1500 square feet of surface area per cubic foot. Individual wall thickness averages only 0.005 inch; weight is only 30 pounds per cubic foot.

This material can withstand temperatures up to 1800° F. with virtually no thermal expansion, and can be operated continuously at 1290° F. At either temperature you don't have to worry about thermal shock or oxidation.

To provide additional strength, a ceramic coating can be bonded to the exterior of most cellular forms.

The composition of the Cercor materials may be changed to provide desired physical and chemical properties, and further development is expected to result in a broadening of potential configurations and product shapes.

Suggested uses so far include structures for use in gaseous heat exchangers, catalyst supports, burner plates, column packing, and acoustical filtering, flow control, insulation, and structural materials in high-temperature applications.

Inquiries invited. And/or ask for a just published bulletin detailing all pertinent data and characteristics.

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next to nothing of the biochemical role of boron. It is possible the element takes part in the transport of sugars by forming ionizable sugar-borate complexes, but evidence for this is meager.

Encouraging progress is being made in the study of trace elements as components of enzymes. Within the past few years several enzymes containing molybdenum have been isolated from living tissues. One of these is nitrate reductase, a plant enzyme which abets the synthesis of proteins by converting nitrate nitrogen from the soil into nitrite nitrogen. When this enzyme is deprived of its molybdenum, it ceases to function; when the molybdenum is restored, the enzyme is reactivated. In the nitrate reductase molecule the molybdenum serves as an electron carrier, alternately undergoing oxidation and reduction. It is not surprising that some plants lacking in molybdenum contain high levels of raw nitrate nitrogen. Of course this does not apply to clover, which fixes nitrogen from the air, or to plants that obtain their nitrogen from the soil as ammonia.

Zinc also plays a part in enzymes, notably the carbonic anhydrase of animals, which breaks down carbonic acid into carbon dioxide and water. Carbonic anhydrase must play an important role in respiration, for it helps convert carbon dioxide flushed from body tissues into blood-borne bicarbonate, and to convert bicarbonate back into carbon dioxide in the lungs. Though the role of this and several other zinc-containing enzymes has been well established, no one so far has been able to connect any deficiency-disease symptom to a reduction of their activity, even in gravely zinc-deficient animals. The symptoms of zinc deficiency—failure of growth and appetite, skin lesions and, in birds, poorly formed bones and feathers—remain unexplained.

More is known about the complex role of copper in enzymes. Recently investigators at the University of Utah and the University of London have traced certain of the signs caused by copper starvation in rats and pigs to a lack of the enzyme cytochrome oxidase, which is essential for the respiration of cells. While there is no copper in cytochrome oxidase, this enzyme has an iron component, called heme *a*, the synthesis of which is catalyzed by copper. Without heme *a*, cytochrome oxidase cannot be formed. It has been known for some time that copper deficiency plays a similar role in anemia; copper-starved bone marrow fails to mobilize the available iron and incorporate it in the red blood cells which the marrow manufactures. In addition it now seems that the red blood cells themselves utilize copper. Radioactive-tracer studies conducted at the University of Utah suggest that the cells require copper in order to complete their normal life span.

Investigators at the University of London have established a suggestive connection between lack of copper and ataxia, or poor coordination, in newborn lambs. The ataxia of the lambs is caused by underdevelopment of the myelin, or fatty outer coating of the nerve fibers, in their brains and spinal cords, and this in turn is due to a lack of the phospholipids of which myelin is largely composed. The lambs' tissues require copper to catalyze a crucial stage in the synthesis of the phospholipids.

Many recent studies suggest that trace-element disorders tend to involve pairs or triads of elements. A striking instance is the interplay of copper, molybdenum and inorganic sulfate in a disorder afflicting some Australian sheep. This disease develops on pastures rich in copper but poor in molybdenum. Sheep on such land will succumb to copper poisoning unless their molybdenum intake is increased. But molybdenum will not counteract the effect of copper except in the presence of a third substance: inorganic sulfate. The chemical reactions involved are not simple, and there are indications that still other substances are involved.

What of trace elements in man's own diet? The indications are that civilized man is not likely to suffer trace-element deficiencies. Unlike range-fed cattle or sheep, modern man derives his diet from many localities and soil types. The inadequacies of one food source are made up from another. After 100 years of study, iron and iodine are still the only trace elements that human populations are known to lack. While iodine deficiency is a genuinely regional disease, iron deficiency stems from loss of blood or poor choice of foods rather than from a local lack of iron in the soil.

So trace-element deficiencies have little direct effect upon man. Their indirect effects, on the other hand, are profoundly important. How we husband the chemical health of our crops, our stock and our land may have immense import for the future of man. As population pressure mounts, we will have to evolve ever faster-growing and higher-yielding strains of domestic plants and animals. Will the quality of our food keep pace with its quantity? That may well depend upon how carefully we monitor its content of the trace elements.

The Perfect Solution

(you spray it)

"Hargreaves, you're still living in the dark ages," bellowed the fist pounding pharmaceutical manufacturer. "Aerosols are what we need. Aerosols with a capital 'A'. . . as in spray. Spray. SPRAY."

"Yes, sir," the harried Hargreaves murmured. "Fast, uniform application. No waste. Better stability. Many distinct advantages. I'll relay your instructions to the lab, sir."

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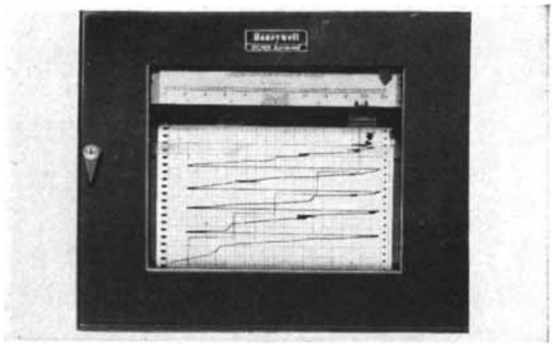

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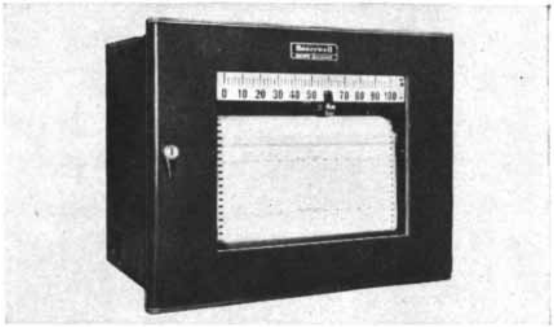

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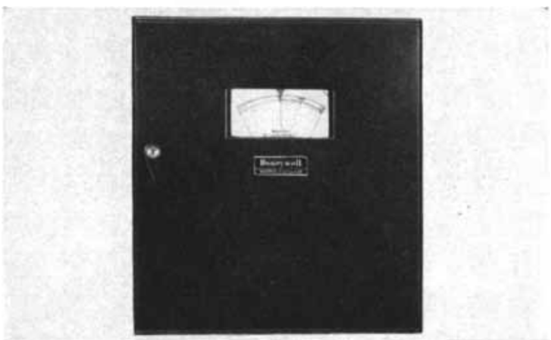

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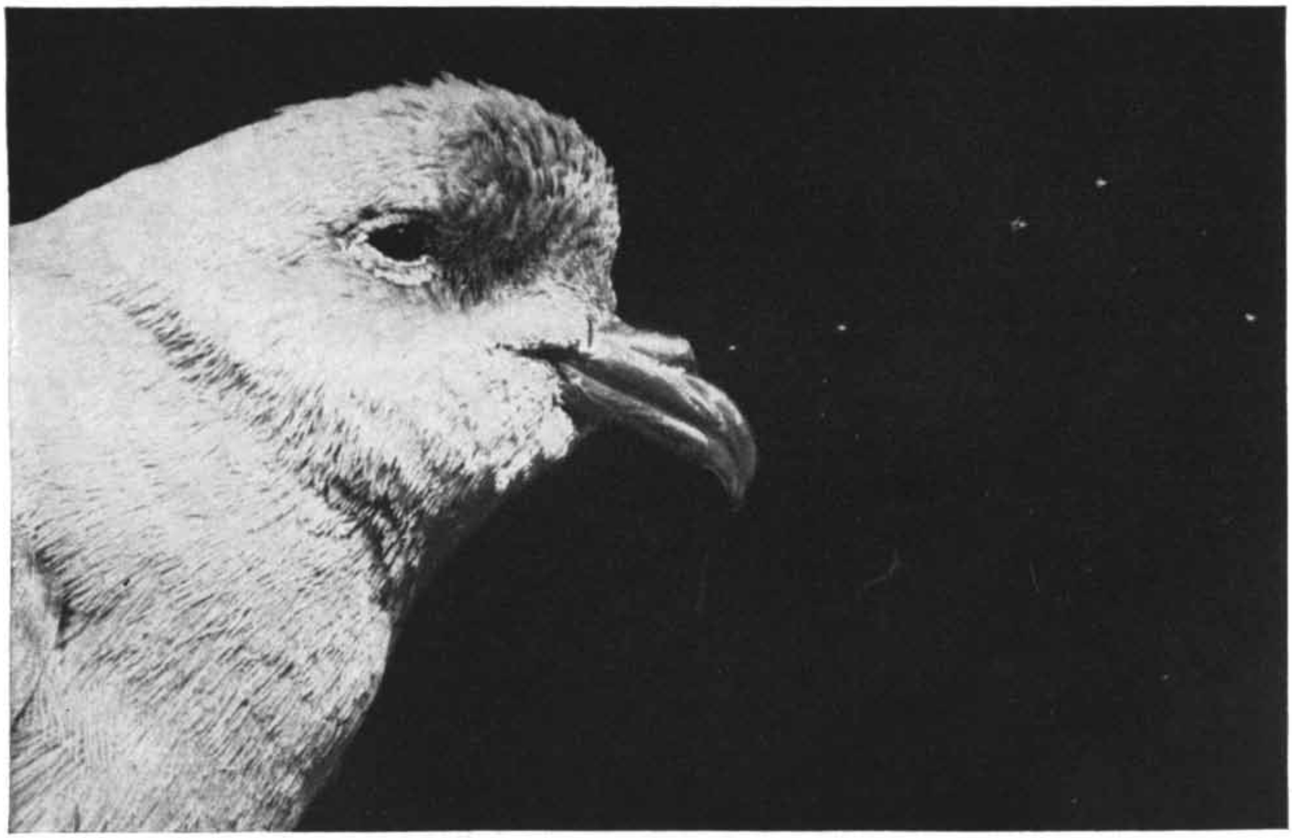
SALT GLANDS

A special organ which eliminates salt with great efficiency enables marine birds to meet their fluid needs by drinking sea water. Similar organs have been found in marine reptiles

by Knut Schmidt-Nielsen

As the writers of stories about castaways are apt to point out, a man who drinks sea water will only intensify his thirst. He must excrete the salt contained in the water through his kidneys, and this process requires additional water which is taken from the fluids of his body. The dehydration is aggravated by the fact that sea water, in addition to common salt or sodium chloride, also contains magnesium sulfate, which causes diarrhea. Most air-breathing vertebrates are similarly unable to tolerate the drinking of sea water, but some are not so restricted. Many birds, mammals and reptiles whose ancestors dwelt on land now live on or in the sea, often hundreds of miles from any source of fresh water. Some, like the sea turtles, seals and albatrosses, return to the land only to reproduce. Whales, sea cows and some sea snakes, which bear living young in the water, have given up the land entirely.

Yet all these animals, like man, must limit the concentration of salt in their blood and body fluids to about 1 per cent—less than a third of the salt concentration in sea water. If they drink sea water, they must somehow get rid of the excess salt. Our castaway can do so only at the price of dehydrating his tissues. Since his kidneys can at best se-



PETREL EJECTS DROPLETS of solution produced by its salt gland through a pair of tubes atop its beak, as shown in this high-speed photograph. The salt-gland secretions of most birds drip from the tip of the beak. The petrel, however, remains in the air almost continuously and has apparently evolved this "water pistol" mechanism as a means of eliminating the fluid while in flight.

crete a 2-per-cent salt solution, he must eliminate up to a quart and a half of urine for every quart of sea water he drinks, with his body fluids making up the difference. If other animals drink sea water, how do they escape dehydration? If they do not drink sea water, where do they obtain the water which their bodies require?

The elimination of salt by sea birds and marine reptiles poses these questions in particularly troublesome form. Their kidneys are far less efficient than our own: a gull would have to produce more than two quarts of urine to dispose of the salt in a quart of sea water. Yet many observers have seen marine birds drinking from the ocean. Physiologists have held that the appearance of drinking is no proof that the birds actually swallow water, and that the low efficiency of their kidneys proves that they do not. Our experiments during the past two years have shown that while the physiologists are right about the kidneys, the observations of drinking are also correct. Marine birds do drink sea water. Their main salt-eliminating organ is not the kidney, however, but a special gland in the head which disposes of salt more rapidly than any kidney does. Our studies indicate that all marine birds and probably all marine reptiles possess this gland.

The obvious way to find out whether birds can tolerate sea water is to make them drink it. If gulls in captivity are given only sea water, they will drink it without ill effects. To measure the exact amount of sea water ingested we administered it through a stomach tube, and found that the birds could tolerate large quantities. Their output of urine increased sharply but accounted for only a small part of the salt they had ingested. Most of the salt showed up in a clear, colorless fluid which dripped from the tip of the beak. In seeking the source of this fluid our attention was drawn to the so-called nasal glands, paired structures of hitherto unknown function found in the heads of all birds. Anatomists described these organs more than a century ago, and noted that they are much larger in sea birds than in land birds. The difference in size suggested that the glands must perform some special function in marine species. Some investigators proposed that the organs produce a secretion akin to tears which serves to rinse sea water from the birds' sensitive nasal membranes.

We were able to collect samples of the secretion from the gland by inserting a thin tube into its duct. The fluid turned out to be an almost pure 5-per-cent solution of sodium chloride—many times saltier than tears and nearly twice as salty as sea water. The gland, it was plain, had nothing to do with rinsing the nasal membranes but a great deal to do with eliminating salt. By sampling the output of other glands in the bird's head, we established that the nasal gland was the only one that produces this concentrated solution.

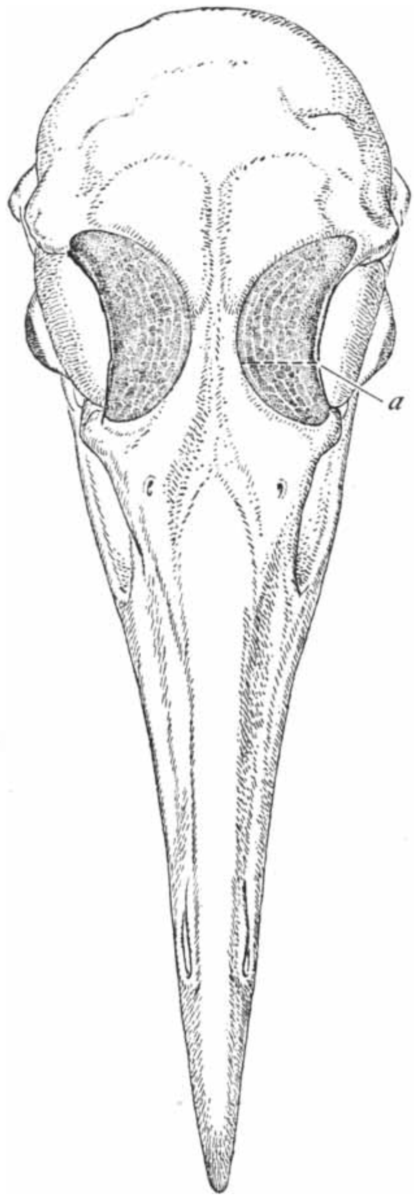
The nasal glands can handle relatively enormous quantities of salt. In one experiment we gave a gull 134 cubic centimeters of sea water—equal to about a tenth of the gull's body weight. In man this would correspond to about two gallons. No man could tolerate this much sea water; he would sicken after drinking a small fraction of it. The gull, however, seemed unaffected; within three hours it had excreted nearly all the salt. Its salt glands had produced only about two thirds as much fluid as its kidneys, but had excreted more than 90 per cent of the salt.

The fluid produced by the salt gland is about five times as salty as the bird's blood and other body fluids. How does the organ manage to produce so concentrated a solution? Microscopic examination of the gland reveals that it consists of many parallel cylindrical lobes, each composed of several thousand branching tubules radiating from a central duct like bristles from a bottle brush. These tubules, about a thousandth of an inch in diameter, secrete the salty fluid.

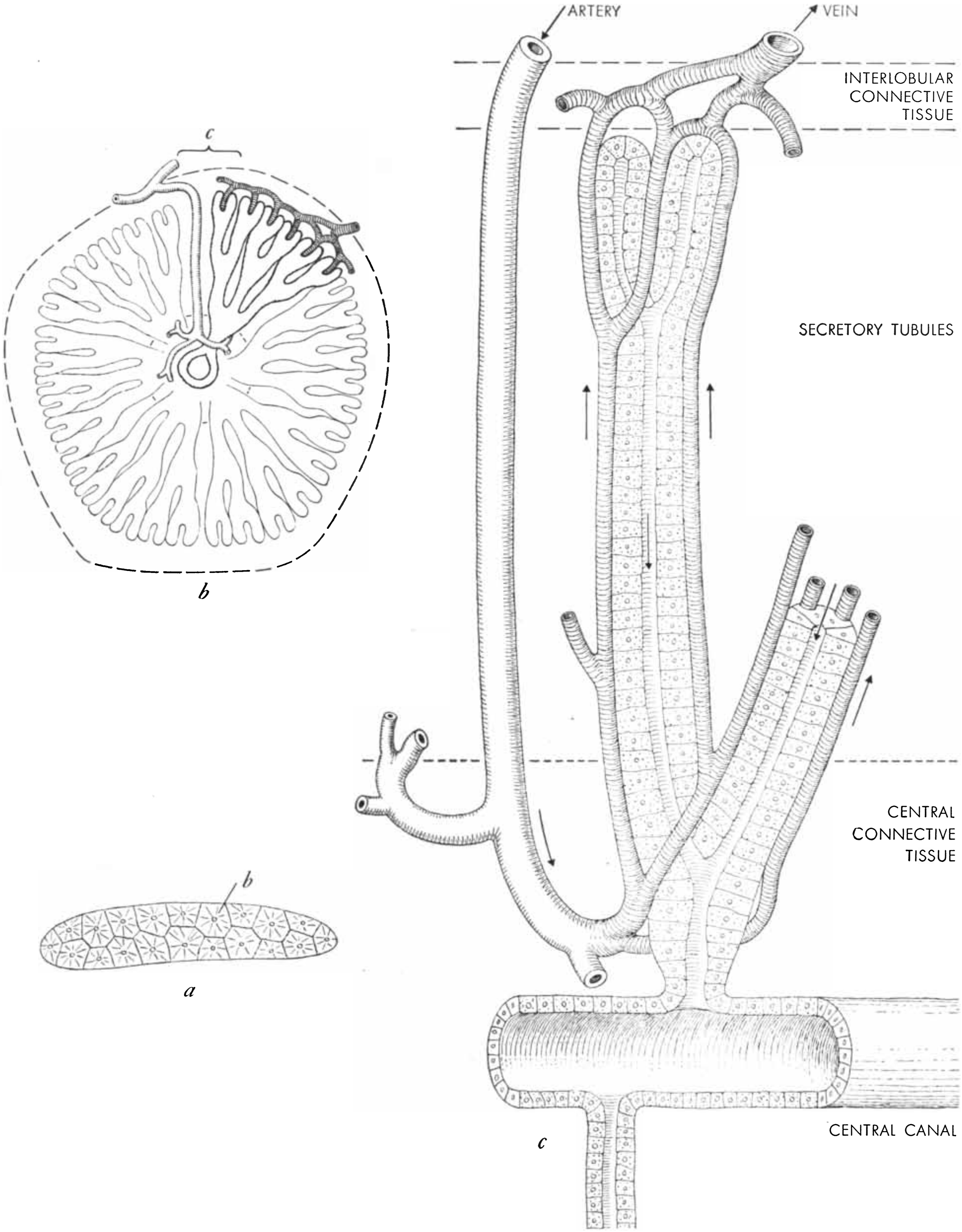
A network of capillaries carries the blood parallel to the flow of salt solution in the tubules, but in the opposite direction [*see illustration on opposite page*]. This arrangement brings into play the principle of counter-current flow, which seems to amplify the transfer of salt from the blood in the capillaries to the fluid in the tubules. A similar arrangement in the kidneys of mammals appears to account for their efficiency in the concentration of urine [see "The Wonderful Net," by P. F. Scholander; SCIENTIFIC AMERICAN, April, 1957]. No such provision for counter-current flow is found in the kidneys of reptiles, and it is only slightly developed in birds.

Counter-current flow, however, does not of itself account for the gland's capacity to concentrate salt. The secret of this process lies in the structure of the tubules and the cells that compose them.

