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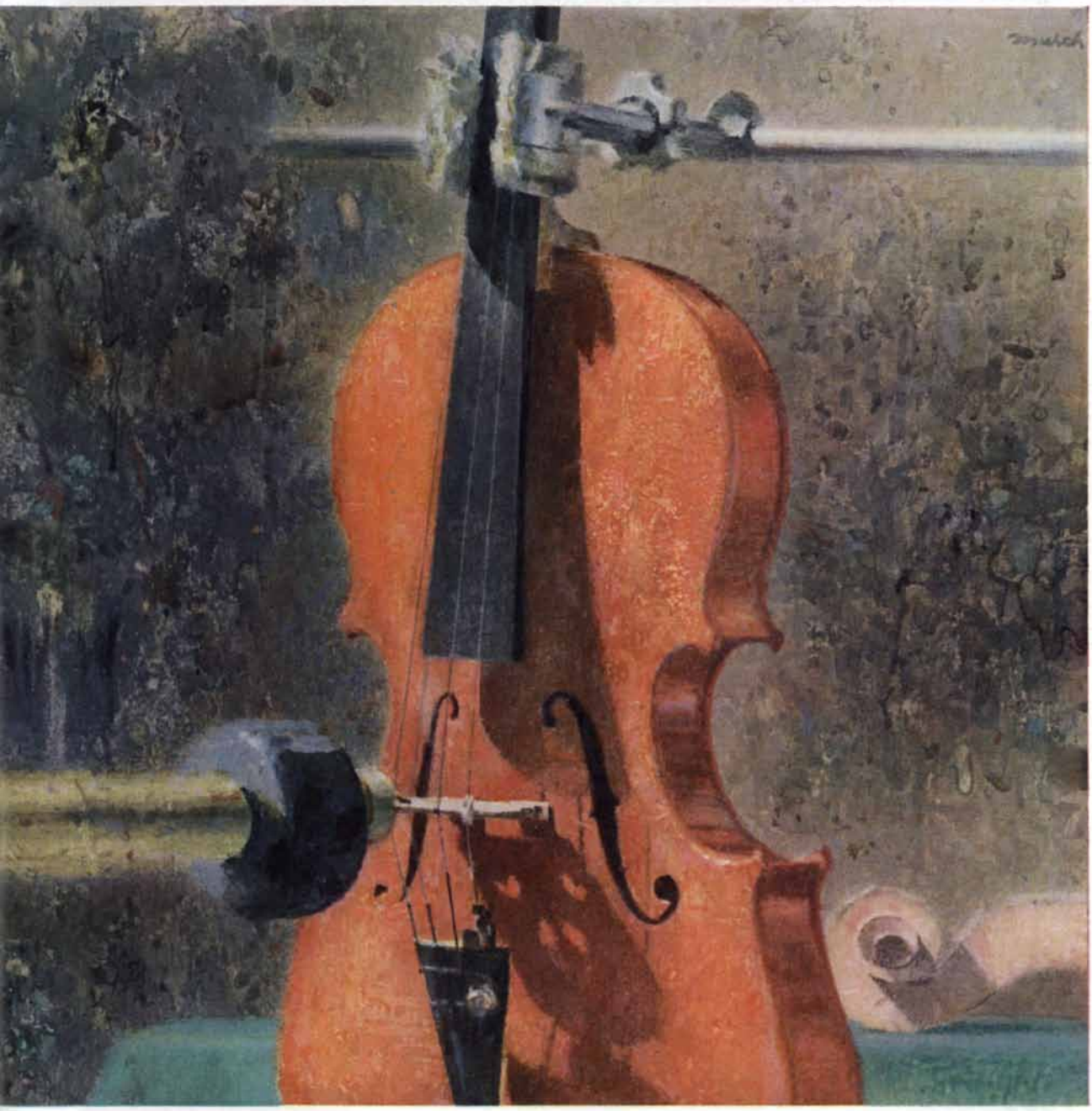
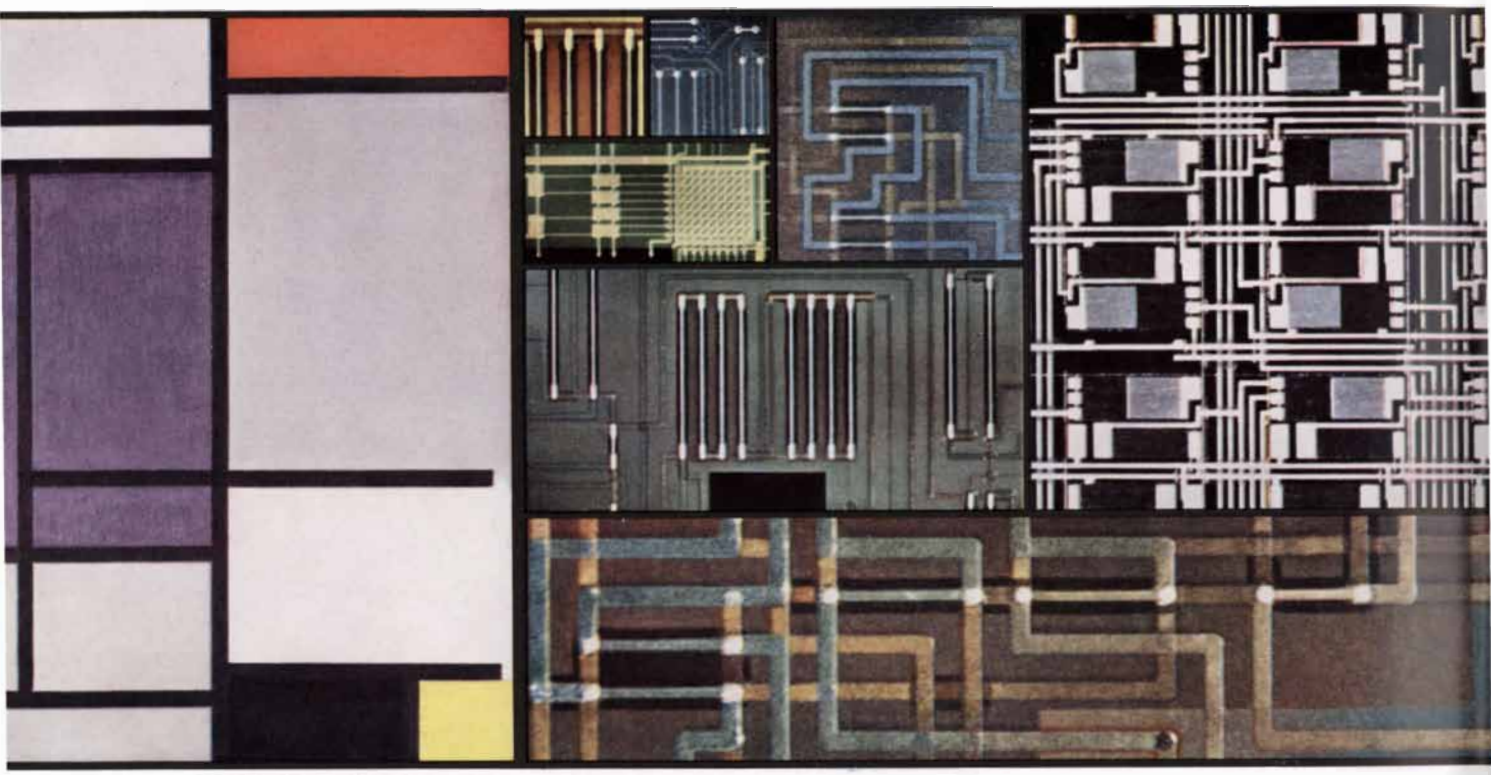


THE PHYSICS OF VIOLINS

FIFTY CENTS

November 1962

Form or Function...



PIET MONDRIAN: COMPOSITION. 1921. COLLECTION, MUSEUM OF MODERN ART, NEW YORK

Structure or purpose...which one contains the essence? In art, in science and in technology the essence is never in the form or the function alone but in both at once ... a matter of conceptual symbiosis...of order...of unity.

Scientists and engineers at IBM are fashioning thin film circuits such as these to handle information with ever greater elegance and economy. The aesthetic appeal of these circuits strikes many at first glance. Perhaps this is because they possess a measure of artistic truth or inevitability; their form and their function of transmitting, switching, and storing are one.

To this extent they suggest the essentially aesthetic nature of information processing: to transform raw data into meaningful information, to bring order and unity out of chaos.

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LITTLE BY LITTLE, SPACE IS YIELDING its mysteries to man's inspection... the previously unknown is becoming knowledge to help attack further unknowns. ● One important attack is NASA's manned space flight program leading to exploration of the moon. Bellcomm was formed by the Bell Telephone System to carry out systems planning and evaluation for this exciting effort. ● This new company offers fine opportunities to experienced men in physics, mathematics, engineering, flight mechanics, propulsion, man-machine relationships, aerodynamics and aeronautical engineering in general. ● The work is creative, the staff is highly professional, and the location is stimulating. Bellcomm, an equal opportunity employer, works in Washington, D. C. Interested? Bellcomm will give your résumé prompt and thoughtful study. It should be sent to Mr. W. W. Braunwarth, Personnel Director, Bellcomm, Inc., Room 500K, 1737 L Street, N. W., Washington 6, D. C.

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ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover shows a violin mounted to test its response to various sound frequencies (see "The Physics of Violins," page 78).

THE ILLUSTRATIONS

Cover painting by Walter Murch

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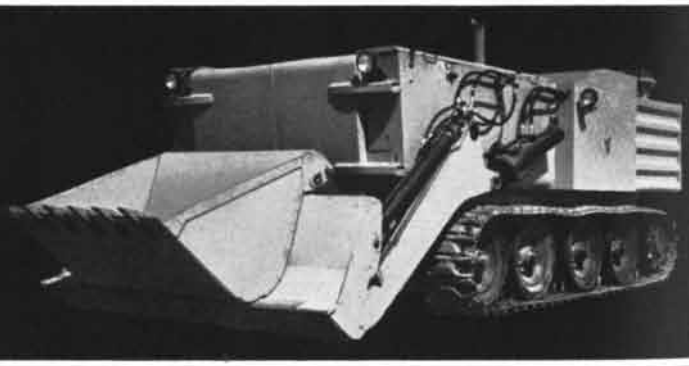

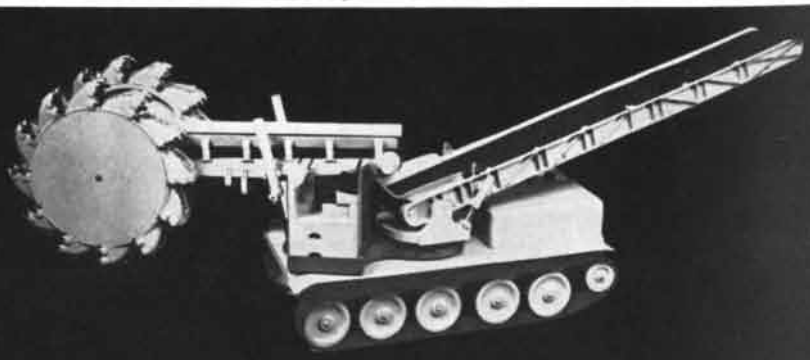

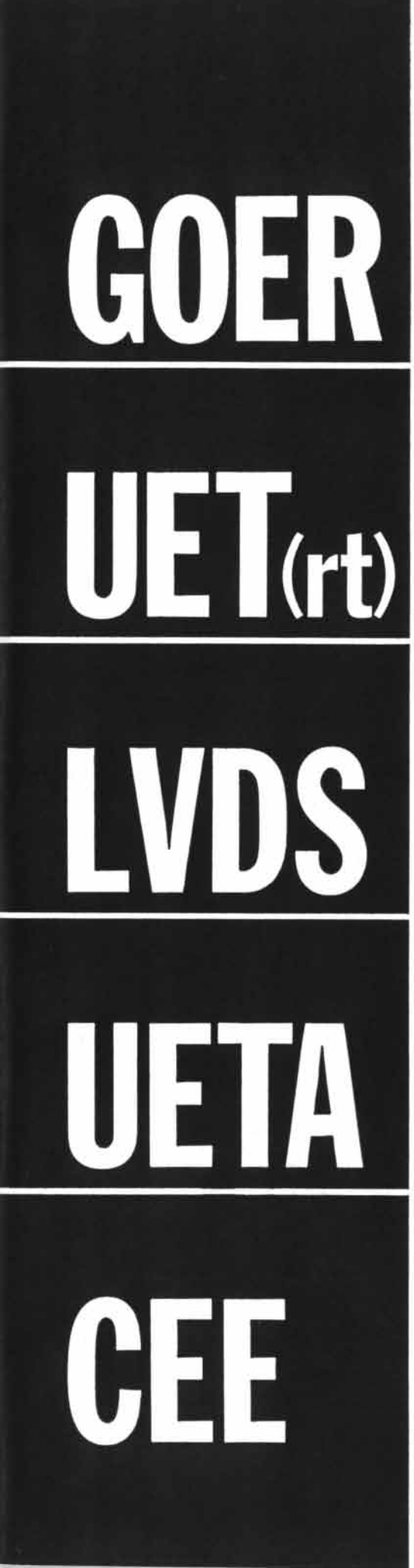

PROGRESS REPORT ON DEFENSE PRODUCTS FROM CATERPILLAR

GOER The 8-ton GOER—one of a family of tactical vehicles developed by Ordnance Tank Automotive Command—can operate at speeds up to 30 MPH. It swims inland waters, climbs 60% slopes, negotiates the roughest terrain. Caterpillar-built GOERs are now on test by the U. S. Army.

UET (RT) This is a ballastable 4-wheel drive tractor designed for bulldozing, earthmoving and drawbar operations. The Universal Engineer Tractor (Rubber Tired) developed by the Engineer Research and Development Laboratories travels at speeds up to 30 MPH and can be air transported. Its scraper bowl has a capacity of 8 cubic yards. Caterpillar is manufacturing a limited number for the Army, based on the Corps of Engineers design.

LDS-750; LVDS-1100 Developed for use in tactical vehicles, these aluminum compression ignition engines deliver 475 HP and 700 HP respectively from remarkably compact packages. The LDS-750 is a 5 cylinder engine and weighs about 4.2 lbs. per horsepower. The LVDS-1100 has 8 cylinders and weighs 3.6 pounds per horsepower. Both engines use a 5.4 x 6.5 inch bore and stroke. The engines operate smoothly in temperatures ranging from minus 65° F. to 115° F. plus. Caterpillar Engineers developed them in conjunction with Engine Specialists at Ordnance Tank Automotive Command.

UETA Protected with aluminum armor the Universal Engineer Tractor, Armored, will serve as a bulldozer, multipurpose loader, prime mover and personnel-and-cargo carrier. Its distinctive hydro-pneumatic suspension system will provide a smooth ride on or off the highway—at speeds up to 30 MPH. Caterpillar's development contract is with the U. S. Army Engineer Research and Development Laboratories.

CEE A concept study and scale model of the Combat Emplacement Excavator has been submitted, under contract, to the U. S. Army Engineer Research and Development Laboratories. The concept is designed to excavate an emplacement of approximately 100 cubic yards in 15 minutes to provide nuclear blast protection for both materiel and personnel. Highway and cross-country travel speeds are to be 25 MPH and the unit is to be air transportable.

In addition to this lineup of specialized vehicles, Caterpillar has produced a large quantity of high-speed wheeled tractors; airborne track-type tractors for combat Engineer Battalions; and low ground pressure tractors for work in arctic and antarctic missions. And Caterpillar Electric Sets are on duty the world over providing prime and emergency power for missile launch and tracking sites, military bases and communication centers.

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Kel-O-Rad —communications where it counts

A ten foot space craft bobbing in the vast Pacific Ocean makes a very small ripple. But when that space craft contains Astronaut Walter M. Schirra, Jr., the ripple laps the shores of the world. From countdown to splashdown a vast communications network links Astronaut Schirra with his earthbound colleagues. A unique Kel-O-Rad Radio Transceiver installed in the Astronaut's survival kit was available to keep him in constant voice communication with nearby rescue aircraft if he elected to leave the space craft. The microminiaturized Kel-O-Rad unit permits hands free communications in a host of operations—flight line maintenance, warehouse areas and special test and fire fighting teams—where people work in hazardous or extremely noisy surroundings. Kel-O-Rad's two basic units—the portable transceiver and base station—are compact battery-powered packages. The 12-ounce transceiver contains a crystal controlled transmitter and receiver powered by two rechargeable batteries. Two base stations are available—a small unit operating from an internal battery pack and a slightly larger unit powered by a battery or an AC power supply. With a wide selection of operating frequencies, Kel-O-Rad puts reliable voice communications where they count—in any military or industrial environment.

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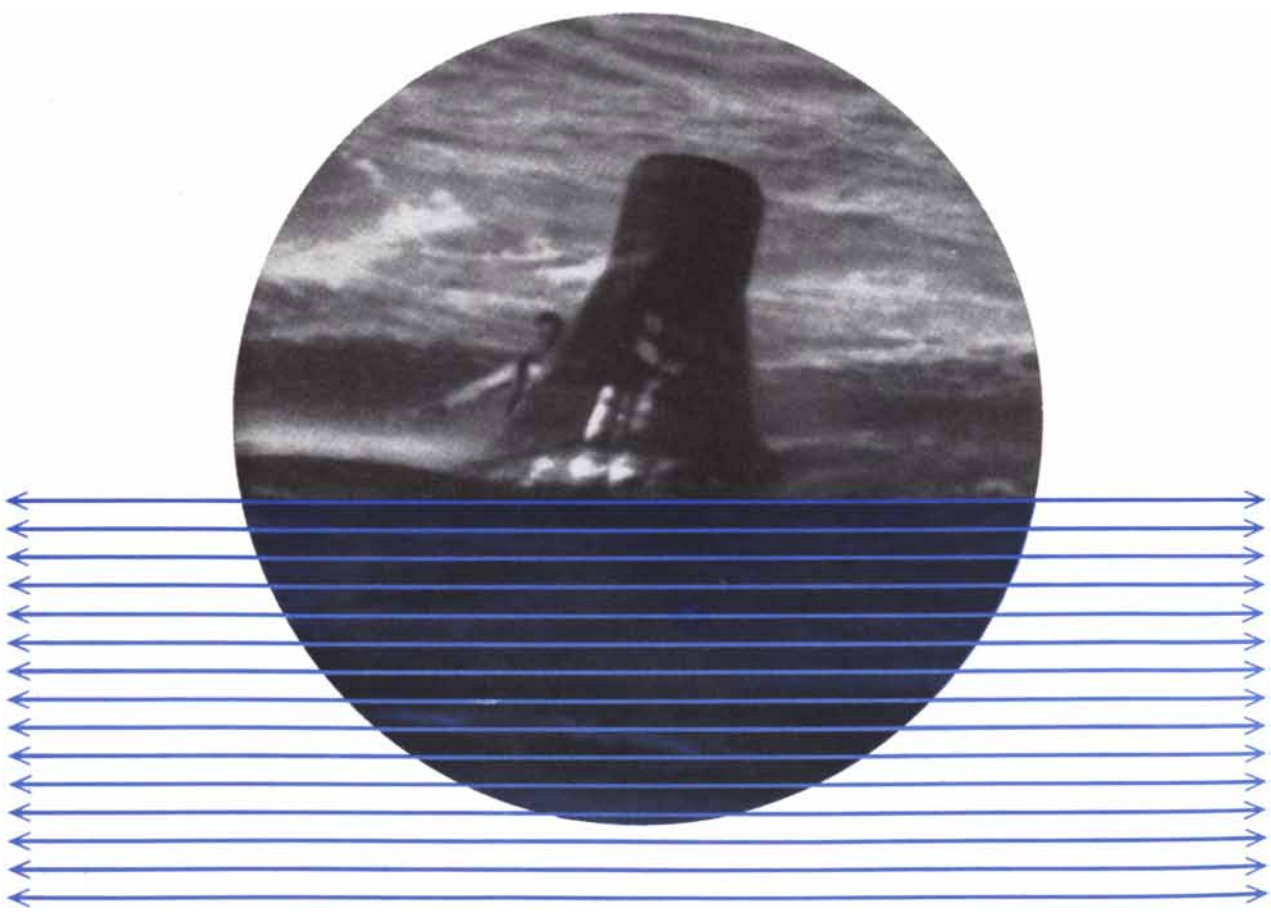

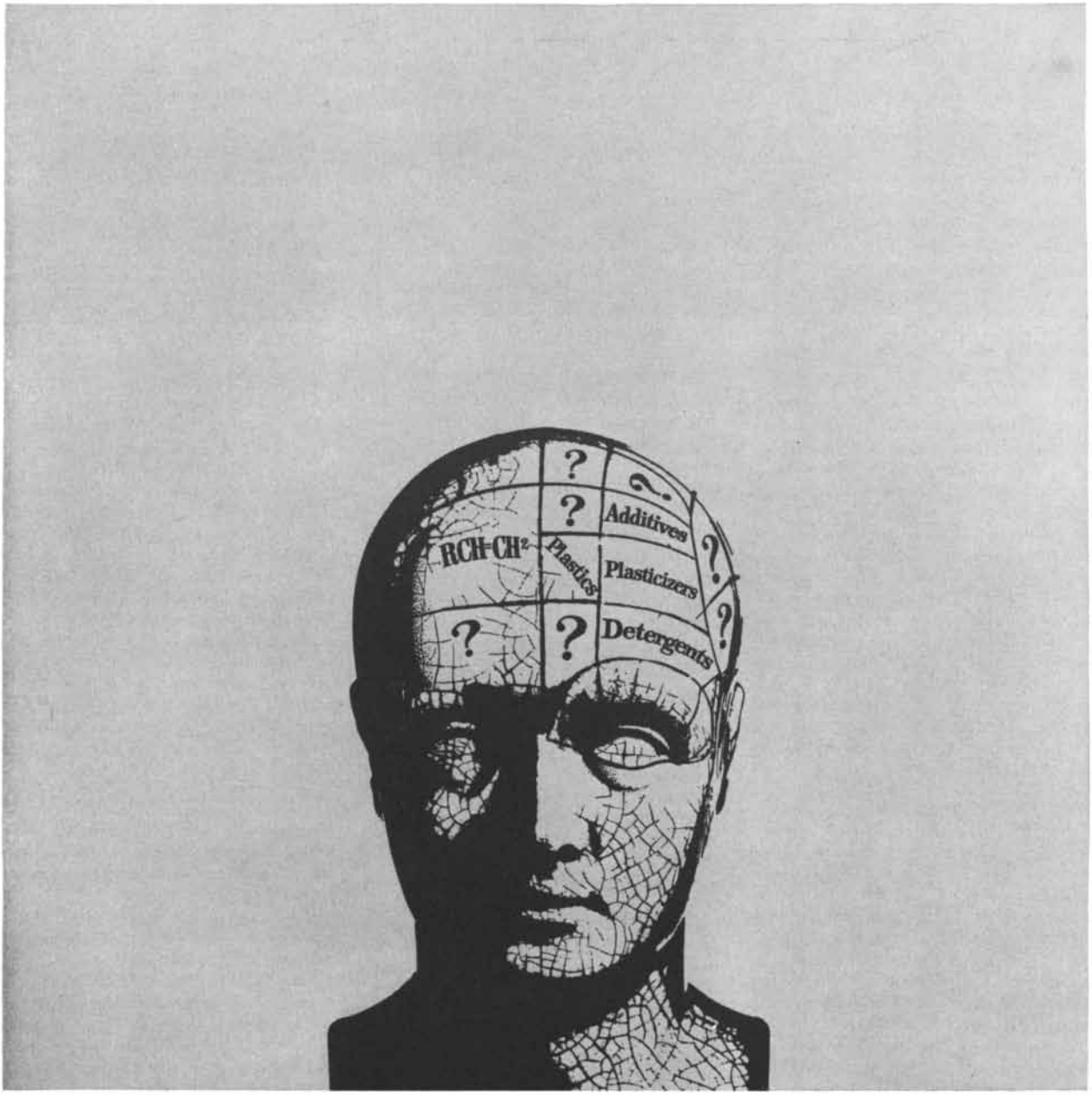

Mind over matter

Gulf predicts a big future for normal alpha olefins. For years chemists have recognized the exciting potential of these highly-reactive straight-chain olefins. But no one could produce a high quality grade economically. ☐ Then as part of its basic research, Gulf developed a concept that promised to break the bottleneck. The principle was put to practice in the laboratory, then refined in a pilot plant. Results: a practical process that produces olefins virtually free of paraffins, diolefins and cyclic compounds with normal alpha olefin contents approaching 100%. ☐ Interested companies were given samples to evaluate in alkylation, polymerization, halogenation, esterification and other olefin reactions. Results have been so encouraging that Gulf will soon produce larger quantities of normal alpha olefins for developmental use. ☐ Perhaps Gulf's resources in raw materials, research, process ingenuity and product know-how can help you translate your most promising ideas into profitable products. ☐ Contact Gulf Petrochemical Sales Office, 360 Lexington Ave., New York 17, N. Y. to explore the numerous possibilities. **Gulf Petrochemicals for that certain quality**

GULF

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Today's instruments are reporting every conceivable kind of measurable variable. Temperature. Strain. Liquid level. Pressure. Vacuum. Humidity. Flow. Viscosity. Torque. pH. emf. Voltage . . . and many more. They bring to their jobs an accuracy, perseverance, and freedom from coloration that the most objective city room couldn't begin to match.

The only catch comes in designing them. It's a foregone conclusion that they be reliable. Then they have to measure extremely small or extremely large amounts of change, taking place at very rapid or very slow rates. The data they turn in must be usable, so that it can actuate recording, controlling, or indicating mechanisms, or serve as inputs for data processing equipment. All in all, it's quite a job for Honeywell, and you'll excuse us if we take a discoverer's pride in the successful accomplishment of assignments such as these:

• •

BED OF ZEROS. In many petrochemical processes, gas or vaporized petroleum is passed over a heated bed of finely divided catalyst to crack it into components. But what, exactly, is the heat-transfer mechanism involved? Researchers at a leading Eastern university are seeking the answer, under the sponsorship of the National Science Foundation. To determine the bed's response to sinusoidally varied temperature, the differential temperature below and above the bed is measured, as well as that of the gas leaving. However, the differential signal is so small that equipment used must measure accurately in the microvolt region. Honeywell answered this complex problem by installing a complete pre-tested packaged system, and guaranteed it would work. It consists of a Honeywell 2745 potentiometer for system calibration and zero suppression, three Honeywell Deviation Amplifiers, and six Honeywell T6GA amplifiers, with a Honeywell 906C Visicorder for readout. By recording temperature phase and amplitude change, the gas-particle heat transfer coefficient is calculated for use in setting up new petrochemical processes.

• •

SHIVERING TIMBERS. The Ship Structure Committee, representing various government agencies, assigned Lessells & Associates, Inc. of Boston the task of developing long-range data on ocean wave loading of seagoing vessels.

For the past two years, two oceangoing freighters plying the turbulent North Atlantic trade routes have been recording stress data for the project. They will eventually be joined by other ships in the study. Stress data are picked up by transducers on the hulls, and recorded on Honeywell Magnetic Tape Systems. Since the voyages take from 30 to 40 days, an extremely low recording speed was needed: 0.3 ips. A programmer working through balance and calibration circuits records for 32 minutes every 4-hour watch, and rough seas automatically turn on the recording apparatus. Sea and weather information from the ship's log is correlated with the time-marked tape. Back in Boston, the tapes are reproduced and amplified, played onto a Honeywell Visicorder oscillograph unit and finally, into a probability analyzer. The Ship Structure Committee will make this reduced data available to marine engineers for improving design and increasing safety of projected new vessels.

• •

UNDERGROUND DETECTIVE. Project VELA holds promise of becoming a highly significant factor in international relations if agreement to cease nuclear testing is reached. Established at Geneva in 1958, VELA is concerned with the detection of underground, surface, and atmospheric nuclear explosions.

To detect seismic disturbances of any kind, VELA is simultaneously carrying on research and establishing observation posts around the world. To record accurately one brief moment of seismic history for electronic data processing takes hundreds of hours of continuous recording, and ordinarily, mountains of tape. Honeywell slowed down a standard magnetic tape recorder to 0.3 ips, and by using special tape, three full days' surveillance can be recorded on one roll. One of the most recent orders Honeywell received for seismic research called for the exceedingly slow recording speed of 0.06 ips, a pace that makes an indolent snail look like a speed demon. Honeywell was able to brake down to specification. And at highly satisfactory signal-to-noise ratios, too.

• •

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LETTERS

Sirs:

In his article "The Oceanic Life of the Antarctic" [SCIENTIFIC AMERICAN, September] Robert Cushman Murphy presents an explanation for the occurrence of bottom invertebrates and large fish on the surface of the Ross Ice Shelf. Further observations made during 1960 and 1961 make it possible to modify this explanation and in so doing strengthen its plausibility.

On December 14, 1960, I helped to cut a hole with a chain saw in two meters of two-year-old sea ice near McMurdo Station. This hole was approximately 30 meters offshore over 19 meters of water. Embedded throughout the sea ice were found undamaged specimens of sea urchins (*Sterechinus*), clam shells and many pebbles. During April, 1961, I dip-netted live *Sterechinus* from one to two meters of open water at Cape Evans near McMurdo Station. These animals were found on and around large patches (up to several square meters) of ice crystals frozen to the mud and pebble bottom. The ice crystals adhered loosely to one another and to the sea floor. Consequently large masses of ice rose to the water's surface when the ice patches were disturbed. Such ice patches were seen at least down to four meters in sea depth and can probably form at any depth. The occurrence of bottom invertebrates in sea ice that certainly never touched the sea floor is therefore probably caused by such material rising with masses of bottom-formed ice crystals to the lower surface of growing sea ice. It seems likely that the bottom invertebrates found on the surface of the Ross Ice Shelf could have also been frozen into the shelf ice in a similar manner. Actual touching of the sea floor by the shelf ice, as suggested by Frank Debenham and followed by Charles W. M. Swithinbank and Dr. Murphy, is therefore not necessary.

Retrieval through collecting holes in sea ice of large fish caught by Weddell seals can further explain the occurrence of remains of similar fish on the surface of the Ross Ice Shelf. One of four such fish retrieved near McMurdo Station in 1961 is depicted in Dr. Murphy's article. The other three fish were missing large portions of their heads and were found floating in collecting holes, two without the presence of seals. Many of the fish remains found on the Ross Ice Shelf were either missing large portions of their heads also or consisted only of head portions. In view of this, these fish remains probably represent fish killed by seals but not completely devoured. The fish remains could then float up to and freeze into the lower surface of the shelf ice, again without the necessity for the shelf ice to touch the sea floor.

My explanation agrees with Debenham's by assuming that a considerable portion of the shelf ice is formed by accumulation of sea ice. Indeed, virtually all the shelf ice now in the vicinity of the exposed marine life must have been derived from the sea. It differs, however, by rejecting the supposed necessity for shelf ice to freeze all the way to the sea floor to imprison fish and bottom invertebrates.

J. S. PEARSE

Stanford University
Stanford, Calif.

Sirs:

Philip Morrison's article "Neutrino Astronomy" [SCIENTIFIC AMERICAN, August] is very interesting. But there is an essential difficulty that he does not mention.

Even if we had a very large and efficient neutrino detector, the problem of finding their *direction* of incidence is still orders of magnitude more difficult than merely counting them. Because of their weak interaction they cannot be

Scientific American, November, 1962; Vol. 207, No. 5. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York 17, N.Y.: Gerard Piel, president; Dennis Flanagan, vice president; Donald H. Miller, Jr., vice-president and treasurer.

Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York 17, N.Y. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

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Model 094446
SINGLE STAGE COOLER
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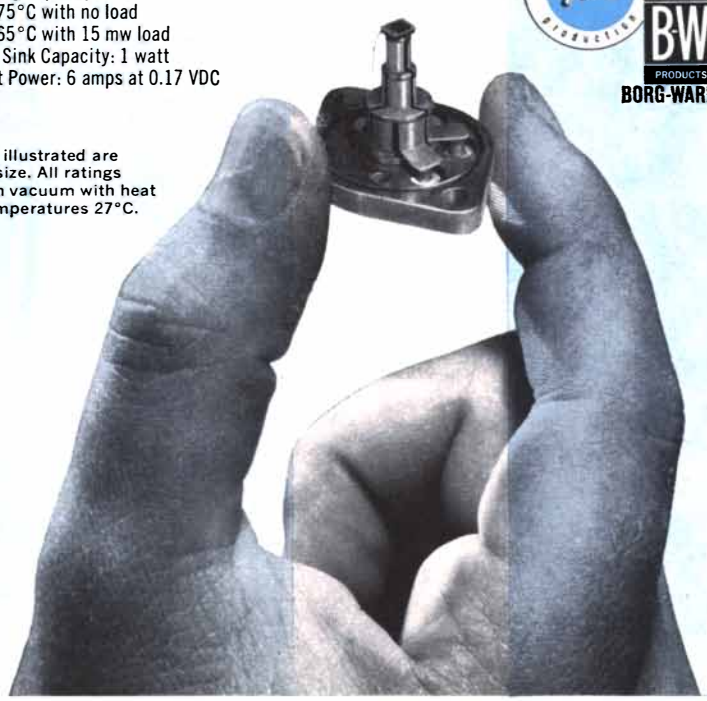
—33°C with no load
—31°C with 50 mw load
Heat Sink Capacity: 3 watts
Input Power: 7 amps at 0.4 VDC

Model 094447
TWO-STAGE CASCADE COOLER
Cooling Capacity:
—53°C with no load
—50°C with 20 mw load
Heat Sink Capacity: 4 watts
Input Power: 3 amps at 1.2 VDC

Model 094520
THREE-STAGE CASCADE COOLER
Cooling Capacity:
—75°C with no load
—65°C with 15 mw load
Heat Sink Capacity: 1 watt
Input Power: 6 amps at 0.17 VDC

Models illustrated are actual size. All ratings taken in vacuum with heat sink temperatures 27°C.



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focused or even collimated. Imagine trying to find the direction of a light source without the use of either refracting or absorbing material. There are no beams and no shadows. With respect to the neutrinos we are transparent jellyfish swimming in an infinite goldfish bowl.

There is one method left for determining the direction of the incident neutrino. Both the final particles in the collision reaction would have to be detected in coincidence and their momenta measured. From conservation of momentum one could then deduce the direction of the incoming neutrino, assuming the target particle to be at rest. But that is difficult. If the two final particles are charged, as in neutrino-neutron collisions, they are indistinguishable from the products of ordinary beta decay. If one of them is a neutron, as in the inverse beta decay, that is much harder to see than a charged particle.

I conclude that neutrino astronomy is far away.

ROGER G. NEWTON

Indiana University
Bloomington, Ind.

Sirs:

Professor Newton is of course right, and he is graphic in his account of the neutrino goldfish bowl in which we live.

But for me astronomy need not imply the directional mapping of sources. Cosmic ray astronomy, and now gamma ray astronomy too, have obtained valuable results from entirely nondirectional detectors. *What* is coming in, and *how much*, and *at what times*, are questions less conventional in astronomy but just as important as *where from*? Indeed, the *where from* may need to be inferred, as it has been for cosmic rays.

I still think neutrino astronomy is not so far away that we can ignore it.

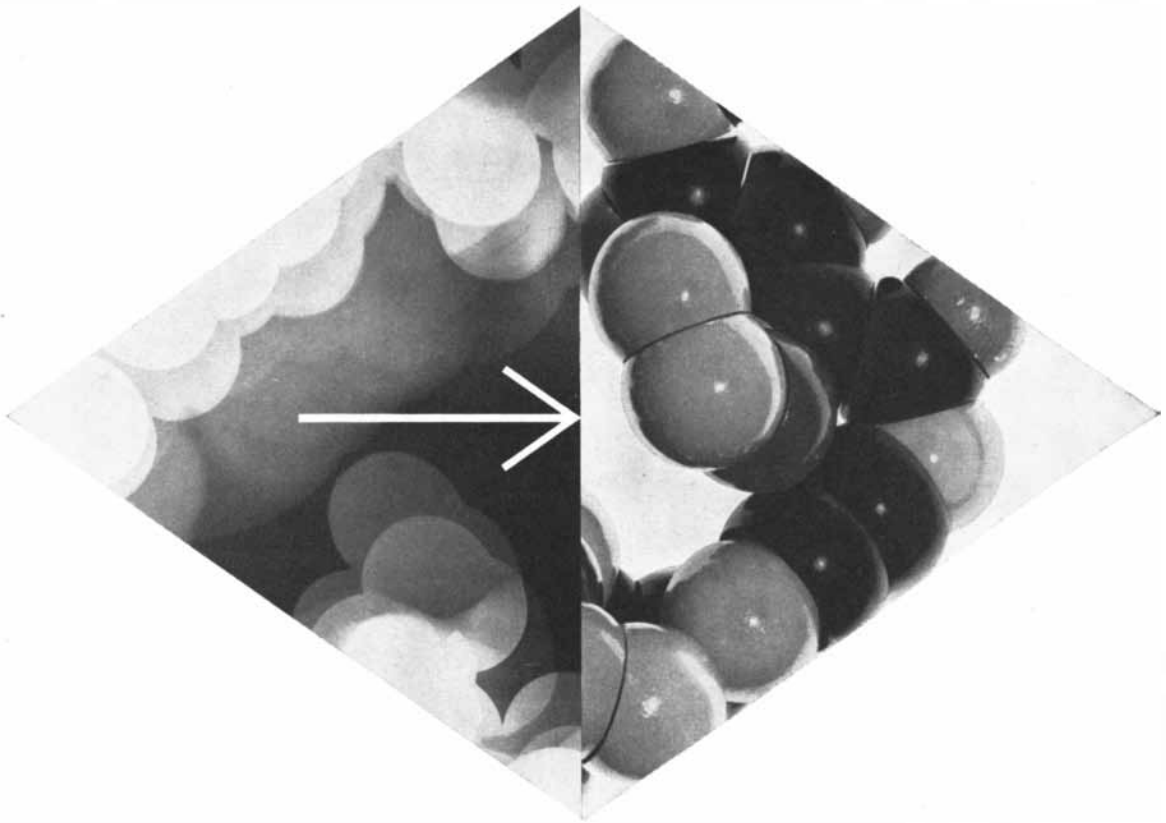
PHILIP MORRISON

Cornell University
Ithaca, N.Y.

ERRATUM

The two middle photographs on page 212 of the article "The Terrestrial Life of the Antarctic" (SCIENTIFIC AMERICAN, September) were erroneously credited to George A. Llano. They were made by F. W. Goro.

POLYMERIZATION



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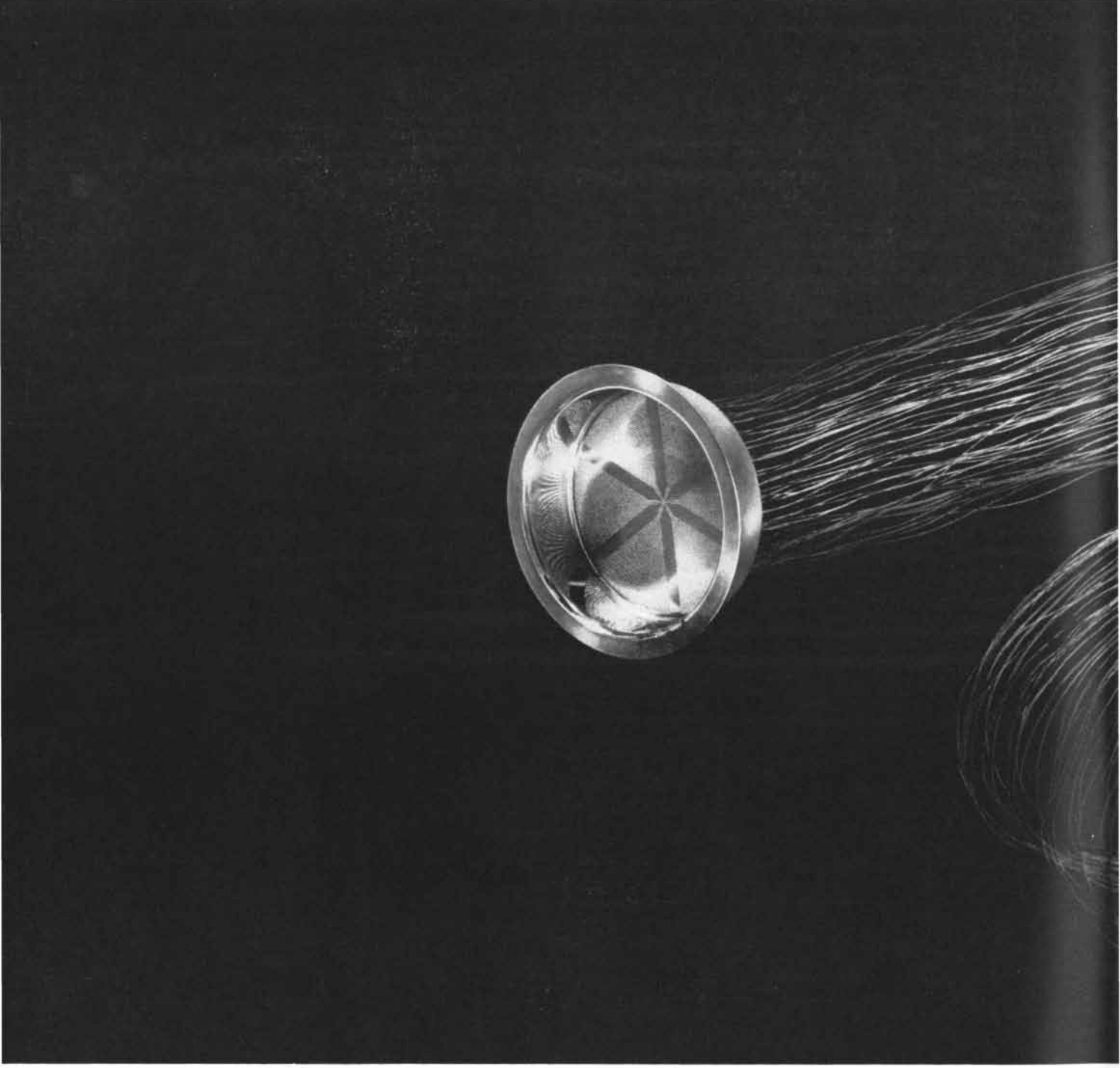

Where no metal but Platinum

How Platinum helps rayon manufacturers beat back attack on spinnerettes

Spinnerettes are at the heart of the viscose process for producing rayon. They're metal cups made of platinum alloys, and have as many as 10,000 precisely-shaped hair-fine holes. In the manufacturing process, an alkali cellulose solution is extruded through these minute holes into an acidic coagulating solution. The final result? Fine rayon filament.

Why are platinum alloys used for spinnerettes? Because they can withstand both the erosion and the extreme alkaline and acidic conditions to which the spinnerettes are constantly subjected.

And these are dramatic reasons why—in so many industrial applications—no metal but Platinum will do the job as well.

It could pay you to use a Platinum Metal

Your problem might be readily and economically solved with Platinum Metals—where a combination of severe corrosion and erosion must be met, as in the case of spinnerettes for rayon production...where high temperature corrosion and spark erosion are involved, such as in aircraft spark plugs...where reliable make-and-break electrical contact is indicated, such as in low noise high fidelity transmission...where wear-resisting, non-tarnishing surfaces are required, such as for printed electrical circuits...where peak catalytic efficiency is required, as in the refining of high octane gasoline...or where product purity must be retained despite high temperatures, as in the case of lens glasses... the Platinum Metals have proved to be the most economical for certain critical equipment.

Industry is going to higher temperatures and higher pres-

will do the job as well...

sures. Perhaps your own progress has been blocked by the limitations of materials to withstand such severe conditions. The Platinum Metals have removed many barriers. Have you considered them for your problems?

Platinum, palladium, rhodium, ruthenium and iridium have unique potentials, well worth your attention. Specialists are prepared to work closely with you in evaluating these metals for new commercial and scientific uses.

As a first step, write us for additional data on the outstanding characteristics and successful applications of the six Platinum Metals and their alloys—indicating your field of interest or how we might be of assistance.

CAN THESE PROPERTIES OF THE PLATINUM METALS HELP YOU?

Exceptional Chemical Inertness
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The six Platinum Metals are:

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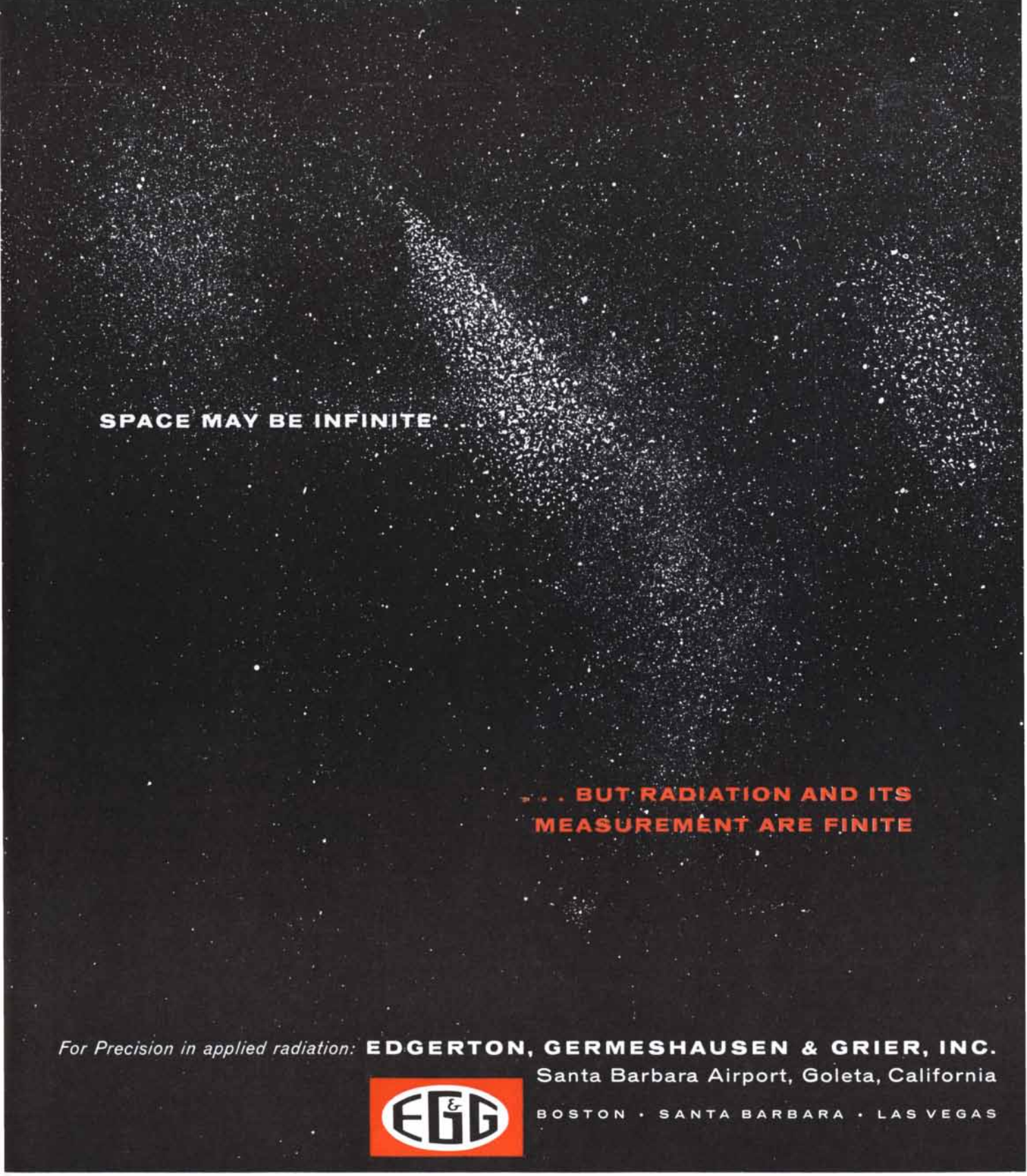
JIM LING KNOWS GROWTH FIRST HAND

Guiding corporate growth is a way of life for Jim Ling, Chairman of the Ling-Temco-Vought Executive Committee. His wide experience has been brought to bear in financial matters, policy-making that led to streamlining a complex company, and long-range planning that is keyed to increasing the importance of Ling-Temco-Vought as a partner in our country's space and defense efforts. Rapid progress at LTV stems from the company's ability to utilize the talents of a unique management team. Already the LTV depth management team has proved its ability to guide such important programs as Scout, V/STOL, Crusader and others. Under the guidance of these men, the company has made significant investments in research, development and production facilities, and in company-funded studies that have earned LTV the reputation of having the answers when the questions are asked. This kind of management . . . and this kind of investment in the future, coupled with proved technical competence in aerospace, electronics, communications and consumer products, are the reasons why Ling-Temco-Vought will continue to grow as it keeps pace with our country's needs.

LING-TEMCO-VOUGHT, INC. LTV DALLAS, TEXAS



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Make sure your new computer does both

Don't settle for data processing alone. If your company is planning to buy or replace a computer, get one that can also handle today's increasingly complex scientific, engineering and management problems. A good medium priced machine should be able to meet *all* of your computer needs.

What should you look for? First, it must have *both* binary and decimal capabilities. It should have a full-scale scientific language *and* a competent business-oriented language. It should have high speed arithmetic, a large and effective memory, and built-in floating point. It should be able to handle a number of input-output devices at the same time. And, of course, it should be designed to grow . . . as your organization grows.

It should, in short, be just like the GE-225.

When the question of a new computer comes up, investigate the GE-225. We think you'll be impressed. It's a lot of computer for the money. General Electric Computer Department, Section U11, Phoenix, Arizona.

Progress Is Our Most Important Product

GENERAL ELECTRIC

Long look at space by Schirra

COMMUNICATION BY COLLINS

Again, the voice and the minute-by-minute position of a U. S. space explorer have been transmitted to earth by Collins communication equipment. Astronaut Walter M. Schirra talked and listened over Collins transceivers. His spacecraft was capable of being tracked, controlled and monitored from earth by radio and telemetry. The Mercury spacecraft also carried Collins-supplied homing beacons and rescue systems. All National Aeronautics and Space Administration astronauts have used communications by Collins. The crews of the upcoming Gemini spacecraft and the Apollo moon landing spacecraft will also depend on Collins and its suppliers for communication.

COLLINS RADIO COMPANY • Dallas • Cedar Rapids • Los Angeles • New York • International Division, Dallas.

ALSO BY COLLINS:
AMATEUR RADIO. For over 30 years, Collins equipment has been the most preferred brand in the amateur radio fraternity. Its singleside-band technique and many other radio innovations originated in Collins amateur equipment.

COLLINS

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

NOVEMBER, 1912: "In a recent communication in *Nature* on the subject of the pattern produced by X rays passing through crystalline bodies, Mr. W. H. Bragg writes: 'Messrs. Friedrich, Knipping and Laue have recently published some remarkable effects obtained by passing a fine stream of X rays through a crystal before incidence on a photographic plate. A curious arrangements of spots is found on the plate, some of them so far removed from the central spot that they must be ascribed to rays that make large angles with the original pencil. The positions of these spots seem to depend on simple numerical relations and on the mode in which the crystal presents itself to the incident stream. I find that when a zinc-blende crystal is placed so that the incident rays are parallel to an edge of the cube in the crystal, the positions of the spots are to be found by the following simple rule. We have to seek for all the cases in which the sum of three squares is also a square, and we then recover the positions of all the spots on the diagram. For example, secondary pencils take the directions (2, 3, 6) (4, 1, 8), and so on. There is at least one direction that ought by the rule to be on the diagram and is not. Otherwise the rule is quite successful. The rule has suggested itself to me as a consequence of an attempt to combine Dr. Laue's theory with a fact that my son pointed out to me, viz., that all the directions of the secondary pencils in this position of the crystal are "avenues" between the crystal atoms.' "

"Amundsen's North Polar Expedition is now assured, thanks to the liberality of Pedro Christofferson, a rich Norwegian living in Buenos Aires, whose financial aid also made possible the journey that resulted in the discovery of the South Pole. Amundsen will push as far north as possible before engaging his vessel in the ice, with which she is expected to drift still farther north. However, no special effort will be made to reach the Pole. The object of the expedition is to make a thorough exploration of the polar sea, including its currents, depths, the character of the bottom and the meteorological conditions. It is just possible that the Norwegian party will encounter the American Crocker Land expedition, which is to proceed westward over the ice from Grant Land next year, and that one or both of these parties will explore the land that Peary saw to the westward during his march to the Pole."

"A few years ago steam-railway officers were considerably exercised on account of the actual and prospective inroads on their passenger business caused by the rapid development of the net work of electric interurban railways, with their smokeless, frequent service and low fares. Many railway officers are now alarmed because of the effect of the automobile on their passenger business. Although some have deemed it too insignificant or inevitable for serious consideration, others have investigated the subject and have been able to trace distinctively appreciable losses in earnings to the increasing popularity of the automobile."

Scientific American.

NOVEMBER, 1862: "The Atlantic has been united to the Pacific by an electric cord 3,500 miles in length, and through this, the largest electric circuit in the world, messages were flashed on the 6th inst. New York and San Francisco now hold daily converse. This is one of the grandest commercial and scientific achievements of the age. It is but 18 years since the first line of telegraph was laid on our continent, between Washington and Baltimore, and now more than 50,000 miles of wire throb daily with messages of love, hope, fear and business, conveyed between every city and almost every hamlet in our land. Let us cherish the hope that a railroad across the continent will soon follow the telegraph."

"In his book of travels in the United States, Mr. Anthony Trollope says :—'I was at Chicago and at Buffalo in October, 1861. I went down to the granaries, and climbed up into the elevators. I saw the wheat running in rivers from one vessel to another, and from railroad vans up into huge bins on the top stories of the warehouses; for there rivers of food run up hill as easily as they do

News from Bell Telephone Laboratories

WE'RE "FINGERPRINTING" VOICES...TO FIND BETTER WAYS OF TRANSMITTING THEM

Acoustics scientists at Bell Telephone Laboratories study voices to learn how one voice differs from all others, what makes yours instantly recognizable to friends and family, and what the elements of a voice are that give it the elusive qualities of "naturalness."

To enable us to examine speech closely, we devised a method of making spectrograms of spoken words. We call them voiceprints. They are actual pictures of sound, revealing the patterns of voice energy. Each pattern is distinctive and identifiable. They are so distinctive that voiceprints may have a place, along with fingerprint and handwriting identification, as an important tool of law enforcement.

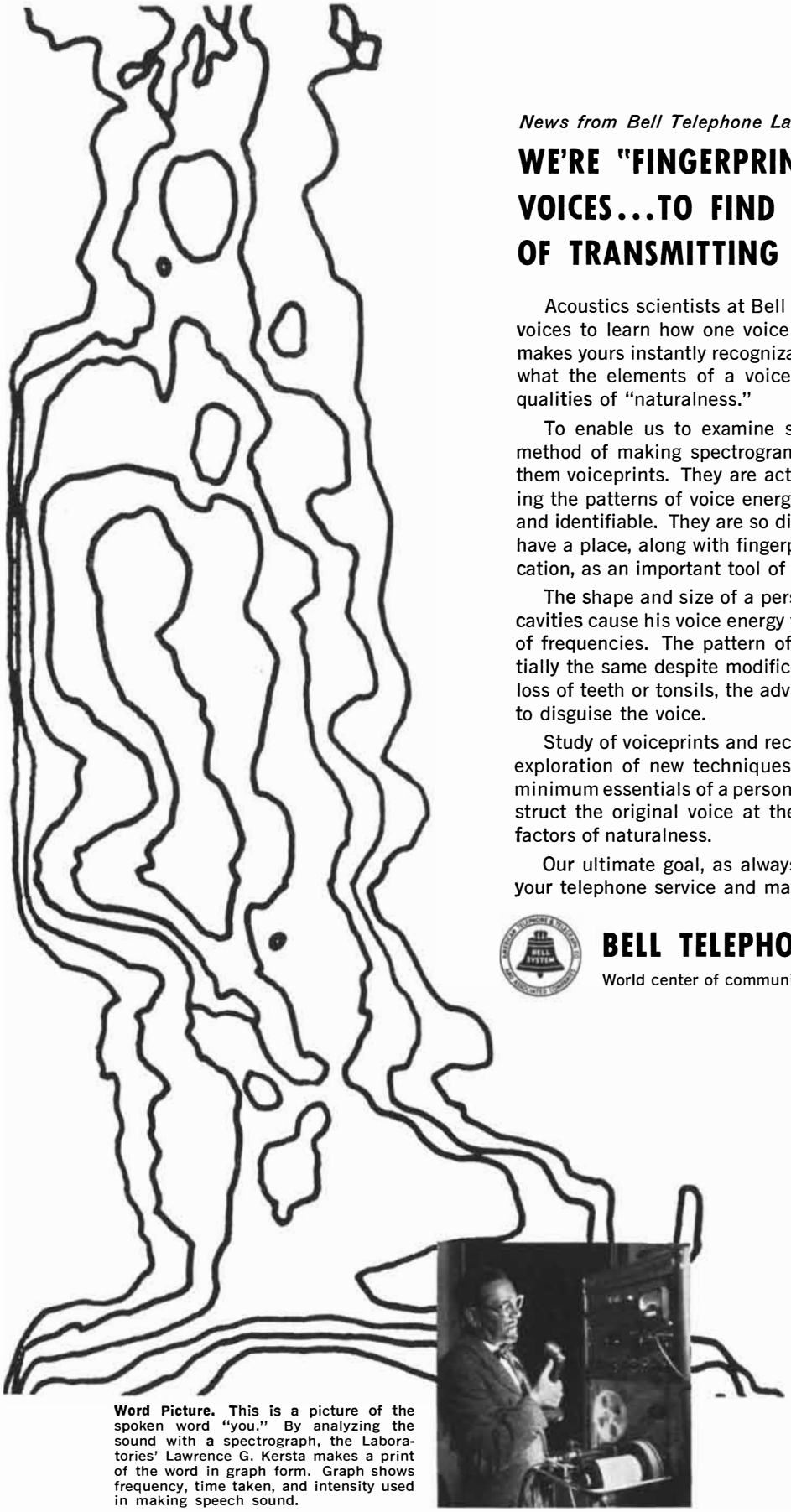
The shape and size of a person's mouth, throat and nasal cavities cause his voice energy to be concentrated into bands of frequencies. The pattern of these bands remains essentially the same despite modifications which may result from loss of teeth or tonsils, the advancement of age, or attempts to disguise the voice.