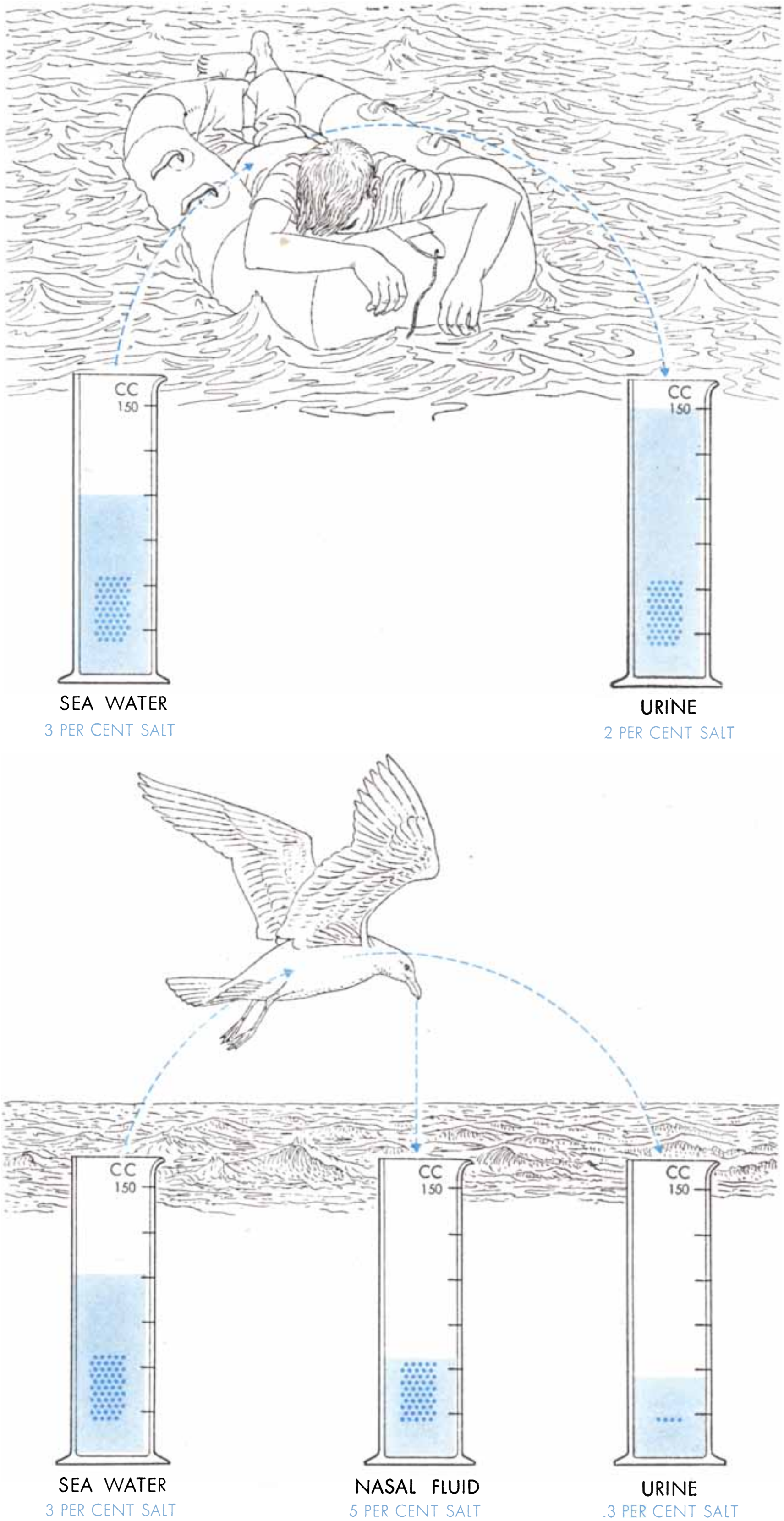
The microscopic structure of a salt-gland tubule resembles a stack of pies with a small hole in the middle. Each "pie" consists of five to seven individual



STRUCTURE of salt gland is essentially the same in all sea birds. In the gull the glands lie above the bird's eyes, as shown at left. Cross section of a gland (*a*) shows that it consists of many lobes (*b*). Each of these



lobes contains several thousand branching tubules which radiate from a central duct like the hairs of a bottle brush. Enlargement of a single tubule (*c*) reveals that it is surrounded by capillaries in which blood flows counter to the flow of salt secretion in the tubule. This counter-current flow, which also occurs in the kidneys of mammals, facilitates the transfer of salt from the blood to the tubule. The tubule wall, only one cell thick, consists of rings of five to seven wedge-shaped cells. These rings, stacked one on top of another, encircle a small hole, or lumen, through which the salty secretion flows from the tubule into the central canal of the lobe.



SALT EXCRETION IN MEN AND BIRDS is compared in these drawings. Castaway at top cannot drink sea water because in eliminating the salt it contains (*colored dots*) he will lose more water than he has drunk. His kidney secretions have a salt content lower than that of sea water. Gull (*below*) can drink sea water even though its kidneys are far less efficient than a man's. It eliminates salt mainly through its salt, or "nasal," glands. These organs, more efficient than any kidney, secrete a fluid which is nearly twice as salty as sea water.

cells arranged like wedges. The hole, or lumen, funnels the secretion into the central duct. When we inject dye into the lumen, colored fluid seeps out into a system of irregular crevices in the walls of the tubule. More detailed examination with the electron microscope reveals a similar, interlocking system of deep folds which extend inward from the outer surface of the tubule. This structure may be important in that it greatly multiplies the surface area of the cell. It is worth noting that cells with similar, though shallower, folds are found in the tubules of the mammalian kidney.

Evidently some physiological mechanism in the cell "pumps" sodium and chloride ions against the osmotic gradient, from the dilute salt solution of the blood to the more concentrated solution in the lumen. Nerve cells similarly "pump" out the sodium which they absorb when stimulated [see "The Nerve Impulse and the Squid," by Richard D. Keynes; SCIENTIFIC AMERICAN, December, 1958]. Of course the mechanisms in the two processes may be quite different. In the tubule cells the transport of sodium and chloride ions seems to involve the mitochondria, the intracellular particles in which carbohydrates are oxidized to produce energy.

The similarities between the salt gland and the mammalian kidney should not obscure their important differences. For one thing, the salt gland is essentially a much simpler organ. The composition of its secretions, which apart from a trace of potassium contain only sodium chloride and water, indicates that its sole function is to eliminate salt. In contrast, the kidney performs a variety of regulatory and eliminative tasks and produces a fluid of complex and variable composition, depending on the animal's physiological needs at a particular time.

The salt gland's distinctive structure, elegantly specialized to a single end, enables it to perform an almost unbelievable amount of osmotic work in a short time. In one minute it can produce up to half its own weight of concentrated salt solution. The human kidney can produce at most about a twentieth of its weight in urine per minute, and its normal output is much less.

Another major difference between the two glands is that the salt gland functions only intermittently, in response to the need to eliminate salt. The kidney, on the other hand, secretes continuously, though at a varying rate. The salt gland's activity depends on the concentration of salt in the blood. The injection of salt solutions into a bird's bloodstream causes the gland to secrete, indicating that some center, probably in the brain, responds to the salt concentration. The gland responds to impulses in a branch of the facial nerve, for electric stimulation of this nerve causes the gland to secrete.

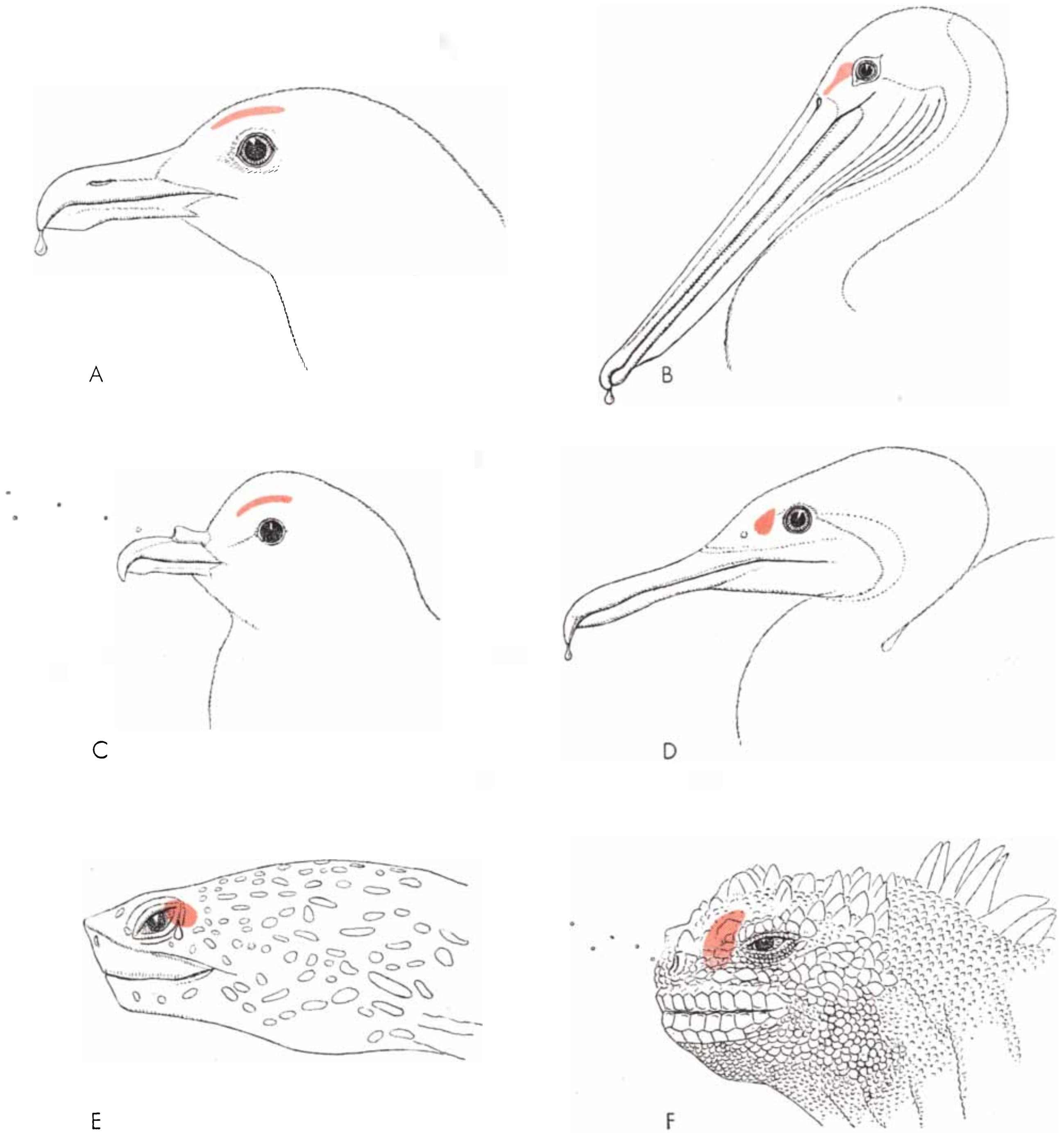
While the structure and function of the salt gland is essentially the same in all sea birds, its location varies. In the gull and many other birds the glands are located on top of the head above the eye sockets [*see illustrations on next page*]; in the cormorant and the gannet they lie between the eye and the nasal cavity. The duct of the gland in either case opens into the nasal cavity. The salty fluid flows out through the nostrils of most species and drips from the tip of the beak, but there are some interesting variations on this general scheme. The pelican, for example, has a pair of grooves in its long upper beak which lead the fluid down to the tip; the solution would otherwise trickle into the pouch of the lower beak and be reingested. In the cormorant and the gannet the nostrils are nonfunctional and covered with skin; the fluid makes its exit through the internal nostrils in the roof of the mouth and flows to the tip of the beak.

The petrel displays an especially interesting mechanism for getting rid of the fluid. Its nostrils are extended in two short tubes along the top of its beak. When its salt glands are working, the bird shoots droplets of the fluid outward through the tubes [*see illustration on page 109*]. This curious design may reflect a special adaptation to the petrel's mode of life. Though the bird remains at sea for months at a time, it rarely settles down on the water to rest. Presumably the airstream from its almost continuous flight would hamper the elimination of fluid from the bird's nostrils, were it not for the water-pistol function of the tubes.

Our studies so far have demonstrated the existence of the salt gland in the herring gull, black-backed gull, common tern, black skimmer, guillemot, Louisiana heron, little blue heron, double-crested cormorant, brown pelican, gannet, petrel, albatross, eider duck and Humboldt penguin. These species, from a wide variety of geographical locations, represent all the major orders of marine birds. There is little doubt that this remarkable organ makes it possible for all sea birds to eliminate salt and live without fresh water.

The discovery of the salt gland in sea birds prompted us to look for a similar organ in other air-breathing sea animals. In *Alice's Adventures in Wonderland* the Mock Turtle weeps perpetual tears because he is not a real turtle; real turtles, at least the marine species, also weep after a fashion. A. F. Carr, Jr., a distinguished specialist in marine turtles, gives us a vivid account of a Pacific Ridley turtle that came ashore to lay its eggs. The animal "began secreting copious tears shortly after she left the water, and these continued to flow after the nest was dug. By the time she had begun to lay, her eyes were closed and plastered over with tear-soaked sand and the effect was doleful in the extreme." Thus Carr makes it clear that the turtle's tears do not serve to wash its eyes free of sand, an explanation that otherwise might seem reasonable. The suggestion that the turtle weeps from the pangs of egg-laying is even wider of the mark.

With the loggerhead turtle as our subject, we have found that the sea turtle's tears come from a large gland behind its eyeball. The tears have much the same composition as that of the salt-gland secretions of the sea bird. Thus it would seem more than likely that the turtle's



LOCATION OF SALT GLAND (*color*) **varies in different species of marine birds and reptiles. In the gull (*A*) the gland's secretions emerge from the nostril and drip from the beak; in the cormorant (*D*) the fluid flows along the roof of the mouth. The pelican (*B*) has grooves along its upper beak which keep the fluid from dripping into its pouch; the petrel (*C*) ejects the fluid through tubular nostrils. In the turtle (*E*) the gland opens at the back corner of the eye; in the marine iguana (*F*) it opens into the nasal cavity.**

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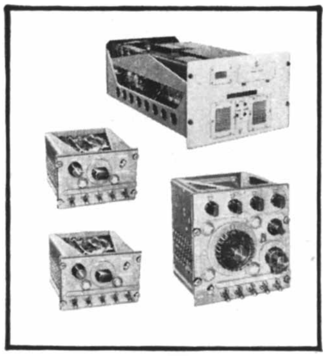

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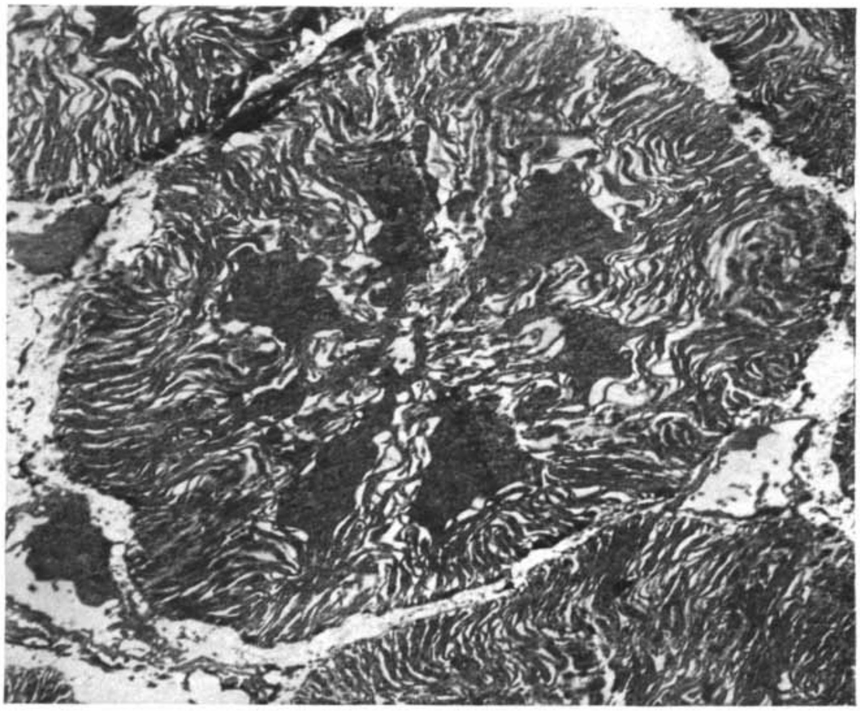


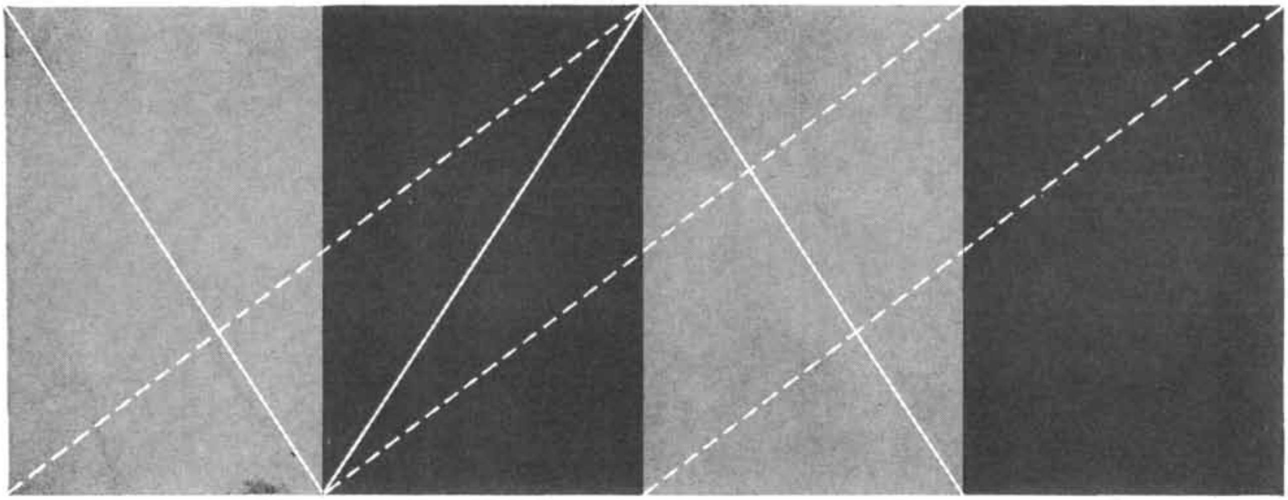
CROSS SECTION OF SALT-GLAND TUBULE is shown magnified about 5,700 diameters in this electron micrograph made by William L. Doyle of the University of Chicago. To emphasize the cell-structure the specimen was kept in a solution which shrank and distorted the cells and their nuclei. Most of the material of the cells lies in folded, leaflike layers; cells with a somewhat similar structure are found in the kidney tubules of mammals.

"weeping" serves to eliminate salt. The salt gland of the turtle has a structure similar to that of the gland in sea birds, with tubules radiating from a central duct, and it seems that this structure is essential for the elaboration of a fluid with a high salt concentration. The similarity is the more striking because the location of the gland in the turtle indicates that it has a different evolutionary origin. Still a third independent line of evolution may be represented by the salt gland in the Galápagos marine iguana, the only true marine lizard.

Anatomical studies of the other marine reptiles—the sea snakes and the marine crocodiles—have established that their heads contain large glands whose function may be similar to that of the salt gland. When we succeed in obtaining living specimens of these creatures, we expect to determine whether their glands have the same function.

Investigations of marine mammals thus far indicate that these animals handle the elimination of salt from their systems in a more conventional manner. The seal and some whales apparently satisfy their need for water with the fluids of the fish on which they feed. The elimination of such salt as these fluids contain requires kidneys of no more than human efficiency. But other whales, and walruses, whose diet of squid, plankton or shellfish is no less salty than sea water, must surely eliminate large quantities of excess salt even if they do not drink from the ocean itself. Our knowledge of their physiology suggests that their kidneys, which are more powerful than ours, can eliminate all the salts in their food. Some mammalian kidneys do function at this high level. The kangaroo rat, whose desert habitat compels it to conserve water to the utmost, can produce urine twice as salty as the ocean, and thrives in the laboratory on a diet of sea water and dried soybeans [see "The Desert Rat," by Knut and Bodil Schmidt-Nielsen; SCIENTIFIC AMERICAN, July, 1953].

We should like to study salt excretion in whales, but these animals are obviously not easy to work with. We have undertaken, however, some pilot studies on seals. When we injected them with salt solutions that stimulate the salt glands of birds and reptiles, they merely increased their output of urine. Methacholine, a drug which also stimulates the salt gland, gave equally negative results. Whatever the seal's need to eliminate salt, its kidneys are evidently adequate to the task. We must therefore assume that the salt gland has evolved only in the birds and reptiles, animals whose kidneys cannot produce concentrated salt solutions.