Study of voiceprints and recognition factors is part of our exploration of new techniques to extract and transmit the minimum essentials of a person's voice and from these reconstruct the original voice at the receiving end, retaining its factors of naturalness.

Our ultimate goal, as always, is to learn how to improve your telephone service and make it a better value.

BELL TELEPHONE LABORATORIES

World center of communications research and development



Word Picture. This is a picture of the spoken word "you." By analyzing the sound with a spectrograph, the Laboratories' Lawrence G. Kersta makes a print of the word in graph form. Graph shows frequency, time taken, and intensity used in making speech sound.

down. I saw corn measured by the 40-bushel measure with as much ease as we measure an ounce of cheese, and with greater rapidity. I breathed the flour, and drank the flour, and felt myself to be enveloped in a world of breadstuffs. I began to know what it was for a country to overflow with milk and honey, to burst with its fruits and be smothered by its own riches. From St. Paul down the Mississippi, along the shores of Wisconsin and Iowa, in the ports of the Great Lakes, through Michigan, Illinois and Ohio, up to Buffalo, the great gate of the Western Ceres, the loud cry was this—"How shall we rid ourselves of our corn and wheat?" The result has been the passage of 60,000,000 bushels of breadstuffs through that gate in one year!' "

"In *Macmillan's Magazine* for last month Dr. Phipson concludes an interesting paper as follows:—'Reflecting upon the powerful decomposing chemical force with which we are furnished by the electric current, it occurred to me that I might be able to render sea-water potable by decomposing and extracting its salt, by means of a moderately powerful battery. The experiments were made at Ostend a few years ago. My apparatus consisted of three vessels containing sea-water to be operated upon, connected by two bent U-tubes filled with sea-water. As the only battery I could procure in Ostend was rather weak, I passed the current through the water for about 14 hours, after which one of the outside vessels had become acid and the other alkaline. The sea-water was then filtered through charcoal and was nearly drinkable. It would have been, I doubt not, quite potable had the battery employed been more powerful; as it was, I found it difficult to extract the last particles of salt, and the water, after subsequent trials, still presented a slightly brackish taste. I have not had an opportunity of repeating this experiment since, but from the results obtained I think it probable that sea-water may be rendered potable by means of the electric current.' "

"The first postage stamp was issued in London on the 10th of January, 1840, and for nine years England alone made use of it. France adopted it on the 1st of January, 1849; and it is now in use in 69 countries in Europe, nine in Africa, five in Asia, 36 in America and 10 in Oceania. Van Diemen's Land possesses its own, and so do Hayti, Natal, Honolulu and Liberia."

HOW TO MAP THE MOON

An electronic imaging system designed by Fairchild can survey the lunar surface with resolutions up to one meter. Charts of this precision can help our first moon explorers locate themselves with pinpoint accuracy. But how to make them? Fairchild studied the problem in depth, designed a system that can acquire terrain data from a lunar satellite, receive and process the data on earth, then convert it to highly detailed maps. The system can also provide high resolution photos of potential landing sites.

Advanced systems like this illustrate Fairchild's unique combination of capabilities in electronics, photography and in cartographic and data processing technologies. Other examples are outlined in a brochure, "Facilities and Capabilities—an Eye to the Future." For your copy, write Dept. 92, 750 Bloomfield Ave., Clifton, N.J.

FAIRCHILD
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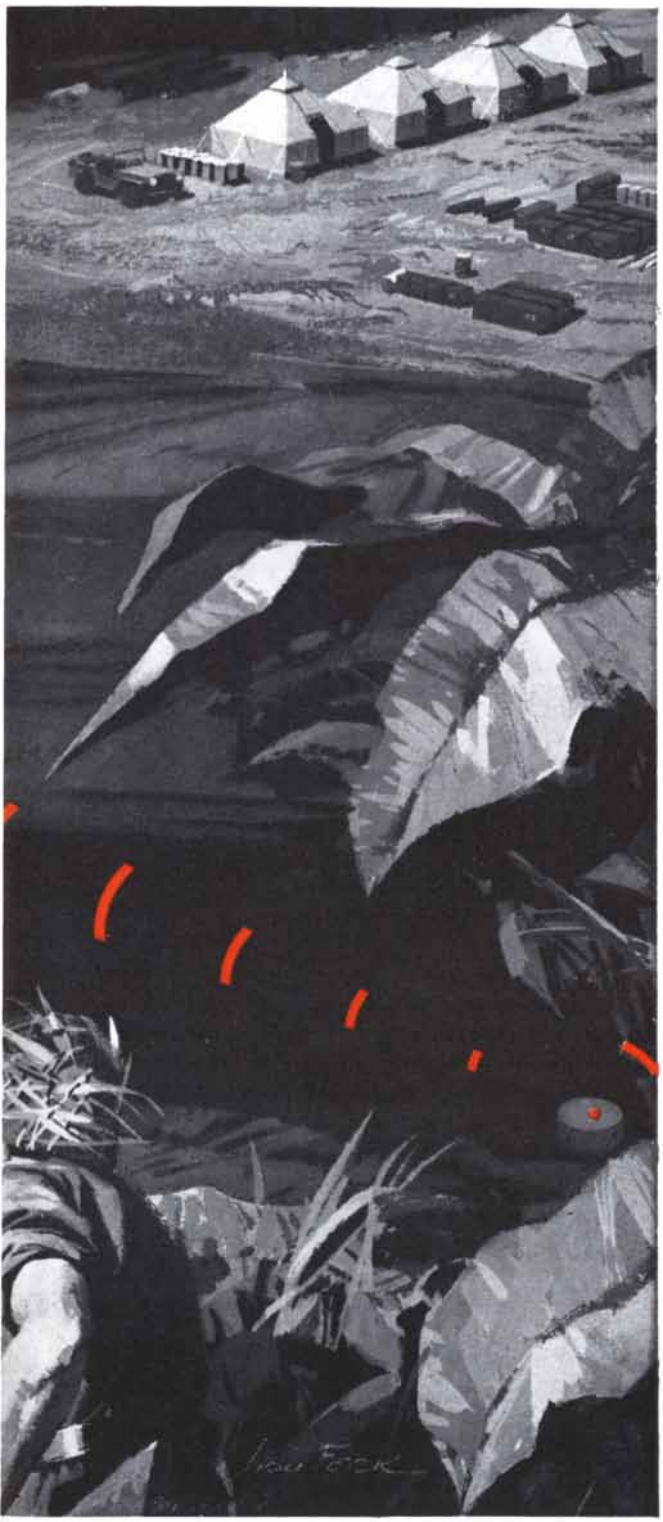
A COMPLETE VISUAL IMAGING SYSTEMS CAPABILITY

URGENT:

DETECT THE INTRUDER— KEEP MILITARY ZONES SAFE!



Finding ways to detect the "uninvited" who sneak too close to military operations is one of the many ways General Telephone & Electronics scientists and engineers serve the nation.

Recently our subsidiary, Sylvania, developed a detection system concept that permits guerrilla forces in such strategic and sensitive locales as parachute drop zones to alert themselves against intruders. This motion-sensitive system responds to any movement across or near the perimeter of the area to be protected, thus warning the guerrilla team of danger. Because of its unusual design, the system does not respond to light, sound, vibration or atmospheric disturbance. It will operate over an extremely wide range of temperatures. Yet there is no known method of deceiving it. Even an attempt to tamper with it or jam it will result in an alarm.

Other examples of our capabilities in detection and complete security systems apply many of these same principles to volumetric systems. In these, any movement is detected in a defined area—enclosed or even underground. Sylvania now has contracts for security systems safeguarding Minuteman and Atlas-Titan missile launch sites.

Protecting key military operations from unwanted intrusion is one more way the scientists and engineers of General Telephone & Electronics contribute to national security. The vast communications and electronic capabilities of GT&E, directed through Sylvania Electronic Systems, can research, design, produce, install and service complete electronic systems. These systems include detection and tracking, electronic warfare, intelligence and reconnaissance, communications, data processing and display.

That is why we say—the many worlds of defense electronics meet at Sylvania Electronic Systems, Division of Sylvania Electric Products Inc., 40 Sylvan Road, Waltham 54, Massachusetts.

GENERAL TELEPHONE & ELECTRONICS

Total Communications from a single source through

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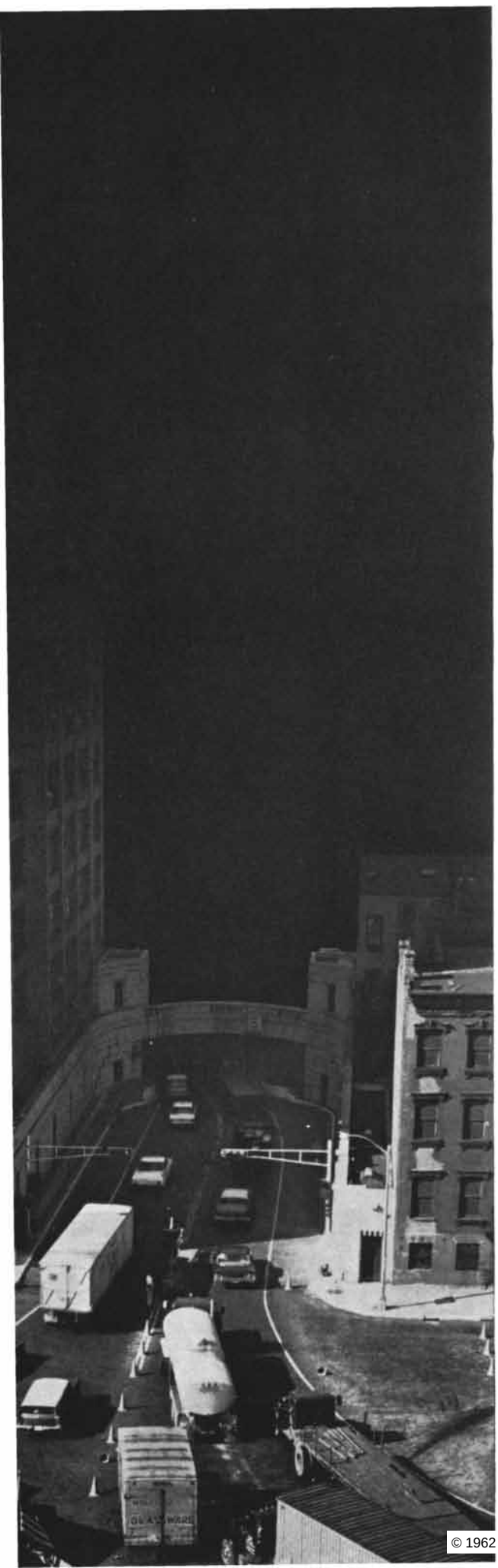


One of a series briefly describing GM's research in depth

At the Holland Tunnel, traffic is stopped to make it go: Why?

In their theoretical studies of traffic flow, scientists at the GM Research Laboratories have been developing mathematical models to describe how one car follows another. To check the validity of these models, mass flow experiments were conducted in the Holland Tunnel in close collaboration with The Port of New York Authority which is trying to relieve congestion at this vital traffic artery.

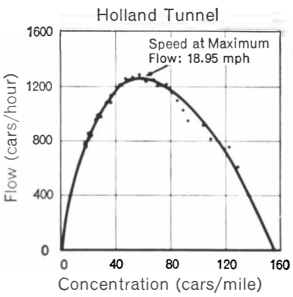
Observations indicated that the car-following models do give a highly consistent description of the steady-state stream of traffic. One interesting point: Both car-following theory and analysis of mass flow data showed that the optimum speed for maximum traffic flow in the tunnel is a surprisingly low 19 mph.

These cooperative studies are contributing significantly to the evolution of unique traffic control systems by the Port Authority for the Holland and Lincoln Tunnels. With the control system now being developed, the number of vehicles allowed to enter per minute is automatically adjusted as the speed and density of traffic in the tunnel changes. Test results to date show a significant reduction in congestion and increase in traffic volume during rush hours.

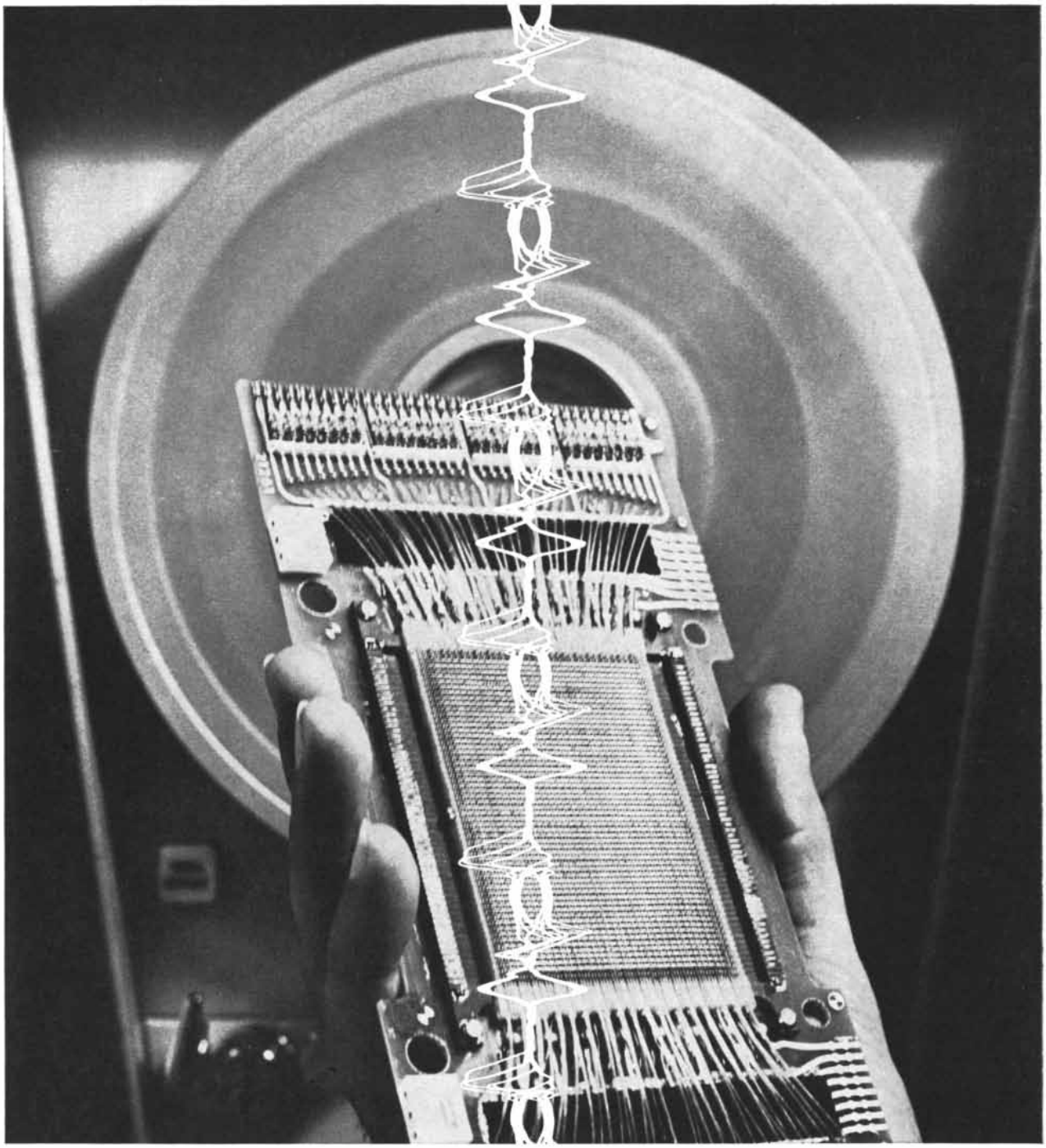
At General Motors, we believe information from such fundamental traffic studies may well have wide applications . . . for the cars, drivers, and perhaps, automatic highways of the future.

General Motors Research Laboratories

Warren, Michigan



Curve is a "least squares" fit of theoretical car-following model to mass flow data.



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Do you prefer to have your ferrite cores already wired into arrays and assembled into memory stacks? Good. We can supply every possible configuration and frame design—including word select and coincident current types. Would you rather have production line delivery of your memories? We can help you there, too. Ampex Computer Products Company has the widest range of off-the-shelf solid state core memories with random and sequential access operating modes. Plus the finest high and medium speed tape transports. Plus computer tape. Plus an extensive field engineering program in both Europe and the United Kingdom. In other words: when it comes to advanced, reliable computer components, Ampex has them. And the widest possible selection. It's the only company with recorders, tape and memory devices for every application: Ampex Corp., 934 Charter St., Redwood City, Calif.; Ampex International S.A., 1 rue des Pilettes, Fribourg, Switzerland.

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TO MARS...BUT WHAT ABOUT THE LAUNDRY?

Picture a Mars-bound astronaut rocketing through space at 25,000 miles per hour. All systems are functioning perfectly. The spaceship's cabin is small but comfortable. He has plenty of food and water for his 300-day journey. He has taped music and reading material to keep his mind occupied.

But how in the world does he do his laundry?

The answer, of course, is... he doesn't. Washing clothes in outer space would require prohibitive amounts of water and energy.

Disposable clothing is the only solution. Warm, light clothing that can be jettisoned.

And of all the fibers and fabrics known to modern man, one that is being seriously considered for the job is *paper*. Good, old, plentiful, inexpensive *paper*.

Until comparatively recently, paper would never have been in the running for a role like this. Paper was to write things on. And to wrap things in. And that was it.

But, today, paper has undergone a startling transformation. You can redecorate a room with wallpaper that not only pastes itself, but kills flies and repels dirt, too. You can brighten your kitchen with vinyl-coated paper flooring. Manufacturers are even experimenting with a paper bathing suit.

This paper breakthrough really began back in the early 1940's. Until that time, paper had one fatal drawback. When exposed to water, it degenerated into a soggy, useless mass of pulp. No bathing suit material, this!

Then one day a chemist at Cyanamid's Central Research Laboratory added a small amount of a melamine-formaldehyde resin-acid colloid to paper stock. And a practical process for making wet-strength paper was born.

Cyanamid's Industrial Chemicals Division, which supplies a broad range of products to paper manufacturers, was rushed into action. In a relatively short time, an inexpensive and commercially feasible wet-strength process was developed. Special wet-strength resins were created for the paper industry.

However, it remained for the U. S. Army to dramatize the advantages of this exciting new kind of paper.

During World War II, the army had an urgent need for paper maps that would stand up under battlefield conditions. Cyanamid turned the problem over to the new wet-strength resins. The resulting maps not only stood up under pelting downpours, they stood up under the treads of a Sherman tank!

This new map sparked the paper industry's interest in resin-treated products. Wet-strength facial tissues, rainproof grocery bags, shower scuffs and paper bathmats were just a few of the many practical uses for this new and better kind of paper.

Today, paper's progress has really just begun. Chemically-treated paper can now be woven or knitted into upholstery materials extremely resistant to weather and wear. These same fabrics have been used for fashionable accessories in milady's wardrobe: paper fabrics that can be washed, dry cleaned and re-used as many as 30 times.

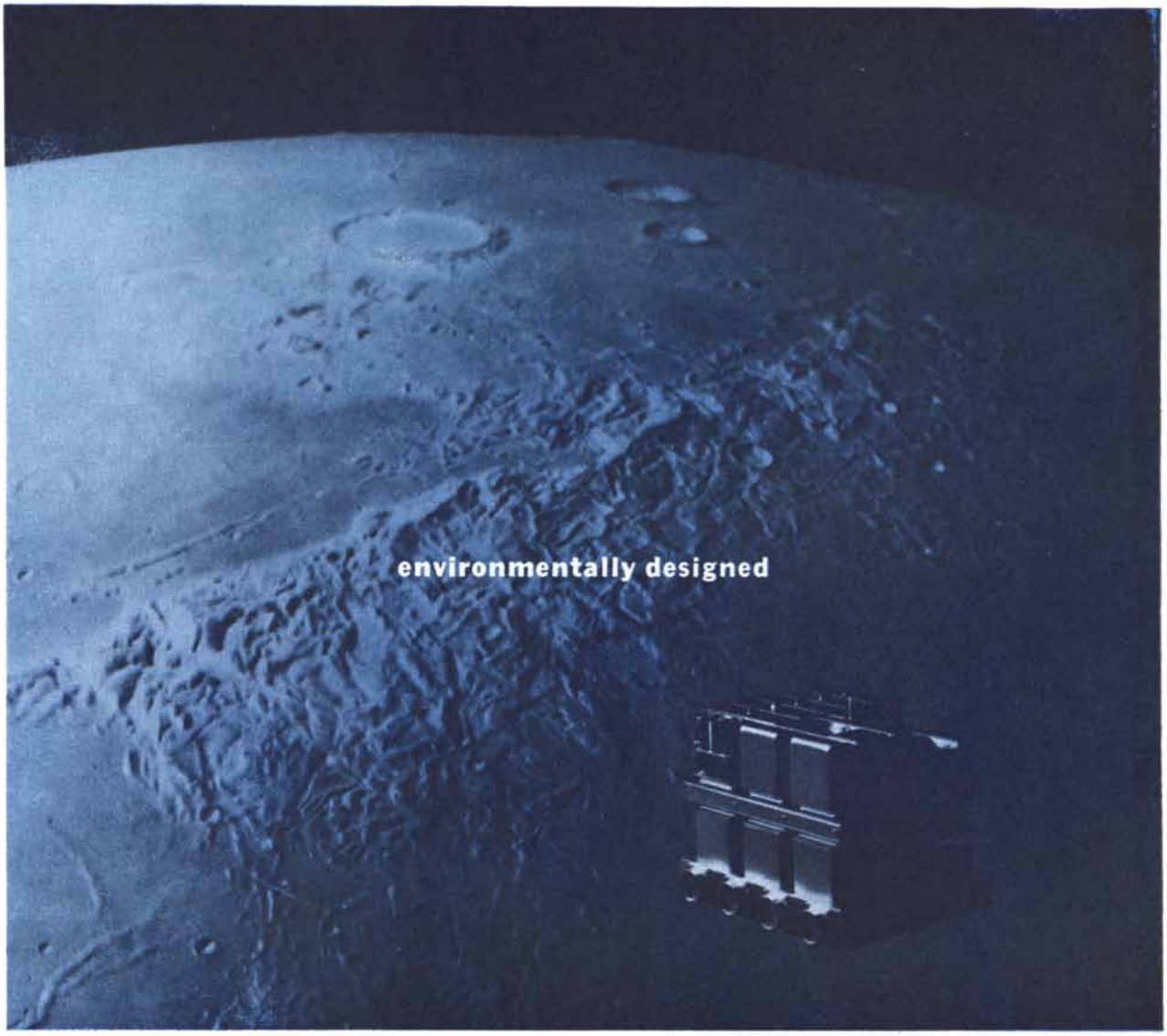
Clearly, paper is ready to take its rightful place alongside the other miracle materials of our space age.

And, of course, paper possesses one special talent that spurs *all* progress on. It has the ability to be printed upon with green ink... and cut into delightful little rectangular sheets called *money*.

CYANAMID

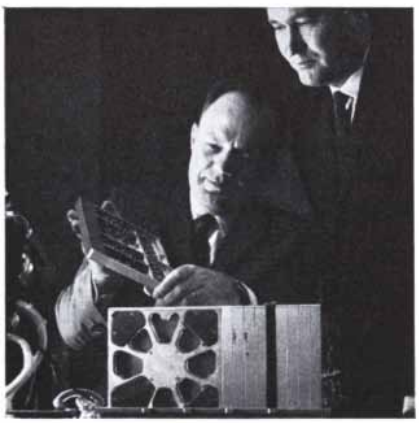
AMERICAN CYANAMID COMPANY

Agricultural/Building Products/Davis & Geck/Fibers/Formica Corporation
Industrial Chemicals/Lederle Laboratories/Organic Chemicals/Pigments
Plastics and Resins/Cyanamid of Canada Limited/Cyanamid International



...to survive in space: the moon and a Librascope computer

Shown metaphorically floating in circumlunar space is the first computer specifically designed to guide an exploratory instrument package to a soft landing on the moon. It is one of a line of Librascope computers designed to perform in space vehicles and missiles. The premium demand for minimum weight is met with



a variety of general-purpose digital computers. These computers are designed with maximum simplicity, commensurate with functional requirements and operate in their environment with highest reliability and long life. In space as well as at sea and in the air, Librascope computers pace man's expanding mind.

LIBRASCOPE DIVISION
GENERAL PRECISION
808 Western Avenue, Glendale 1, California

G2-525

THE AUTHORS

DAVID JORAVSKY ("The Lysenko Affair") is associate professor of history at Brown University. Born in Chicago in 1925, Joravsky attended the University of Pennsylvania, where his studies were interrupted for two years by World War II. Receiving a B.A. from Pennsylvania in 1947 and an M.A. from Columbia University in 1949, Joravsky did graduate work in the Russian Institute at Columbia until 1954, when he began teaching at the University of Connecticut. Columbia awarded him a Ph.D. in 1958, and he went to Brown the same year. The subject of his dissertation was "the development of Soviet Marxist philosophy from the 1917 Revolution to the triumph of Stalinism," a topic, he notes, that "also has a practical advantage for the Western student of the Russian Revolution: the intellectual historian suffers much less than his political and economic colleagues from the virtual impossibility of archival research." Joravsky's work soon involved him in the study of natural science, which he describes as one of the chief problems of Marxist philosophers. The work on which his article is based was supported by the National Science Foundation, the American Council of Learned Societies and the Russian Research Center of Harvard University.

SIR MACFARLANE BURNET ("The Thymus Gland") directs the Walter & Eliza Hall Institute of Medical Research at the Royal Melbourne Hospital in Australia. In the course of a long and distinguished career, Burnet has become one of the leading authorities on viruses and virus diseases. His many contributions to these studies brought him membership in the Royal Society in 1942, the Society's Royal Medal in 1947 and a knighthood in 1951. For the theory of the immunological mechanism that he proposed in 1949, Burnet shared (with P. B. Medawar of University College London) the 1960 Nobel prize in medicine and physiology.

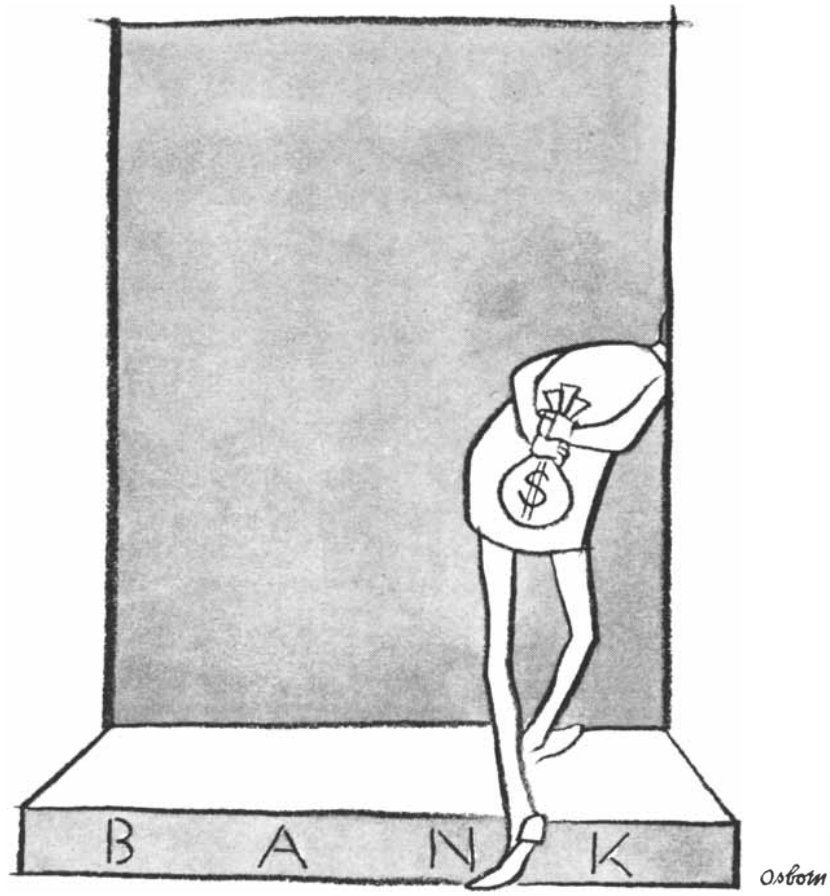
D. NELSON LIMBER ("The Pleiades") is associate professor of astronomy at the University of Chicago and a member of the staff of the university's Yerkes Observatory in Williams Bay, Wis. Limber's interest in astronomy began with his discovery, while walking home one night, of his "nearly total ignorance of the whole business." "I couldn't even find the Big Dipper," he continues, "and didn't have the slightest idea why the moon wasn't around or when I might expect it." Limber subsequently studied physics and astronomy at Ohio State University, where he received both his A.B. and M.Sc. in 1950. He acquired a Ph.D. in astronomy and astrophysics at the University of Chicago in 1953. Two years of postdoctoral work at the Princeton University Observatory were completed in 1957. Limber went to Chicago in 1958.

CARLEEN MALEY HUTCHINS ("The Physics of Violins") has been designing and constructing violas and other stringed instruments of the violin family for the past 15 years. Her first step toward a career as a luthier came in 1942, when, as she describes it, "I bought an inexpensive weak-toned viola because my musical friends complained that the trumpet I had played was too loud in chamber music, as well as out of tune with the strings—and besides they needed a viola." The viola was unsatisfactory and Mrs. Hutchins turned for help to her uncle, William Harvey Fletcher (not the well-known acoustical physicist Harvey Fletcher), who had made many violins himself. Fletcher declined to try his hand at making a viola and instead directed his niece to a dealer who could supply her with the requisite books, blueprints and wood. In 1947 Mrs. Hutchins took a leave of absence from the Brearley School in New York, where she had taught science since 1937, to have her first child. Encouraged by her husband, she also embarked on the task of making her first viola, a job that took two years. Mrs. Hutchins has produced 55 instruments, selling some of them to help pay for further research. A graduate of Cornell University, where she studied entomology, Mrs. Hutchins retired from teaching in 1949. For the past 12 years she has collaborated with Frederick A. Saunders of Harvard University in the study of the acoustics of the instruments of the violin family. At present she is continuing this work under her second Guggenheim Fellowship.

EDEL WASSERMAN ("Chemical Topology"), a member of the technical staff of the Bell Telephone Laboratories, is spending the current academic year as visiting professor of chemistry at Cornell University. Born in New York City, Wasserman took his B.A. at Cornell in 1953 and then did graduate work at Harvard University, where he studied under the late William Moffitt. He received his Ph.D. in chemistry in 1959.

How to tell the difference between a Full Service Bank and all those other "banks"

(AND WHY IT WILL PAY YOU TO KNOW)



Viewed from the sidewalk, most financial institutions look pretty much alike. But once you look behind the doric columns and "Time and Temperature" signs, you'll find a difference. *Doing something* about this difference can save you cash money. It might even speed your financial growth. It will certainly enhance your credit reputation.

You see, different financial institutions do different things. Some take in savings and make real estate loans. Others make mostly personal and auto loans. But there is one kind of institution which, by law, does all of these things, and more. We're talking about a Full Service commercial bank.

A Full Service bank is a sort of "financial department store," capable of performing a wide variety of functions. It is not limited to savings and a few types of loans. It can accept both checking accounts and savings deposits, and can make home loans, personal loans, auto loans, travel loans, business loans, as well as loans for practically any other legitimate purpose you can name.

Why concentrate on a Full Service commercial bank?

The kind of people who have made the most of their money take *all* of their money matters to one place. They rely heavily on the personal counsel that one Full Service bank can give them. In addition to any checking accounts in the family, they put all their long-range funds into a *savings* account. (This savings account may earn a little less than in some other places but it's *worth* a lot more, as you will see.) They make a point of getting to know at least one of the bank's officers and they have their Personal Financial Statement on file with him.

When they need money to buy a car or take a vacation, they borrow it from the bank, leaving their savings account intact and growing. Having this savings account assures them favorable treatment in getting a loan. *Paying it back* as promised enhances their credit reputation. (The low rate that Full Service banks offer on loans usually far overshadows the sometimes slightly lower rate of interest paid on savings.) What's more important, they are building their reputation for the time when they might need a sizeable loan – for buying a home, sending the kids to college, taking advantage of a new business opportunity.

Get to know your banker before you need him!

If your money affairs are scattered all over town, take advantage of the one-stop benefits of a Full Service commercial bank. Let your checking and savings accounts be an introduction to the partnership benefits of a Full Service commercial bank. There *is* a difference between a Full Service bank and all those other "banks." It will profit you to put that difference to work for you. The sooner the better.

FULL BANK SERVICE®

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Wasserman joined the chemistry department of the Bell Laboratories in 1957.

HAROLD BERGER ("Neutron Radiography") is associate physicist with the Nondestructive Testing Group of the Metallurgy Division at the Argonne National Laboratory. Berger studied physics at Syracuse University, receiving B.S. and M.S. degrees there in 1949 and 1951 respectively. From 1950 to 1959 Berger was a physicist in the Advanced Development Laboratory of the General Electric Company in Milwaukee, Wis. After a brief period as senior physicist with the Solid State Devices Division of the Battelle Memorial Institute, Berger went to Argonne in 1960.

W. A. H. RUSHTON ("Visual Pigments in Man") is a Fellow and director of medical studies at Trinity College of the University of Cambridge. The son of a London dental surgeon, Rushton numbered among his schoolmates at Gresham's School the poets W. H. Auden and Stephen Spender, the composer Benjamin Britten and the physiologist A. L. Hodgkin. Rushton studied medicine at Cambridge and did research under the direction of the physiologist E. D. Adrian. Rushton came to the U.S. in 1929 as one of the original members of the Johnson Foundation of the University of Pennsylvania. He returned to Cambridge in 1931. Since 1948, when he was elected a Fellow of the Royal Society for his work on nerve excitation, Rushton has become increasingly interested in the role of pigments in vision.

HARRY F. and MARGARET KUENNE HARLOW ("Social Deprivation in Monkeys") are respectively George Cary Comstock Professor of Psychology at the University of Wisconsin and project associate at the Wisconsin Regional Primate Research Center, which Harry Harlow directs. The former, who also directs Wisconsin's Primate Laboratory, obtained a B.A. from Stanford University in 1927 and a Ph.D. from the same institution in 1930. He joined the Wisconsin faculty the same year. Margaret Harlow received A.B. and A.M. degrees from Washington University in 1939 and 1940 respectively. The State University of Iowa awarded her a Ph.D. in 1944.

ENRICO PERSICO, who in this issue reviews *Enrico Fermi: Collected Papers*, edited by Edoardo Amaldi *et al.*, is professor of physics at the University of Rome.

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The advent of integrated circuits demands new approaches to circuit and system designs. The new Motorola MECL logic circuits are designed around the properties of integrated circuits rather than those of individual components, therefore capitalizing on the advantages of this new technology.*

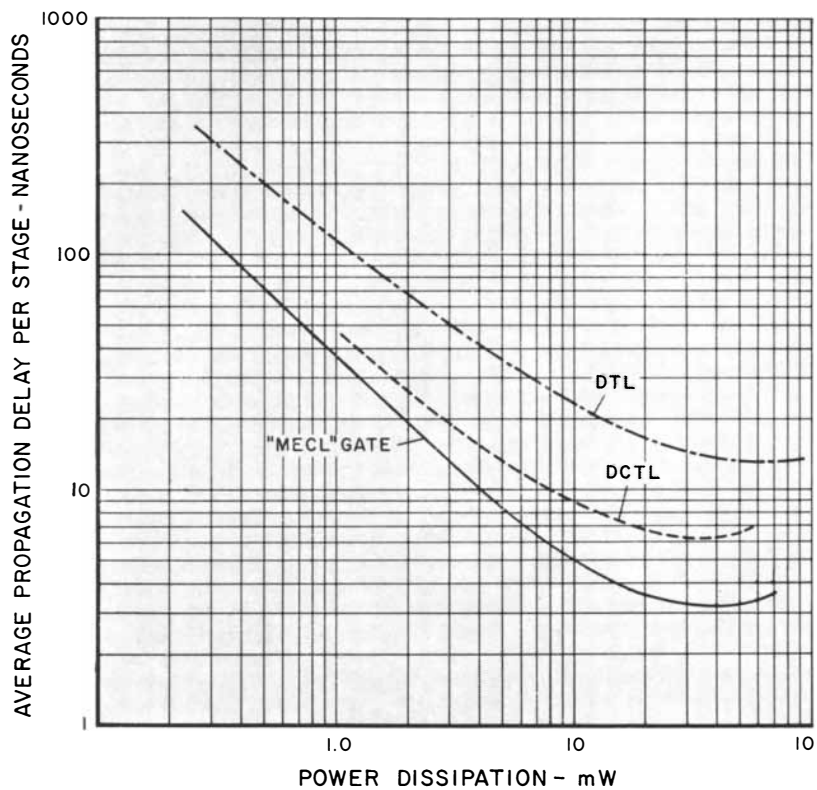
Motorola MECL Circuits...For 3rd Generation Integrated Circuit Computers

Integrated circuits offer the computer industry a new and powerful tool for satisfying the demand for space-age computer designs of ever-increasing complexity. They not only provide solutions for the widely publicized requirements of reduced size and weight, improved reliability and, eventually, lower costs, but new circuits developed by Motorola also operate at higher speed and with lower power consumption than obtainable with standard transistor circuits.

These benefits cannot be achieved merely by taking circuits *designed for use with discrete components* and translating them into integrated circuit form. Such redesign does not provide all of the improvements possible with this new technology. For, just as the transistor required a departure from tube circuit design, so the unique characteristics of integrated circuits benefit from a design approach specifically geared to their particular advantages and limitations.

For example, the inherent properties of integrated circuits provide greater freedom for circuit design than is apparent at first glance. In designing integrated circuits for large-scale production, transistors should be considered as no more expensive than diodes, and diodes, in turn, as no more expensive than passive elements. This, to some degree, will free the circuit designer from the economic restrictions of present techniques.

On the other hand, the present state of the integrated circuit art also presents some limitations. Among these are: 1) inherent parasitic coupling between components through a common semiconductor substrate; 2) restricted ranges of component values, and 3) limitations on individual component tolerances.



Speed versus power-dissipation comparison between three practical forms of computer logic designs illustrates the higher speed capability and lower power consumption of MECL circuits.

Taking into account both the additional design freedoms and limitations of the integrated circuits art, Motorola engineers have developed an advanced form of logic circuitry, called MECL circuits, which we believe are superior to any other circuit presently available — whether made from discrete components or integrated circuits. The series consists of an ORNOR gate, a flip-flop, and a half-adder — all the ingredients for the arithmetic portion of even the most complex digital computer.

Design Considerations

Motorola MECL circuits were the result of exhaustive research of all major logic configurations from a standpoint of integrated circuit compatibility. In every comparison, the current-mode logic approach demonstrated indisputable performance superiority over such commonly used forms as DTL (diode-transistor logic) and DCTL (direct-coupled transistor logic) circuits.

*MECL — trademark of Motorola Inc.

It eliminates, for example, the parameter of transistor storage time as a speed-limiting factor[1] – thus extending the maximum potential circuit speed beyond the limits of other logic forms.

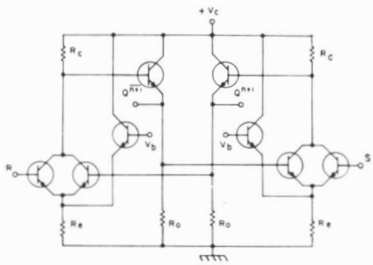
It is uniquely tolerant of component values[1]. Absolute values of resistors are relatively unimportant so long as proper ratios between circuit resistances is maintained. This is highly compatible with integrated circuit processes where absolute parts values are difficult to achieve, but where resistance ratios can be held to very close tolerances.

It is non-critical of transistor parameters, maintains constant power supply loading, has unexcelled DC stability, and contributes to high noise immunity[1] – factors that greatly influence performance reliability.

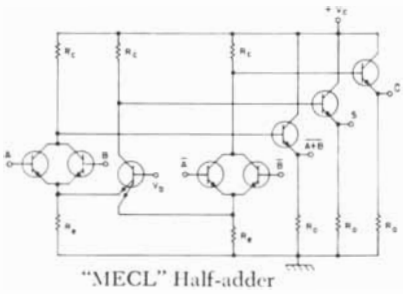
In fact, the only area in which the basic current-mode approach suffered by comparison with other logic forms, was in the relatively large number of transistors it requires. While this has been a major economic deterrent, preventing the widespread adoption of current-mode logic with discrete components, it becomes an insignificant factor in the cost of integrated circuits.

MECL Circuit Advantages Over DTL and DCTL

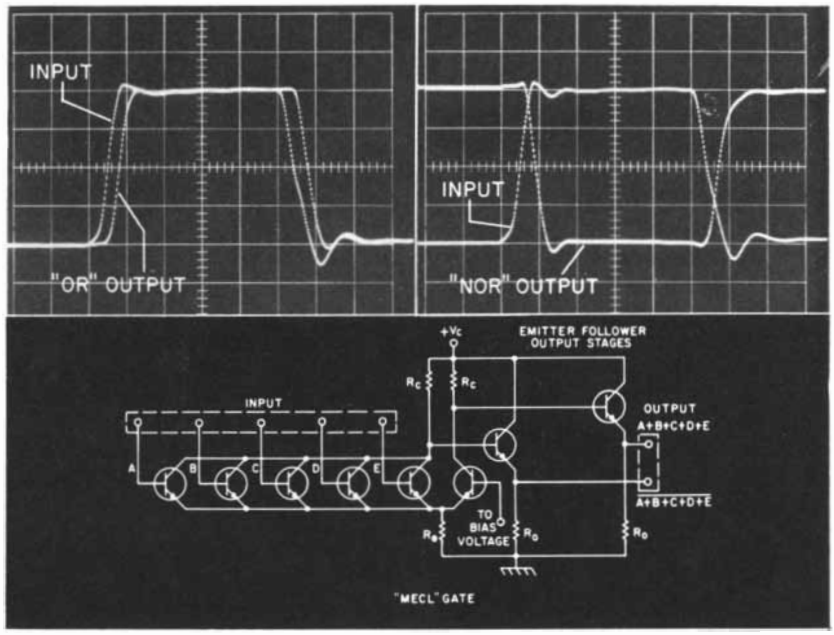
The dynamic advantages of MECL circuits over other forms of logic are apparent from an examination of the input-output characteristics shown in conjunction with the schematic diagram of the gate circuit.



"MECL" Flip-flop



"MECL" Half-adder



"OR" and "NOR" outputs of a typical Motorola "MECL" gate circuit show transient response times in the order of 3.5 nanoseconds with a fan-out of 1. (Horizontal scale = 10 nsec/Div., Vertical scale = 0.2 V/Div.)

● High Speed Operation – Delay time of less than 5 nanoseconds per stage. Circuit speed is increased not only by the elimination of the storage time limitation, but also by the high inherent feedback in the circuit which greatly reduces input capacitances, and by the low impedance of the common-emitter outputs which reduces the deteriorating effects of parasitic and lead capacitances.

● High Logic Capability – The direct signal and its complement are both available from the same gate. The availability of both direct and complementary outputs from the same circuit provides a simplification of the overall logic. This not only reduces the number of stages required, but further increases system speed by eliminating the propagation delay associated with such extra stages.

● Large Fan-In and Fan-Out Capability – For greater logic power. Fan-in capability is high because of the high input impedance resulting from the large amount of feedback provided by the common emitter resistance. Fan-out capability is high because of the low output impedance of the emitter follower circuit. With a fan-out of 12, a propagation delay of only 5.5 nsec can be achieved. Each additional loading stage adds only about 0.25 nsec to the total delay.

● Low Noise and Crosstalk – High input and low output impedances of MECL circuits greatly reduce both inductive and capacitive cross talk between adjacent signal lines. Noise generated in power supply and ground lines is minimized due to the constant-current requirements of this logic family.

● Fewer Interconnecting Problems – The simultaneous availability of complementary signals reduces interconnecting problems by a factor of 2 or more. Utilization of a ten-pin header provides additional inputs as compared to eight-pin headers.

Speed-Power Range

Ultra-high-speed MECL logic circuits are being made available as standard components with a typical propagation delay of only 4 nanoseconds. Standard circuits for operation at lower speeds are rated at 100 nanoseconds with less than 1 mw power dissipation. Applications requiring intermediate speeds will be met by "custom-designed" MECL circuits.

Further information about Motorola MECL logic circuits can be obtained by writing Motorola Semiconductor Products Inc., Technical Information Department, 5005 East McDowell Road, Phoenix 8, Arizona.

[1] Techniques Of Current-Mode Logic Switching – W. D. Roehr, Motorola Semiconductor Products Inc., *Electronic Design*, September 13, 1962

SOFTWARE

The hardware for space travel is coming along nicely. The software for space travel is people, about whom a great many issues are clear and some are not. Clear: a man can survive a few hours out there. (Nikolayev, 96½ hours, no known after-effects.) To be determined: can a man survive in space for weeks, or months? (On a round-trip to the moon, for example. Or in an orbiting space station.)

The most versatile and valuable component of any space system is man. His welfare out there is going to depend (in part) on the environment inside his vehicle. And the composition and pressure of that environment will depend on engineering requirements: weight, power, reliability. Suppose a pure oxygen, low-pressure environment were selected. How would our Astronauts function during a two-week mission?

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The theory is simple enough. The procedure is not. It starts with our Environmental Test Chamber, a steel cylinder 30′ x 18′ in which we can produce various combinations of temperature, pressure, humidity, vibration and atmospheric composition. Inside, in groups of 6, go healthy young men to breathe pure oxygen for two weeks. For each group the pressure is changed. Pure oxygen at 5 psi for the first group, 7.4 psi for

the second and 3.8 psi for the third. A fourth group, breathing air at 14.7 psi, serves as control.

Outside the chamber are specialists in aerospace medicine, physiology, psychology, microbiology, biochemistry and environmental testing. During each two-week period this team performs 683 specific tests on each man (mental, sensory, motor, pulmonary, hematological and microbiological.) The group is assisted by instruments (polygraphs, oscillographs and the like) that automatically monitor and record each subject's reactions.

Probably the most significant oxygen pressure in the test program is 5 psi. That's the environment currently used for Project Mercury. It is also under consideration for Project Gemini, a planned two-week orbit for two Astronauts. Long before they go up, the "unknowns" of living in an oxygen environment will have become knowns. And the hazards thereof, if any, will have been pinned down, studied and eliminated.

This research, supported by NASA, is being carried on in our Space Environment and Life Sciences Laboratory, to determine the effects of space travel upon the software as well as the hardware.

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The Lysenko Affair

A case study of one aspect of the celebrated controversy that still troubles Soviet science: the dispute between Lysenkoites and others over the practical problem of curing virus diseases of the potato

by David Joravsky

The Lysenko affair, now 30 years old, is central to any comparison of Soviet and Western science. Those who stress the differences between the two vividly recollect the extraordinary meeting in August, 1948, when the agronomist Trofim D. Lysenko crushed all public resistance to his attack on conventional biology by announcing that he had the support of the Communist Party's Central Committee. Those who stress the similarities between Soviet and Western science note that the Central Committee has never explicitly endorsed any other attack on conventional natural science; they also note that Lysenko's influence has considerably declined since Stalin's death. From one point of view ideology is a powerful force in Soviet science, tending to make it different; from the other, the need for conventional science in industry and agriculture is the dominant force in Soviet science, tending to make it similar. Both views lead to puzzles that they cannot solve.

If Soviet ideology produced a unique school of biology, why did it do so abruptly in the middle 1930's, just when a decade of generous support for conventional genetics was transforming the U.S.S.R. into a major world center of the science? This historical puzzle is usually overlooked or brushed aside, but even the most up-to-date observers of Soviet science cannot avoid another puzzle. If Soviet ideology created a unique school of biology, why has it failed to do the same in other fields of natural science? There has been no lack of Marxist-Leninist prophets decrying "bourgeois" chemistry, physics and mathematics, but their influence has been slight and transient. For the most part Soviet natural science has shown no more than the usual differences of emphasis and approach that distinguish the national communities working in the international institution of science. Lysenko's school of biology is the outstanding exception to this rule. It is drastically different from international biology—so much so that communication between the two is virtually impossible—yet it has had a deep and prolonged influence in the Soviet community of biologists. Nor is the end in sight. Although Lysenko has been twice in and twice out of the presidency of the Lenin All-Union Academy of Agricultural Sciences, the incumbent president is an old colleague of his. His followers boast that they hold almost a monopoly in agricultural institutes and experiment stations, although they confess annoyance at the growth of opposition in academic centers of biology. How can this exceptional case be attributed to an ideology that has been at work in all fields of natural science?

The other approach leads even more quickly into insoluble puzzles. Lysenko and his followers claimed to be revolutionary farm experts even before they spoke as dialectical materialists. They have steadily depicted their school of biology as the partner of progressive agriculture, each stimulating and nourishing the other. Indeed, they have coined the term "agrobiology" to describe their new school. If their claim is justified, one cannot understand the failure of Western farm experts to adopt their recommendations, beginning with the "vernalization" of wheat in the 1930's and coming most recently to training cows to produce more butterfat. Lysenko's critics maintain that his biology has actually harmed Soviet agriculture. If they are right, the strong support he has received from Soviet authorities, including Premier Khrushchev, seems incomprehensible. They are pictured as sacrificing the progress of agriculture to—what? If the answer is ideology, then the original puzzle returns with a vengeance, because Khrushchev disclaims competence in theoretical biology even as he endorses Lysenko's agricultural proposals.

A consistent understanding of the Lysenko affair, it is plain, requires a closer study of the facts than we have had so far. It also requires, as the reader will see, re-examination of some of the basic assumptions that we bring to the urgent and baffling questions arising in every society where science, economics and politics interact in the making of public policy.

The Lysenko affair is amply documented in an enormous mass of Soviet publications on agriculture and biology. One can even find an initial case study that forces preconceptions to be set

aside: Lysenko's 30-year struggle with virus diseases of the potato. Since genetics is only secondarily involved in this case, one can ignore stereotypes about theories of heredity East and West and see what pattern is suggested by the facts of potato culture East and West.

Virus diseases have plagued the potato in hot, dry summers ever since it was brought from the Andean highlands to feed the rising urban populations of Europe during the Industrial Revolution. Of course, 18th- and 19th-century agriculturists knew nothing of viruses, but experience taught them control measures and explanations to suit. The symptoms—curling, wrinkling and speckling of the leaves and an attendant drop in the harvest of tubers—are cumulative when the potato is grown in the usual way, by the planting of tubers. They are cut short when the potato is propagated sexually, with true seed. The natural inference from this fact was that a clone—the aggregate of individuals propagated asexually—is like an individual organism: it ages, or "degenerates," and needs to regenerate itself by periodic sexual reproduction. This cure has serious economic disadvantages. Frequent male sterility in the potato flower makes it hard to produce true seed in quantity; plants must be started in greenhouses and then transferred to the fields; and even if one is willing to put up with these large expenses, the desirable varieties are usually unstable hybrids that segregate in the course of sexual reproduction, thereby ruining the varietal purity of a crop.

Fortunately, a different cure, revealing facts inconsistent with the theory of aging or degeneration, was soon discovered. In cool, moist areas potato plants suffer little from degeneration no matter how old the clone is, and their tubers, when shipped to hot, dry areas as "seed potatoes," produce fairly healthy plants for a year or two. The natural inference from these facts was the theory of ecological depression: the diseases of "degeneration" are actually physiological disorders caused by an unfavorable ecology and curable by a favorable one. This cure proved economically advantageous in countries undergoing industrialization. Declining transportation costs and the growing urban demand for potatoes made it profitable to develop regional specialization. Seed tubers were produced in such cool, moist areas as Scotland for shipment to southern growers of food tubers. The rising premium on healthy seed tubers, however, called attention ever more insistently to facts that the theory of ecological depression could not explain. For instance, the fact that a favorable climate mitigates but does not eliminate the "degenerative" diseases not only frustrated the potato grower's desire for higher yields but also challenged the plant scientist's desire for complete and consistent explanations.

The escape from this puzzle into the richer problems of virology came at the beginning of this century, when several countries sharply increased governmental support of agricultural research and at the same time brought such agricultural enterprises as the production of seed tubers under governmental regulation. Historians of biology have paid little attention to these developments, but many salient facts suggest that there is rich material here for comparative studies in the symbiotic development of biology and agriculture. Consider, for example, the contrast between Russia, one of the major potato-growing nations but one of the most backward, and the Netherlands, long a world center of intensive, scientifically oriented agriculture, potato-growing included. A Russian discovered plant viruses at the turn of the century, while studying a disease of tobacco that is very similar to the degenerative diseases of the potato. He lost interest in the subject. This can happen to an individual scientist in any nation. In Russia, however, no one picked up where he left off. Plant virology, both as a theoretical study and as applied to agriculture, simply lapsed in Russia until 1930. The Soviet government then established the first virus laboratory as part of the characteristic effort to catch up with the West. In the Netherlands the significance of the new subject was grasped early in the century; there plant virology began a continuous development as both theoretical and applied science. Indeed, government officials and commercial producers of seed tubers did not wait for many essential questions to be answered. As soon as it had been demonstrated that some types of degeneration are infectious, the Dutch began to apply prophylactic measures, such as the isolation of seedbeds, the systematic discovery and elimination of diseased tubers and the development of rules for official certification of healthy tubers.

A thorough history of these developments in Great Britain and the U.S. as well as the Netherlands would probably show that scientists and potato growers have become increasingly specialized units of an increasingly interdependent complex, while the government has become steadily more the planner and director of both science and agriculture. This has been an unpalatable truth for Republican potato growers and proud doctors of philosophy. It has been a palpable truth nevertheless, causing awkward shifts in the ideologies of all concerned. It seems just as likely that social support for virology and its applications to potato culture has depended not so much on a rational understanding of the science and its complex relations with economic developments as on the simple assumption that promoting science boosts yields. This widespread assumption, held in common by the Russians and ourselves, is a great oversimplification, and a potentially dangerous one, as Russian experience shows.

Nearly all the U.S.S.R. is more northerly than Maine, but its southern area—the steppe—has the hot, dry summers that are bad for potatoes. Nature being fairly constant, economic and scientific developments have shaped the changes in the southern peasants' practices. Until collectivization they tended to leave potatoes alone. Only the few whose farms were close to the slowly extending rail lines and urban markets found it profitable to import northern seed tubers. Fewer still, who had bottom land that was flooded in the spring, got tolerable yields by planting in midsummer, a practice also known in parts of southern France and Oklahoma. The forced industrialization and collectivization that began at the end of the 1920's drastically changed this situation. To supply the urban markets, now growing rapidly, the government pushed the peasants into large-scale collective farms and demanded a large volume of produce from them. To get funds for industrialization, however, the government held agricultural prices at a low level. The peasants shirked, concentrating their efforts instead on the little household plots that had been left them.