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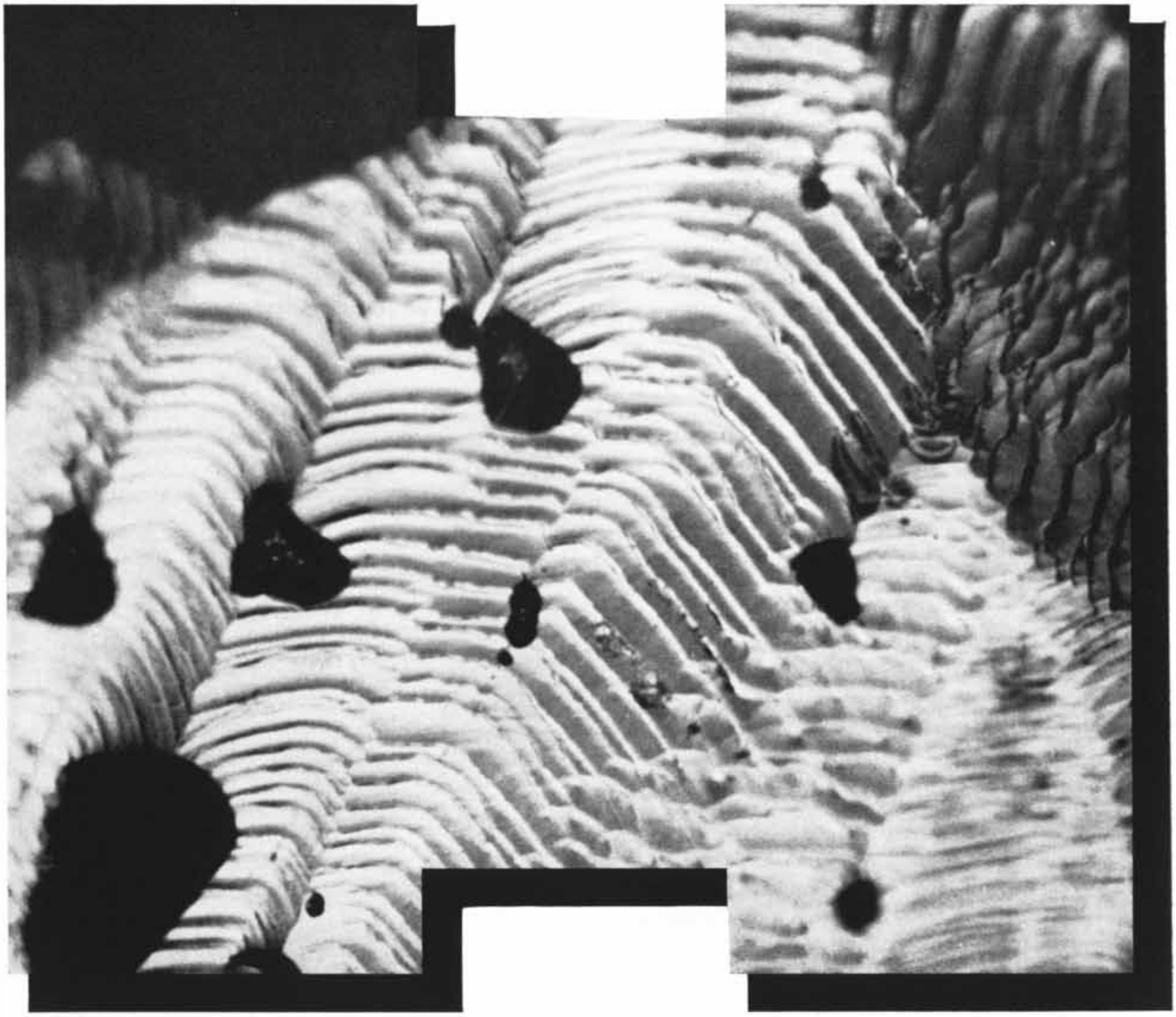

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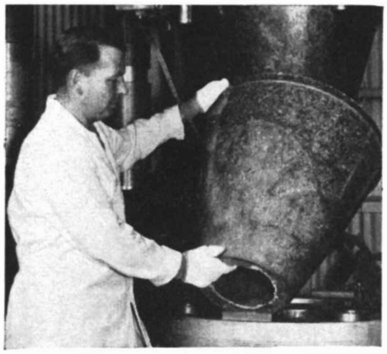

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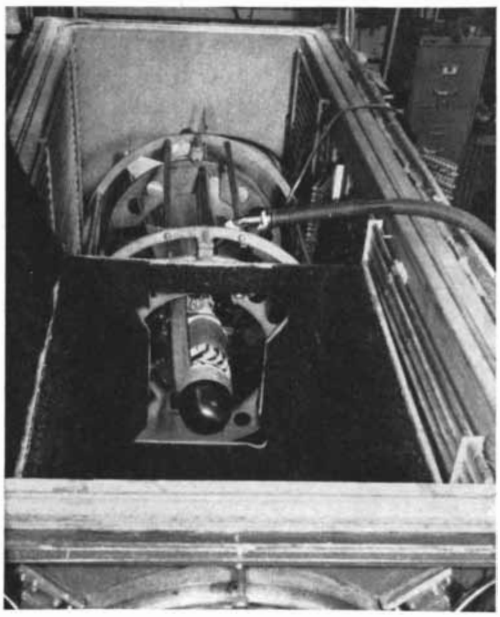


Falcon air-to-air guided missiles, *shown in an environmental strato chamber are being developed and manufactured by Hughes engineers in Tucson, Arizona.*

TWO SCENES OF THE TRIAL show the Prosecution (*top*) and the Defense (*bottom*). Leaning to his left with his hand to his lips in the top picture is William Jennings Bryan. Standing in the bottom picture is John Randolph Neal, one of the Defense attorneys. To Neal's left is Clarence Darrow; to his right, Dudley Field Malone. Farther down the table, his hands clasped together, is Scopes.

A Witness at the Scopes Trial

In 1925 a Tennessee teacher of biology named Thomas Scopes was tried for teaching the theory of evolution. An expert witness at the trial relates how evolution lost in court but won in the eyes of the nation

by Fay-Cooper Cole

"This is Clarence Darrow," said the voice at the other end of the wire, "I suppose you have been reading the papers, so you know Bryan and his outfit are prosecuting that young fellow Scopes. Well, Malone, Colby and I have put ourselves in a mess by offering to defend. We don't know much about evolution. We don't know whom to call as witnesses. But we do know we are fighting your battle for academic freedom. We need the help of you fellows at the University, so I am asking three of you to come to my office to help lay plans."

That afternoon in Darrow's office three of us from the University of Chicago—Horatio Hackett Newman, professor of biology; Shailer Mathews, dean of the Divinity School; and I—met to outline the strategy for what turned out to be one of the most publicized trials of the century. The Scopes trial proved also to be a historic occasion in the cause of popular understanding of science. A century ago the educated world was shaken by the discoveries of Charles Darwin and Alfred Russel Wallace, and the evidence they presented for the evolution of life on this planet. In 1959, as we celebrate the centenary of the *Origin of Species,* few informed persons, if any, question the theory of evolution. However, the century has witnessed several attempts to stifle investigation and outlaw the teaching of the theory. The best known of these was the Scopes trial, held in Dayton, Tenn., in 1925. The trial resulted in an immense revival of public interest in Darwin and in evolution; there has been no comparable effort since then to suppress this advance in man's understanding of himself and the world he lives in.

To understand the trial and what lay back of it, one must recall the climate of the 1920s. It was a time of uncertainty, unrest and repression. We had just emerged from a world war. Old standards were badly shaken; the young were labeled "the lost generation"; intolerance was rampant. The Ku Klux Klan was on the march, not only in the South but in the North as well. In many towns in Illinois, Indiana and other parts of the Midwest, staid business men—even members of the clergy—put on "white nighties" and burned fiery crosses to put the Negro, the Jew, the Catholic and the immigrant "in their places." The Fundamentalists, under the leadership of William Jennings Bryan, had organized in some 20 states and were putting pressure on all institutions of learning to curb the teaching of science, particularly evolution, which they considered in contradiction to the Bible. Prohibitive bills had been passed in Tennessee and Mississippi and were pending in six other states.

Then came the great opportunity. In the little town of Dayton the high-school science teacher and football coach, 24-year-old John Thomas Scopes, found himself engaged in a discussion of the new law with George W. Rappelyea, a young mining engineer and superintendent of the local coal mines. Scopes expressed bewilderment that the state should supply him with a textbook that presented the theory of evolution, yet make him a lawbreaker if he taught the theory. Rappelyea agreed that it was a crazy law and clearly unconstitutional. Then suddenly he asked: "Why don't I have you arrested for teaching evolution from that text and bring the whole thing to an end?" Scopes replied: "Fair enough."

Scopes was duly arrested. But neither of the principals had any idea of what they were starting. Within a few hours the Chattanooga papers carried the story. Soon it was spread across the nation. The Fundamentalists were quick to realize the opportunity to dramatize their battle against evolution. Bryan and his associates offered their services to the Prosecution. They were accepted. Here was big news.

At this point, it happened, three lawyers met in New York City for a conference on some business matters. They were Clarence Darrow, controversialist and defender of unpopular causes; Bainbridge Colby, an eminent corporation lawyer and, like Bryan, a former Secretary of State; and Dudley Field Malone, a leading Catholic layman and a fashionable barrister. Their conversation turned to the Tennessee situation. One said: "It is a shame. That poor teacher, who probably doesn't know what it is all about, is to be sacrificed by the Fundamentalists." Another said: "Someone ought to do something about it." The third replied: "Why don't we?" Through the American Civil Liberties Union they offered to defend young Scopes. Their offer was accepted.

This was real news! Bryan, three times candidate for the presidency of the U. S., the great Fundamentalist leader and orator, on one side. On the other, three of the nation's most famous lawyers, including Darrow, master jury-pleader. The papers were full of the story.

This was the background of Darrow's call to me and of our meeting at his office in Chicago early in the summer of 1925. By telephone, wire and letter we proceeded to assemble a panel of expert witnesses: scientists to testify on the theory of evolution and theologians to give evidence on the history and interpretation of the Bible. In addition to

COMMITTEE OF LOCAL CITIZENS welcomes Bryan (*center*) to Dayton, Tenn., scene of the trial. The group stands in front of the home of F. R. Rogers, who was Bryan's host during the trial. None of the residents would provide accommodations for the Defense.

Newman, Mathews and myself, our panel finally included Kirtley Mather, professor of geology at Harvard; Jacob G. Lipman, director of the New Jersey Agricultural Experiment Station at Rutgers University; W. C. Curtis, professor of zoology at the University of Missouri; Wilbur Nelson, state geologist of Tennessee; Maynard Metcalf, professor of zoology at Johns Hopkins University; Charles Judd, head of the University of Chicago School of Education; and Rabbi Herman Rosenwasser of San Francisco, a noted Hebrew scholar. All of us, along with our counsel, undertook to go to Dayton at our own expense and to serve without fee.

The trial was scheduled for Friday, July 10. But long before that date the town was crowded with newspapermen, Fundamentalist supporters and others who were just curious. No one was willing to house "the heretics," that is, the scientific witnesses and defense attorneys. So an old "haunted house" on a hill overlooking the town was fitted out as a dormitory.

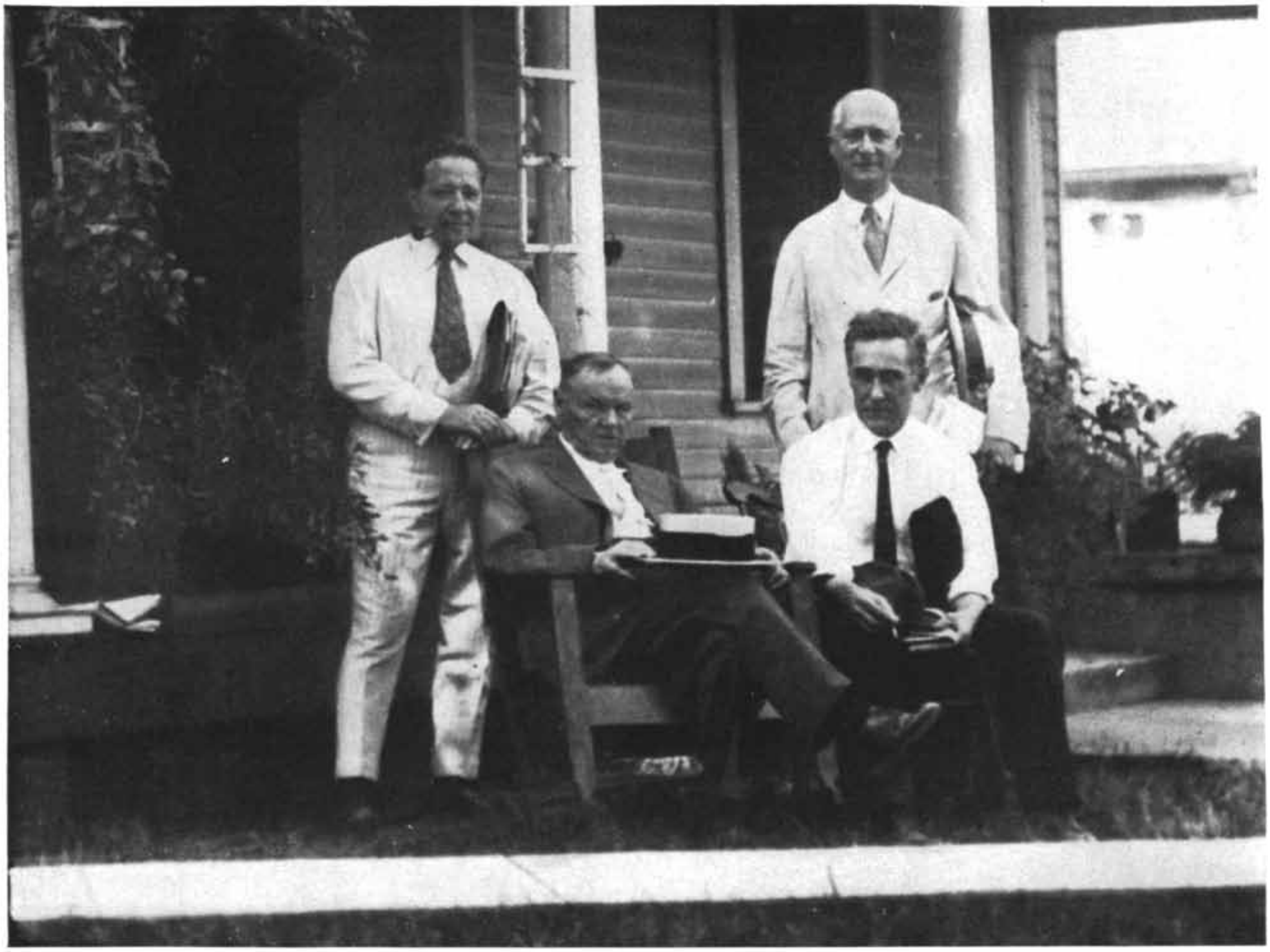
When I reached town, I took care not to associate myself at once with the Defense group, and was able to wander about for a time listening to the talk of the local people. For the most part they were extremely partisan to the Fundamentalist cause. But they were apprehensive of the famous Darrow, and they were not yet aware of his plan to present expert testimony on evolution and the scriptures.

That evening I joined the group at the "haunted house" and there met young Scopes for the first time. He was a fine, clean-cut young man, a little shy and apparently overwhelmed by the controversy he had stirred up. He expressed amazement that famous lawyers like Darrow, Colby, Malone and Arthur Garfield Hays (counsel to the American Civil Liberties Union) should come to his defense, and that a group of well-known scientists should join them.

Little happened on the first day of the trial beyond the selection of the jury. A panel was offered, and Darrow accepted it without change after a casual examination. But he did bring out the fact that 11 jurors were Fundamentalist church members. All admitted that they knew little about science or evolution. One said that the only Darwin he had ever heard about ran a local notion store. One could not read or write.

The events of Sunday provided us with an interesting insight into the local climate of opinion. Charles Francis Potter, a liberal Unitarian minister and writer who had been invited to conduct services at the Methodist-Episcopal church, was barred from the pulpit by the parishioners. Meanwhile Bryan addressed an overflow house at the Southern Methodist church. That afternoon, in an open courtyard in the center of town, Bryan talked to an immense audience. He said he welcomed the opportunity to bring "this slimy thing, evolution, out of the darkness. . . . Now the facts of religion and evolution would meet at last in a duel to the death." It was a fine example of Bryan's oratory, and it swept the crowd.

The court opened on Monday with a



FOUR ATTORNEYS FOR THE DEFENSE lived in a "haunted house" which was fitted out for the occasion. Seated are Darrow (*left*) and Neal (*right*). Standing are Arthur Garfield Hays (*left*) of the American Civil Liberties Union and W. L. Thompson (*right*).

prayer in which a local clergyman urged God to preserve his sacred word against attack. It was a scarcely veiled plea to the jury.

The Defense filed a motion to quash the indictment on the ground that the act violated the Constitution of the State of Tennessee and Section I of the Fourteenth Amendment of the Constitution of the United States, which extends the Bill of Rights to limit action by the governments of the states. The Defense argued further that the indictment was contrary to a U. S. Supreme Court decision which says: "The law knows no heresy, and is committed to the support of no dogma, nor to the establishment of any sect." In support of this attack on the indictment, the Defense declared that it wished to offer the testimony of scientists and biblical scholars. These expert witnesses, the Defense contended, would show that there was no necessary conflict between evolution and Christianity.

Though the Defense asked that judgment on its motion to dismiss should be reserved until its witnesses had been heard, Judge John T. Raulston ordered the argument to proceed. On motion of the Prosecution, he sent the jury from the courtroom. Apparently the introduction of scientific witnesses had taken Bryan and his associates by surprise. Their ultimate response to our efforts to argue the underlying issues of the case was to lose them the trial in the minds of the American people.

That afternoon Darrow pressed for dismissal with an eloquent attack on ignorance and bigotry. Coatless in the sweltering courtroom, tugging at his suspenders, he paced up and down, firing shot after shot at the Prosecution. He stressed the danger to freedom of press, church and school if men like Bryan could impose their opinions and interpretations on the law of the land. "The fires of bigotry and hate are being lighted," he said. "This is as bold an attempt to destroy learning as was ever made in the Middle Ages. . . . The statute says you cannot teach anything in conflict with the Bible." He argued that in the U. S. there are over 500 churches and sects which differ over certain passages of the Bible. If the law were to prevail, Scopes would have to be familiar with the whole Bible and all its interpretations; among all the warring sects, he would have to know which one was right in order not to commit a crime.

Darrow said: "Your Honor, my client is here because ignorance and bigotry are rampant, and that is a mighty strong combination. . . . If today you can make teaching of evolution in the public schools a crime, tomorrow you can make it a crime to teach it in the private schools. At the next session of the Legislature you can ban books and newspapers. You can set Catholic against Protestant, and Protestant against Protestant, when you try to foist your own religion upon the minds of men. If you can do the one, you can do the other. After a while, Your Honor, we will find ourselves marching backward to the glorious days of the 16th century when bigots lighted the fagots to burn men

JUDGE AND JURY were photographed in front of the Dayton courthouse. Standing at right, straw hat in hand, is Judge John T. Raulston. Eleven of the jurors were Fundamentalists. One of them stated that the only Darwin he had heard of ran a local store.

SCOPES AND FRIENDS re-enacted the scene in the local drugstore which led to the trial. Scopes is seated second from left. Leaning over his shoulder is George W. Rappelyea, the mining engineer whose complaint tested the Tennessee anti-evolution law.

who dared to bring any intelligence and enlightenment to the human mind."

The speech made a profound impression. Townspeople agreed that anything might happen with that man Darrow around. Judge Raulston adjourned court until Wednesday in order that he might consider the motion to quash.

That night, as we gathered in our haunted house for a conference, a terrific storm swept the town. When a brilliant flash of lightning struck nearby, Darrow said: "Boys, if lightning strikes this house tonight . . . !"

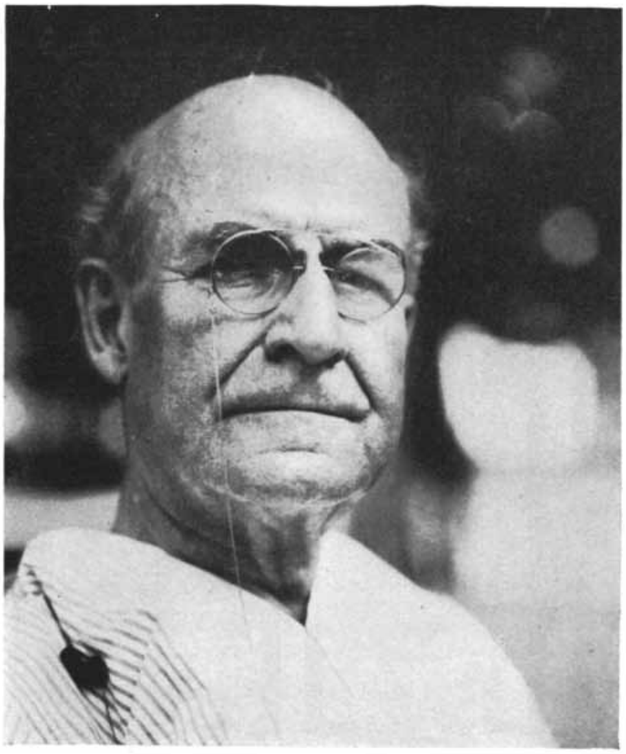
Tuesday was a quiet day. At Rappelyea's office, where he had been invited to take advantage of the secretarial facilities, Potter found that the stenographer would not take dictation from any Unitarian minister. Rappelyea himself was arrested three times for speeding in the course of his service to us as guide and chauffeur. We were besieged by Holy Rollers, who came in from the hills to convert us. We also had to protect ourselves from a supporter. H. L. Mencken had come to town. His vitriolic articles so antagonized the people we wanted most to reach that we had to persuade him to leave the scene.

After the jury was sworn in on Wednesday, the Court ruled against the Defense motion to quash the indictment. The law, said Judge Raulston, did not deprive anyone of speech, thought or opinion, for no one need accept employment in Tennessee. He ruled the law constitutional, saying that the public has the right to say, by legislative act or referendum, whether Latin, chemistry or astronomy might be taught in its schools.

The Prosecution then called the county superintendent of schools, the heads of the school board and seven students. All testified to what Scopes had taught. Darrow limited his cross-examination to establishing simply that the State had furnished the textbook. After offering the King James version of the Bible as an exhibit, the Prosecution rested.

The first witness for the defense was Maynard Metcalf. A recognized scientist, he was also an eminent Congregational layman and teacher of one of the largest Bible classes in the country. Darrow established his competence as a witness, then asked a question on evolution. The Prosecution at once challenged the testimony as irrelevant; according to them the only question was: Did Scopes violate the law?

The judge agreed to hear arguments on this point the next day. Meanwhile he excused the jury, with instructions not



BRYAN was 65 at the time of the trial. He died only a few days later. He had run unsuccessfully for the Presidency three times.

SCOPES was 24. He was the high-school science teacher and football coach. Later he studied geology at the University of Chicago.

DARROW reads his daily mail in the courtroom. He had achieved fame largely through his defense of the Socialist leader Eugene V. Debs in 1894, and of Nathan Leopold and Richard Loeb in 1924. Sixty-eight at the time of the Scopes trial, he lived until 1938.

to enter the courtroom or to remain within hearing of the loudspeakers. A lot of angry jurors filed out. They had not only lost their reserved seats, but also were barred from the proceedings entirely.