In 1935, for example, *Pravda* complained that the peasants of Saratov district planted less than half the acreage of potatoes planned for their collective fields, while overfulfilling the allowance for their household plots by 63 per cent. At the same time an acute transportation crisis made Saratov and other cities in the steppe highly dependent on local farms for potatoes. The local farms, in turn, found it increasingly difficult to import the northern seed tubers that were essential for acceptable crops. As yields per acre fell, the government

forced a great increase in potato acreage, enlarging its problems rather than solving them.

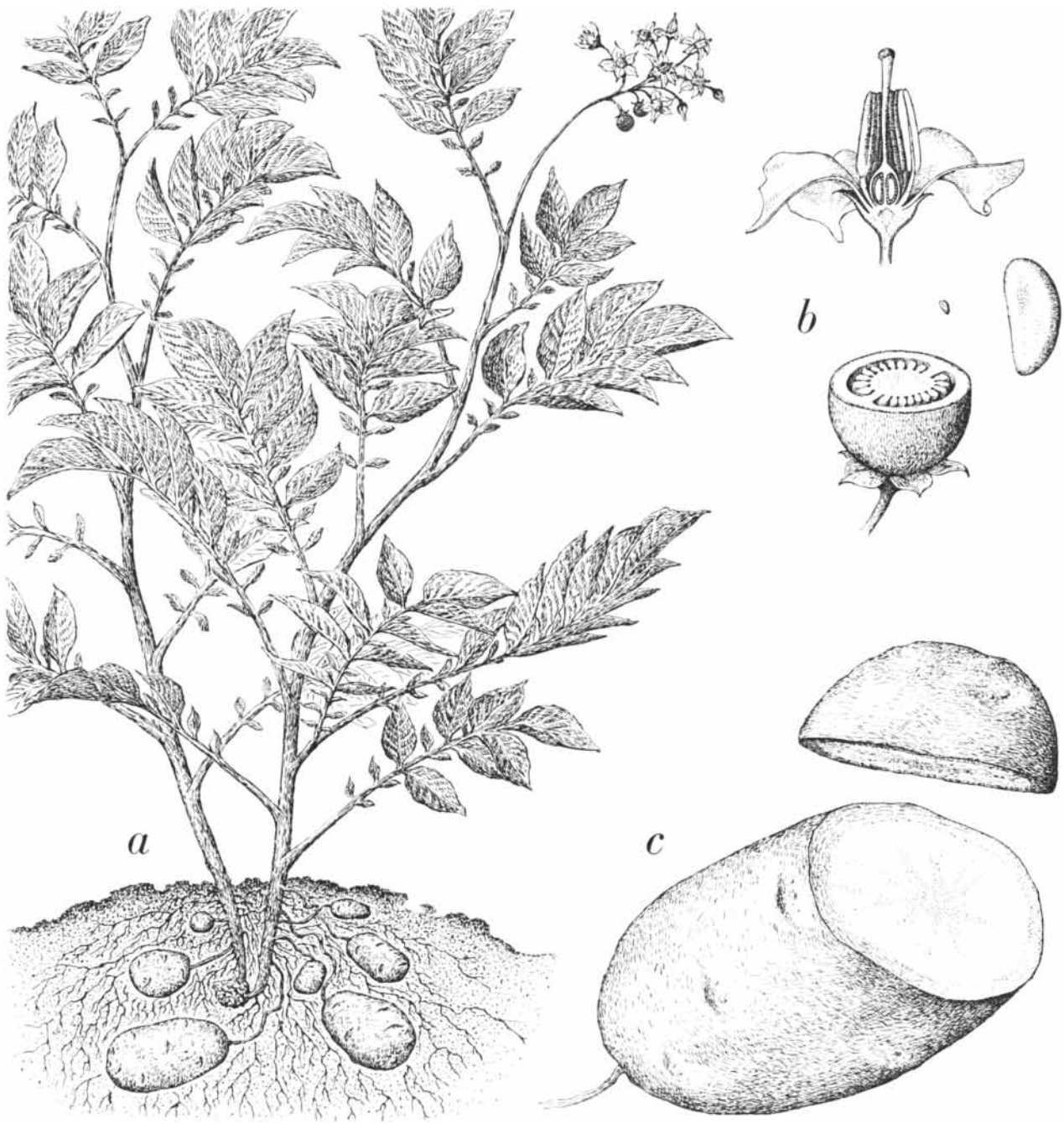
A continuous complaining filled the agricultural press: the inherent efficiency of large-scale farms and the government's great investment in modern equipment, education and research were providing everything necessary for a steep rise in yields; the perverse decline in yields showed that peasants and local farm officials were bunglers, slackers, even criminal "wreckers." This applied not only to peasants and local farm officials but also to scientists. From 1930 the press reflected a gradual shift in official attitudes toward N. I. Vavilov's Academy of Agricultural Sciences and the large network of research stations and institutes that it headed. Benign confidence that they were doing great things for Soviet agriculture gave way to a short-tempered suspicion that their costly puttering was irrelevant to the crushing problems of socialist agriculture. In August, 1931, a decree "On Plant Breeding and Seed Production" testily ordered plant scientists to prove the obvious truth that socialist organization made possible a rate of agricultural progress undreamed of in capitalist countries. This story is not concerned with the parts of the decree that prepared the ground for Lysenko's repudiation of genetics. (Scientists were ordered to breed improved varieties within four to five years rather than the 10 to 12 years that had been regarded as minimal.) The decree required that each district, including those in the south, become self-sufficient in the production of potatoes for its own needs, both for food and for seed. Scientists were to discover how to raise healthy seed potatoes in the southern districts, and they were to do so within four years, the period set for the complete conversion of Soviet potato plantings to the use of seed tubers certified for varietal purity and health. At present, the decree complained, less than 1 per cent of the potato crop was planted with certified seed tubers.

Less than 1 per cent of the potato crop was planted with certified seed tubers of existing varieties, but the U.S.S.R. was then winning a reputation as perhaps the leading center for the scientific breeding of improved varieties. Evidently there was truth in the official cliché, endlessly repeated from 1930 on, that plant scientists were "divorced from agricultural practice." But they were not "lagging behind socialist agriculture," as the cliché charged; they had run far ahead of it. They found themselves

LYSENKO, who was then the president of the Academy of Agricultural Sciences, is shown at a meeting of the Supreme Soviet of the U.S.S.R., to which he was a delegate in 1950.

berated for their obvious failure to help agriculture—were not yields declining?—just when they were winning worldwide fame for advanced research. And the irony bites deeper than coincidence. Vavilov, whose legendary enthusiasm sparked the rapid advance of Soviet plant science, was inspired in part by the conviction that socialism makes possible a rate of co-ordinated scientific and agricultural progress impossible in capitalist countries, the very conviction that now inspired distraught officials to make impossible demands on him.

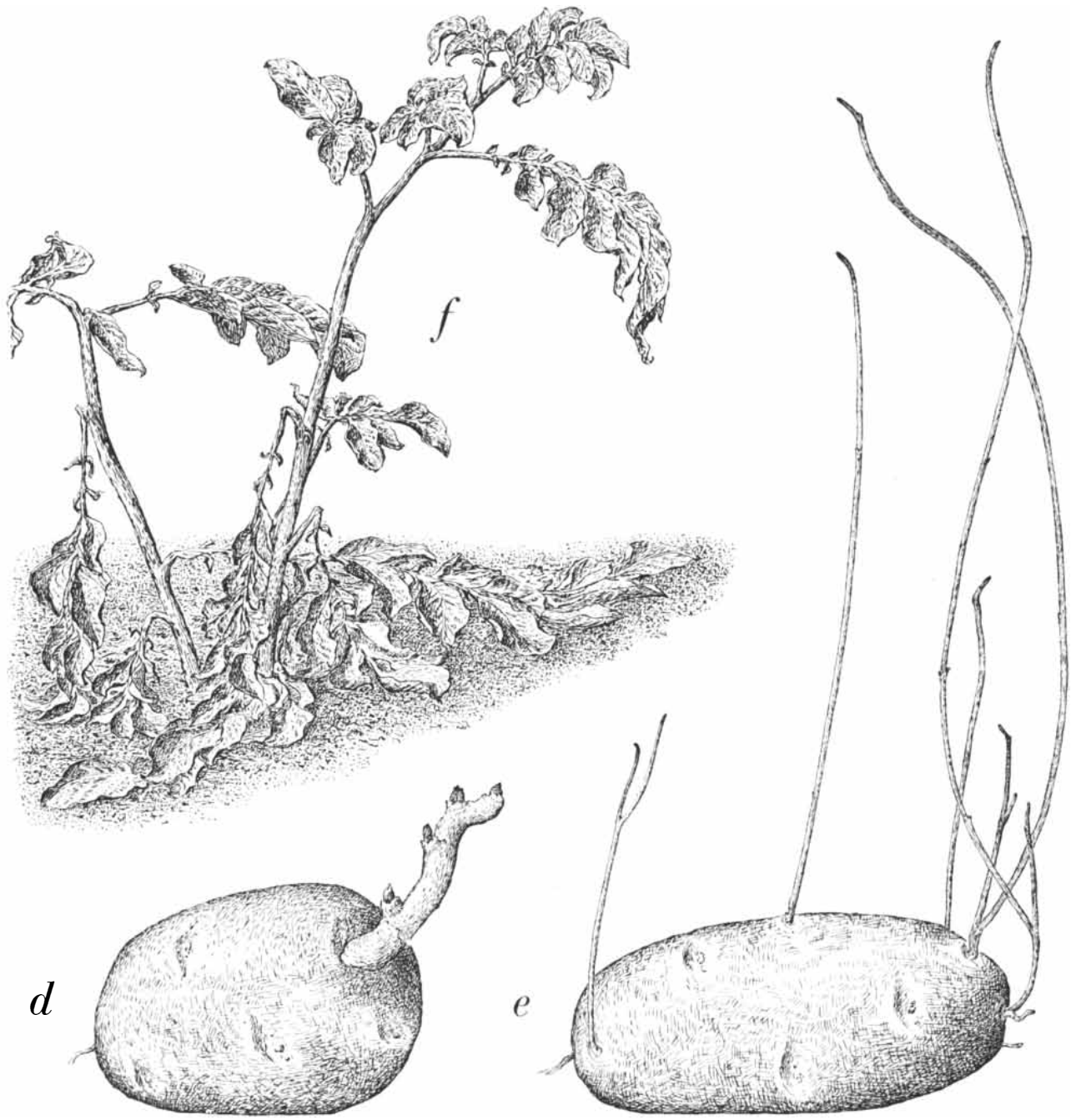
Soviet potato specialists were not entirely nonplused by the demand for the production of healthy potatoes in the south, where degenerative diseases cannot be held to a tolerable minimum by the usual prophylactic measures. For such districts they suggested the use of true seed. They pointed out the advantages (seed tubers are infected by any virus in the parental plant but true seed is not) and they acknowledged the disadvantages (frequent male sterility in the potato flower, a tendency not to breed true and the extra labor of raising sets in greenhouses and transferring them to the fields). Perhaps this was the crucial mistake of the potato specialists: they presented their solution in a tentative way, calling attention to its disad-



HEALTHY AND DISEASED potato plants are illustrated on this page and the opposite page. A healthy plant is shown at *a*. Its flower, fruit and seeds are enlarged at *b*. The potato (*c*) is not a root but a tuber, an underground stem swollen to store food for the plant; as a stem it has buds, or "eyes," each in the fold of a vestigial leaf. Potatoes are propagated vegetatively rather than from seed: when

vantages and urging careful trials of various techniques before some of them could be firmly recommended to southern farmers. Lysenko made no such mistake when he presented his solution for the problem early in 1935: within two years, he declared, the south could become entirely self-sufficient in the production of healthy seed tubers by adopting the simple method of planting in midsummer.

Potato specialists must have gaped in astonishment at this announcement. It was first presented to them not in a technical journal but at the Second Congress of Collective Farm Shock-Brigade Workers, with Stalin interjecting "Bravo, Comrade Lysenko!" A little later the official newspaper of the Commissariat of Agriculture presented Lysenko's claims, and without the tag "For discussion" that would have made it possible to disagree. Lysenko presented summer planting as his discovery, failing to mention—much less evaluate—the experience of farmers who had long practiced various forms of it in scattered parts of the U.S., France and his native Ukraine. He declared degeneration to be not the result of infectious diseases but an "aging" or "enfeeblement" of the plant caused by excessive heat at the time of tuber formation; summer planting kept potatoes



a tuber or part of one is planted, one or more of the eyes sprout to form a new plant (*d*). Spindling sprout (*e*) is one of the few degenerative diseases that may not be an infection; it may be a physiological disorder caused by excessive heat. Lysenkoites have concentrated on it while ignoring other degenerative diseases, such as rugose mosaic (*f*), that are caused by known viruses.

from degenerating because the tubers formed in the cool of the fall. Briefly and vaguely he reported the following experiment in support of his explanation: healthy tubers stored at 85 to 95 degrees Fahrenheit produced very unhealthy plants. (In later recollections he pictured the tubers as cut in half; the control halves were stored in a cellar and produced healthier plants than did those stored at the higher temperatures.)

As Lysenko warmed to his subject in further newspaper articles, speeches and pamphlets, he added the famous "stage theory" to this explanation. He claimed to have revolutionized plant physiology with a new understanding of the stages of development in a plant's life—stages that were nowhere defined clearly or consistently. Vague enough to begin with, the stage theory became little more than a phrase when Lysenko added it to his explanation of degeneration. Heat, he now said, caused tubers and the plants they produced to become "stage-aged or feeble." In support of this theory he mentioned the following experiment: when the tops of potato plants were bent to the earth and rooted, the resulting plants flowered sooner and produced fewer tubers than did cuttings taken from the lower part of the stem. This was supposed to prove that the growing tip of a plant is "stage-older" than the lower parts and therefore that the eyes of the tubers formed in hot weather are "stage-aged." The reader who fears that this is a willful travesty of Lysenko's method of experimenting and reasoning should read the original. (In the 1941 version that appears in his book *Agrobiology,* Lysenko has added a touch of his new genetics.) When the bombast is cleared away, one finds nothing more than a combination of the obsolescent theory of ecological depression and the quite obsolete theory of aging.

Of course, the officials in the Commissariat of Agriculture had little interest in theoretical plant physiology. They wanted a practical method of producing healthy potatoes in the south. Lysenko convinced them early in 1935 that he had discovered such a method. He had tried summer planting only twice, on a quarter-hectare experiment plot in 1933 and on 31 hectares scattered in 16 collective farms in 1934 (one hectare is equal to 2.47 acres). The results, which he has never published in full, were far from providing clear support for his hopes. Nevertheless, in March, 1935, he published his flat assertion that he had discovered how to make the south entirely self-sufficient in the production of healthy seed tubers. He had thrown aside not merely the complex statistical canons of modern agricultural research but even the simple wisdom of the Russian proverb "Measure seven times to cut once." "Do we have the right," he asked, while pushing another of his innovations on a mass scale, "to lose two to three years in preliminary trial of this method on little plots at several plant-breeding institutions? No, we haven't the right to lose even a single year." The Commissariat of Agriculture apparently agreed; it ordered 500 to 600 southern farms to begin summer planting on 1,600 hectares in 1935, not as a test so much as the start of regular production of seed tubers by midsummer planting.

In 1936 the Commissariat of Agriculture made the plan for summer-planting 35,000 to 40,000 hectares (17,000 to 18,000 were actually planted). In 1937 summer planting was endorsed by the highest organ of government: the Council of People's Commissars ordered that the method be used on 65,000 hectares (about 20,000 was the result). In 1938 the council decreed that the success of summer planting justified the cessation, starting the following year, of all rail shipment of potatoes between districts (*oblasti*). The south was to assure itself of healthy seed tubers by midsummer plantings on nearly 50,000 hectares (this time the plan was exceeded: 54,000 were actually planted). In 1939, if one can believe a Lysenkoite report that was made many years after the fact, summer planting increased to 107,000 hectares; in 1940 it rose to 153,000; in 1941 the German attack cut off a plan for forcing summer planting to 250,000 hectares. These figures seem to show that Lysenko had won his audacious gamble, that he had found a truly practical way to make the south self-sufficient in the production of healthy seed tubers.

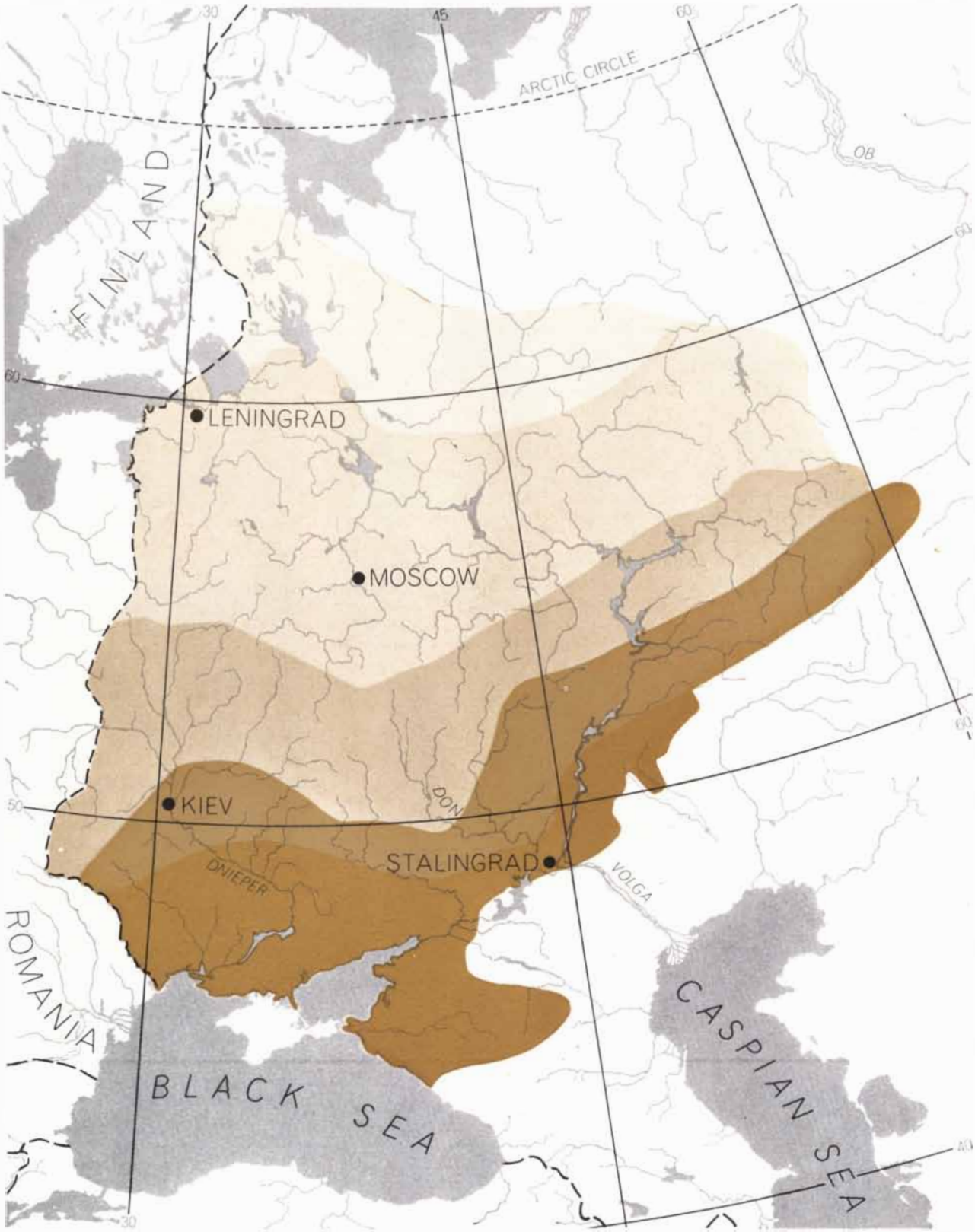
Paradoxical as it may seem, other data published by Lysenko and the potato specialists who joined his cause reveal the opposite. For example, Lysenko wrote that questionnaires were sent to the 500 to 600 farms that were obliged to try the method in 1935; 420 replied, but Lysenko published the results only for the 50 best. This kind of extremely selective reporting is characteristic of all but two of the eight or nine years in which summer planting was pushed on a mass scale. In those two years Lysenko's chief potato specialist announced that "not only individual farms but also many counties [*raiony*] and even districts [*oblasti*]" had reported successful experience with summer planting.

Of the 17,000 to 18,000 hectares planted in 1936, to take the year that was crucial for approval on the highest level of government, results were published for only 407 hectares. Yet the Council of People's Commissars decreed that the experience of 1936 "fully proved the possibility of obtaining a yield of non-degenerated potato tubers twice as great as the yield of the usual [spring] plantings in the southern part of the Ukraine."

If one stresses "possibility," one begins to understand the council's paradoxical support of a method that must have been a failure on the overwhelming majority of farms that had tried it. The experience of the unsuccessful farms simply did not count. Lysenko said as much when he published results for only 10 per cent of the farms that had tried the method in 1935: "Positive reports on summer planting of potatoes are given not only by those collective farms that obtained good harvests but also by those collective farms that obtained poor harvests. To the collective farmers of those collective farms, and also to agricultural officials, it became perfectly clear that the causes of their low harvest from summer plantings, and also the removal of those causes, depended entirely on them. Thus the collective farm 'Soviet Farmer,' in the Bereznigovatskii *raion* of Odessa *oblast*, characterizes the method of summer planting in the following manner: 'Summer plantings are very good, but because of poor cultivation of the land we obtained a low harvest.' "

In the 1930's and 1940's that sort of argument was in complete harmony with the dominant trend of Soviet official thought on agriculture. Why should the summer planting of potatoes stand or fall according to the average results for all the farms that tried it, when the collective-farm system itself could not pass such a test? It was standard practice to prove the great potential of the new system by citing the spectacular achievements of the best units in it. The failure of the other units to measure up was to be explained only by such subjective factors as laziness, incompetence, poor administration and "wrecking." That was the burden of Stalin's speeches, hopelessly confounding the possibility of objectivity in agricultural economics.

In the tangled thickets where economics and plant science grew together, Lysenko absorbed Stalin's passionate subjectivity and infused it into plant science. Yields, after all, are the complex product of social and natural factors. The economic authorities were unable to analyze the alternative costs of local



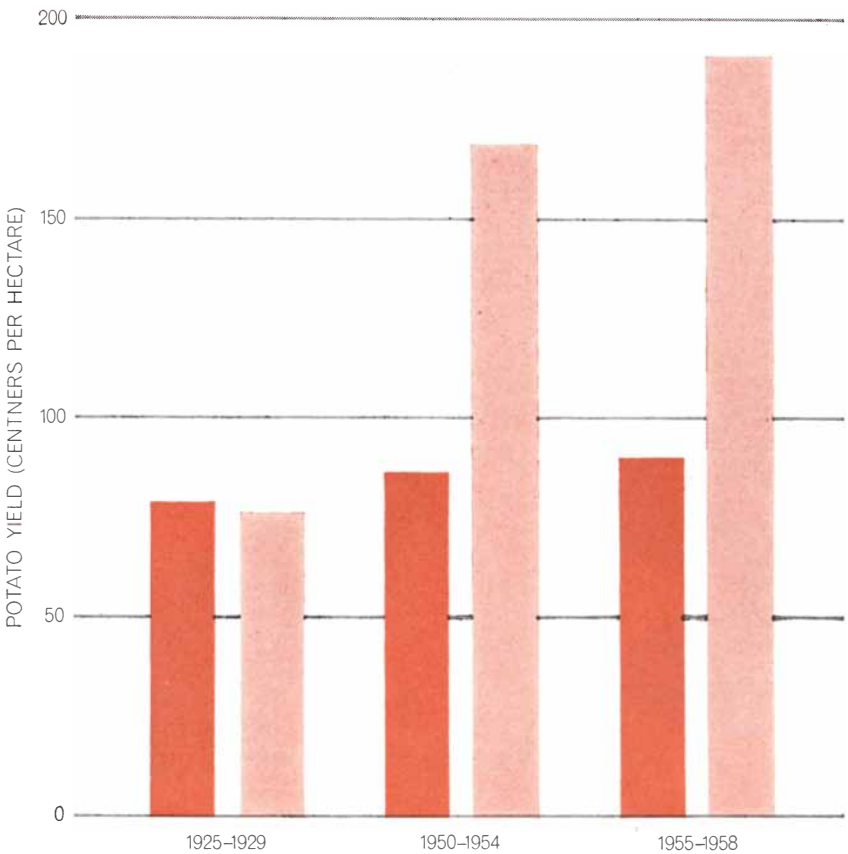
REGIONAL DISTRIBUTION of degenerative diseases of the potato is shown on this map, which is adapted from one in a Soviet publication of 1930. Because of incomplete data, the Soviet author wrote, it was impossible to characterize the various zones precisely, but it was clear that the impact of the diseases increased from north to south (*lighter- to darker-colored areas*). In the northernmost zone the diseases had little effect except on seed tubers sent south; in the next zone yields were reduced 1 to 3 per cent by disease. Degenerative diseases were of "great economic significance" in the center zone, from which the extreme south got most of its seed tubers. In the second zone from the bottom these diseases affected 30.6 per cent of all potato plants. And in the southernmost zone 30 to 40 per cent of all plants grown from northern tubers developed serious diseases in two to four years and yields were very low. Lysenko's ascendancy cut off such studies for two decades, with the result that a more precise map has yet to be published.

seed-tuber production in the south as against long hauls from particularly favored northern areas. Indeed, Soviet economists are only now developing such an ability. Intuitively reacting to a severe transportation crisis, the agricultural officials decided for local self-sufficiency. As the potato specialists hemmed and hawed, Lysenko justified this decision by a snap judgment on the cause and cure of degeneration. He was able to brush aside the failure of his cure on most of the farms, because officialdom was quite ready to believe that the farmers could not be trusted to do the simplest things right. Small wonder, then, that the Soviet press made Lysenko the model for plant scientists, or that Stalin exclaimed, "Bravo, Comrade Lysenko!" toward the end of Lysenko's speech to the Second Congress of Collective Farm Shock-Brigade Workers in 1935.

Against this background the reaction of potato specialists and virologists becomes comprehensible. None of them publicly questioned the practical value of summer planting. A few became enthusiastic supporters of Lysenko. Many uttered a perfunctory endorsement of summer planting and then dropped the subject of degenerative diseases. A few, granting the practical success of Lysenko's method, diffidently questioned his theoretical explanations. The notion of degenerative diseases as a product of aging was untenable, they suggested; the contagious nature of the diseases had been established beyond doubt, and the examination of ecological factors must proceed on that basis. Lysenko made short work of such critics. If their theoretical understanding was so great, why did they have no practical solution for degeneration? If his theory was so poor, how had he accomplished a cure? Besides, he did not deny the possibility that viruses might be present in degenerated potatoes; he simply pointed out the main cause of degeneration, which was "stage-aging" as a result of excessive heat at the time of tuber formation.

Lysenko's position threw doubt on the necessity of virus-control measures in the production of seed tubers. At the same time, however, it opened a way for a few virologists to defend such measures. Some tried to square Lysenko's views with their own by attributing the supposed success of summer planting to a decline in aphid infestation during the last part of summer. On this basis some even compared Lysenko with Jenner and Pasteur, who had discovered cures for other virus diseases without knowing about viruses. Such arguments implicitly rejected Lysenko's theory of "stage-aging," and gradually such voices fell silent.

Lysenko's potato experts, notably A. M. Favorov, filled the silence with arguments against the view that degenerative diseases are infectious. Ultimately the boldest Lysenkoites began to argue against the very existence of plant viruses, picturing them as a metaphysical construct of bourgeois science, comparable to genes. On a practical level the seed-certification law ceased to regard degenerative diseases as contagious. Diseased plants were allowed to remain in the seedbeds until harvest, when their tubers could be gathered for food, whereas the tubers of plants that still appeared healthy could be certified as seed. In effect Lysenko had solved the problem of virus diseases of the potato by getting everyone to ignore them. How much the Soviet economy saved in reduced costs of production (notably transportation, labor and research) and how much it lost in reduced potato yields the public record does not reveal.



POTATO YIELDS in the U.S.S.R. and U.S. are compared. The dark bars give the average annual yield in the U.S.S.R. for three different periods and the light bars give the comparable U.S. figures. (One centner per hectare is equal to 89 pounds per acre.) Of course many factors can affect potato yields in addition to the incidence of degenerative diseases.

As World War II ended, some diffident criticism of Lysenko was expressed. But the famous conference in 1948 silenced the critics—forever, it seemed at the time. In the aftermath an intensive drive was launched to re-establish the summer planting of potatoes among southern farmers, who had apparently abandoned it en masse during the war. By 1950 summer plantings were halfway to the peak acreage of the prewar period, but they were doomed to climb no higher. Nearly all the summer plantings of 1949 and 1950 were cut down by drought and disease. Favorov admitted as much in 1952, when he published his magnum opus on summer planting, a strange book that opens with the usual breath-taking arrogance but quickly retreats to defensive and unconvincing arguments against unpublished criticisms. One gathers from Favorov's book that agricultural officials were quietly tolerating another mass flight from summer planting in the south. And there were other signs in 1952 that the foundations of Lysenko's imposing es-

tablishment were already shifting and crumbling.

Stalin died early in 1953. Within six months Khrushchev made his famous report on the bleak condition of Soviet agriculture. In the aftermath long-silent voices uttered bitter truths. Little more than a third of all potato plantings were done with certified seed tubers, 25 years after the Party had decreed a complete conversion to certified seed tubers within four years. Worse yet, surveys showed that certified seed was often as badly infected with degenerative diseases as noncertified. Vavilov's world-famous program of potato-breeding had been stalled; new varieties, representing years of labor, had been destroyed by runaway virus infections as soon as they left the plant-breeding stations. A potato specialist who had access to the raw data from which the Lysenkoites drew their arguments for summer planting went so far as to charge Favorov and Lysenko with deliberate distortion and misrepresentation.

When the editorial board of the *Botanical Journal* was dismissed for printing such direct attacks on Lysenko, potato specialists and virologists moderated their tone. They had already won crucial changes in research opportunities and agricultural practice. In February, 1958, a conference of potato specialists resolved to include virus-control measures in the law on seed certification. But the conference also endorsed summer planting as a useful measure in the south.

An uneasy compromise has since been characteristic of the Soviet seed-tuber business. Non-Lysenkoite specialists discreetly urge a tightening of the requirements for certification and an increase in the regional specialization that is slowly under way. They look forward to the time when the production of seed tubers will be concentrated in such favored spots that truly rigorous standards of certification will be feasible. In the meantime S. M. Bukasov, a former student of Vavilov's who is now the dean of Soviet potato specialists, gives southern farmers the following advice on summer planting, probably the wisest summation of all: If the farmer has irrigated land available for a seedbed; if he uses an early variety whose tubers have a brief enough rest period to make possible summer planting with freshly dug tubers; and if he calculates the midsummer planting date to coincide with the time when the aphid and leaf-hopper populations drop in his area—then summer planting will give him a tolerable amount of fairly good seed tubers for next spring's sowing. (It seems likely that the concurrence of such factors gave rise to the tradition of summer planting in parts of Oklahoma, France and the Ukraine.)

POTATO FARMERS who produced a particularly large yield on a collective farm near Khorog, in the Tadzhik Republic of Soviet Central Asia, are shown in this Tass photograph.

Fully reliable generalizations about the Lysenko affair cannot be made on the basis of a single case study. Similar studies will have to be made of Lysenko's role in the hybrid corn program, the improvement of wheat culture and the development of systems of crop rotation. On the basis of such studies an analysis of the turmoil in theoretical biology will become possible. Certain tentative generalizations can nonetheless be hazarded. In a time of great upheaval Lysenko created a crude, bullying, self-deceiving "agrobiology" to accord with a crude, bullying, self-deceiving agricultural policy. Recently that policy and its partner in plant science have been fitfully disintegrating. It remains to be seen whether or not the necessities inherent in the modern agriculture that industrialized populations require will bring the full restoration of objectivity in economics and plant science, and along with that the restoration of full freedom of scientific discussion. Perhaps this proposition should be restated on a comparative basis, for scientific objectivity and freedom of scientific discussion are not absolutes. It remains to be seen whether or not a government preaching communism and the collective spirit can manage farmers and scientists as efficiently as governments preaching free enterprise and individualism.

A final word on ideology, which can influence science in three fairly distinct ways. The ideologists can insist that science respect the letter of sacred texts, as Galileo's judges did. In this sense ideology played no part in the Soviet quarrel over potatoes and viruses and very little in the Lysenko affair as a whole. Ideology can also be used heuristically, and a fair number of Soviet biologists have claimed that they have used Marxism in this way. The results range from the absurd (as in the attack by Olga B. Lepeshinskaia on cytology) to the quite important (as in A. I. Oparin's theorizing on the origin of life). In this second sense ideology had almost no influence on the Soviet quarrel over potatoes and viruses and, one suspects, little influence on the Lysenko affair. Those are direct influences. Ideology can also have a third influence that is indirect, since it helps to shape the cultural milieu of the scientist. In this sense Marxism-Leninism has been a major force in the Lysenko affair, the potato war included. Marxist-Leninist ideology played a part in the spectacular, perhaps excessive, expansion of government-supported plant science during the Vavilov era, in the violent collectivization of agriculture that made Vavilov's kind of plant science seem a useless luxury, in creating the self-deceiving and bullying style—Madison Avenue with a club—that Lysenko brought into plant science while other militants were bringing it to other pursuits. To make a precise assessment of this, the indirect influence of ideology on Soviet biology, would be tantamount to writing a complete history of the U.S.S.R.

THE THYMUS GLAND

Its function has been poorly understood, largely because the gland atrophies after childhood. Now it appears that the thymus founds a line of cells that is responsible for the production of antibody

by Sir Macfarlane Burnet

In trying to understand how the body develops immunity to disease, investigators have been finding more and more clues pointing to a crucial role for the thymus gland. Since the thymus of an adult human being is an organ that is barely discernible in the chest, its role in immunity has come as something of a surprise. As the picture has unfolded, however, it is becoming clear that in man and other animals the thymus finishes its task quite early in life. This task is evidently to stock the body with cells of a very special kind called lymphocytes. These cells have the ability to travel freely through the body and are more abundant than any other of the body's wandering cells. It has therefore been a persisting challenge that the function of neither the lymphocyte nor the thymus (except as a producer of lymphocytes) is stated in any textbook of cytology or physiology.

This gap in knowledge is rapidly being filled. It appears, moreover, that the function of the thymus is deeply entwined with the information-carrying role of deoxyribonucleic acid (DNA), the long-chain helical molecule whose genetic role has been so widely discussed of late. There is a certain irony in this emerging view: 20 years ago, when the genetic role of deoxyribonucleic acid was not known, it was called thymonucleic acid because it was found abundantly in calf thymus. This source was also reflected in the name "thymine," which was given to the constituent base now known to be unique to DNA.

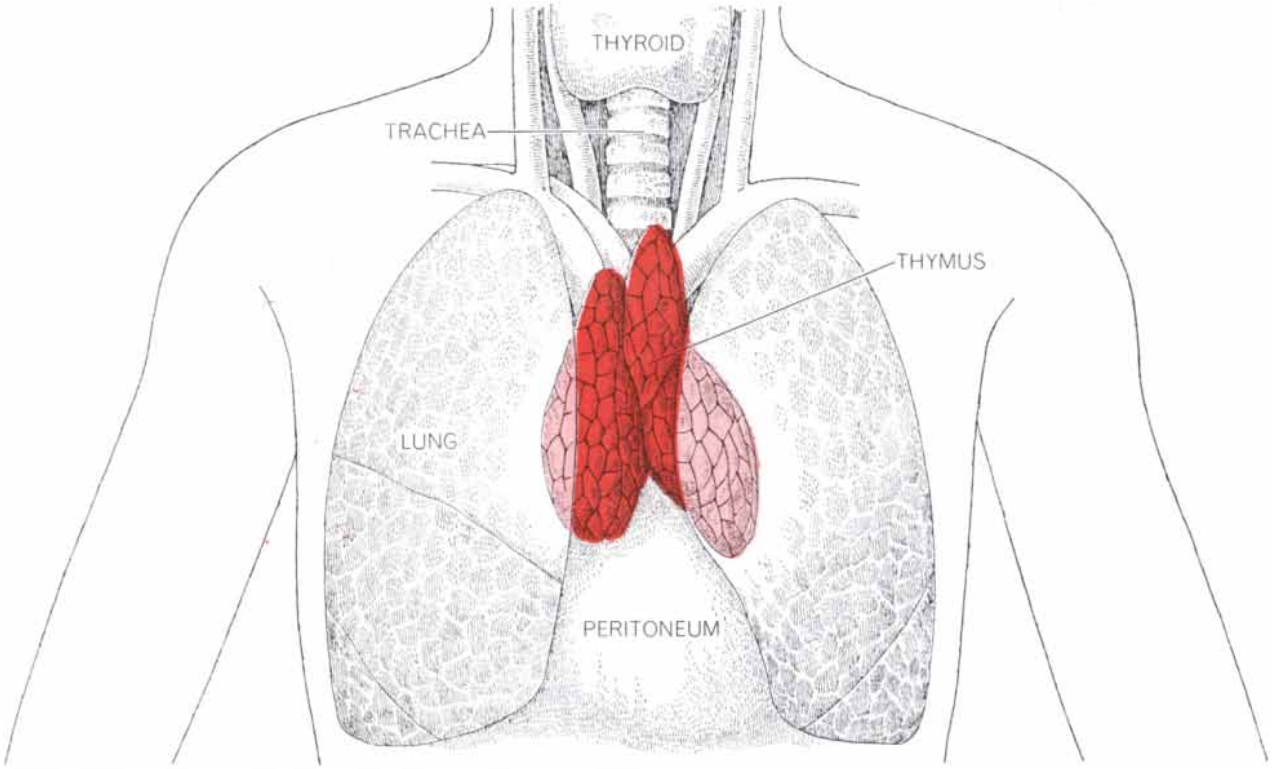
There are good reasons why the thymus should be the most convenient source of DNA, the most important component of the cell nucleus. The large majority of the cells in the thymus are lymphocytes, which of all mammalian cells have the greatest ratio of nucleus to cytoplasm. In a young animal the thymus is a big organ; early in the life of a mouse it accounts for .5 to 1 per cent of the total body weight. In such an animal the metabolic activity of the thymus, judged by the turnover of DNA or by the number of cells actually dividing at any given time, is five to 10 times greater than that of the spleen or the lymph nodes, which are the other main reservoirs of lymphocytes in the body.

Today most physiologists would probably agree that the thymus is the primary source of lymphocytes in mammals, and that when these cells are liberated into the circulation, they settle down in organs such as the spleen or a lymph node. There the cells from the thymus, or their descendants, give rise to the cells responsible for some of—perhaps all—the immunological functions of the body. High among these functions is the ability to produce antibodies: substances that help the animal organism to repel invasion by bacteria and viruses. Another major function is to help the body distinguish between "self" and "not self"; that is, between its own tissue proteins, or other large molecules, and those found, for example, in tissue transplanted from another animal.

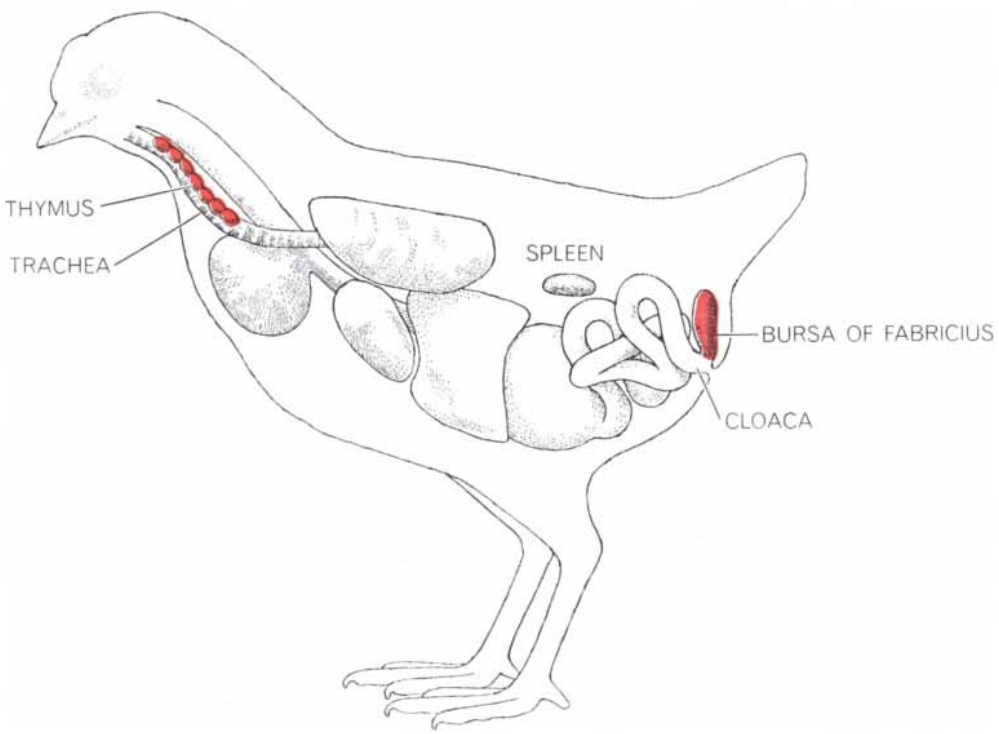
Without going into detail, one can say that two main theories have been proposed to explain the ability of certain cells to produce antibody. The "instructive" theory holds that the invading protein, or antigen, acts as a template against which an antibody protein somehow molds itself. So molded, the antibody can combine with the antigen and inactivate it. The "selective" theory, of which I have been a strong advocate, proposes that individual cells responsible for immunity are genetically endowed with the ability to "recognize" one kind or perhaps several kinds of antigen, and that collectively these cells can recognize all foreign proteins [see "The Mechanism of Immunity," by Sir Macfarlane Burnet; SCIENTIFIC AMERICAN, January, 1961].

If one accepts the selectivity theory, it seems reasonable to ascribe to the lymphocyte two intimately related functions. First, it must be the primary bearer of information that endows its descendants with immunological activity. Second, it may provide a mobile reserve of chemical building blocks from which new populations of descendant cells can be rapidly produced when and where they are needed.

Anyone with even faintly exotic tastes in food is familiar with calf thymus in the form of sweetbreads. (The term "sweetbread" is also applied to calf pancreas.) In shape and location, but not in size, the thymus of the calf closely resembles that of man or any other of the higher mammals. Some of our Australian marsupials have two thymuses, but the meaning of that is still to be elucidated. In a child the thymus takes the form of two roughly oval lobes that lie in the front of the chest just behind the top of the sternum (breastbone) and in front of the aorta and other great blood vessels in the region where they emerge from the heart. The size of the thymus increases more or less in step with general growth up to the age of eight or 10 years. Thereafter the gland lags behind and slowly begins to atrophy. In an adult the actual substance of the thymus is often hard to distinguish from the fat in which it is normally embedded. The thymus is not easily visualized by X rays and is too close to vital structures to allow the use of biopsy-needle techniques to obtain a small piece of thymic tissue for histological examination. As a

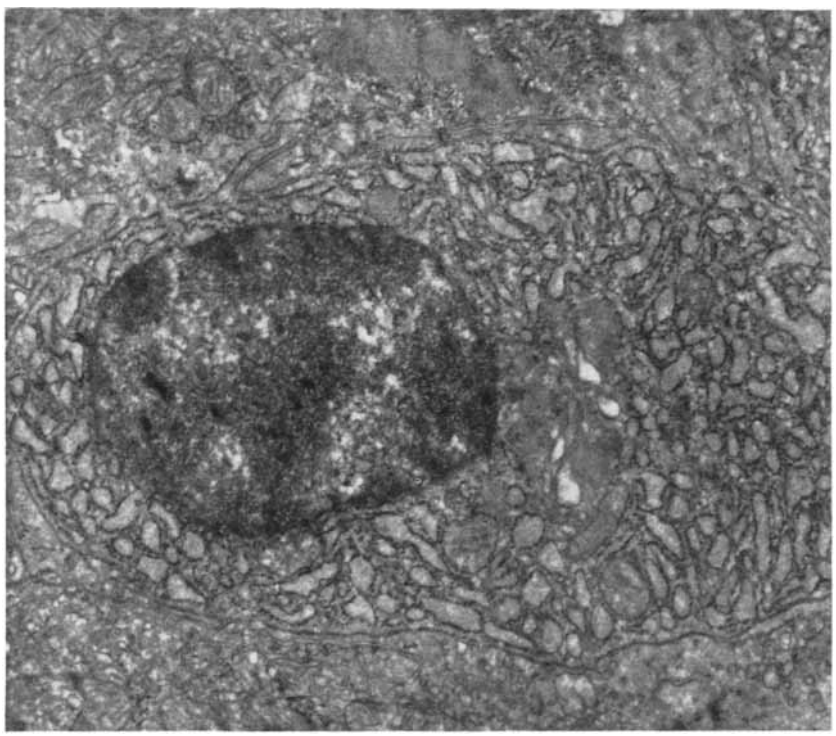


HUMAN THYMUS (*shown here in a child*) is a flat, pinkish-gray, two-lobed organ that lies high in the chest, in front of the aorta and behind the breastbone and partly behind the lungs. The thymus is large in relation to the rest of the body in fetal life and in early childhood; then it grows less quickly, and by the age of puberty it has stopped growing and then begins to atrophy. This course of events suggested that the thymus completes its work early in life, but until recently its exact function was unknown.



CHICKEN THYMUS (*shown here in a young chicken*) is composed of 14 separate lobes, seven of which are strung out along each side of the bird's neck. The chicken has another organ, called the bursa of Fabricius, which is active in early life and later disappears. The bursa seems to share with the chicken thymus some of the functions performed in the human by the thymus alone.

LYMPHOCYTE from rat thymus, enlarged some 29,000 times, fills center of this electron micrograph made by George D. Pappas of the Columbia University College of Physicians and Surgeons. The large nucleus contains a high concentration of DNA, the genetic material. The relatively thin rim of cytoplasm contains energy-supplying mitochondria but no other well-developed organelles; the small, dark grains of ribonucleoprotein are not organized for the task of protein synthesis. Portions of three more nuclei can be seen at the corners.



PLASMA CELL from an immunized guinea pig's lymph node is seen, enlarged 24,000 diameters, in an electron micrograph made by Richard A. Rifkind of the College of Physicians and Surgeons. Note the well-organized folds of endoplasmic reticulum filling the cytoplasm. The attached ribonucleoprotein particles, or ribosomes, synthesize protein antibody, which is visible as the amorphous gray material filling the channels of the reticulum.

result most of our knowledge of the human thymus has come from observations made at post-mortem examination.

This limitation gives rise to an interesting difficulty. Of all the organs in the body the thymus is the most responsive to "stress." Acute infection or severe injury, X-irradiation or a large dose of cortisone—any of these will within a day or two destroy millions of lymphocytes in the thymus and shrink its mass to half or less. A child who has died after an illness lasting more than a few days will therefore have a thymus much smaller than that of a healthy child of the same age. Because most children examined post-mortem have died after an illness, the opportunity to see a normal thymus is quite rare. This gave rise to a rather paradoxical situation in the first quarter of this century, when children dying suddenly from no clearly recognizable cause were said to have died from *status thymicolymphaticus.* Such children had a large thymus, and for a long time this was considered the cause of the sudden death. In point of fact the thymus was large because death had been sudden and no stress atrophy had occurred.

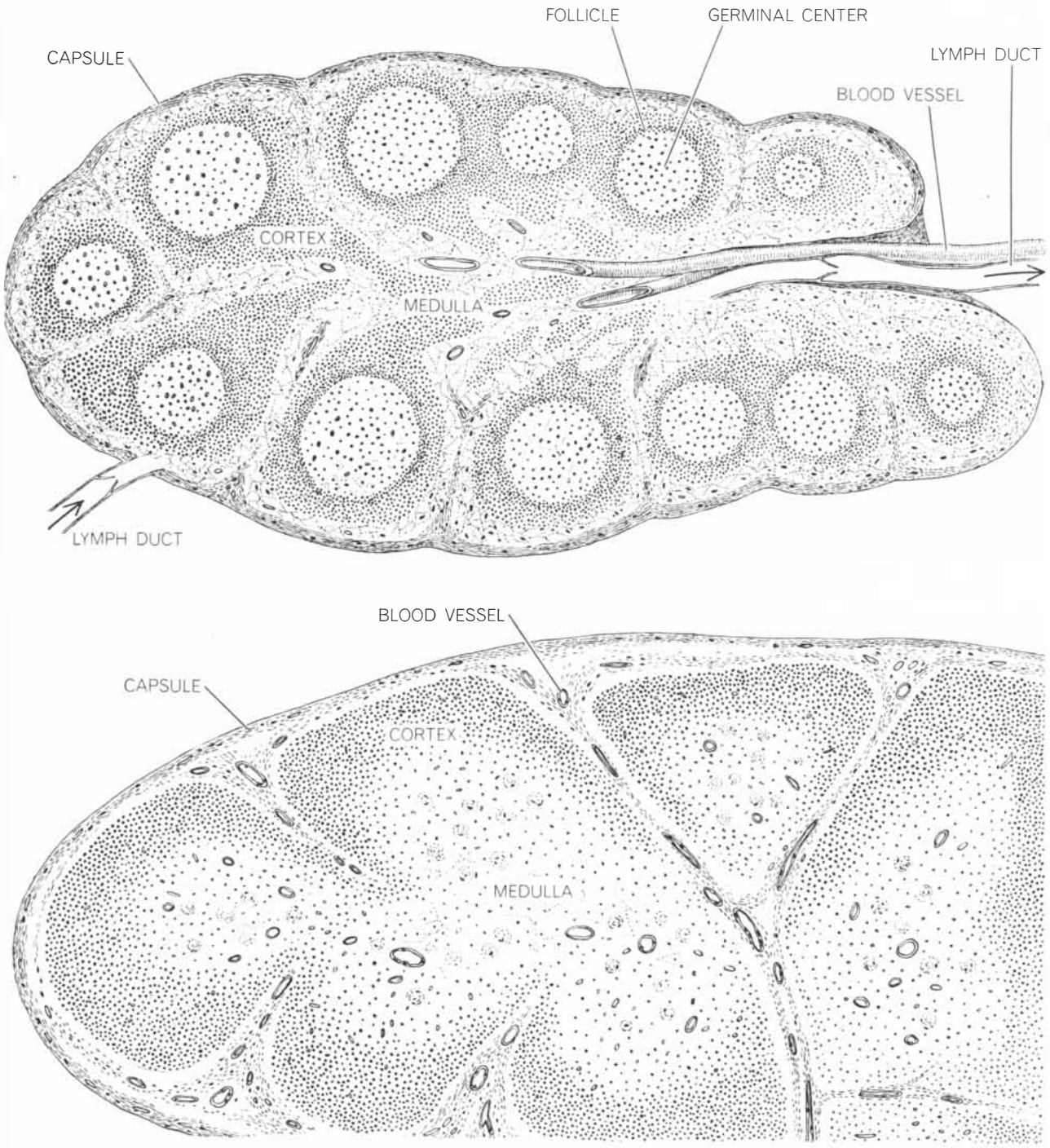
Under the microscope a stained section of the thymus has a thick outer cortex of closely packed, deeply stained lymphocytes and an inner medulla with many fewer cells, most of them with nuclei that have taken the stain more lightly. To the microscopist, however, the thymus is a rather uninteresting organ. To the immunologist, on the other hand, the organ is interesting largely because of what is *not* present.

In the body of a mature animal or human being the chief concentrations of lymphocytes are found in the spleen and the lymph nodes. Both are deeply involved in immunity, and there are well-known microscopic changes by which the pathologist can recognize that the organs are responding to an immunological stimulus, such as an infection or an experimental implantation of foreign cells. For example, in a lymph node that is draining an area of skin infection one will find areas of lymphocytic proliferation (germinal centers) often surrounded by accumulations of mature lymphocytes (lymph follicles). Elsewhere in the lymph node one will see accumulations of cells (plasma cells) whose staining qualities depend on the fact that they are actively synthesizing protein; in their case the protein being synthesized is antibody directed against the infecting microorganism. None of these things can be seen in the thymus. There lymphocytes multiply freely but move about in the process and never pro-

duce fixed germinal centers, and plasma cells are not formed.

The standard first step toward elucidating the function of an organ is to remove it and analyze the resulting disabilities. In the history of physiology clues have often been obtained from observing what happened in human beings when an organ was destroyed by accident or disease. In more recent times surgical procedures occasionally gave unexpected results that subsequently led to important new understanding of organ function. Removal of large amounts of thyroid gland in cases of goiter, for instance, sometimes caused serious spasms; these were eventually traced to the unintentional removal of the parathyroid glands, resulting in a disturbance of the calcium balance of the body.

The conventional approach of the physiologist is to remove the organ by appropriate surgery in some suitable ex-

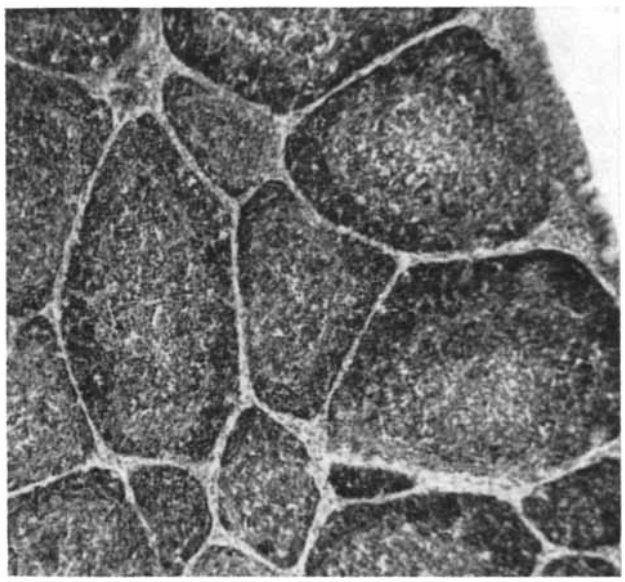


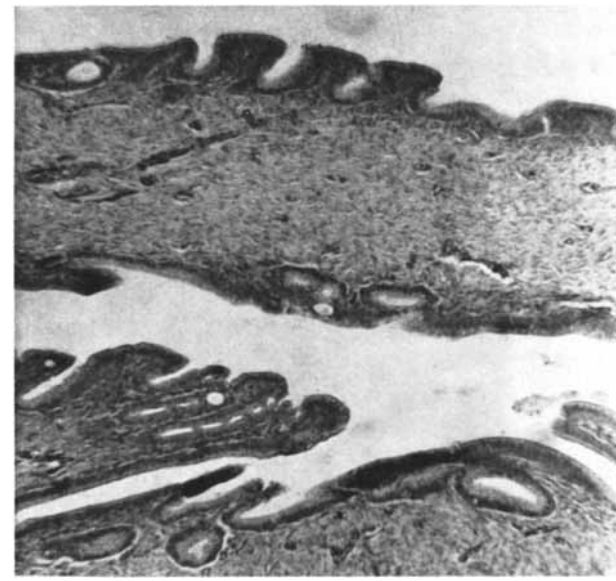
LYMPH NODE AND THYMUS TISSUE are compared in these drawings. The two are somewhat similar, both having a spongy network of structural cells. In the case of lymph node tissue (*top*) lymph filters through this network from the afferent to the efferent ducts. Both tissues have large numbers of lymphocytes. But in the lymph node, and particularly in one that is stimulated immunologically, there are dense round or ovoid concentrations of lymphocytes called follicles, or nodes, surrounding germinal centers in which lymphocytes are proliferating. Elsewhere in the cortex of an active node, plasma cells, which produce antibody, are found. In thymus tissue (*bottom*), on the other hand, lymphocytes do not proliferate in fixed germinal centers and there are no plasma cells.

perimental animal. Until 1961 neither approach had given any clue to the function of the thymus. If one removes the thymus from a mouse a few weeks old, the only significant effect is a minor reduction in the number of lymphocytes in the blood and in the size of the lymph nodes and the spleen. The sole functional effect observed is a beneficial one: a great reduction in the incidence of leukemia in strains of mice genetically predisposed to this disease.