The trial reached its high point on Thursday. After an impassioned plea by the State's Attorney against the admission of expert testimony, Bryan took over for the Prosecution. Instead of making good on his challenge of "a duel to the death," he argued against the presentation of scientific evidence. He said that the jury did not need the help of scientists or Bible experts to decide the facts and to interpret the law: "The law is what the people decided." He then presented an enlargement of the picture of the evolutionary tree from the textbook Scopes had used; it showed man in a circle with other mammals. Bryan shouted: "Talk about putting Daniel in the lions' den. How dare these scientists put man in a little ring with lions and tigers and everything that smells of the jungle. . . . One does not need to be an expert to know what the Bible says. . . . Expert testimony is not needed!"

With that speech Bryan lost the argument with the press and with the radio audience. When Malone had finished his reply, Bryan had also lost the argument, for a time, with most of his Dayton followers.

Malone was a Patrick Henry that day. He asked whether our children are to know nothing of science beyond that permitted by certain sects. "I have never seen greater need for learning," he declared, "than is exhibited by the Prosecution, which refuses information offered by expert witnesses. . . . Why this fear of meeting the issue? Mr. Bryan has said this is to be a duel to the death. I know little about dueling, Your Honor, but does it mean that our only weapon, the witnesses, is to be taken away while the Prosecution alone carries the sword? This is not my idea of a duel. . . . We do not fear all the truth they can present as facts. We are ready. We stand with progress. We stand with science. We stand with intelligence. We feel that we stand with the fundamental freedoms in America. We are not afraid. Where is the fear? We defy it." Then, turning toward Bryan and pointing his finger, he cried: "There is the fear!"

The crowd went out of control—cheering, stamping, pounding on desks—until it was necessary to adjourn court for 15 minutes to restore order.

I was sitting next to the aisle. Beside

me was a Chattanooga policeman, one of the squad brought in to protect us from the Ku Klux Klan. As Malone finished, my guard beat the desk in front of me so hard with his club that a corner of the desk broke off. His chief came up and asked: "Why didn't you cheer when Malone made that speech?" My guard replied: "Hell. What did you think I was doing? Rapping for order?"

We had won for the day. Even the hostile crowd was with us.

That night Darrow said: "Today we have won, but by tomorrow the judge will have recovered and will rule against us. I want each one of you to go to the stenographer's room the first thing in the morning and prepare a statement for the press, saying what you would have said if allowed to testify in court."

As we were preparing our statements next morning, Judge Raulston looked in. I was nearest to the door. He asked what we were doing. When I told him, he asked the others in turn. Then he went to Darrow and told him he must not release the testimony: "It might reach the jury." Darrow replied: "Your Honor, you can do what you please with that jury. You can lock it up, but you cannot lock up the American people. The testimony will be released."

When court resumed, the judge ruled against us on all points. Rising and pushing his long hair from his forehead, Darrow spoke slowly and clearly. "The outcome is plain. We expect to protect our rights in some other court. Is that plain?" The judge replied: "I hope, Colonel Darrow, you don't attempt to reflect upon the Court." To which Darrow drawled: "Your Honor has the right to hope." The insult was deliberate. For an instant there was complete silence; then the judge mumbled that he had the right to do something else. A moment later he adjourned court until Monday.

Public reaction to the ruling was emphatic, and Bryan's prestige was shaken. Townspeople admitted to me, one of the "heretics," that they could not understand why Bryan had backed down. They asked: "What can you do now, if you can't talk?"

On Monday Darrow apologized to the Court, momentarily relieving the tension. Then, in order to secure the foundation for appeal, Hays read into the record the prepared statements of the scientific and other scholarly witnesses, and concluded by placing in evidence three versions of the Bible that differed from one another and from the King James version submitted by the Prosecution. Suddenly Hays electrified the crowd with the announcement that the Defense wished to call Bryan to the stand "as a biblical witness."

Darrow submitted Bryan to grueling examination. In reply to Darrow's questions Bryan stated that he accepted the Bible literally as God's revealed word. What he didn't understand he accepted on simple faith. He believed that Eve was the first woman, created from Adam's rib; that God had sent childbirth pains to all women because of her transgression; that the snake must crawl on its belly because it tempted Eve; that everything outside the Ark, except fish, perished in the flood; that all existing animals had descended from the pairs saved by Noah; that all men spoke one language until the tower of Babel; and that present languages had developed since then. Only once did he falter, when he admitted that the seven days of Creation might mean seven epochs. He conceded that he was not familiar with the work of archaeologists, who had uncovered civilizations more than 5,000 years old, but he declared that he had never had much interest in those scientists who disputed the Bible. Repeatedly the State's Attorney tried to stop the questioning, but always Bryan replied: "No. Let it go on. I am not afraid to defend my religion."

Finally Malone intervened, saying he would have asked the same questions, but only to challenge Bryan's literal interpretation of the King James version. As a churchman and a Christian, however, he objected to any effort by counsel for the State to pin Darrow's views of religion on the defense. "I don't want this case to be changed by Mr. Darrow's agnosticism or Mr. Bryan's brand of religion." Malone further observed that this was supposed to be a trial by jury, yet the jury had not been permitted in the court for more than 15 minutes since being sworn in.

On Tuesday Judge Raulston struck the examination of Bryan from the record. The only question remaining, he said, was: What did Scopes teach? To this ruling Darrow replied: "Your Honor, we are wasting time. You should call the jury and instruct it to bring in a verdict of guilty." The Court did so, and Scopes was fined $100.

Scopes had come on to graduate study in geology at the University of Chicago when the Tennessee Supreme Court heard Darrow's appeal and at last handed down its decision in January, 1927. The court narrowly affirmed the anti-evolution statute but threw out the $100 fine on a technicality. It brought

$$\dot{x}_{j+1}(t)=\dot{x}_j(t-h) \text{ if } x_j(t-h)-x_{j+1}(t-h)=\beta S_c$$

● Problem: what doctrine for a motorized military convoy will mean the highest over-the-road speed? Solving such a problem by experimental, trial-and-error methods is difficult, long, and costly . . . yet answers to such questions are vital to our modern, mobile U. S. Army. Scientists of *tech/ops* solved this one by devising and applying a mathematical model to describe a convoy, programming this model for a large digital computer. *Result:* another application of tech/ops' research techniques to solve a problem whose solution by conventional means would have been prohibitively expensive . . . and a typical example of *tech/ops*' pioneering work in *operations research and broad scientific research and development for industry, business and government.*

Two other formulas complete this model:

$$\dot{x}_{j+1}(t) = V_c \text{ if } \beta S_c < x_j(t-h) - x_{j+1}(t-h) \le S_c \quad (2)$$

$$\dot{x}_{j+1}(t) = \frac{1}{T}[x_j(t-h) - x_{j+1}(t-h)] \text{ if } x_j(t-h) - x_{j+1}(t-h) > S_c \quad (3)$$

The symbols have these significances: $x_j(t)$ is the position of the j^{th} vehicle at time t; V_c is the assigned convoy speed; S_c is the assigned spacing between succeeding vehicles in the convoy; h is the driver reaction time; β is a constant. Boundary conditions: $\dot{x}_j(t) \ge 0$; $\dot{x}_1(t)$ is a given (known) function.

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an end to the formal proceedings by advising the State to desist from further prosecution: "We see nothing to be gained by prolonging the life of this bizarre case."

The Defense was also content to accept the Court's advice. No attempt at repression has ever backfired so impressively. Where one person had been interested in evolution before the trial, scores were reading and inquiring at its close. Within a year the prohibitive bills which had been pending in other states were dropped or killed. Tennessee had been made to appear so ridiculous in the eyes of the nation that other states did not care to follow its lead.

At the University of Chicago I had been teaching modest-sized classes. When the University resumed in the autumn my lecture hall was filled. Students were standing along the walls and sitting in the windows. I thought I was in the wrong room. When I asked a boy at the door what class was meeting, he replied: "Anthropology. The prof who teaches it defended that fellow Scopes." From that time on Introductory Anthropology had to be limited to lecture-hall capacity. My mail, mostly hostile, increased until the University gave up trying to put it in my box, but tied it in bundles and sent it to my office.

Some time after the trial I was summoned to the office of Frederick Woodward, acting president of the University. He handed me a long document, a series of resolutions from a Southern Baptist conference. They took the University to task for the part members of its faculty had taken in the trial, taking note of the University's strong Baptist origins. They voiced objections to Professors Judd, Newman and Mathews, but reserved the real condemnation for me—the witness on human evolution. I was "a snake in the grass corrupting the youth of a nation," and so on, concluding with "and we have been investigating Professor Cole still further, and we find that he is not even a Baptist."

I began to laugh, but the president said: "This is no laughing matter. You are a rather new man here, but already we have more demands for your removal than any other man who has been on our faculty. These resolutions are typical and were considered of such importance that they were read yesterday at the meeting of the Board of Trustees." "Yes," I replied. "And what did they do?" He reached across his desk and handed me a piece of paper. They had raised my salary.

MATHEMATICAL GAMES

About mazes and how they can be traversed

by Martin Gardner

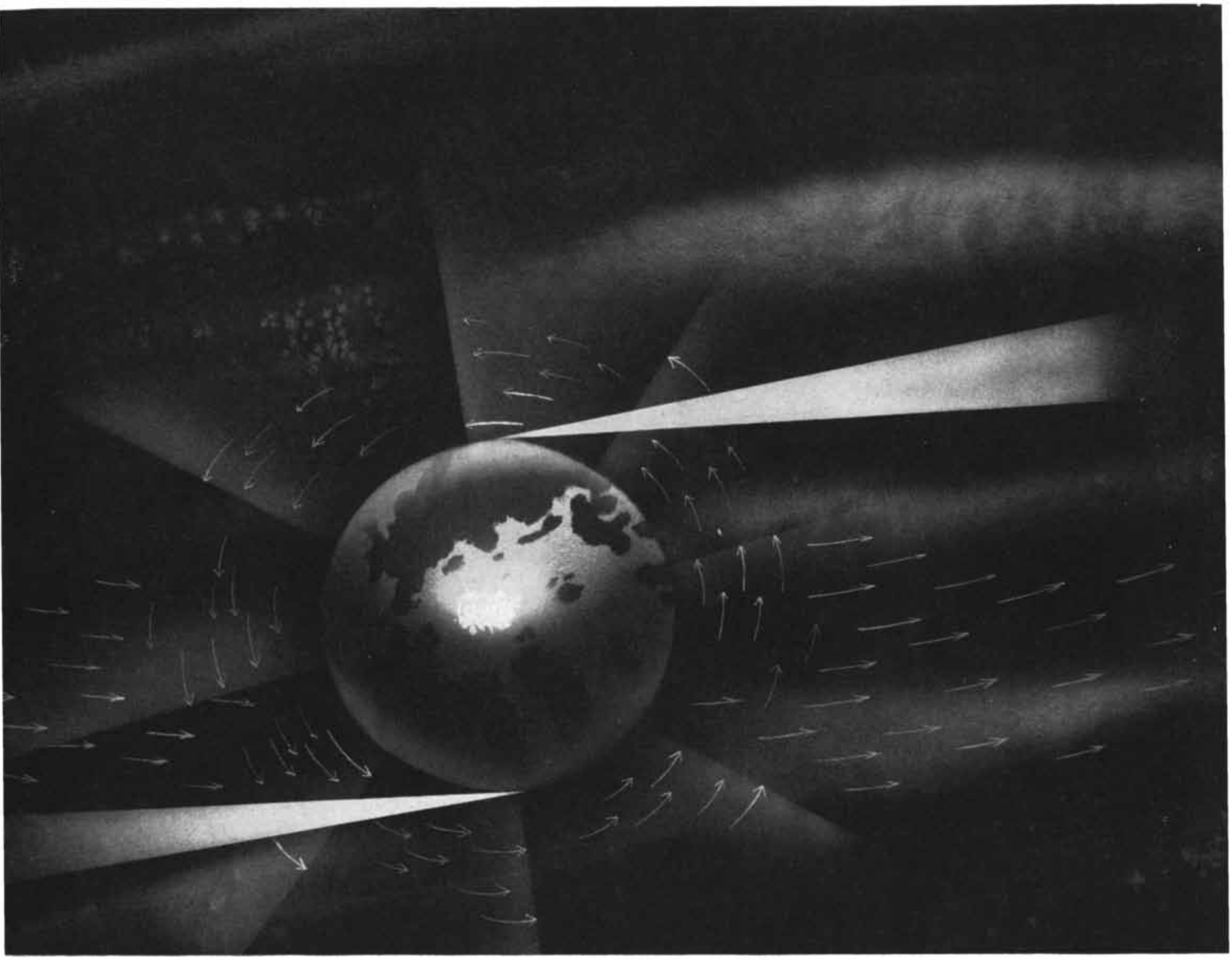
When young Theseus entered the Cretan labyrinth at Knossos in search of the dreaded Minotaur, he unwound a silken cord given him by Ariadne so that he could find his way out again. Architectural labyrinths of this sort—buildings with intricate passageways designed to bewilder the uninitiated—were not uncommon in the ancient world. Herodotus describes an Egyptian labyrinth that contained 3,000 chambers. Coins of Knossos bore a simple maze design, and more complicated maze patterns appeared on Roman pavements and on the robes of early Roman emperors. Throughout the Middle Ages the walls and floors of many cathedrals in Continental Europe were decorated with similar designs.

In England the most famous architectural labyrinth was Rosamond's Bower. It was reportedly built in a park at Woodstock in the 12th century by King Henry II, who sought to conceal his mistress, Rosamond the Fair, from his wife, Eleanor of Aquitaine. Using Ariadne's string technique, goes the tale, Eleanor found her way to the center of the bower, where she forced the unhappy Rosamond to drink poison. The story caught the fancy of many writers—notably Joseph Addison, who wrote an opera about it, and Algernon Charles Swinburne, whose dramatic poem "Rosamond" is perhaps its most moving literary version.

Curiously the Continental custom of decorating the interior of a cathedral with maze mosaics was not adopted in England. It was a common English practice, however, to cut mazes in the turf outside the church, where they were traversed as part of a religious ritual. These "quaint mazes in the wanton green," as Shakespeare called them, flourished in England until the 18th century. Garden mazes made of high hedges and intended solely for amusement became fashionable during the late Renaissance. In England the most popular of the hedge mazes, through which confused tourists still wind their way, was designed in 1690 for the Hampton Court Palace of William of Orange. The present plan of the maze is reproduced at the bottom of this page.

The only hedge maze of historic significance in the U. S. was one constructed early in the 19th century by the Harmonists, a German Protestant sect which settled at Harmony, Ind. (The town is now called New Harmony, the name given it in 1826 by the Scottish socialist Robert Owen, who established a Utopian colony there.) The Harmony labyrinth, like the medieval church mazes, symbolized the snakelike twists of sin and the difficulty of keeping on the true path. It was restored in 1941. Unfortunately no record of the original

Plan of a hedge maze at Hampton Court



A further confirmation of special relativity

An extremely high-precision experiment, giving added evidence of the correctness of Einstein's Special Theory of Relativity, has recently been conducted by a joint team of scientists from the IBM Watson Research Laboratory and Columbia University. These tests are perhaps the most precise in the history of measurement.

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This research was made possible by the knowledge of microwaves accumulated at the IBM Watson Research Laboratory in New York City. The diverse scientific interests and the computing facilities at this Laboratory have helped scientists of five continents solve problems in basic research in such fields as engineering, astronomy, chemistry, physics and psychology.

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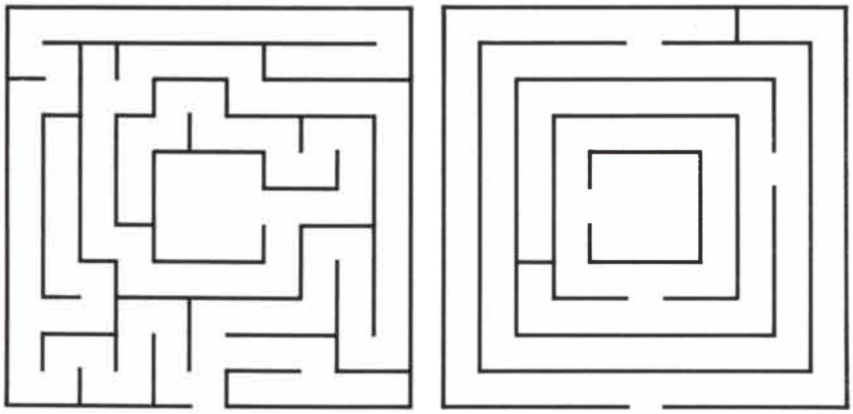

A "simply connected" maze (left) *and a "multiply connected" one* (right)

plan had survived, so the restoration was made in an entirely new pattern.

From the mathematical standpoint a maze is a problem in topology. If its plan is drawn on a sheet of rubber, the correct path from entrance to goal is a topological invariant which remains correct no matter how the rubber is deformed. You can solve a maze quickly on paper by shading all the blind alleys until only the direct routes remain. But when you are faced, as Queen Eleanor was, with the task of threading a maze of which you do not possess a map, it is a different matter. If the maze has one entrance, and the object is to find your way to the only exit, it can always be solved by placing your hand against the right (or left) wall and keeping it there as you walk. You are sure to reach the exit, though your route is not likely to be the shortest one. This procedure also works in the more traditional maze in which the goal is within the labyrinth, provided there is no route by which you can walk around the goal and back to where you started. If the goal is surrounded by one or more such closed circuits, the hand-on-wall method simply takes you around the largest circuit and back out of the maze; it can never lead you to the "island" inside the circuit.

Mazes that contain no closed circuits, such as the maze shown in the illustration at left at the top of this page, are called by topologists "simply connected." This is the same as saying that the maze has no detached walls. Mazes with detached walls are sure to contain closed circuits, and are known as "multiply connected" mazes (an example is depicted in the illustration at right). The hand-on-wall technique, used on simply connected mazes, will take you once in each direction along every path, so you are sure, somewhere along the route, to enter the goal. The Hampton Court maze is multiply connected, but its two closed loops do not surround the goal. The hand-on-wall technique will therefore carry you to the goal and back, but one corridor will be missed entirely.

Is there a mechanical procedure—an algorithm, to use a mathematical term—which will solve all mazes, including multiply connected ones with closed loops that surround the goal? There is, and the best formulation of it is given in Edouard Lucas's *Récréations mathématiques* (Volume I, 1882), where it is credited to M. Trémaux. As you walk through the maze, draw a line on one side of the path, say your right. When you come to a new juncture of paths, take any path you wish. If in walking along a new path you return to a previously visited juncture, or reach a dead end, turn around and go back the way you came. If in walking along an old path (a path marked on your left) you come to a previously visited juncture, take any new path, if one is available; otherwise take an old path. Never enter a path marked on both sides.

The illustration at right on this page shows a multiply connected maze in which two closed circuits surround the central cell. If the reader will apply Trémaux's algorithm, using a red pencil to mark his trail, he will find that it will indeed take him to the center and back to the entrance after passing twice (once in each direction) through each portion of the maze. Better still, if you stop marking the paths once the goal is reached, you will have automatically recorded a direct route from entrance to goal. Simply follow the paths marked with one trail only.

For readers who might care to test this technique on a more difficult labyrinth, the illustration at the bottom of the next page shows the plan of a multiply connected maze which the British

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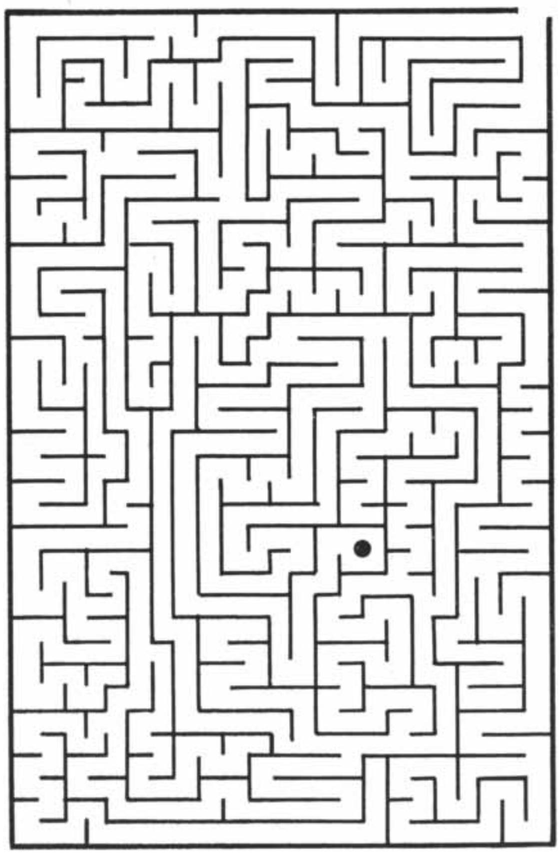
mathematician W. W. Rouse Ball had traced out in his garden. The goal is the dot inside the maze.

Today's adults are no longer entertained by such puzzles, but there are two fields of science in which interest in mazes remains high: psychology and the designing of computers. Psychologists have of course been using mazes for several decades to study the learning behavior of men and animals. Even the lowly earthworm can be taught to run a maze of one fork, and the ant can learn mazes with as many as 10 points of choice. For computer designers, robot maze-runners are part of an exciting program to build machines which, like animals, profit from their experience.

One of the earliest of these picturesque devices is Theseus, the famous maze-solving robot mouse invented by Claude E. Shannon, now at the Massachusetts Institute of Technology. (Theseus is an improvement on Shannon's earlier maze-solving "finger.") The "mouse" first works its way systematically through an unfamiliar maze, which may be multiply connected, by using a variation of Trémaux's algorithm. When the mouse reaches a juncture where it must make a choice, it does not do so in a random manner, as a man might, but always takes the nearest path on a certain side. "It is rather difficult to trouble-shoot machines containing random elements," Shannon has explained. "It is difficult to tell when such a machine is misbehaving if you can't predict what it should do!"