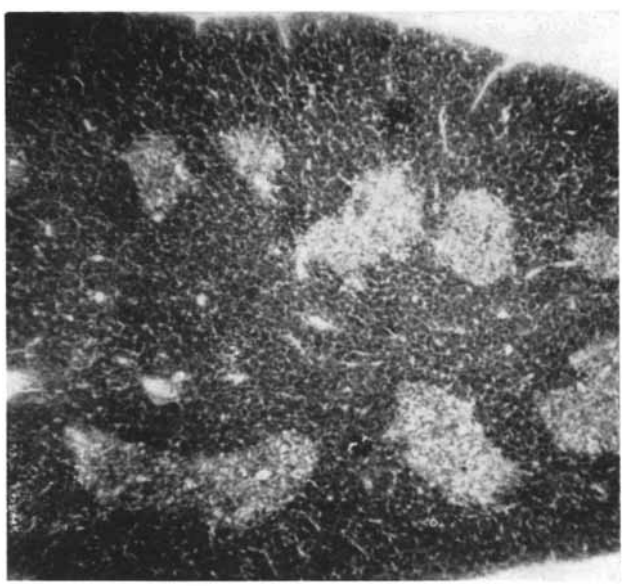
There is a rare human disease, myasthenia gravis, which is just what its Latin name means—a severe weakness of some of or all the muscles. For somewhat obscure reasons it was treated in the 1930's by complete surgical removal of the thymus with rather variable results, but there were enough apparent cures to make this operation a popular method of treating early cases. Most of the patients were young adult women, and evidently complete removal of the thymus did them no harm at all.

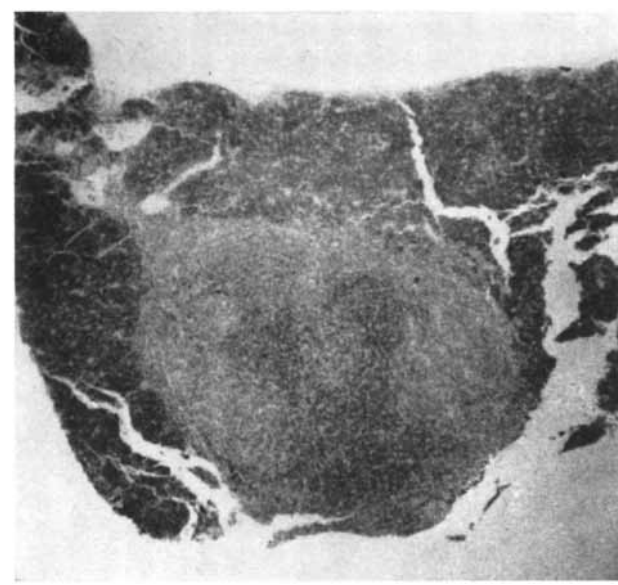
Perhaps this is to be expected of an organ that spontaneously atrophies as its owner ages, but a logical study based on that observation was undertaken only last year. Jacques F. A. P. Miller, a young Australian cancer researcher working at the Chester Beatty Research Institute in England, decided to see what would happen if the thymus were removed from mice on the first day of life. It was a tricky operation to suck out the whole of the thymus from an anesthetized newborn mouse without doing other damage, but the results were striking. Most of the mice developed normally for three or four months; then many of them died for reasons that are not yet fully under-





BURSA OF FABRICIUS apparently gives rise to the cells that will produce antibody in the chicken. As shown in the section at the left, a normal bursa has separate follicles packed with lymphocytes. Injection into the chicken embryo of the male sex hormone testosterone "bursectomizes" the chicken; the bursa (*right*) atrophies and no lymphoid tissue develops. A chicken so treated produces no antibody. The photomicrographs, in which the sections are enlarged 100 diameters, were made by Noel A. Warner and the author.

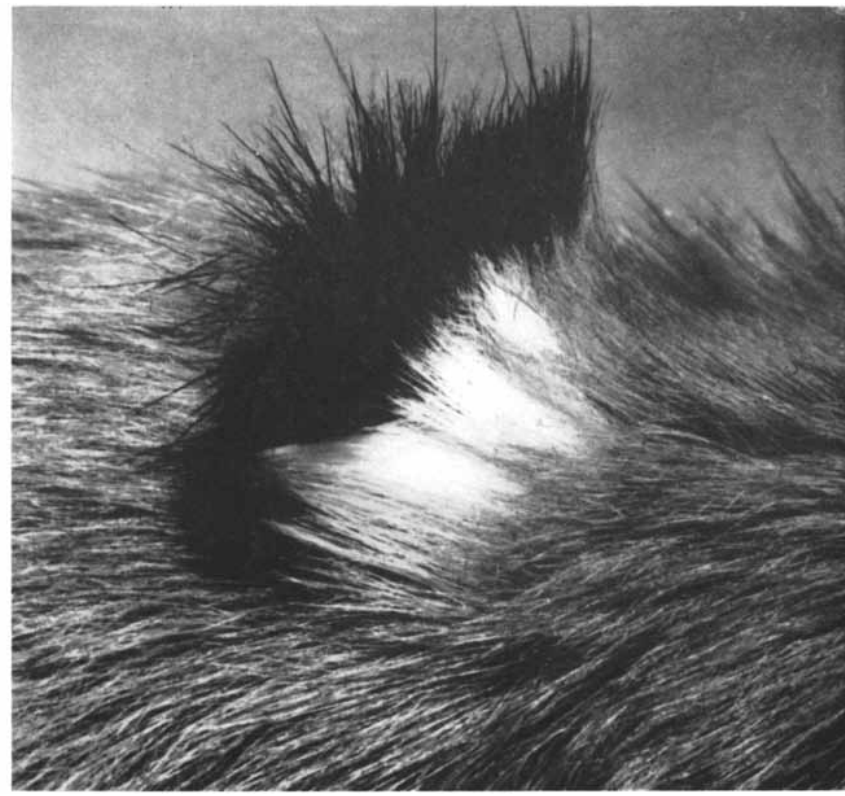




AUTOIMMUNE DISEASE may be initiated by changes in the thymus. Here a section of normal mouse thymus (*left*) is compared with thymus from a New Zealand Black mouse suffering from autoimmune hemolytic anemia (*right*). In the latter the medulla (*the paler area*) is enlarged and lymphocytes proliferate as in a lymph node. The author's photomicrographs enlarge the tissue 40 diameters.

stood. During the period of development, however, the mice showed some important departures from the normal. When the thymus was removed from mice of a particular strain at birth and then, two to four weeks later, skin was transplanted to them, it was found that a majority would retain grafts from any one of several strains of mice and even from rats [*see illustration at right*]. Normal mice reject such grafts in 10 days or less. This work has been confirmed in several laboratories, and extensive investigations are under way to sort out the limitations of the technique and to account for the big differences that seem to exist from one strain of mice to another. Several investigators, including Miller, have also found that a variable proportion of mice, rats and rabbits thymectomized at birth lose most or all of their capacity to produce antibodies.

It seems, then, that the functional activity of the thymus is at its peak in the first few days of life and perhaps also in the last few days of existence *in utero*. Miller's view is that the thymus produces and liberates into the blood the lymphocytes that pass to spleen and lymph nodes and there settle down and mature into the populations of cells that look after the integrity and security of the body.



REMOVAL OF THYMUS from mice on the first day after birth leads to their toleration of skin grafts that would be quickly rejected by a normal mouse. This picture made by Jacques F. A. P. Miller of the Chester Beatty Research Institute shows such a mouse carrying two healthy grafts: skin from an unrelated mouse (*black hair*) and from a rat (*white hair*).

In studies of the kind just described the mouse yields one great advantage to the chicken. The chicken embryo is easily accessible to experimentation: separated from the mother in the avian egg, it can be treated with drugs or altered surgically. The possibility therefore arises of influencing the immune reactions of the hatched chicken by manipulations of the embryo. In my laboratory in Melbourne, Aleksander Szenberg and Noel A. Warner have developed a method based on one devised by Harold R. Wolfe and his associates at the University of Wisconsin. The method has provided results that have interesting differences from those observed in mice.

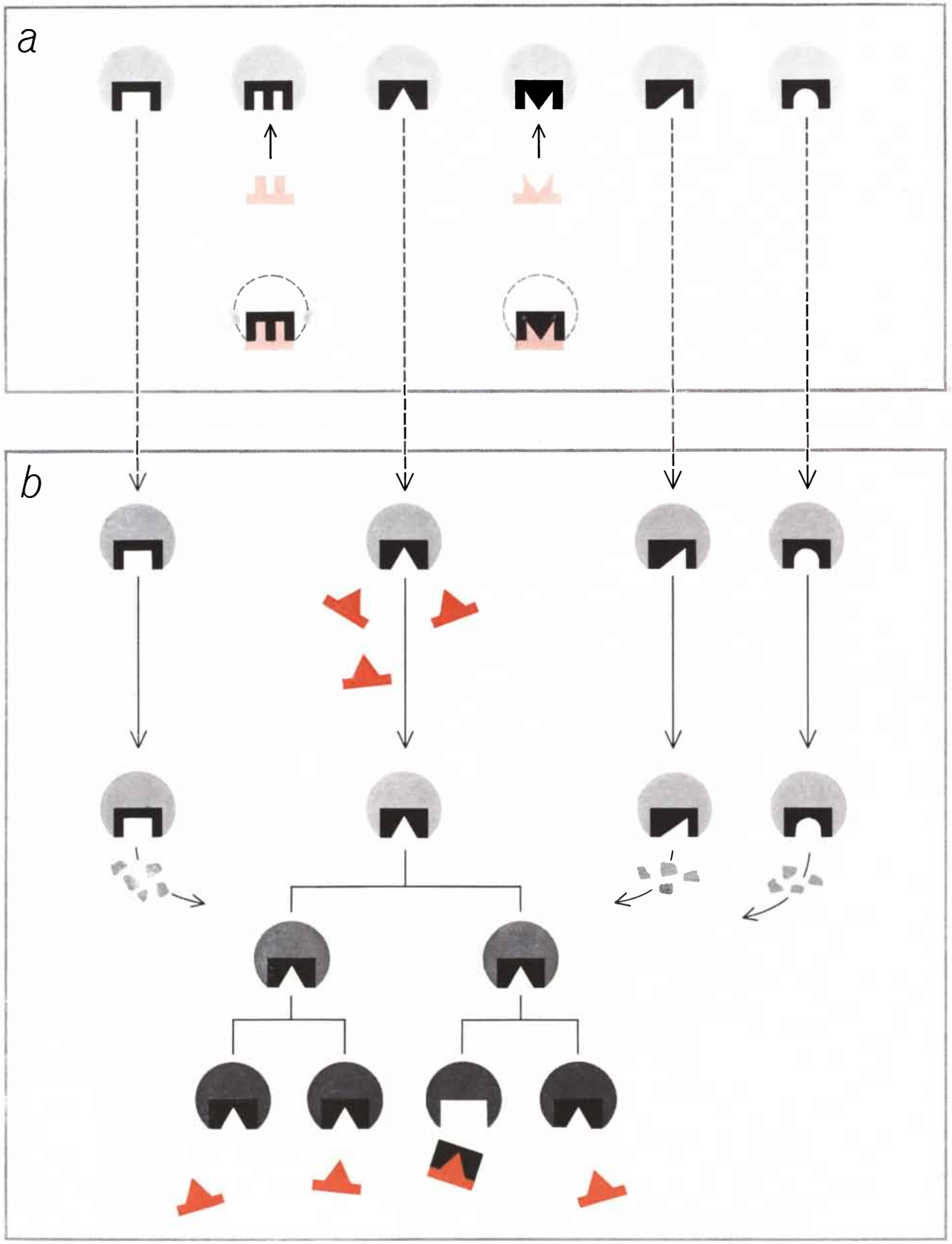
The chicken has a thymus whose shape is totally unlike the shape of the thymus in mammals; it takes the form of two strings of seven separate lobes running down each side of the neck. Nevertheless, it has a cellular structure similar to that of the mammalian thymus and evidently its function is similar also. In the chicken, however, there is another organ, somewhat like the thymus in structure, that is situated at the end of the intestinal tract just above the cloaca. This organ is called the bursa of Fabricius. Its main microscopic feature, like that of the thymus, is closely packed masses of lymphocytes. Its chief activity is in early life; it vanishes completely at sexual maturity.

This last characteristic may be related to the effect that the male sex hormone testosterone has on the embryo. If two milligrams of testosterone are injected into an embryo 12 days old, the development of the bursa is cut short. It remains a flabby appendage to the bowel and does not produce lymphocytes. The chickens are somewhat unhealthy, but many survive indefinitely and can be used for various immunological studies. The most striking result is that such "hormonally bursectomized" chickens fail completely to produce antibody in response to any of the standard antigenic materials such as serum albumin or bacterial vaccines. Most such birds nonetheless reject skin transplants from other chickens in quite normal fashion.

Szenberg and Warner have found, however, a small proportion of these treated chicks in which both bursa and thymus have failed to develop lymphocytes. In these they have obtained the same kind of result that Miller and others observed in mice thymectomized at birth. Skin grafts from unrelated chickens are *not* rejected for the period that the chicken survives. All such chickens are sickly; the longest survival to date is six weeks from hatching.

There is much more that might be said about the immune responses of chickens, but I can summarize by saying that there are apparently two organs concerned with primary production of lymphocytes. One, the bursa, gives rise to those cells whose descendants are responsible for antibody production; the other, the thymus, seems to produce in chickens, as in mammals, the cells whose descendants are responsible for the rejection of foreign skin grafts. Perhaps the most interesting phase of immunology still to be uncovered is the real function that we recognize by the highly artificial test of transplanting skin.

The results in chickens are almost decisive in showing that the thymus is not involved in antibody production as such, nor in cellular reactions against bacterial components, such as the tuberculin reaction. The cells involved in both of these are derived from the bursa. Perhaps the best suggestion is that the thymus, in both birds and mammals, liberates the cells whose descendants are primarily involved in the surveillance of cellular integrity in the body. When



HYPOTHESIS OF THYMUS FUNCTION suggests that lymphocytes are produced in the thymus (*a*) and give rise to populations of cells (large numbers of which are represented here by only six cells) that have specific antibody potentialities. In the thymus these cells are exposed to "self-components" (*light-colored figures*); any that react are destroyed to guard against autoimmune activity. The descendants of those that remain are concentrated in the spleen and lymph nodes (*b*). When one of these descendent lymphoblasts is stimulated by an antigen (*dark-colored figures*), it proliferates; its own DNA provides "information" and that of unneeded fellow cells provides raw material. The progressively more mature plasma cells thus formed produce the antibody that neutralizes the antigen.

cell surfaces are changed by toxins or viruses or by simple aging, or, more important, when they are changed as a result of somatic mutation, it is necessary for the survival and proper functioning of the individual that the anomalous cells should be recognized and dealt with. This may be the function of the cell populations that descend from the ancestral lymphocyte cells liberated from the thymus. In mammals it is highly probable that the thymus also carries out the function performed by the bursa of Fabricius in the chicken, which is to feed into the body the cells whose descendants will produce antibody.

Such suggestions represent at present no more than a good working hypothesis to account for the experimental results of removing the thymus and, as we shall now see, for the relation of changes in the thymus to "autoimmune" disease.

Under the heading of autoimmune disease we include a number of conditions in which cells or tissues of the body seem to be attacked by antibodies or immunologically active cells. Rheumatoid arthritis, hemolytic anemia, myasthenia gravis and perhaps multiple sclerosis are examples.

Until recently there were no satisfactory models for the study of these diseases in the laboratory. Now we believe that a strain of mice called New Zealand Black provides a true analogy to one such human disease: acquired hemolytic anemia. This strain of mice was developed at the Cancer Research Laboratory of the University of Otago in New Zealand by Marianne Bielschowsky; she, with her collaborators, first recognized the existence of hemolytic anemia in the mice. The results of breeding experiments indicate that the mice differ from a healthy strain by one or more genetic factors. Their abnormal constitution is manifested by the development, usually at about six months of age, of antibody against their own blood cells. There is also evidence that in some cases there is an attack, either by antibody or perhaps by cells, against one or more components of their other tissues.

My colleague Margaret C. Holmes and I have many lines of study in progress on these mice, but the only finding that is relevant here is the occurrence of immunological activity in the thymus. At approximately the same time as evidence of antibody against their own red cells appears, we find in the medulla of the thymus enlarged areas where lymphocytes are multiplying in germinal centers and producing plasma cells, just as they would be expected to do in a lymph node but never in a normal thymus.

These results find a close and rather exciting parallel in the thymuses of patients with myasthenia gravis. Sections from specimens of thymus removed at operation contain many germinal centers quite similar to those in mice of the New Zealand Black strain. There is a hint here that changes in the thymus may play an essential part in the initiation of autoimmune disease generally, and at the present time there is an urgent need both to determine if other human autoimmune diseases also show the thymic lesions and to locate other strains of animals that will permit comparable laboratory studies.

Obviously there is much more to be learned about the thymus and the lymphocytes it produces. No final interpretation will be possible until we have a better understanding of how cells produce antibodies or exert immunological functions in other ways. The new developments nonetheless seem to be very much in line with selective theories of immunity, although they may demand a more flexible interpretation of how cells can sort themselves out into different clones (descendants of a single cell) in the process of differentiating from unspecialized cells.

All selective theories of immunity and antibody formation are based on the axiom that in the healthy animal or human being no cells should emerge and multiply that can immunologically damage any of the normal components of the body. Autoimmune disease represents a breakdown of the means by which this control is maintained.

The appearance of similar signs of abnormal immunological activity in the thymus of mice with autoimmune anemia and in humans with the autoimmune disease myasthenia gravis strongly suggests that the control process is located predominantly in the thymus. Our present findings fall neatly into place if we look on the thymus as an important source of the lymphocytes involved in what we may call tissue integrity. In the thymus the lymphocytes are produced by proliferation, differentiated into groups with varying immunological potentialities and sorted over to detect any potentiality of reacting with "self-components"; that is, the body's own components. Any reactive cells are inhibited or destroyed, and eventually those that pass the test are liberated into the circulation to help populate the lymphoid tissues elsewhere in the body.

Perhaps we should finish with a look at the lymphocyte—a literal and simple-minded look at an ordinary "small" lymphocyte such as one sees in any stained specimen of blood under a standard optical microscope. (In fact, not much more can be learned by using an electron microscope.) The small lymphocyte has a large, dense nucleus, indicating a rich content of DNA. Surrounding the nucleus one sees little cytoplasm, and the cytoplasm is empty except for a few mitochondria, the granules responsible for supplying energy. Functionally the lymphocyte is a highly mobile cell, able to pass out of the small blood vessels with ease and likely to be found wandering in any tissue or accumulating in areas where there has been mild cellular damage of almost any sort.

There are two ways to look at the cell nucleus that may be particularly important in relation to the lymphocyte. The nucleus is the repository of information that when called into action may determine the conversion of the lymphocyte into a proliferating mother cell from which a clone of functioning cells, plasma cells for example, could develop. At the same time the nucleus is a concentrated source of nucleotides (DNA constituents) and amino acids (protein constituents), which could be drawn off and used as building blocks in the construction of new cells. This may be particularly relevant to the lymphocyte in view of the extreme ease with which it breaks down under stress.

The modern view of lymphocyte function brings us back to our starting point: the high content and rapid synthesis of DNA in the thymus. It is a logical but still unproved hypothesis that the enormous populations of lymphocytes in the body have a double function. Each cell carries a limited range of potentialities for immunological activity and under rare and specific conditions can be stimulated to proliferate by contact with an appropriate antigen. There is much to suggest that active multiplication is only possible when a free supply of the necessary nutrients can be brought into the site of proliferation. For this purpose the DNA of those lymphocytes whose specific activity is not required can readily be made available in the form of nucleotides, or smaller fragments, to allow swift new production of nucleic acid and active proliferation of the cells whose specific qualities are needed to deal with whatever alarm has called them into activity. The best use can thus be made of both qualities of the nucleus and its DNA. The many provide raw material for the construction of new nuclei; the few provide information as to how the new generation of cells should be constructed.

THE PLEIADES

The stars in this familiar cluster move majestically about like bees in a swarm. These motions are a clue to how the stars came to be formed out of interstellar gas some 60 million years ago

by D. Nelson Limber

There are two ways of thinking about stars. On the one hand they are essentially point masses held together by gravity and hurtling through space like the molecules in an infinite container of gas. On the other they are nuclear furnaces in the process of evolutionary change. The astronomer's point of view depends on the problem he is considering. Sometimes it is useful to keep both aspects in mind. This is particularly true in the study of clusters of stars.

It seems likely that most stars were formed in clusters, condensing out of large local concentrations of gas and dust. In the ensuing millions or billions of years many of the groups have lost their cohesiveness and have been smeared out into the general stellar population. Any cluster that is still recognizable as such—and there are thousands in our galaxy—embodies, as it were, a double history: the spatial and dynamical evolution of the ensemble of its constituent stars considered as point masses and the internal and surface evolution of the individual member stars resulting from the nuclear processes taking place within them. As might be expected, each of these processes throws considerable light on the other, and the whole story turns out to be bigger than the sum of its parts.

For several reasons this twofold approach to the study of star clusters has not previously been attempted. My own work for the past few years at the Yerkes Observatory has been largely devoted to just such an attempt at understanding a cluster that is familiar to almost everyone: the Pleiades. To the naked eye the Pleiades consists of half a dozen loosely grouped stars in the constellation Taurus. The telescope reveals an association numbered at least in the hundreds, looking somewhat like a swarm of bees. If the apparent motions of the stars were speeded up some billions of times, the analogy would be still closer, with the individual members darting this way and that while the swarm as a whole retained its coherence.

At one crucial point, however, the analogy breaks down. Knowing where all the individual bees in a swarm are now, and how fast they are going, would be of no help in predicting where they will be a minute hence or where they were a minute ago. But if the present mass, position and velocity of every star in the cluster were known (plus the distribution of any uncondensed interstellar gas and dust), an observer could, in principle, trace the detailed behavior of the group backward and forward in time as far as he wished—with certain restrictions. Unfortunately, although not surprisingly, no such complete specification of the present state of the cluster is available. From the fragmentary picture that we do have of the Pleiades cluster as it is now, we can hope to derive only an average dynamical history.

What are the details that can be made out? As far as stellar masses are concerned, these can be closely estimated from the observed luminosities and spectral properties of the stars identifiable as members of the cluster. Knowledge of the present positions and velocities of the individual member stars is less complete because neither their distances nor their velocities can be determined very accurately along the line of sight.

Incomplete as the data are, they do exhibit a striking pattern. There is a strong correlation between the distances of the member stars from the center of the cluster and their brightnesses, or, what is the same thing, their masses. The more massive stars are much more strongly concentrated toward the center than are the less massive ones. This may reflect an original tendency of heavier stars to form nearer the center. Or the pattern may have evolved through systematic dynamical effects after the stars had condensed. One of the major goals of my investigation has been to decide between these alternatives.

So far I have sketched the picture of the Pleiades that is actually visible in astronomical photographs. What about the part we cannot see? The cluster lies at a distance—about 400 light-years—such that stars much fainter than our sun are not visible at all, or at least cannot at present be identified as cluster members with any certainty. If there are many such stars, they will have a major effect on the dynamical behavior of the group as a whole. Moreover, there may also be a substantial mass of uncondensed gas, and it too would have to be taken into account. Some gas and dust actually shows up in photographs as glowing clouds around the brighter stars. But the clouds provide no reliable estimate of the total quantity of gas the cluster contains.

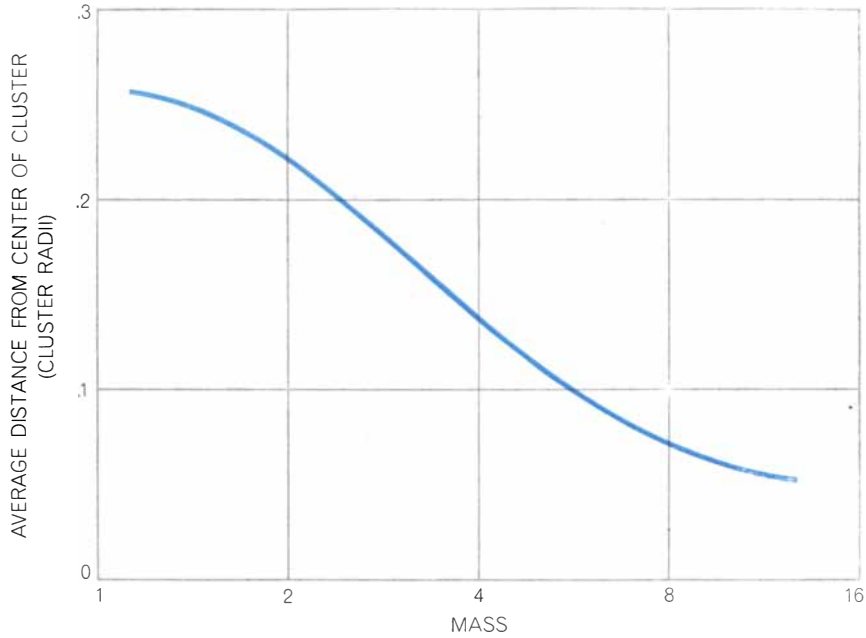
Fortunately radio astronomy now offers a direct method for estimating the

COLOR PHOTOGRAPH of the central region of the Pleiades on the opposite page was made with the 48-inch Schmidt telescope on Palomar Mountain. The bright star at top center and its fainter companion are Atlas and Pleione respectively. The central star is Alcyone; to the left and right below are Merope and Maia, both obscured by interstellar matter. The bright star at bottom center is Electra. The seventh member of the group, below and to the right of Maia, is Taygeta. The halos and spikes around the brighter stars result from the diffraction of light around the telescope's photographic-plate holder and its supports.

LARGER-FIELD PHOTOGRAPH, made with the 18-inch Schmidt telescope on Palomar Mountain, shows the configuration of the cluster's seven brightest stars and the faint, diffuse nebulosity around Merope. The structure of the cluster itself is difficult to discern because many stars outside the cluster at varying distances in the foreground and background appear to fall within its limits.

amount of interstellar material if, as is probable, most of the material is in the form of neutral hydrogen gas. This method involves the measurement of the total energy emitted at a radio wavelength of 21 centimeters by neutral hydrogen [see "Radio Waves from Interstellar Hydrogen," by Harold I. Ewen; SCIENTIFIC AMERICAN, December, 1953]. Two groups of radio astronomers have recently measured the 21-centimeter radiation from the Pleiades. Their work offers a splendid example of the stumbling gait that so often characterizes scientific progress. One group reports a concentration of interstellar gas with a mass equal to 470 times the mass of the sun, which would be by no means negligible in the dynamical history of the cluster. The second group finds practically no gas at all! Needless to say, further studies will point to the source of error, wherever it may be, and eventually there will be a reliable figure for the mass of the interstellar matter. At that time it will also be possible to arrive at an unambiguous value for the total mass of the unseen stars. Meanwhile the latter figure can only be estimated on the alternative assumptions that one or the other group of radio astronomers is right. Presumably these two sets of calculations should at least roughly bracket the truth.

To deal mathematically with a large assemblage of stars, the astronomer finds it convenient to use the virial theorem, originally developed by physicists in a somewhat different form for dealing with the interacting molecules of a gas. In the form in which it is used here the theorem states that if an aggregation of stars, and possibly of interstellar matter, is neither explosively expanding nor rapidly collapsing, the disruptive tendency of the velocities of the individual members must be balanced on the average by the gravitational forces acting to collapse the cluster. The applicability of this theorem to the Pleiades in the present epoch seems well justified on several counts, both theoretical and empirical. Translated into mathematical terms, the virial theorem provides an equation relating the total stellar mass of the cluster, the total mass of the interstellar matter, the relative degrees of concentration toward the center of the cluster of the stars and of the interstellar matter, the dimensions of the cluster and an appropriate average velocity for the stars. Each of these quantities except for the total stellar mass can be estimated from observations. Therefore the equation

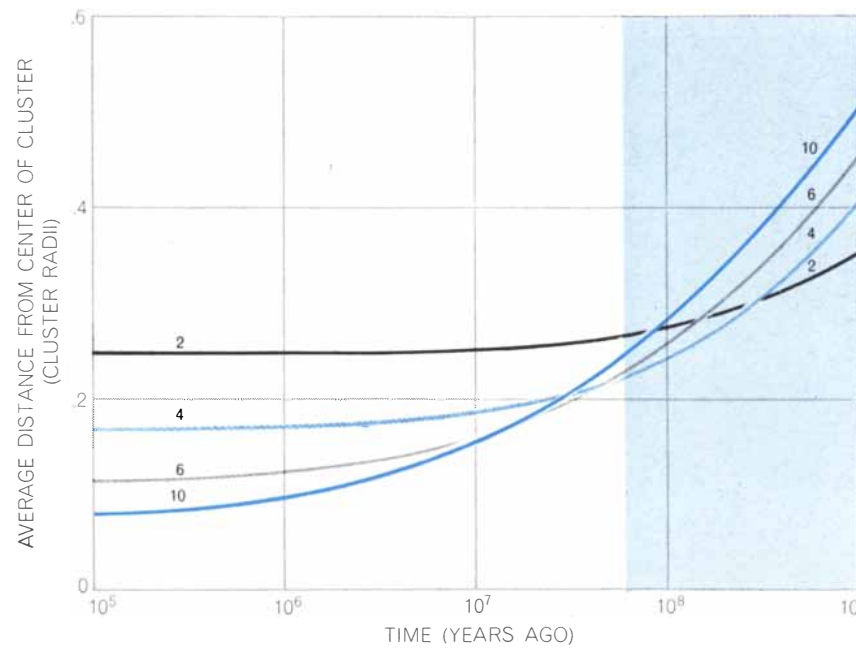


DISTRIBUTION OF STARS in the Pleiades cluster according to mass (in units of solar mass) reveals a preferential concentration of more massive stars toward the cluster center.