Once the mouse has found its way to the goal, memory circuits enable it to run the maze a second time without error. In terms of Trémaux's system, this means that the mouse avoids all doubly traversed paths and tracks only the paths it has traveled once. This does not guarantee that it will take the shortest route to the goal, but only that it will reach the goal without entering any blind alleys. A real mouse is much slower in learning a maze because its exploration technique is largely (but not entirely) random trial and error, calling for many successes before the correct path is memorized.

Other robot maze-runners have been built more recently. The most sophisticated, devised by Jaroslav A. Deutsch of the University of Oxford, is capable of transferring its training from one maze to another which is topologically equivalent even though its lengths and shapes have been altered. Deutsch's maze-runner also takes advantage of short cuts added to the maze, and does several other surprising things.



A maze in the garden of W. W. Rouse Ball

These devices are surely only crude beginnings. Future learning machines are likely to acquire enormous powers and to play unsuspected roles in the automatic machines of the space age. Mazes and space flight—the combination carries us back to the Greek myth mentioned at the beginning of this article. The maze of the Minotaur was built for King Minos by none other than Daedalus, who gave man wings and whose son perished from flying too near the sun. "So cunningly contrived a mizmaze was never seen in the world, before or since," writes Nathaniel Hawthorne in his *Tanglewood Tales* account of the story. "There can be nothing else so intricate, unless it were the brain of a man like Daedalus, who planned it, or the heart of an ordinary man. . . ."

Here are the answers to the problems posed in this space last month.

The total resistance of the cubical network is 5/6 ohm. If the three corners closest to A are short-circuited together, and the same is done with the three corners closest to B, no current will flow in the two triangles of short circuits because each connects equipotential points. It is now easy to see that there are three one-ohm resistors in parallel between A and the nearest triangle (resistance 1/3 ohm), six in parallel between the triangles (1/6 ohm), and three in parallel between the second triangle and B (1/3 ohm), making a total resistance of 5/6 ohm.

The three ways to number the faces of an octahedron so that the total around each corner is 18 are: 6, 7, 2, 3 clockwise (or counterclockwise) around one corner, and 1, 4, 5, 8 around the opposite corner (6 adjacent to 1, 7 to 4 and so on); 1, 7, 2, 8 and 4, 6, 3, 5; and 4, 7, 2, 5 and 6, 1, 8, 3.

The shortest distance the fly can walk to cover all edges of an icosahedron is 35 units. By erasing five edges of the solid (for example, edges FM, BE, JA, ID and HC in the illustration presented last month) we are left with a network that has only two points, G and K, where an odd number of edges come together. The fly can therefore traverse this network by starting at G and going to K without retracing an edge—a distance of 25 units. This is the longest distance it can go without retracking. Each erased edge can now be added to this path, whenever the fly reaches it, simply by traversing it back and forth. The five erased edges, each gone over twice, add 10 units to the path, making a total of 35. The Christmas message conveyed by the letters is "Noel" (no "L").

THE AMATEUR SCIENTIST

How to make an electrostatic machine to accelerate both electrons and protons

Conducted by C. L. Stong

The particle accelerator has about the same relationship to nuclear physics that the telescope has to astronomy. The accelerator probes the microcosm; the telescope, the macrocosm. Like the telescope, the accelerator can open exciting vistas to the amateur. But unlike the telescope, the accelerator has failed to attract a large amateur following. The notion seems to have got around that a small particle accelerator is little more than a toy. But in 1932 the British physicists J. D. Cockcroft and E. T. S. Walton did important pioneer work in nuclear physics with a 150,000-volt accelerator of the electrostatic type which today can be built for less than $200. With it Cockcroft and Walton succeeded in transmuting lithium into unstable beryllium, which then broke down into helium with the release of energy on the order of 17 million electron volts—scarcely the performance of a toy. A beam of particles from a machine of this size is capable of cutting the time of chemical reactions, of inducing mutations in living organisms, of altering the physical properties of organic compounds and of producing scores of other interesting effects.

F. B. Lee, a chemical engineer and faculty member of the Erie County Technical Institute in Buffalo, N. Y., has designed an electrostatic accelerator suitable for amateur construction which is similar to the Cockcroft-Walton machine but has more than twice its power. "Unlike the accelerator preferred by the physicist," writes Lee, "this one is designed for the amateur chemist. The beam of electrons it produces is brought out of the accelerator to irradiate targets in the open air. The physicist usually requires a closely collimated beam in which all particles have about the same energy, whereas the chemist is satisfied with a more diffuse beam in which the energy of the particles varies considerably. Since the targets irradiated by the chemist are usually rather thick, it is almost impossible to provide all sections of the irradiated material with electrons of uniform energy even if this were desirable. Fortunately it is usually satisfactory to have a large percentage of the electrons penetrate the target completely. The ions produced within the target by the beam are largely independent of the energy of the beam, but the permissible thickness of the target increases with the accelerating voltage. Electrons accelerated to an energy of 250,000 volts will penetrate metallic aluminum to a depth of about .25 millimeter; polyethylene, to a depth of some three millimeters; air, to a depth of some two meters. The depth of penetration is roughly inversely proportional to the density of the target material and to the square of its atomic weight.

"With the machine I shall describe amateurs can perform endless experiments based on the ionization of target materials by electrons. In the case of hydrocarbon targets numerous hydrogen atoms are dislodged from their sites in the molecule by the stream of fast-moving charged particles. Some of the atoms promptly combine into molecules of hydrogen (H_2) and escape as gas. Pairs of carbon atoms so stripped can then combine to cross-link the hydrocarbon molecules. Such cross-linking has a profound effect on the physical properties of the irradiated substance. For example, when molecules of the plastic polyethylene are cross-linked by irradiation, the plastic becomes much harder and melts at a higher temperature. The field is new and full of opportunities for the amateur who enjoys original work.

"The electrostatic accelerator may be thought of as a highly developed two-element electronic tube. It consists of an evacuated tube fitted with a source of electrons or protons at one end, an accelerating electrode at the other end, and a high-potential electric field between the two. If the accelerating electrode is made positive and the source is either a filament, a radioactive or photoelectric surface, or even a sharp point of metal, the resulting beam will be composed of electrons. If the accelerating electrode is made negative and a tiny amount of hydrogen is admitted to the tube, the gas will ionize and the beam will consist of hydrogen nuclei (protons).

"The major requirements for constructing a linear accelerator are a source of high potential and a vacuum system capable of reducing atmospheric pressure (760 millimeters of mercury in a mercury manometer) down to .00001 mm. of mercury. The high potential may be generated by a Van de Graaff machine such as the one described in 'The Amateur Scientist' for May, 1957. A machine capable of delivering 20 millionths of an ampere (20 microamperes) at a potential of 500,000 volts can be built for less than $30.

"The tube for my accelerator was constructed from a junked piece of Pyrex pipe two inches in diameter and about three feet long. A 24-inch length would have been preferable, but the dimensions are not critical. A hardwood plank eight inches wide, two inches thick and five feet long serves as a common base for the accelerator and vacuum pumps. The accelerator tube is mounted vertically near one end of the base, as shown in the accompanying drawing [*see opposite page*]. The cathode fitting, which closes the lower end of the tube, was machined from a piece of brass 2½ inches in diameter and one inch thick. A hole is drilled in one wall to receive the half-inch copper pipe which connects the tube to the vacuum pumps. Another hole, in which an 1/8-inch pipe thread is cut, receives a standard quarter-inch compression fitting which serves as a gland for the filament assembly. The filament assembly is comprised of a quarter-inch rubber rod about half an inch long, through which two No. 18 enameled copper lead wires are run to support a half-inch length of No. 30 Nichrome wire. The lead wires were coated with vacuum grease before they were forced through the holes in the rod. The rod was then greased lightly and slid into the compression fitting, after which a collar of rubber tubing was slid over it. Finally the compression nut was run home to seal the assembly. Details of the gland are shown at upper left in the second illustration [*see next page*]. The entire unit is vacuum-tight, easy to assemble and has given no trouble.

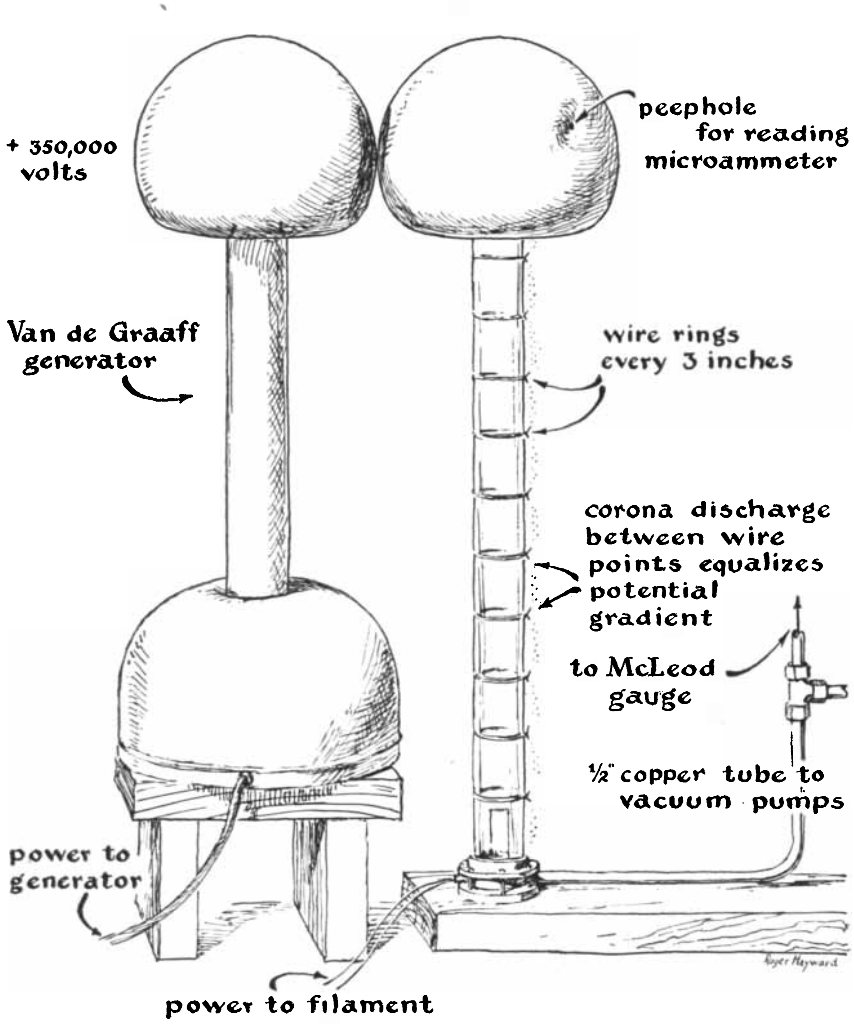
"With the Van de Graaff machine suggested, the tube develops a beam of only 10 to 20 microamperes, and the filament operates at a proportionately low temperature. The optimum filament-temperature must be determined experimentally. The temperature is controlled by a rheostat in series with the power supply, which may be a simple doorbell transformer. When the temperature is too high, excessive emission lowers the resistance of the tube and consequently the voltage of the Van de Graaff machine. Lowered tube-voltage of course means lowered beam-energy. In contrast, low filament-temperature results in scanty filament-emission, which lowers the beam current and increases the tube resistance. Thus at low filament-temperature the tube develops maximum voltage, and proportionately higher energy is imparted to individual particles in the beam. This compensates somewhat for the lower beam-current. For this reason downward departures from the optimum value of the filament temperature are preferable to upward departures.

"The electron beam is restricted to the axis of the tube by a symmetrical electrostatic field established by a series of rings spaced at three-inch intervals along the tube. The rings consist of four turns of 26-gauge bare copper wire. The ends of the wire are twisted tightly enough to hold the coil in place on the glass and are spread about half an inch apart. The points so formed act as corona electrodes and pick up charge from the surrounding air until electrical equilibrium is established between the air and the rings. In larger tubes, fixed resistors are substituted for the corona points. This, however, is not necessary in machines operating at 500,000 volts or less.

"The upper end of the accelerator is closed by a window of aluminum foil through which the beam passes into the air. To prevent the foil from rupturing under atmospheric pressure, it is supported by an aluminum grid made of quarter-inch aluminum plate. The plate is drilled with 37 holes 3/16 of an inch in diameter and arranged in a hexagonal pattern [*see illustration on page 141*]. Approximately 50 per cent of the grid area is thus open. The grid is cemented to the upper end of the tube with vacuum wax. The foil window, which should not exceed .001 inch in thickness, is similarly cemented on top of the grid.

"High-vacuum equipment is sealed with special waxes which have a low vapor-pressure, *i.e.*, they evaporate so slowly that their vapors exert very little pressure. These include de Khotinsky wax, which has a vapor pressure of one micron of mercury; Dennison waxes, with a pressure of .01 micron; and Picein and Apiezon-W waxes, with a pressure of .00001 micron. The experimental physicist John Strong recommends a wax made by melting together equal parts of beeswax and rosin. The vapor pressure of this mixture approaches that of Picein and Apiezon-W. It is applied smoking hot with a medicine dropper, and though it adheres well to cold surfaces, it is good practice to warm the glass or metal parts on which it is spread. I used Picein which chanced to be available. The parts were heated to the softening point of the wax, after which the joints were rubbed with the wax until a thin coating adhered. The pipe and grid were then pressed together until the wax set. Next the side face of the grid was coated, and the foil was pressed in place. The seal was completed by applying a thin bead of wax around the outside edges of both joints.

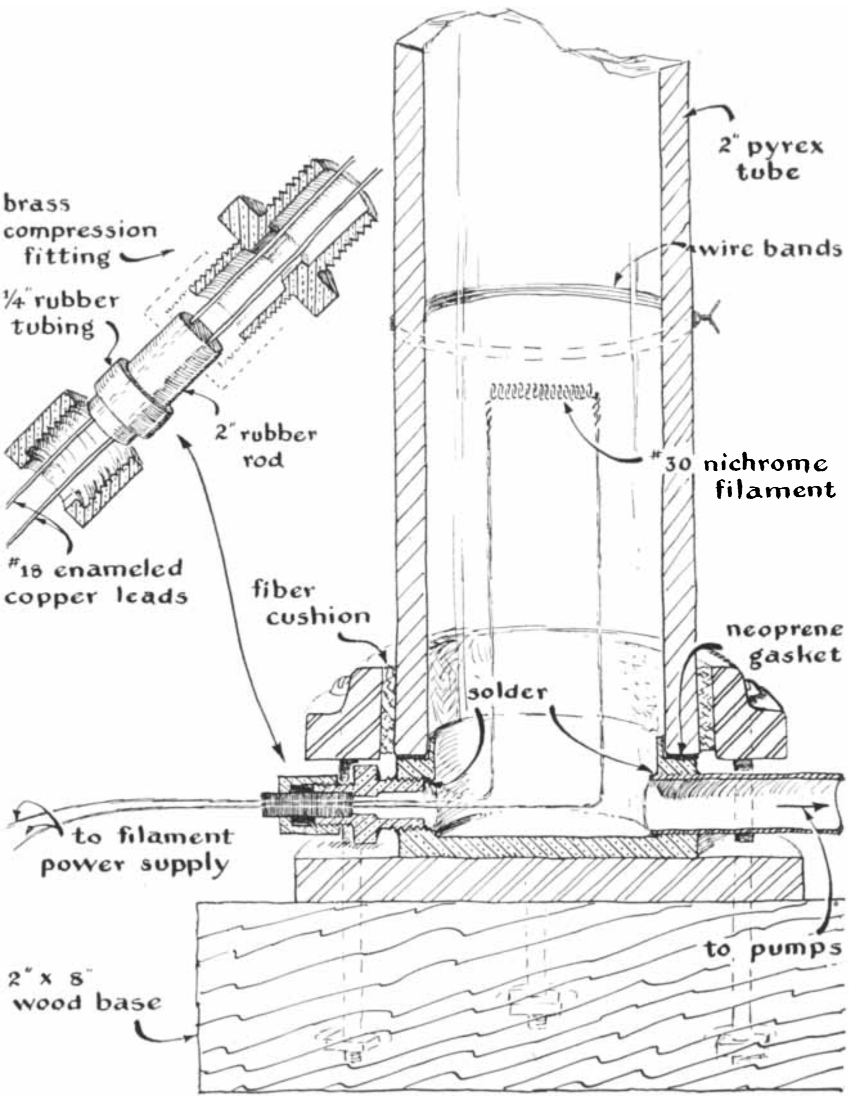
"A loop of 12-gauge brass wire was then attached to the top of the tube by friction tape as a frame to support the 12-inch spherical terminal. A simple microammeter, which consists of a high-resistance capacitor of one microfarad bridged by a 1/25-watt neon tube, is also supported by the frame. The input terminal of the microammeter is a 1½-inch disk of 12-gauge sheet aluminum supported by one axial lead of the capacitor at a height of 3/4 inch above the aluminum window. The remaining lead of the capacitor is soldered to a cross



An electrostatic particle accelerator with a Van de Graaff generator as its power supply wire attached to the brass loop [*see illustration on opposite page*].

"The electron beam enters the disk and eventually charges the capacitor to the firing potential of the neon tube, which then flashes and discharges the capacitor. A current flow of one microampere causes the tube to flash at 15-second intervals, the flashing rate being proportional to the intensity of the beam current. A dimple roughly two inches wide and half an inch deep is made in the spherical terminal opposite the neon tube, and a quarter-inch peephole is drilled at the bottom of the depression. The dimple prevents the concentration of a strong electrostatic field at the sharp edge of the hole and the loss of current through corona discharge. The neon tube can be observed safely at a distance of about two feet. The positive terminal of a 350,000-volt Van de Graaff generator is placed in contact with the accelerator terminal as the source of accelerating potential. Samples of material to be irradiated, such as hydrocarbon compounds or seeds, are placed on a carrier of thin polyethylene sheet between the aluminum-foil window and the disk electrode of the microammeter.

"The accelerator tube must be evacuated to pressure on the order of .01 micron of mercury to prevent excessive collisions between the accelerated particles and molecules of gas. Molecules ionized by such collisions are accelerated toward the filament as positive ions, collide with other molecules and create still more ions until the resulting avalanche of charged particles paralyzes the tube. At a pressure of .01 micron, gas molecules have a mean free path of 15 feet or more, and collisions are accordingly infrequent.



Details of the filament assembly for the accelerator

"A vacuum of this quality requires elaborate pumping equipment and extreme care in eliminating leaks. The most inexpensive commercial equipment capable of attaining the desired pressure is priced at about $200; hence there is substantial inducement beyond the mere challenge of an interesting problem to use a home-built substitute—such as the compressor units from old refrigerators.

"A rough vacuum of 20 millimeters or so is easily pumped either by a water aspirator or a refrigerator compressor (connected backward). Higher vacuums may be attained by connecting two refrigerator compressors of the rotary type in series to make a two-stage unit. Compressors of the piston type are not satisfactory unless they are modified, because the inlet valve which is actuated by gas pressure stops working when the system has been pumped down to a pressure of about 30 millimeters.

"It is possible to make a 50-per-cent improvement in the performance of piston compressors by bypassing the inlet valves. Rotary compressors, such as are used in the Frigidaire, have no valves and are easily adapted to multistage use. My system uses two second-hand units, one of the piston type and the other of the rotary, as "roughing" pumps. These were purchased from a local dealer in used iceboxes for $5 each, including the motors. The intake valve of the piston unit was bypassed by drilling a hole in the side of the cylinder just above the low point of the piston's travel. A short length of copper tubing was brazed to this port as the new intake. The piston covers the port as it ascends, thus eliminating the need of gas pressure to actuate the inlet valve. The intake of this unit is connected by a hose to the discharge port of the rotary compressor. A system of pipes and valves permits the discharge from the rotary compressor to be connected either to the intake of the piston unit or to a two-gallon reservoir. A similar system of pipe- and valve-connections permits the intake of the rotary compressor to be connected either to the outlet of a diffusion pump or to the reservoir. Connected in tandem and exhausted into the air, the pumps will reduce the pressure to about one millimeter. But by exhausting into the two-gallon reservoir (previously pumped to a pressure of one mm.) it is possible to obtain a final vacuum of about .1 mm.

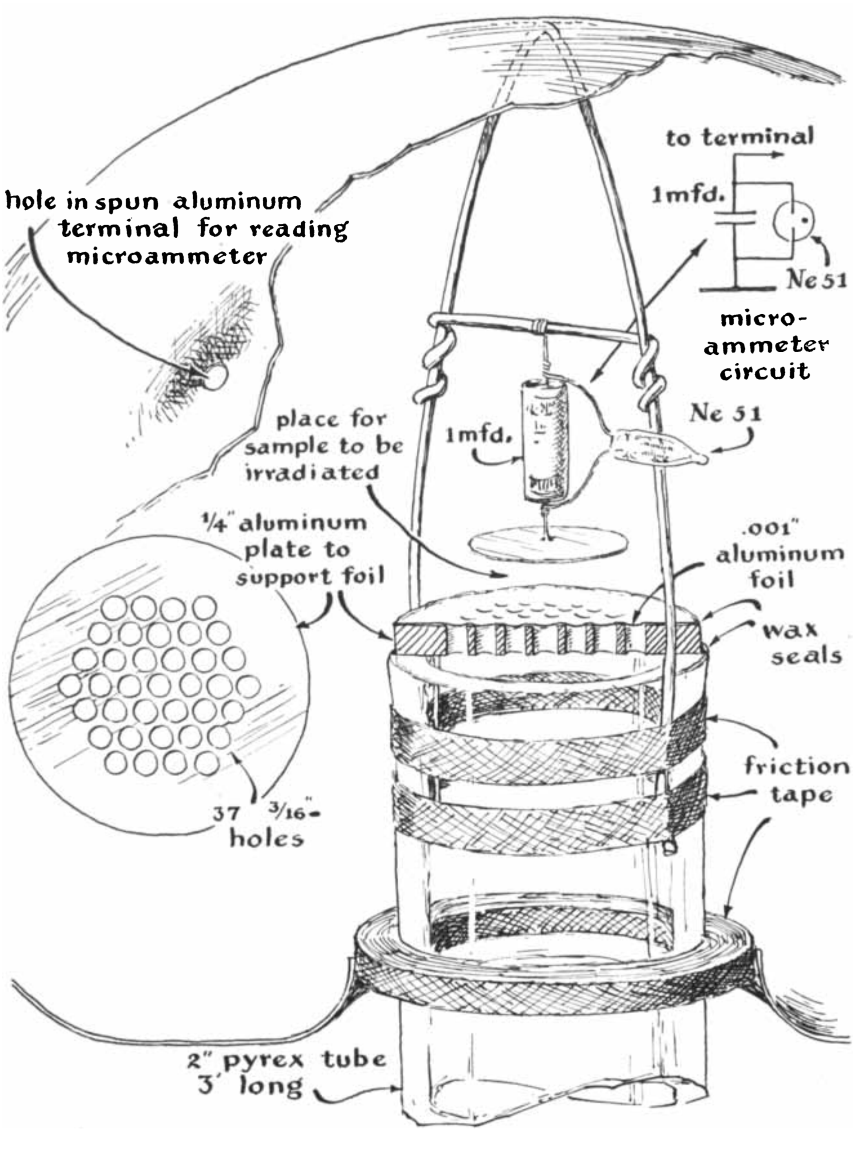
"Special oils of low vapor-pressure must be used for lubrication. The pumps are first drained of conventional oil, then filled with about half a pint of paraffin oil, operated for 10 minutes and drained. If the paraffin oil shows traces of the old oil, the pumps are again flushed with paraffin oil.

"They are now filled with vacuum oil. Some volatile fractions may still remain. These can be removed by several hours of operation. Unlike conventional vacuum pumps, refrigerator compressors have large areas of contact between the oil and gas on the discharge side of the pump and are accordingly susceptible to volatile fluids.

"My vacuum reservoir consists of a pair of one-gallon glass jugs connected with the pumps by half-inch copper pipe inserted through rubber stoppers coated with vacuum grease. The reservoir is first exhausted by the tandem pumps. The pinchcocks are operated to switch the reservoir to the output of the rotary compressor. If the system does not liberate too much gas, one pumping of the reservoir will last many hours.

"The final pressure at which the tube works is achieved by means of a diffusion pump. A half-gallon reservoir is connected between the inlet of the rotary pump and the exhaust of the diffusion pump. Pressure in both reservoirs is indicated by a manometer connected as shown [*see illustration on next page*]. When the pressure of either reservoir rises above three millimeters, it is reconnected to the inlet of the rotary unit and pumped down to one mm.

"My attempt to make a mercury diffusion pump from spare pipe-fittings did not succeed. I must confess, however, that I did not try very hard. The project should not be difficult for those with access to machining facilities. Diffusion pumps of various designs and capacities are available on the market from $30 up. The small sizes require about three pounds of mercury, which costs about $12 more. A heating unit ranging from 100 to 300 watts must also be provided for vaporizing the mercury. My pump [*see illustration on page 144*] was made by a local glass-blower to operate against a back pressure of about four millimeters. Judging by the literature, many commercial pumps require a back pressure of .3 mm. or less. In general, the rate at which diffusion pumps remove gas from the system varies inversely with the back pressure against which they operate. The ultimate pressure they produce depends on the vapor pressure of the pumping fluid, which includes various oils in addition to mercury. Vapor pressure, in the case of mercury pumps, establishes a lower limit of one micron (.001 millimeter) unless the system is equipped with a trap to prevent the mercury vapor from entering the evacuated vessel. A cold trap made by refrigerating



Details of the anode window and microammeter for the accelerator

part of the plumbing between the diffusion pump and the accelerator tube enables the pump to achieve a pressure of .01 micron if the temperature of the trap is maintained at minus 40 degrees centigrade. My trap consists of a U-shaped section in the half-inch copper line. The section is inserted in a tin can insulated by a half-inch layer of cardboard covered by aluminum foil. The cooling mixture consists of equal parts of water and wood alcohol to which crushed dry ice is added as required. The trap is not chilled until the system has been pumped to one or two microns. This procedure prevents the formation of ice in the trap which will subsequently release water vapor as low pressures are attained, and thus increase the pump-down time substantially.

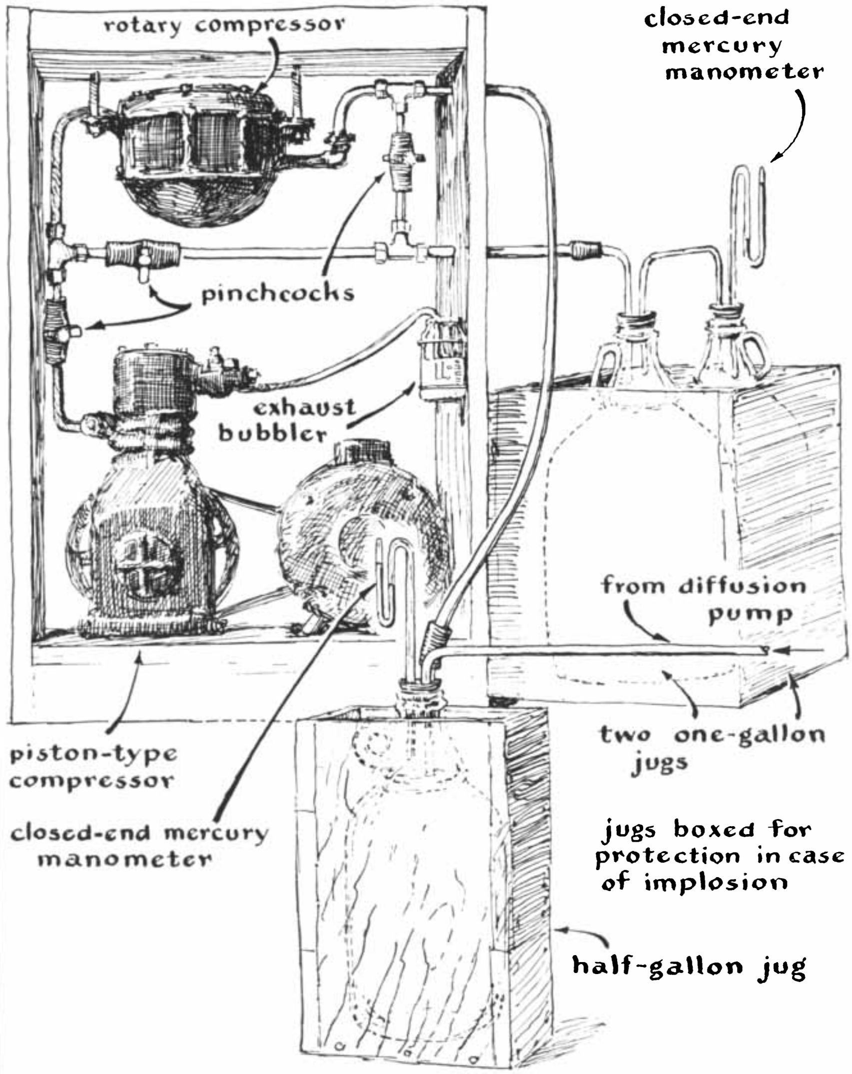
"The mercury is vaporized by a unit from a radiant heater to which an extra winding was added to reduce its rating to 150 watts. The heater is mounted in a tin can and buried in sand up to the top of the ceramic cone. Heat radiated from the center of the cone is sufficient to energize the pump. A 150-watt incandescent lamp would doubtless work as well. In selecting a site for the apparatus keep in mind that most diffusion pumps require a supply of cooling water.

"Once the vacuum system is complete, the easy part of the job is ended. One then locates and seals the leaks. This tedious procedure can consume days or weeks depending upon the experimenter's luck and the efficiency of his leak-detection gear.

"At least three closed-end mercury manometers should be provided. These consist of quarter-inch glass tubes about

24 inches long. If soda-lime glass is used, one end can be sealed over a Bunsen burner. A short section six inches from the closed end is then heated to softness and bent 180 degrees so that it lies parallel to the long portion of the tube. The long portion is then heated at the point opposite the closed end and similarly bent 180 degrees. The result is a flat 'S' [*see illustration below*]. Enough mercury is introduced into the tubing to fill the closed leg of the 'S' and about 20 per cent of the center leg. This can be accomplished by placing the tube in a reclining position and rocking it as the mercury is introduced into the open end. The closed leg must be completely filled without a trace of bubbles. One manometer is inserted in each of the reservoirs and another is temporarily connected to the accelerator tube.

"The roughing pumps are now started. If the mercury has not separated from the closed end of the manometer at the end of 15 minutes, the tube may be tapped gently. If this does not cause separation, check the pumps for faulty operation. After the pressure has been reduced to about one millimeter, the individual elements of the system should be isolated by closing all pinchcocks. The pumps are then stopped. The manometers may be provided with cardboard scales calibrated in arbitrary units. Manometer readings are recorded at the end of the pump-down and compared with a second set of readings made after an interval of 12 to 24 hours. Each section of the system will doubtless show a rise in pressure. Vacuum grease is then applied to all joints where a leak is suspected and the procedure is repeated. Ultimately the system will appear to be tight. A run can then be attempted with the diffusion pump in operation. In my system a pressure of one micron is achieved at the end of about 30 minutes, and a usable vacuum in the accelerator



"Roughing" pump assembly for the vacuum system of the accelerator

METALLURGISTS • PHYSICAL CHEMISTS • SOLID STATE PHYSICISTS • CERAMISTS

ARE YOU OVERLOOKING SOME OF THE MOST CRITICAL CHALLENGES IN THE MATERIALS FIELD?

Listen in on this interview with Dr. A. E. Focke, Manager Materials Development at General Electric's Aircraft Nuclear Propulsion Dept., Cincinnati, Ohio

Q. *Dr. Focke, I have heard it said that the Aircraft Nuclear Propulsion Program adds a new dimension to materials technology. Do you agree?*

A. Strictly speaking, Mr. Walsh, reactor development for any application may be said to do this, since materials must be selected for their nuclear as well as their physical properties.

For some applications we look for high neutron absorption cross sections; for others, low capture cross sections.

For example, the material selected for the *moderator* must be capable of slowing down the neutrons produced by fission to thermal energy, about 1/40 ev from their original energy of several million ev with a minimum loss of neutrons by parasitic capture. *Control rods* on the other hand, must have high capture cross section for neutrons.

In practically all material applications for the nuclear power plant for aircraft which we are developing here, however, we have a high temperature problem of dimensions unique in materials technology.

Q. *Why is that, Dr. Focke? Aren't these problems similar to those already solved for marine nuclear propulsion?*

A. In the ANP program weight and size are severely limiting factors. Here we are dealing with a small, high density reactor a small fraction of the size and weight of the submarine reactor. To jam high energy into small volume requires the development of high temperatures. Generally the higher the reactor exit-air temperature, the better the overall performance of the power plant.

The crux of the problem here is the fact that common materials desired for some parts of the reactor for nuclear considerations, cannot operate at the maximum temperature of the over-all system.

These charts, prepared for a recent paper will give you a better conception of the materials problem. Fig. 1 summarizes the general requirements. Figs. 2, 3 and 4 review a few of the basic physical properties of each of 11 metals selected for discussion.

Q. *Can a materials man work effectively at ANP without previous training in nucleonics?*

A. Certainly. All the orthodox skills of the metallurgist, ceramist or chemical engineer are called into play here. The Aircraft Nuclear Propulsion Department will provide necessary training and information in nucleonics.

Q. *What you've just told me, Dr. Focke, I certainly can discern the challenge to the materials man that you have here. I suppose you are working with alloys of some of the more exotic metals so much discussed in the latest technical literature?*

A. Security limitations forbid my naming specific materials on which we are concentrating our investigations at this time. We have, however, made considerable progress, though a great deal of work remains to be done before our first high performance nuclear power aircraft makes its maiden flight.

One of our principal problems is to be sure we have people with the required technical competence and specific abilities to function effectively.

Component	High Strength At High Temp.	Ability to Resist Oxidation	Neutron Absorption Cross Section	Density	Special Requirements
Fuel Elements	x	x	Low	--	Compatibility with fuel.
Moderator	x	x	Low	Low	Ability to slow neutrons to thermal effectively.
Control	x	x	High	--	
Shield					
a. Gamma	x	x	--	High(1)	(1)Ability to attenuate γ.
b. Neutron	x	x	High(2)	Low	(2)Ability to absorb without producing γ.

FIG. 1

Some characteristics of 11 metals in relation to possible application in Nuclear Power Plant for Aircraft—prepared by Dr. A. E. Focke, Manager, Materials Development.

Thermal Neutron Absorption Cross Section In Barns	
1. Hf	105.0
2. Re	84.0
3. Ta	21.3
4. W	19.2
5. U	7.68
6. Th	7.4
7. Ti	5.6
8. V	5.1
9. Mo	2.5
10. Cb	1.1
11. Zr	0.18

FIG. 2

Melting Point-°F	
1. W	6116
2. Re	5756
3. Ta	5426
4. Mo	4752
5. Cb	4474
6. Hf	4032
7. V	3452
8. Zr	3375
9. Th	3308
10. Ti	3020
11. U	2071

FIG. 3

Crystal Structure		Allotropic Transformation
1. Re	h.c.p.	NONE (known)
2. Hf	h.c.p.	b.c.c. 3020°F
3. Ti	h.c.p.	b.c.c. 1620°F
4. Zr	h.c.p.	b.c.c. 1584°F
5. Th	f.c.c.	b.c.c. 2426°F
6. W	b.c.c.	NONE
7. Ta	b.c.c.	NONE (known)
8. Mo	b.c.c.	NONE
9. Cb	b.c.c.	NONE
10. V	b.c.c.	NONE
11. U	ortho	tetra 1220°F; b.c.c. 1427°F

FIG. 4

Metallurgists, ceramists, physical chemists, solid state physicists with background in hi-temperature materials are invited to inquire about professional opportunities in these areas. Nuclear experience, while desirable, is not essential.

Write in confidence including salary requirements to: Mr. P. W. Christos, Professional & Technical Personnel—Division 55-MA.

AIRCRAFT NUCLEAR PROPULSION DEPARTMENT

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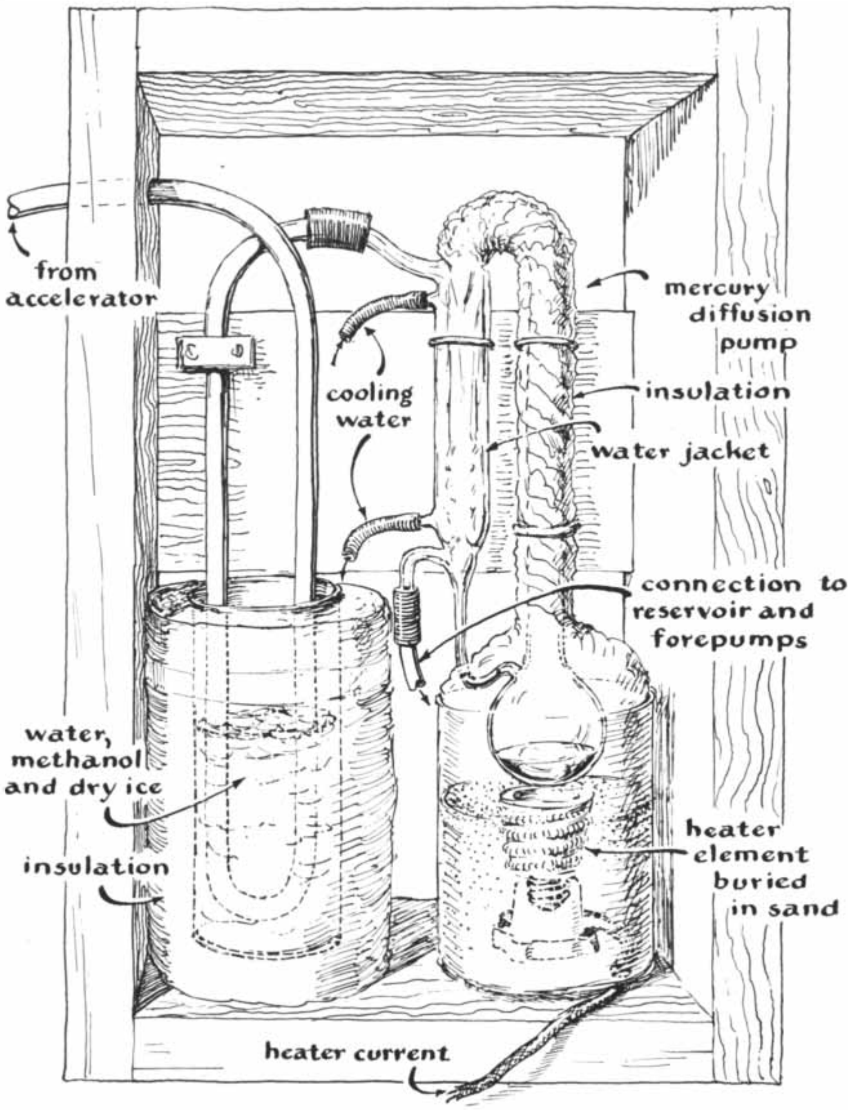
A FEW OPENINGS IN OTHER AREAS OF THE PROGRAM FOR: NUCLEAR ENGINEERS • THERMODYNAMICISTS • MATHEMATICIANS



Mercury diffusion pump and cold trap for the vacuum system

tube is attained about eight hours later. The roughing pumps are used for about an hour or until the tube pressure drops to .5 millimeter, after which they are valved off and shut down. The half-gallon reservoir on the outlet of the diffusion pump has sufficient capacity to receive the exhaust for several days of continuous pumping.

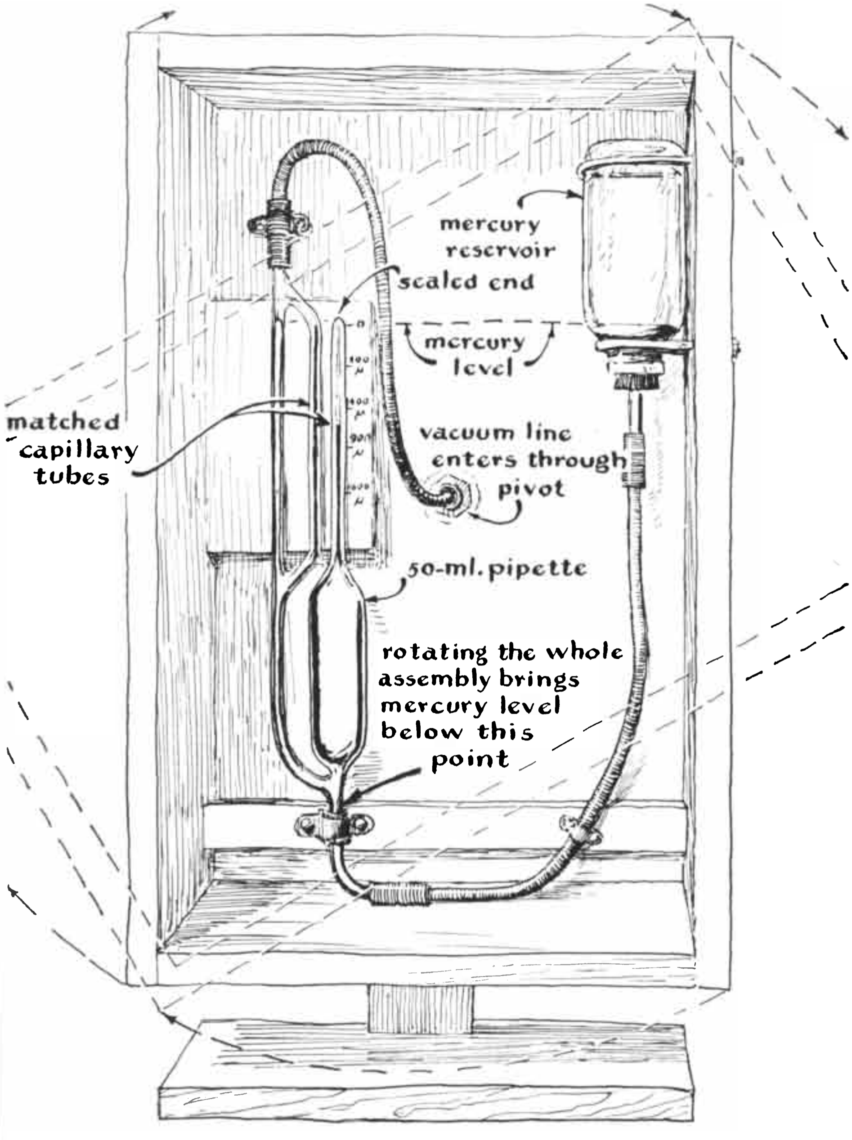
"Most experimenters will want at least one high-vacuum gauge of the McLeod type to check leaks too slow to show on the manometers. The McLeod gauge operates on the principle of trapping gas in a chamber of substantial volume and then compressing it by a column of mercury into a closed capillary tube. The pressure of the compressed gas is then compared with that in the vacuum system by observing the difference in height to which a column of mercury rises in a matching capillary connected to the system. One of my gauges is shown in the accompanying illustration [*page 146*]. It was made of discarded laboratory pipettes that had broken tips but were otherwise usable. Readings made with it are accurate down to about 10 microns, but gas released from the rubber connections prevents measurements at lower pressures. A second gauge made by a professional glass-blower detects .1-micron pressures. The instruments require about three pounds of mercury. Dibutylphthalate ($1 per pound) has been substituted for mercury as an economy measure; I have also tried salad oil and olive oil. These are usable if they are boiled for a few minutes at one millimeter of pressure, but they absorb volatile materials easily and in time become erratic.

"Those who build this accelerator would be well advised to read the sev-

eral reference texts listed in the bibliography [*page 162*] before purchasing supplies.

"Several hazards should be noted. First, a large evacuated glass vessel can, if it breaks, scatter glass at high velocity over a large area. It is essential that the glass reservoirs be enclosed in wooden or metal containers. Second, keep in mind that the accelerator is a close relative of the X-ray tube. The penetrating power of X-rays is determined in part by the atomic weight of the target bombarded by electrons. X-radiation emitted by light elements such as aluminum is readily absorbed by glass, thin metal or even air. But heavy metals, such as copper, generate penetrating and dangerous radiation. It is important, therefore, to expose only materials of low atomic weight to the beam. Third, the inexperienced worker should observe care in handling mercury, particularly when it is confined in glass tubes. If air is admitted abruptly to a manometer of the closed-end type, it is astonishing what damage the 'water hammer' (in this case mercury hammer) can do. Enclose the manometers in transparent plastic bags. Just having a few pounds of mercury around constitutes a substantial hazard because the vapor pressure of mercury is high enough to worry about even at temperatures as low as 80 degrees Fahrenheit. Fourth, although the voltage of the Van de Graaff generator is not necessarily hazardous in itself, an unexpected shock can throw one off balance and thus lead to an accident.

"I will be glad to provide assistance in locating supplies. Letters addressed to F. B. Lee, Erie County Technical Institute, Buffalo, N. Y., will be answered as promptly as possible."



McLeod gauge for measuring low pressure in the vacuum system

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BOOKS

A conference on abortion as a disease of societies

by James R. Newman

ABORTION IN THE UNITED STATES, edited by Mary Steichen Calderone. Hoeber-Harper ($5.50).

Abortion is an ancient practice, but even in antiquity it provoked sharp differences of opinion. Plato, in the *Republic*, approved abortion to prevent the birth of incestuous offspring; Aristotle, always a practical fellow, looked upon it as a useful Malthusian governor. The Hippocratic oath, on the other hand, contains the words "I will not give to a woman a pessary to produce abortion"; Seneca and Cicero condemned abortion on ethical grounds; and the Justinian Code prohibited it. There seems little doubt, however, that in the Roman Empire and the Hellenistic world abortion was, as one authority has stated, "very common among the upper classes." The Christian Church took a stern stand against this "pagan attitude," and pronounced abortion a sin. In many states the law followed church doctrine and made the sin a crime. But in Anglo-Saxon law abortion was considered "an ecclesiastical offense only."

Abortion is today a world problem. Surveys and studies by individuals and by UNESCO show the practice to be widespread in, among others, the Scandinavian countries, Finland, Germany, the U.S.S.R., Japan, Mexico, Puerto Rico, Latin America and the U. S. George Devereux's book, *A Study of Abortion in Primitive Societies*, which covers some 400 preindustrial societies as well as 20 historical and modern nations, concludes that abortion "is an absolutely universal phenomenon."

The problem has grown with the growth of population. Poverty, ill health, vanity, social customs, aversion to pain are familiar reasons for resorting to abortion; other factors are the "urban middle-class attitude toward illegitimacy," inadequate sex education, prohibitions against birth control. In most societies the problem has usually been mishandled. Ignorance, hypocrisy and inhumanity have presided in judgment over it. Because a frank admission of the dimensions of the problem might force remedial action which would provoke intense religious and social opposition, politicians, physicians, public health officials and others who make rules and opinion are wont to pretend that the practice is negligible. They are aided in this courageous stand by the general lack of knowledge in the matter. It is true, to be sure, that except for limited samples reliable statistics do not exist. Nevertheless it is clear, on the basis of a mass of data, that an enormous number of abortions—running into the millions—are performed annually the world over. We are faced, therefore, with a matter of the highest medical and social importance: a disease of society, the more serious because many communities refuse to recognize it and do nothing to eliminate its causes and mitigate its effects.

This challenging and engrossing book is evidence that there are men and women who recognize the nature and scope of the problem and are working to bring it into the open. In 1955 a conference on abortion, sponsored by the Planned Parenthood Federation of America, was held at Arden House in Harriman, N.Y., and at the New York Academy of Medicine. The participants, including leading gynecologists, psychiatrists, social workers, lawyers and public health officials, discussed such topics as the incidence of abortion, methods used in illegal abortion, causes of death due to abortion, the psychiatric and legal aspects of abortion. A report on the discussions, together with a concluding statement which summarizes the facts and makes recommendations, is given in this volume. I cannot emphasize too strongly the value of the material as a social document.

The primary concern of the conference was with abortion in the U. S. It is a shocking picture. One has only to look at it from the legal side to understand why.

Of the 49 states, all but six prohibit abortion except when it is necessary "to preserve the life of the woman." Six states permit a therapeutic abortion "to save the life of the unborn child" (whatever this absurd phrase may mean); in only two states is abortion permitted "to preserve the health of the woman." Under the hodgepodge of statutes the physician's position is perilous and uncertain. It is not easy in most cases to prove conclusively that the life of the woman depends on the abortion; moreover, in some jurisdictions a physician on trial for having performed an illegal abortion has to plead necessity as an affirmative defense, and thus the burden of proof is on him and not on the prosecution. Powerful social disapproval operates further to narrow the statutory restrictions. Some hospitals are unwilling to permit use of their facilities even for abortions sanctioned by law. In many states a woman with serious heart disease is not entitled to have her pregnancy interrupted. Though the child of a woman who in early pregnancy contracts German measles has about a 20-per-cent chance of being born blind, mentally retarded or otherwise affected, the woman cannot claim the right to a therapeutic abortion.

The law is not merely, as Mr. Bumble said, "a ass"; it is much worse. In the U. S. neither rape nor incest, even if the victim is a very young girl, is ground for abortion. Social disgrace or poverty or any other humanitarian reason receives no consideration whatever. And as regards the extraordinary attitude of the law toward the illegitimate child, nothing is more cogent than the view of Iwan Bloch, expressed in his famous book *The Sexual Life of Our Time*. The State, he said, considers as sacred the life of the child before it is born and punishes anyone who interferes with its preservation, but then considers the same child a bastard as soon as it is born and for the rest of its life.

Since it is extremely difficult to obtain a "therapeutic abortion," the illegal practice flourishes. When people want something badly enough they will have it, regardless of the law. The unmarried pregnant woman has the desperate choice of suicide, of bearing and raising an illegitimate child, or of going to an abortionist. The married pregnant woman who does not want to bear her child may be less desperate, but she too is usually beset with anxieties and confused as to what course to follow. One of the participants in the conference, G. Lottrell Timanus, who for years practised in Maryland as an abortionist, vividly described the plight of the average unwilling pregnant woman: "She does not know what to do or where to turn. There is no place available where she can air her situation comfortably and quietly and confidentially. Her only resource at present is to go to a local physician, and, under present standards, he is afraid even to look at her. He has no place to send her. He has no recommendations to make to her. So, consequently, she goes to an abortionist." And that, as Ashley Montagu says in his introduction to this volume, "is how our society deals with the problem of abortion in its most elementary form." It abandons to the abortionist the woman in her greatest need.

The statistics of illegal abortion are, as I have said, not easy to assemble. But consider one or two bits and pieces of relevant data. The late Alfred Kinsey told the conference that of some 5,000 women in the sample interviewed by his Institute, 10 per cent of those married had had induced abortions by 20 years of age; 22 per cent had had at least one induced abortion by 45 years of age; more than 90 per cent of the single women who got pregnant had undergone abortion. And among all the single white females in the Kinsey sample who had had sexual intercourse, 20 per cent had had abortions. The significance of these figures can be judged by examining a single pertinent record of New York City's Board of Health, which shows a ratio of well under five therapeutic abortions per 1,000 live births. No less interesting is the information provided by Dr. Timanus. In 20 years of practice in Baltimore he alone performed 5,210 abortions, all but a tiny fraction of them illegal. He kept careful records of his cases, and the compilations of their various features are given in this report. (Timanus is now retired, having fallen into disagreement with the law. In this connection he made an observation which epitomizes the hypocrisy of the medical profession's stand on abortion. In the 20-year period during which he had operated as an abortionist, he had served 353 doctors; yet of this entire group of estimable men, not one was willing to come forward and testify for him, or even to admit that he had sent Timanus a single patient.) Many other personal estimates of illegal abortions were given by individual participants in the conference. The statistics committee did not feel that these furnished the basis for an exact figure for the total population; however, the members were prepared to subscribe to a range of "plausible estimates," from a minimum of 200,000 to a maximum of 1,200,000 abortions per year in the U. S. Even accepting the lower figure, the consequences of illegal abortion are appalling: incalculable human suffering and misery, illness and death, heavy economic loss, the corruption of social and ethical standards.

What is to be done? Knowledgeable persons with a humane outlook are prepared to act but find it hard to agree on a program. Speakers at the conference presented evidence of the magnitude of the abortion practice in the U. S., discussed its causes and made plain its tragic effects. Yet in the final session on conclusions and recommendations there was a tendency to split hairs, to argue over false issues and irrelevancies and to gloss over essential questions. The participants recognized that they were dealing with an explosive problem and that it was as difficult to draft specific reforms as it would be risky to advocate them. The cake of social custom has a hard crust; prejudices die hard. Moreover, as several speakers pointed out, since the Catholic Church is opposed to abortion on any ground, it was safe to anticipate vehement criticism of any recommendations for modifying existing abortion statutes which the conference might adopt. A statement of conclusions was finally prepared, which more than three quarters of the participants signed; they were careful to state, however, that their signatures represented personal agreement and in no sense committed the hospitals, universities, health boards or other organizations with which they were connected. The statement deserves close attention.

Present laws and mores, the signatories firmly assert, have failed entirely to control illegal abortion. "Rather this has continued to an extent ignored or, perhaps, condoned by a large proportion of the general public and even of the medical and legal professions." Since one cannot legislate the practice out of existence, it is folly to keep on the books laws which do not receive public sanction and observance. The constitutional amendment that prohibited liquor is an example of an unpopular and unenforceable law which led to evils vastly greater

than those it was designed to meet. The signatories make a striking comparison between the high incidence of abortion as a disease of society and the high incidence of venereal disease three decades ago. Both involve health, mores and morals; both are problems in epidemiology. Until recently the venereal-disease problem was kept in the cupboard; prejudice and prudery barred bringing it into the open. Then at last physicians and public health agencies decided to smash the barriers and ventilate the problem. This led to salutary controls even before antibiotics finally broke the back of venereal disease. The majority of those attending the conference felt that "the same type of frontal assault should now be made on the problem of intentional abortion."

The motives for abortion, the report emphasizes, are often complex. Ill health may play a part, but more usually "poor social and economic environment, disturbed marital relations, psychiatric or neurotic disturbance within the family, or, quite simply, a need to keep her family at its present size" induce a woman to seek this way out. Abortion is always a damaging experience, the conferees declare, and while it meets an immediate crisis it frequently does not solve the basic difficulties that created the crisis. To recognize this fact is to recognize that the vast number of illegal abortions each year is many times the number consistent with sound medical or social practice. But to reduce the number is a goal not to be achieved within the framework of present attitudes and laws. Abortion must therefore receive the attention not only of professionals and specialists in medicine, sociology, psychology, education, religion and law, but also of all responsible citizens.

Several remedial measures are recommended.

First, medical, psychological and social studies of women seeking abortion are needed to furnish reliable information on background, motivation, mechanism and results. More must be known about the problem before it can be dealt with intelligently.

Second, consultation centers for women seeking abortion should be set up. These would operate under joint medical and social auspices and, if possible, through sponsorship of state health and welfare departments. Models for such centers are to be found in the Scandinavian countries. Clinics in Norway, Denmark and Sweden give instruction on the use of contraceptives to anyone who asks for it, regardless of economic or marital status. They provide facilities for sex education, and furnish advice on abortion. An enlightened and realistic outlook informs these programs. Bard Brekke, a Norwegian public health official participating in the conference, gave an excellent account of the basic principles that guide the maternal health centers. "We believe," he said, "that when a woman wants an abortion, there must be something wrong either with herself or with her life situation or both, and that frequently she represents not an individual medical and social problem only, but that of a whole family in need of some social or sociomedical treatment." Sometimes an abortion must be part of a "total treatment plan" of social, psychiatric and medical services, and then the center recommends it. But the attempt is always made to correct the underlying situation and to help the woman and her family without resorting to abortion. "In not a few cases," Dr. Brekke added, "we have found it possible to do what we would like to call rehabilitative or reconstructive sociomedical work, but in many cases these women and their families represent chronic social disease; they are in need of continuous social and psychiatric care and, as in other forms of chronic disease, these records can rarely be closed."

The third measure is to extend, under medical supervision, the practice of giving free advice on contraception. There is admittedly little evidence to support the claim that increased availability of contraceptive services will reduce the illegal abortion rate. But until dependable statistics can decide the question there is every reason to adopt and act on the assumption that such services will help. Under present circumstances there is a lamentable inequality of access to contraceptive information. "The law in its majestic equality," Anatole France once reminded us, "forbids the rich as well as the poor to sleep under bridges, to beg in the streets, and to steal bread." But even in the U. S. there are disadvantages to being poor. In most communities contraceptive information can be obtained only through a private physician. Hospitals serving the lower income groups do not furnish routine contraceptive facilities. One has to pay to get what one needs; moreover, one has to know what one needs. It was noted at the conference that among the uneducated it is still not rare to find women who do not connect pregnancy with sexual intercourse. It is not surprising, therefore, that there are many women who know nothing about contraceptives. Free clinics and a vigorous education program are essential if this approach to illegal abortion is to make any headway.

The same inequality marks the availability of legal abortions. Reports made at the conference show a much higher therapeutic abortion rate in private than in voluntary hospitals, and similar differences are reported for private and ward patients in the same hospital. There are more illegal-abortion deaths among poor people than among those better off; more abortion deaths among Negroes than among whites. A participant observed that "the difference between an illegal and a therapeutic abortion is $300 and knowing the right person." This remark is wildly wrong only in respect to the sum mentioned. In most cities it costs more these days to get an abortion.

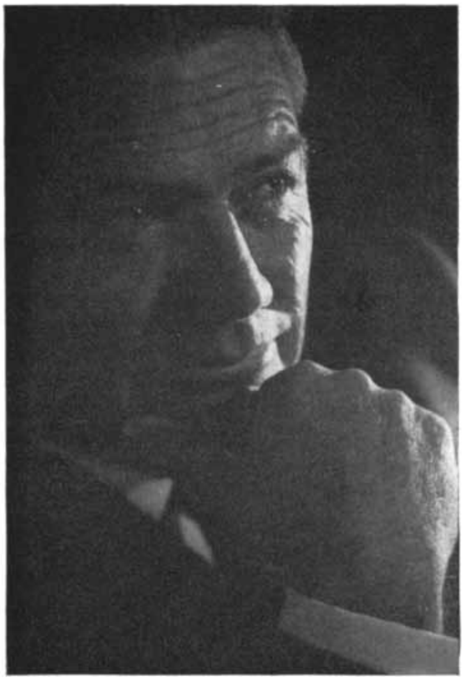
The one formidable obstacle to reform is, of course, the law itself. Existing statutes are so fanatically narrow and backward that the only possible way to live with them is to break them. If they are interpreted in their plain meaning, there is almost no justification for therapeutic abortion, for with improvements in modern medicine it rarely becomes necessary to perform an abortion to save life. From 1951 to 1953, 37.8 per cent of all therapeutic abortions in New York City were based on "psychiatric indications." This means that in each of these 642 cases psychiatrists certified that abortion was necessary to save the woman's life, *i.e.*, to prevent suicide. Obviously this is nonsense. In most instances the certifying psychiatrist knew that he was in a position to predict suicide, yet he knew also that it was dangerous to force a child upon a woman suffering from serious mental illness. The crime then, if there was one, was the legislators', not his.

In their final recommendation the signatories urged that authoritative bodies such as the National Conference of Commissioners on Uniform State Laws, the American Law Institute and the Council of State Governments should frame a model law to replace existing statutes. Again it is to the Scandinavian countries that one must turn for instruction on sensible abortion laws. The statute adopted by the Swedish Parliament accepts "humanitarian" and "eugenic" as well as medical indications for the lawful interruption of pregnancy. The weak, worn-out or exhausted mother who cannot take another child without serious consequences to herself and her family can get relief. A pregnant girl under 15 years of age, a victim of rape, incest or other criminal coercion, a mental defective—each of these is considered entitled to a legal abortion. The eugenic indication applies when it seems probable that the mother or father of the expected child would transmit to the offspring a hereditary mental disease or deficiency or a serious illness or physical defect. In such cases sterilization is usually required to accompany the interruption of pregnancy. And in 1946 Sweden added a paragraph to the law in which an indication of a "sociomedical nature" was established. According to this provision, abortion should be granted when, taking into consideration "the conditions of life of the woman, and other circumstances," it is fair to infer that her physical or mental strength would be damaged by the birth and care of the child.

It must not be supposed that this enlightened law is administered loosely. A committee of the Royal Medical Board exercises strict supervision. Members of the committee are a physician, a layman (usually a woman) and the Chief of the Bureau of Social Psychiatry. A geneticist joins the committee when cases of eugenic indications are to be decided. The applicant is never seen in person; written material and other evidence are the bases for the findings. The effect of the law has been greatly to increase during the last 15 years the number of legally induced abortions; the present rate seems to be about five per 100 term deliveries. Compare this with a rate of about five therapeutic abortions per 1,000 live births in New York City. The difference between these rates is a measure of the difference between the rate of illegal abortion in the U. S. and in Sweden.

Short Reviews

A History of Magic and Experimental Science: The Seventeenth Century, by Lynn Thorndike. Columbia University Press ($20). Lynn Thorndike, authority on the Middle Ages and pioneer historian of science, published the first volume of his great scholarly work, *Magic and Experimental Science*, in 1923. The seventh and eighth volumes, on the 17th century, now bring to completion this history upon which he began to labor more than 50 years ago. The 17th was the century of Kepler and Galileo, of Francis Bacon, Harvey, Leibniz, Descartes, Huygens, Boyle and Newton. The age of science had begun. Yet this great upsurge of the experimental method and rational theory did not sweep away the belief in magic and the occult. Astrology and alchemy continued to flourish and to color the outlook of some of the foremost figures of the revolution in ideas. Nature was personified and regarded in a way favorable to magic by scientists of the caliber of Galileo, Harvey, Leibniz and Newton. The witchcraft delusion prevailed; thoughtful men still believed in demons, souls, cabala, number lore, oracles, sibyls, augurs, dreams, fortune and destiny; superstitions of every kind were cherished and encouraged. As Thorndike observes, while in the case of experimental science "there may be disagreement as to by whom first the new was tried, in the case of magic, at least in the 17th century, the question is rather who was the last to lay the old aside." Thorndike follows the plan of the earlier volumes: the treatment is partly by men, partly by subjects, now topical and now chronological. The examples are extraordinarily varied, and present a vivid picture of the science and pseudo-science of the century. In addition to discussing the well-known men, he sets forth the views and achievements of many of their contemporaries. Aguillon of Brussels, who published a work on optics, related that, on one occasion when he was asleep, his natural spirits were so kindled that he would have burst into flame had he not waked up just in time. Giuseppe Biancani, who had some sensible ideas about astronomy (*e.g.*, that comets may return), also devoted a good deal of thought to the problem of how far a stone would fall if dropped into a hole running through the center of the earth to its opposite side. The Jesuit Cabeo, who rejected Galileo's explanation of tides and correctly attributed them to the moon, incorrectly explained them on the basis of the moon's peculiar virtue of "exciting sulphurous and 'salnitrous' spirits from the bottom of the sea." Daniel Sennert of Breslau, a physician and chemist so respected that the Italian intelligentsia were said to doff their hats at the mere mention of his name, had a world view which was a remarkable mixture of scientific insight (*e.g.*, that a vacuum was possible, that objects set in motion would remain in motion unless impeded, that the movement of light was not instantaneous) and occult rubbish (*e.g.*, that a peony root hung around the neck averted epilepsy, that animals similar to small puppies were generated from the foam of mad dogs, that a magnet works by spiritual qualities). Sir Kenelm Digby concocted a famous "sympathetic powder" which healed wounds as far away as 1,000 miles. Athanasius Kircher wrote a huge, barren, rhapsodical work on the subterranean world "whence all the chief rivers flow through occult channels." These men impeded the growth of science but



HOW LONG HAS IT BEEN SINCE YOUR MIND WAS STRETCHED BY A NEW IDEA?

Oliver Wendell Holmes once wrote: "A man's mind stretched by a new idea can never go back to its original dimensions." The truth of this statement cannot, of course, be denied. A child who suddenly realizes that the letters in the alphabet are not just isolated sounds and shapes, but meaningful symbols that form words, has grasped an idea that will lead to a continuing expansion of his mind. There comes a time, though, in the lives of too many of us when our minds become occupied only with knowledge we have already learned. When that happens our minds cease to grow.

Unhappily, the more successful a person is in his daily work, the more likelihood there is that this unfortunate condition will result. As we become more and more absorbed with our specialty—whether it is law, medicine, engineering, science, business or any one of the hundreds of other engrossing occupations—we cease to absorb the new knowledge that leads to new concepts. With the years, the mind narrows rather than broadens because we cease to stretch it by exploring the great subjects of philosophy, government, religion—the great humanities which have produced our great men and great thought.

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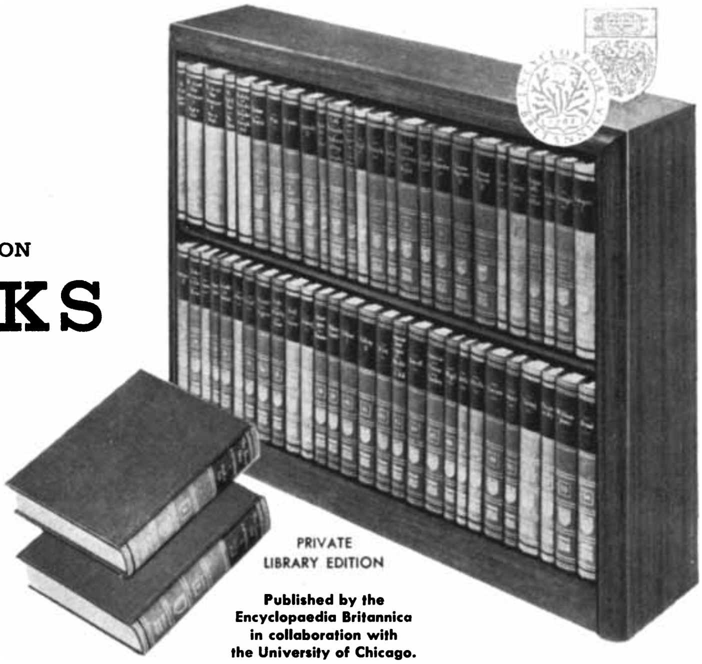

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City __________ *Zone* ______ *State* ______ at the same time—little by little and often despite themselves—promoted it. A few of the other topics to which Thorndike gives attention are chemical courses and manuals, academies and scientific societies, popular science, physiognomy and divination. An indispensable source and the perfect book for dipping and browsing.

RICHARD HAKLUYT, VOYAGES AND DOCUMENTS, selected by Janet Hampden. Oxford University Press ($2.50). This appetizing, chunky little book in the Oxford World's Classics series selects material from Hakluyt's famous 12-volume collection *The Principal Navigations, Voyages, Traffiques and Discoveries of the English Nation.* Among the contents, usually first-hand accounts, are the defeat of the Spanish Armada, Drake's voyage around the world, Sebastian Cabot's voyage to North America in 1497, Sir James Lancaster's expedition to the East Indies (1591-1594), voyages to Brazil, to the Levant and to West Africa, Sir Hugh Willoughby's expedition to Russia, Anthony Jenkinson's overland journey to Persia, the great feats of William and John Hawkins, of Frobisher, Gilbert, Davis, Raleigh and Grenville.

THE DAWN OF EUROPEAN CIVILIZATION, by V. Gordon Childe. Alfred A. Knopf ($7.50). This classic survey of European prehistory by the late V. Gordon Childe was first published in 1925. Excavations and investigations during the next 20 years produced many new facts, thereby not only changing but also complicating the picture. Further researches after the war, together with dates provided by the radiocarbon method, clarified some problems and raised others. Altogether these advances demanded a drastic revision of the text, which now appears in its sixth edition, incorporating, among other things, the results of finds from Eastern Europe which Childe had the opportunity to study at first hand. An enthralling and masterly book.

HANDBOOK OF PHYSICS, edited by E. U. Condon and Hugh Odishaw. McGraw-Hill Book Company, Inc. ($25). This fat, unwieldy tome—1,504 large, double-column pages of small (but perfectly readable) type—completely justifies its obesity. It contains an excellent survey, prepared by a staff of some 80 specialists, of the principles, ideas, concepts and advanced mathematical methods of all branches of classical and modern physics. The literature of physics is immense and keeps growing at an accelerating rate. It has therefore become almost impossible for a physicist to know physics; he has a hard enough time exploring his own little corner. Yet it is often the case that advances and fresh perspectives in one branch of the subject depend upon the use of knowledge won in another branch: the unity of science is a fact as well as an ideal. This intelligently planned and skillfully executed compendium recognizes the physicist's dilemma and tries to help him surmount it. The thermodynamicist can get answers to his questions about optics, the student of mechanics can look up material on spectroscopy, the nuclear physicist can refresh his memory on probability or the tensor calculus or acoustics or rheology or the energy-band theory of solids. When one reads through a chapter on a given topic, one can either find what one is looking for, or learn where to find it. No handbook can do more, and this one does its job admirably. The nine parts of the book deal with mathematics, the mechanics of particles and of rigid bodies, the mechanics of deformable bodies, with electricity and magnetism, heat and thermodynamics, optics, atomic physics, the solid state, nuclear physics. The exposition is generally succinct and clear; some of the articles—for example, C. Lanczos's account of the tensor calculus—are masterful, and the 17 chapters on diverse subjects contributed by the senior editor are not only models of lucidity, but are proof that even a modern physicist does not have to remain cribbed in his specialty.

BIOLOGICAL ASPECTS OF CANCER, by Julian Huxley. Harcourt, Brace and Company ($3.75). This is the kind of synthesis Huxley does supremely well. It is an expanded version of his Alfred P. Sloan lecture in which he surveyed present knowledge of cancer from the biologist's point of view. In preparing the lecture he reviewed a substantial literature, came across many unfamiliar facts and was stimulated as an outsider to a number of fresh ideas. He discusses the concept of the disease (the term cancer, he says, is "a convenient label or pigeonhole for a number of pathological tissue conditions exhibiting certain common characteristics, but all unique in certain other respects"), its many causes, the comparative distribution of cancers in plants and animals, the genetics of tumors, cancer-producing viruses, evolutionary and developmental questions, the prevention of cancer. His essay is a model of clarity, offering the general reader as well as the specialist the most comprehensive and comprehensible introduction to the subject.

A CENTURY OF DARWIN, edited by S. A. Barnett. Harvard University Press ($5.75). The articles in this commemorative volume are well above the usual waffles that contributors resuscitate for such occasions. There are good pieces by C. H. Waddington, Theodosius Dobzhansky, John Hammond, A. S. Romer, Gavin de Beer, W. E. Le Gros Clark, Barnett, C. M. Yonge and others. The book as a whole offers a remarkable conspectus not only of the theory of evolution, but also of Darwin's contributions to other fields and his influence on social thought and ethics.

THE TRAVELS OF WILLIAM BARTRAM, edited by Francis Harper. Yale University Press ($8.50). William Bartram, a botanist like his father (who established the first botanical garden in America, part of which is today preserved in Philadelphia as a park) published this famous record of his 18th-century journeys through the Southern colonies in 1791. It is a most enjoyable narrative, which was for a long time more appreciated abroad than in America, and was the source of some of Wordsworth's and Coleridge's finest poetic images. "The Ancient Mariner" and "Kubla Khan" are among the poems which drew upon the natural-history scenes that Bartram described in a "wondrous kind of floundering eloquence" (Carlyle's comment in a letter to Emerson). But the *Travels* is important not only as literature but also as a scientific account of plants and animals, of Indian life and villages. The present edition, an attractive book prepared with loving scholarly care, is by far the best to have appeared. It is fully annotated and indexed, and will prove especially useful to students of the natural sciences and to geographers, historians and anthropologists.

LAND OF THE TOLLUND MAN: THE PREHISTORY AND ARCHAEOLOGY OF DENMARK, by Palle Lauring. The Macmillan Company ($6). An account of the prehistory and archaeology of Denmark. This is an exceptionally readable story, resting securely on the archeological facts and enriched not only by the author's broad knowledge of other fields but also by his ingenious speculations. Lauring begins with a brief survey of the geological and climatic changes which preceded the appearance of the first settlers in Denmark (millions of years ago the region lay under 3,000 feet of sea), and carries his account through the Stone, Bronze and Iron ages, the great migrations, and the Roman and Germanic Iron ages. For every period he gives a convincing picture, supported by the archaeological finds and related information, of what life was like: food-gathering, homes, tribal customs, tools, weapons and armor, battle tactics, clothing and jewelry, religious beliefs and burial practices, shipbuilding, explorations, migrations and conquests. Beautifully illustrated, this work by an imaginative scholar is one of the happiest contributions to archaeology in some time.

TO WORK IN THE VINEYARD OF SURGERY: THE REMINISCENCES OF J. COLLINS WARREN, edited by Edward D. Churchill. Harvard University Press ($6). The reminiscences of a well-known Boston surgeon who died in 1927. The sketches of social, scientific and academic life in 19th-century America and Europe have a mild flavor, but the descriptions of operations and the general practice of surgery are gruesomely fascinating. It is easy to understand from Warren's account why so many persons were killed by the surgeon's gleefully barbarous attentions or were shattered in health for the rest of their lives; what is hard to understand is how anyone survived.

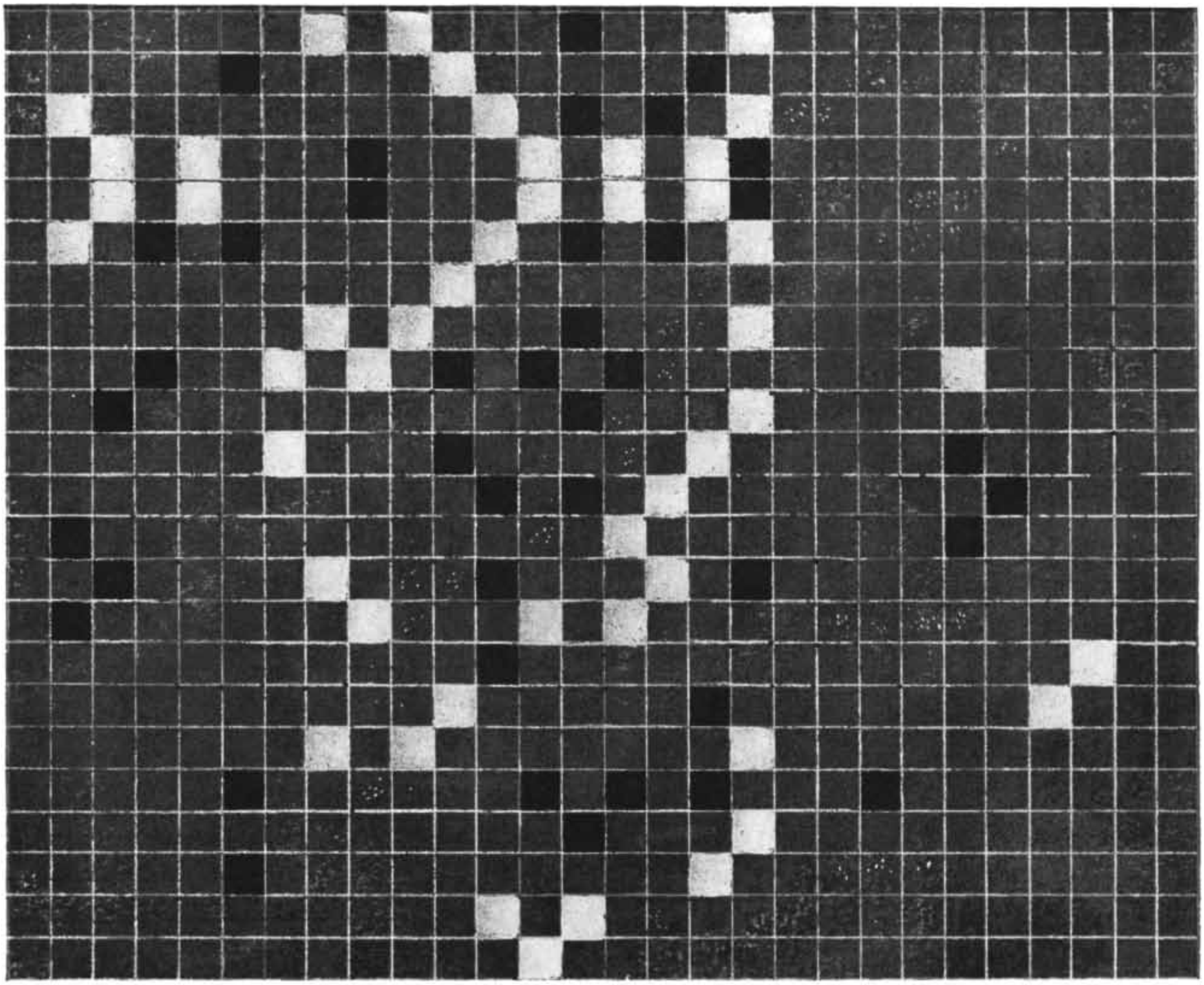
Notes

HISTORY OF MATHEMATICS, by David Eugene Smith. Dover Publications, Inc. ($5). A paperback reprint of a well-known text on the history of elementary mathematics, from arithmetic through the first steps of the calculus. Smith's book is replete with biographical details and contains many excellent illustrations. It is written for students, teachers, and nonspecialists.

ATOMIC PHYSICS AND HUMAN KNOWLEDGE, by Niels Bohr. John Wiley and Sons, Inc. ($3.95). A collection of articles which Bohr wrote for various occasions within the last 25 years. The central theme is the bearing of modern atomic physics on the question: What can we know about the physical world?

RADIATION PROTECTION, by Carl B. Braestrup and Harold O. Wyckoff. Charles C. Thomas ($10.50). A summary of present knowledge of how to protect against all forms of radiation.

THE EFFECTS OF ATOMIC RADIATION ON OCEANOGRAPHY AND FISHERIES. National Academy of Sciences—National



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Research Council ($2). This report of a National Academy Committee deals with the growing problem of the effects of fallout and radioactive wastes on the life of the sea. It is perhaps worth remarking that it is no better these days to be a fish than a man.

MAN, THE PECULIAR ANIMAL, by R. J. Harrison. Penguin Books, Inc. (95 cents). Man contrasted, in respect to the structure and function of various parts of his body, with other mammals. This well-stocked, ably written primer of anatomy is the latest addition to the instructive Pelican Medical Series.

NORTH SOMERSET AND BRISTOL, by Nikolaus Pevsner. Penguin Books ($1.50). The most recent addition to Pevsner's astonishing survey, which gives details of the architectural features of all ecclesiastical, public and domestic buildings of interest in each town and village of England.

WE, THE TIKOPIA, by Raymond Firth. The Macmillan Company ($7.50). Reissue of a 1936 sociological study of kinship in primitive Polynesia, out of print for many years, regarded as one of the founding works of modern social anthropology.

BEHAVIOR AND PSYCHOLOGICAL MAN: ESSAYS IN MOTIVATION AND LEARNING, by Edward Chace Tolman. University of California Press ($1.95). A collection of 19 essays published over a 35-year period by a leading psychologist. Included is his well-known "Cognitive Maps in Rats and Men." Paperback.

MEASUREMENT AND STATISTICS, by Virginia L. Senders. Oxford University Press ($6). A textbook, but so simply and clearly written, and with such intelligent understanding of a beginner's dead ends and perplexities, that it deserves at least a listing in these columns.

AN INTRODUCTION TO MATHEMATICS, by Alfred North Whitehead. Oxford University Press ($1.50). A paperback reprint of Whitehead's famous primer. It is worth remarking that this book in an attractive cloth-bound edition sells in England for the equivalent of $1. The U. S. price defeats the purpose of a paperback.

CHOLESTEROL, by David Kritchevsky. John Wiley and Sons, Inc. ($9.75). A guide which gathers together the widely dispersed literature on the biological function and significance of cholesterol.

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JANUARY, 1959

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

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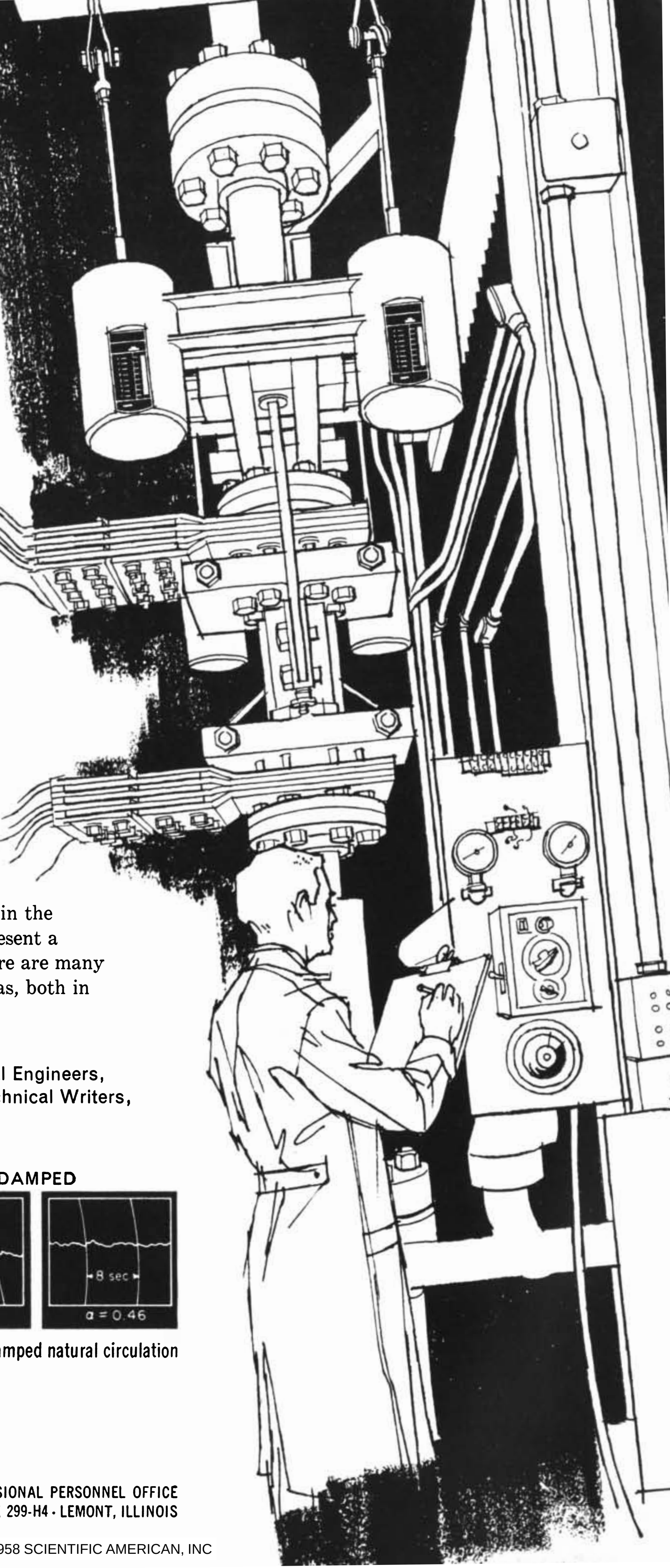

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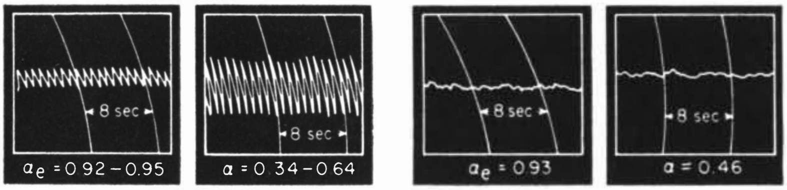

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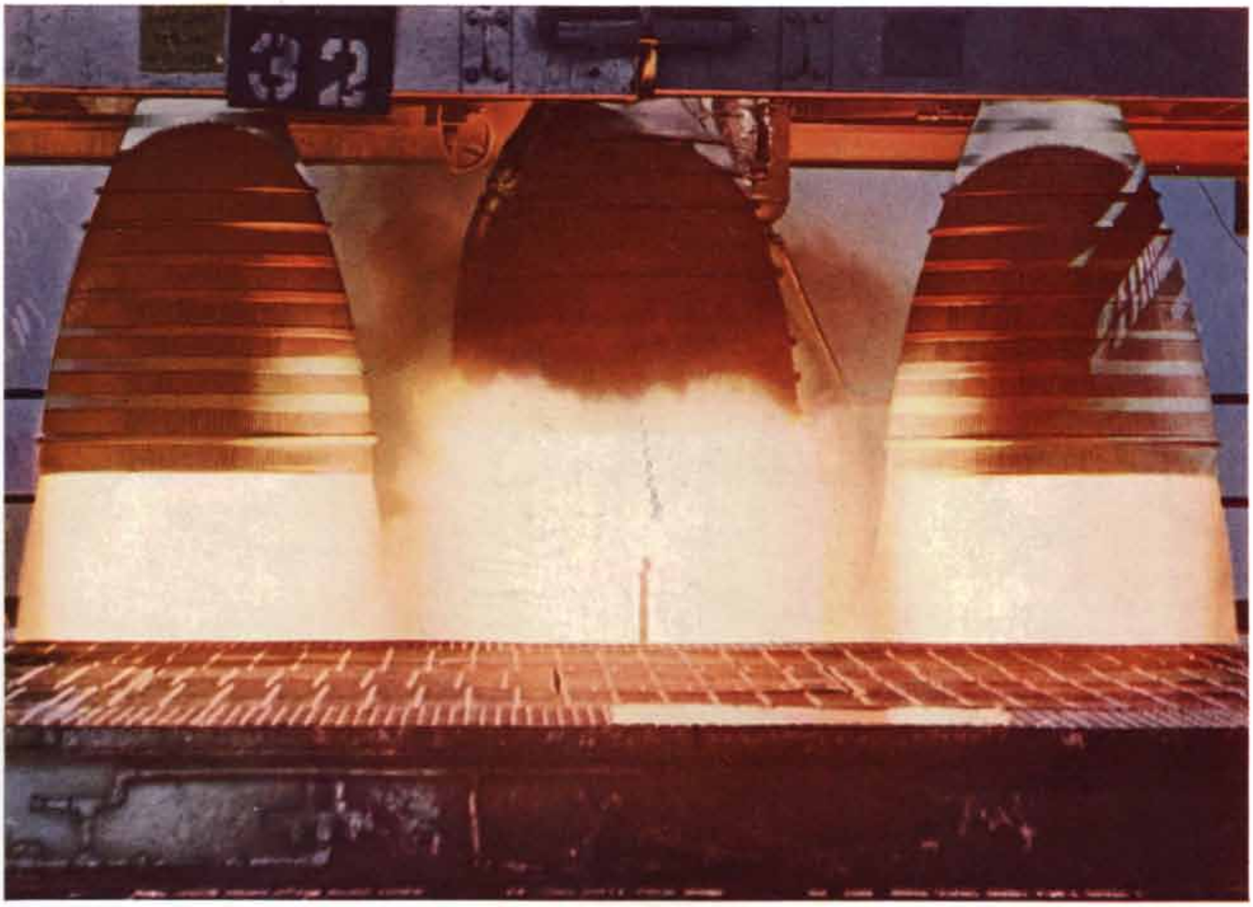

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