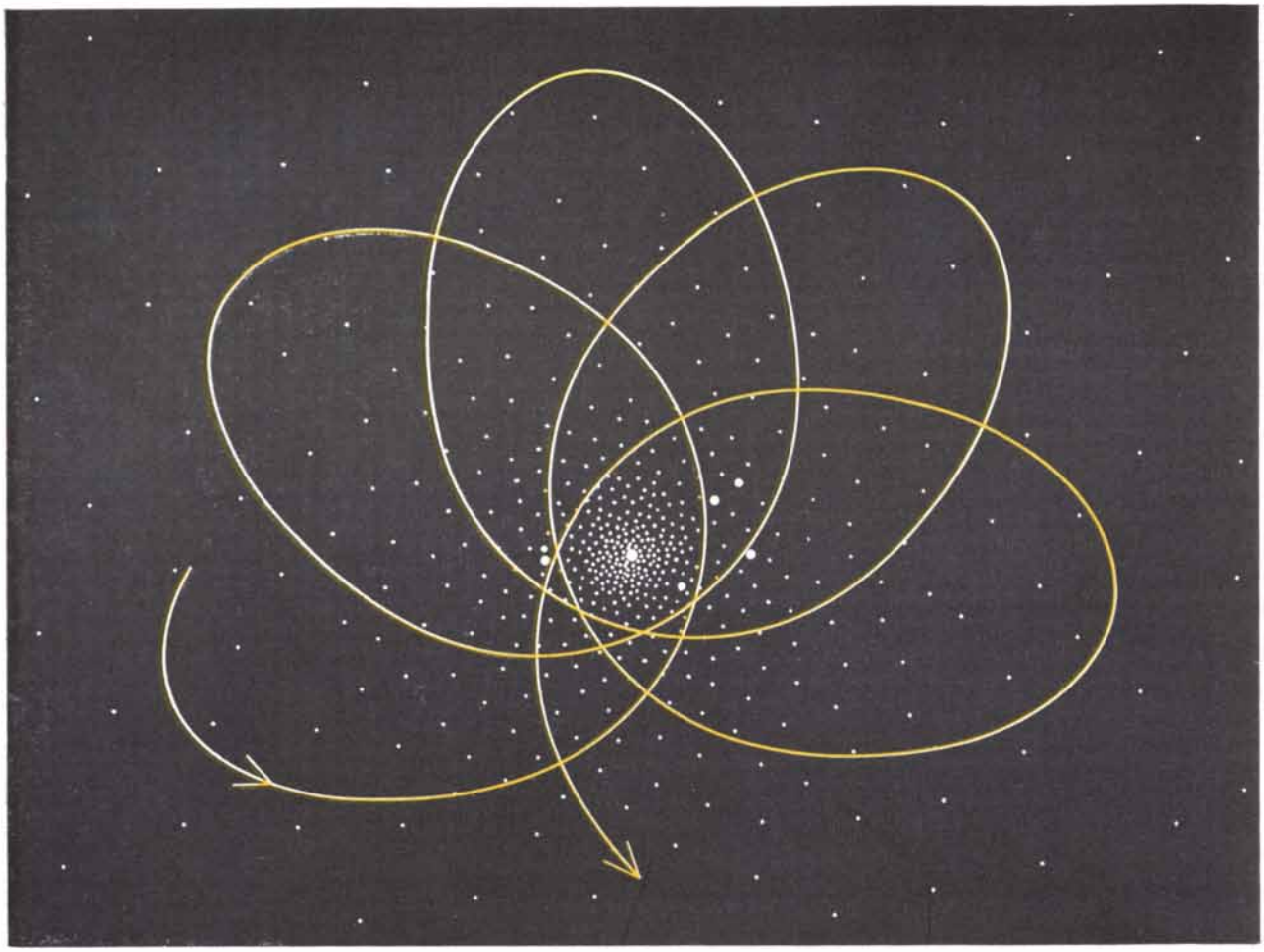
can be solved for its single unknown: the total weight of the member stars.

The answer turns out to be about 760 solar masses if there is a substantial amount of interstellar gas present within the cluster and 900 solar masses if there is not. The total mass of the visible members of the cluster is only about 350 solar masses. Therefore the Pleiades must contain at least twice as much mass in the form of stars as is accounted for by the ones that have so far been identified as cluster members. Consideration of this unseen half of the cluster leads in a logical way to the other aspect of its history: the evolution of its individual stars.

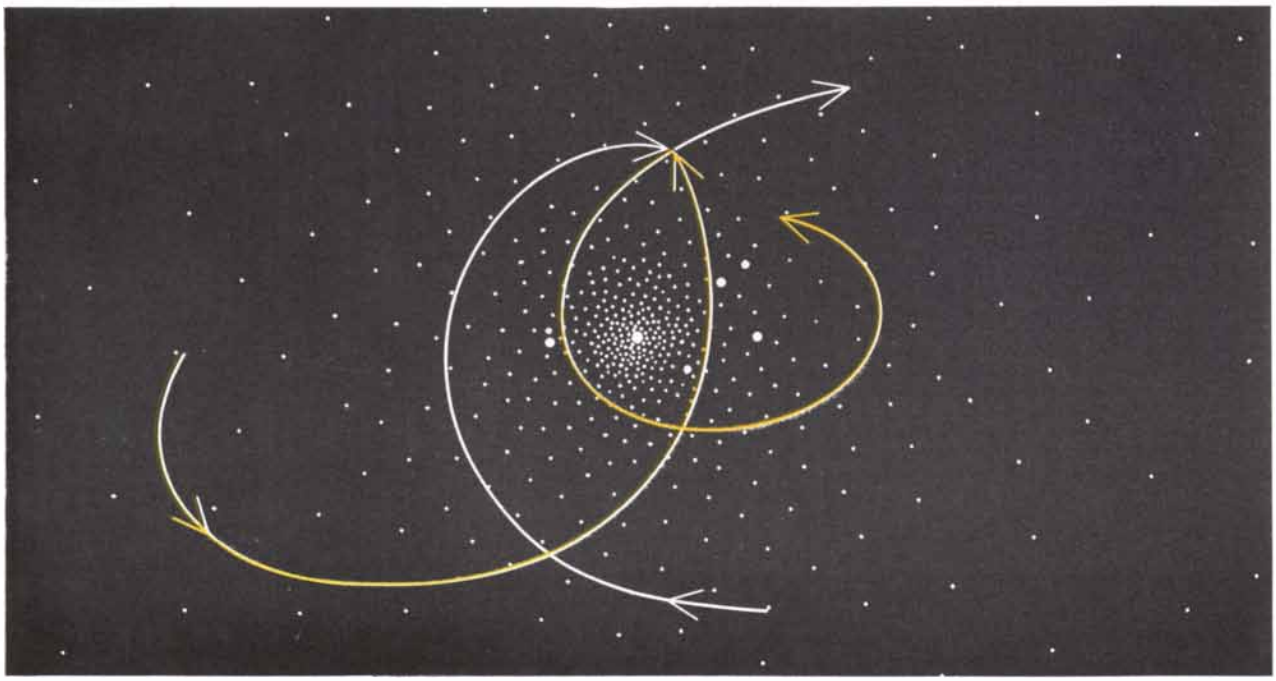
As readers of this magazine are well



CHANGE IN DISTRIBUTION of stars during the past history of the cluster has brought the more massive stars closer to the center. The four curves shown here chart the movement of stars having two, four, six and 10 times the mass of the sun. This distribution has not changed significantly in the past 100,000 years. The colored area represents the period of stellar history before the cluster formed, probably about 60 million years ago.



GRAVITATIONAL INTERACTION of stars in a cluster, in the limiting case where there are no gravitational encounters between stars (*see illustration below*), will give a typical member star the type of motion around the center of the cluster that is shown here.



GRAVITATIONAL ENCOUNTER between two stars, which alters their orbits abruptly and drastically, is the second limiting case of gravitational interaction of cluster stars. A more detailed representation of this encounter appears on the opposite page.

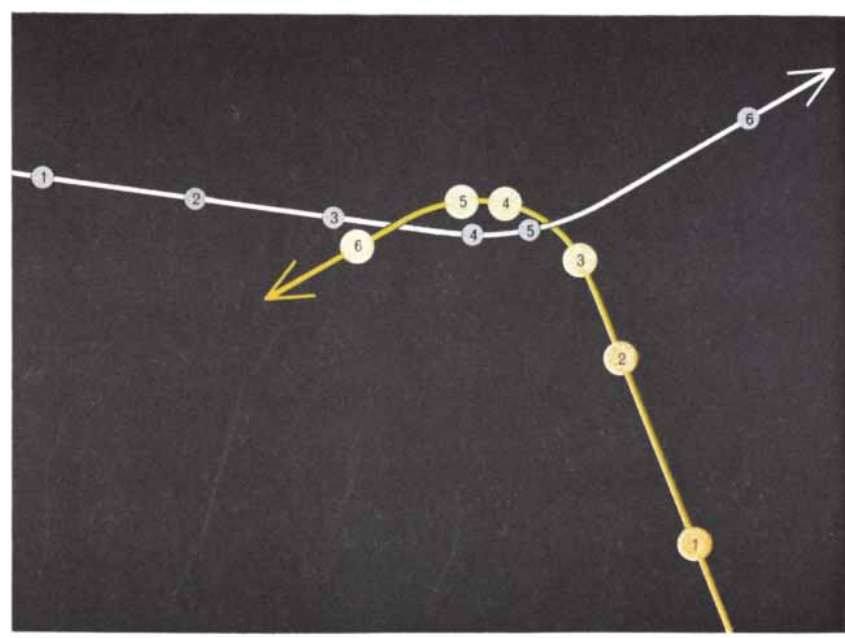
aware, the classic method for sorting out the evolutionary history of a group of stars is to plot the temperature of each star against its luminosity. When the visible members of the Pleiades are plotted in this way, with their surface temperatures measured along the horizontal axis (decreasing to the right) and their intrinsic brightness along the vertical axis (increasing upward), they all cluster around a line running from upper left to lower right known as the main sequence. Stars falling on the main sequence, as our sun does, are those that are deriving their energy from the conversion of hydrogen to helium in their innermost parts. The "initial main sequence" in the illustration on page 66 shows the theoretical positions of stars that have just finished contracting to this hydrogen-burning stage but have not yet consumed any appreciable portion of their hydrogen fuel.

When the temperature-luminosity diagram for the Pleiades is compared with plots of similar groupings of stars formed during the past several billion years, some interesting features emerge. The main-sequence stars in the Pleiades that are intrinsically brighter (and hence more massive) than our sun occur with about the same relative frequency as those in the other groups do. The brightest ones, it is true, tend to deviate from the initial main sequence, lying slightly above it. In the case of the fainter stars the picture is quite different. The Pleiades has far fewer of these on the main sequence than has come to be considered normal. The break between normal and abnormal distribution sets in for stars intrinsically only slightly fainter than our sun. Furthermore, just below this break point the Pleiades' stars begin to depart appreciably from the initial main sequence in the sense of falling above it. If one recalls the dynamical evidence for a large mass in the form of invisible stars, it is clear that many stars in the Pleiades must have not yet approached close enough to the normal main sequence to be observable at all.

This interpretation is consistent with the present state of the theory of stellar evolution. According to the theory each star, once it has somehow begun to condense from the parent interstellar cloud, will continue to contract and to increase in temperature. Its starting point in the temperature-luminosity diagram will obviously be low on the luminosity axis and far to the right in the low-temperature region. (The temperature and color of a star are connected, and a position far enough to the right on the temperature axis would correspond to a star that emits the bulk of its energy in the form of invisible infrared radiation. As the star heats up it first becomes red and then, if the contraction proceeds far enough, blue.) In the course of its contraction and heating it will move up and to the left. Eventually its internal temperature will increase enough to start the process of hydrogen-burning, and the star will attain a state of equilibrium, producing heat as fast as it is radiated away into space and for the time being undergoing no further gravitational collapse. At this point it will have arrived at its initial position on the main sequence [*see illustration on page 66*]. Just where it lands on the main sequence depends largely on its mass alone. Once it starts burning hydrogen the star continues the process until the supply of hydrogen in its hot central regions is exhausted. During the whole of this period it experiences only small changes in over-all structure and shifts its position on the temperature-luminosity diagram only slightly, moving somewhat upward and to the right from its position on the initial main sequence. Not until essentially all the hydrogen at its center is used up does the star undergo a major change that in a comparatively short time carries it far from the main sequence and into the region of yellow or red giants in the upper right-hand section of the diagram.

The time that a star spends in contracting to the main sequence is only about 1 per cent of the time it spends in the hydrogen-burning stage on the main sequence. Both stages of evolution proceed more rapidly the more massive the star is. As the temperature-luminosity diagram of the Pleiades shows, the most massive stars have almost completed their stay near the main sequence and have just begun to move up and to the right. Theoretical calculations indicate that the whole process, from the time they first condensed from the interstellar material, must have taken some 60 million years.

Present indications are that all the stars in a cluster such as the Pleiades are about the same age, having begun their condensation and contraction toward the main sequence at approximately the same epoch. This suggests an explanation at one stroke of all the abnormalities in the temperature-luminosity diagram of the Pleiades: the deficiency of stars on the lower main sequence, the deviation of the fainter stars from the normal main sequence, and the large amount of stellar matter that cannot be seen at all. Suppose the time since the formation of the cluster is such that stars now at the break point between normal and abnormal sections have just had time to contract to the initial main sequence. This would mean that stars



SCHEMATIC DIAGRAM is an enlargement of the gravitational encounter shown in the bottom illustration on the opposite page. Such an encounter is not a collision, which is a highly improbable event. The two sets of numbers represent corresponding positions of the two stars at six distinct instants. One star (*color*) loses and the other gains kinetic energy.

of smaller mass, for the most part, have not had time to brighten enough even to approach the observationally accessible part of the diagram. The explanation is consistent with theory. Within the uncertainties of the theory, the contraction time for a star at the break point is indeed found to be about 60 million years—the same age that was derived independently from the study of the brightest stars. It should be pointed out that the detailed distribution of the stars below the break point in the diagram is not exactly what is predicted by the present theory for the contraction of stars to the main sequence. The reason for this discrepancy is not known. It may or may not be due simply to minor inadequacies in the current contraction theory.

So far a consideration of the present dynamical state of the Pleiades has led to the conclusion that it contains many unseen stars. An investigation of the stellar evolution of the cluster has shown why this should be so. It is now time to return to the dynamical history, armed with one all-important new fact: the cluster is some 60 million years old. In other words, it began to consist of separate, independently moving "point masses" 60 million years ago. It might be thought that any attempt to reconstruct the mechanical history of the past 60 million years would depend critically on the presence or absence of uncondensed interstellar gas. In this case, however, it turns out that the results are nearly the same on either of the two limiting assumptions mentioned earlier, and so here the question is not crucial.

The dynamical history of the Pleiades is really the history of the gravitational interactions of its member stars. The net force experienced by a particular star, at a given instant, due to the totality of gravitational interactions can have two limiting forms. In one limit the star will on occasion find itself temporarily so close to one or more of the other stars that the force due to these chance near neighbors will greatly exceed the force resulting from all the other cluster members combined. If so, the net force on the star at that moment will be of a random sort, with no direct relation to the position of the star in the cluster as a whole. Such a star is said to be undergoing a gravitational encounter. (Actual collisions of stars in clusters are so

EARLY STAGE OF CLUSTER FORMATION in a gaseous nebula (NGC 6611) in the constellation Serpens was photographed with the 200-inch telescope on Palomar Mountain. The cluster, very probably still in the period of star formation, is at an earlier stage in its history than is the Pleiades at present. The nebulosity suggests the importance of interstellar gas to the early history of a cluster.

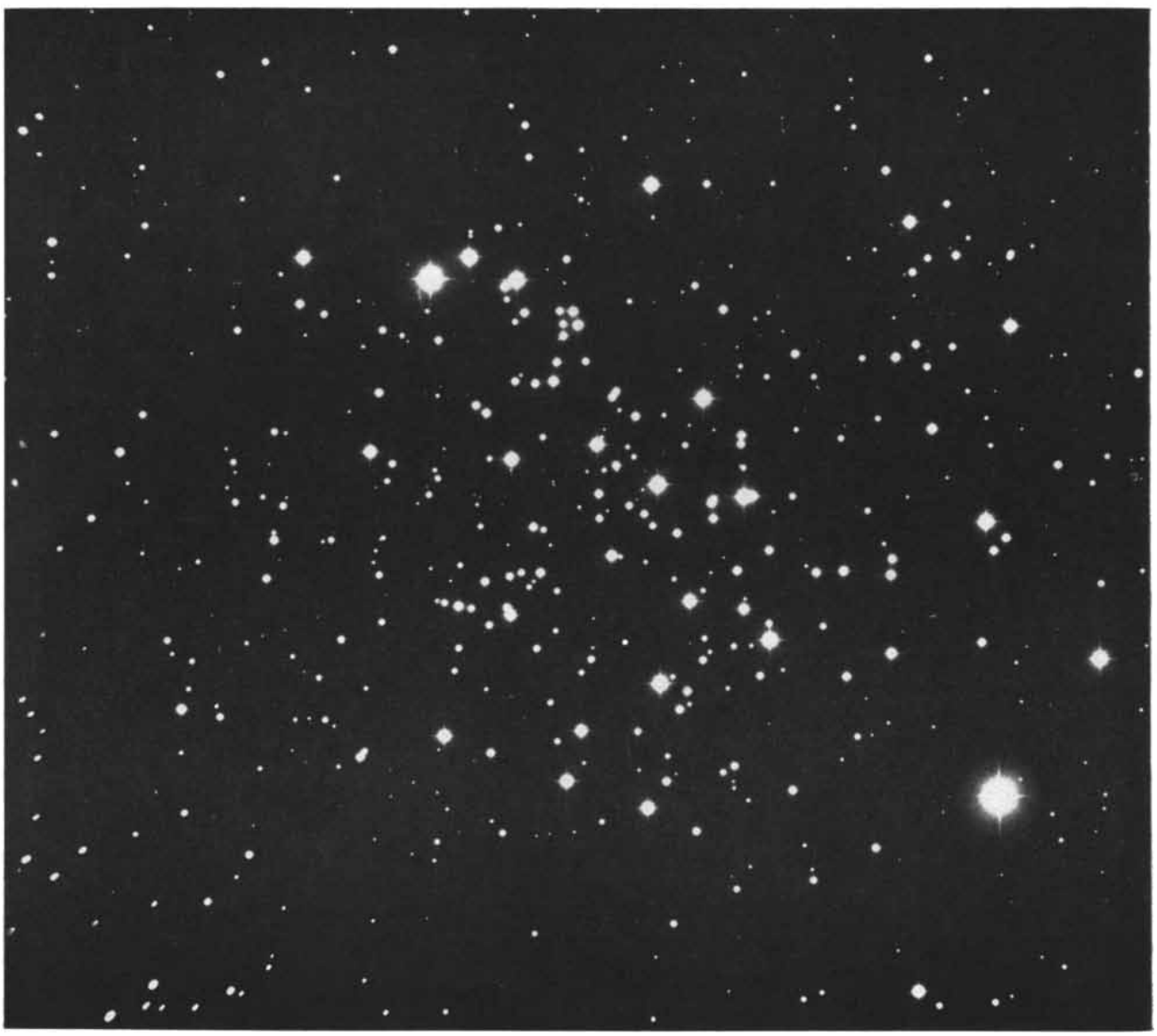
highly improbable as to play no role at all.) The other limit is one in which there are no stars close enough to the given star at the given time to exercise such a dominant role. In this case the net force experienced by the given star represents a smoothed-out average of the forces due to all the other members.

At any instant the force on a typical star in a cluster such as the Pleiades is almost always much closer to this second kind of limit than to the first. In this second limit there would be, strictly, no further changes of a systematic kind in the cluster after an initial adjustment period of several million years in which the member stars had time to move about through distances corresponding to the dimensions of the cluster. But any discrete gravitational encounters, few and weak as they may be, will alter this situation and give rise to systematic changes in the structure of the cluster as a whole.

The resulting systematic effects will be of two general types. Clearly there will be changes of a simple random, diffusive kind, which in the course of time will smooth out structural and dynamical details that may have existed in the initial distribution. Since it is impossible to trace back in time the motions of the cluster's individual stars, there can be no question of reconstructing the original detailed structure. But considering only the large-scale, over-all effects, it can be shown that there have not yet been important changes of this kind in the structure of the cluster.

In addition to diffusive effects on the cluster as a whole, gravitational encounters can also be expected to produce another type of result that is systematically different for stars of different masses. This second effect comes about as a result of a quite general dynamical tendency on the part of interacting bodies to equalize their kinetic energies. The kinetic energy of a body is proportional to its mass and to the square of its velocity. Therefore if two stars of equal velocities but unequal masses undergo a gravitational encounter, the heavier star will, under average conditions, slow down and the lighter one will, under the same kind of average conditions, speed up in order to make their kinetic energies more nearly equal.

Now, the fact that the normal interaction of the stars in the Pleiades tends

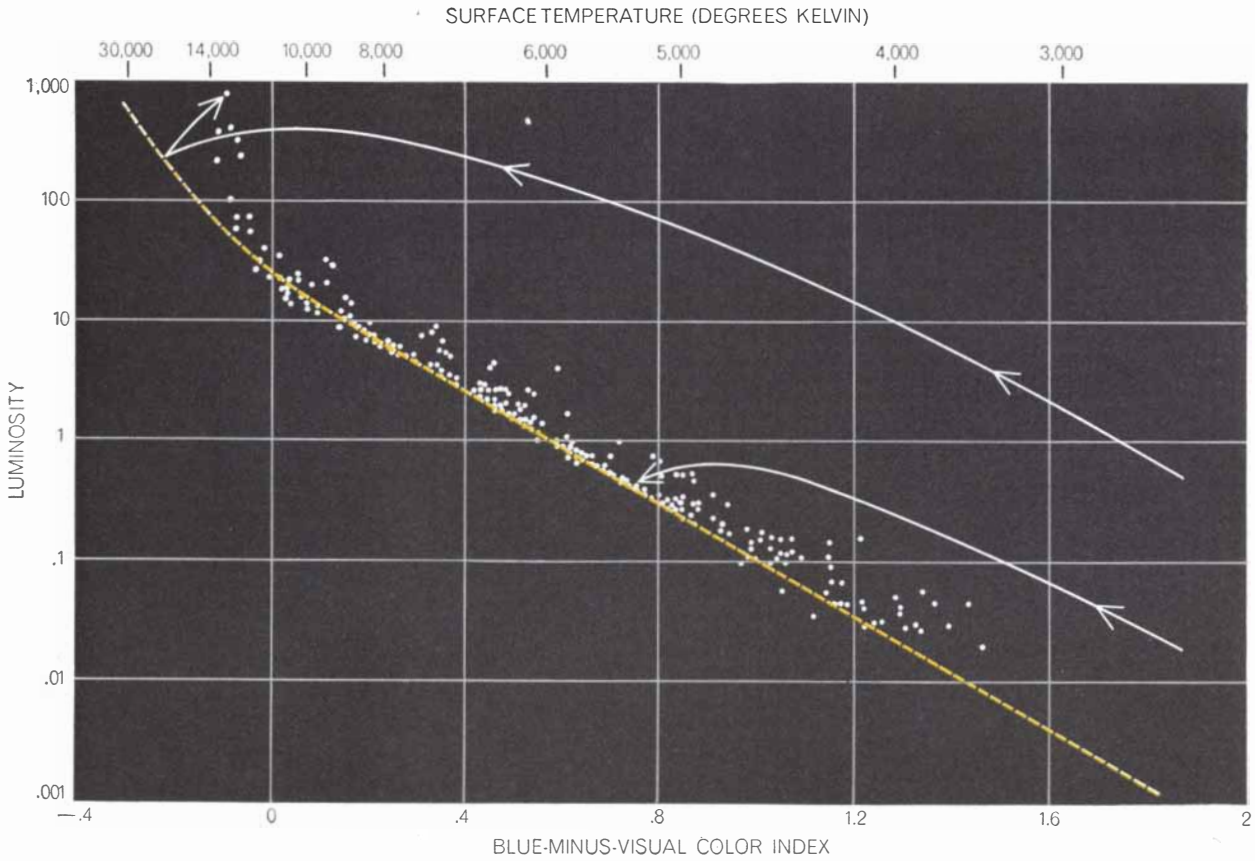


STAR CLUSTER NGC 2682 in Cancer is, like the Pleiades, an "open" cluster. This photograph, made with the 200-inch telescope, provides a more representative view of such a cluster than does that of the Pleiades on page 60, largely because of the smaller field in relation to the apparent size of the cluster as well as the consequent reduction in the number of stars that are not members of the group.

toward the second type of limit discussed above, in which each star is acted on by a smoothed-out average of the forces due to all the others, can be shown to mean that, at any given distance from the center of the cluster, stars will tend to have the same velocity regardless of their mass. Hence the average gravitational encounter, when it does occur, will in fact be between stars of nearly equal velocities. Consequently the heavier stars will tend to slow down and the lighter ones to speed up. This in turn means that the more massive stars will tend to fall in toward the center of the cluster until the speed gained in their fall becomes great enough to maintain them in equilibrium at a smaller average distance from the center, just as an artificial satellite, slowed a little by a retro rocket, say, falls a bit closer to the earth and speeds up. At the same time the lighter stars, having speeded up, will tend to move out to a greater average distance from the cluster's center, as a speeded-up satellite will swing outward into a larger orbit. (One can crudely envisage a large weight as being at the center of mass of the cluster, and the individual members as, on the average, revolving around it under its gravitational attraction.) It should be emphasized that these changes do not take place in a discontinuous way but through a succession of smooth and gradual transitions that are always in process.

Clearly the mechanism just described will have tended to bring about the observed preferential concentration of more massive stars toward the center of the Pleiades. This suggests that we *begin* with the present concentration and work backward, applying a quantitative theory to determine at least approximately the distribution of member stars throughout the ages since the stars were formed. This calculation has been carried through, and the results are shown graphically in the bottom illustration on page 61. It is evident that 60 million years ago stars of different masses had very nearly the same average distance from the cluster's center. This result is important in the attempt to understand the processes that act in star formation, since it indicates that stars of different masses do not form preferentially at different parts of the parent concentration of interstellar gas. This in turn suggests that the formation of stars of different masses does not result from large-scale differences in the physical conditions between different parts of the parent concentration. At best, though, the calculation gives only a clue and nothing like a complete answer to the intriguing problem of the factors involved in star formation.

This takes the story of the Pleiades as far back as it can now be told. But there is every reason to believe that a much more complete history will be written someday. Eventually one would hope to understand the process by which the original parent cloud condensed from the general gaseous substratum of our galaxy. And then the details of actual star formation must be filled in. In the course of extending the study, it will be surprising if some of the "facts" already uncovered do not turn out to need revision. There is, in any case, plenty of work to be done.



TEMPERATURE-LUMINOSITY DIAGRAM for the stars of the Pleiades cluster is discussed at length in the text. On the scale at left the luminosity of the sun equals unity. The color scale at bottom reads from blue at left to red at right. The broken colored line marks the "initial main sequence." The shorter white line with arrows shows the development of an average star of relatively small mass up to the time of its arrival on this sequence; the longer line, the development of a more massive star up to and off the sequence.

Kodak reports on:

a simple little problem in communication . . . picturing slow neutrons . . . a phone number that should perhaps be noted . . . 2 more infrared transmitters that have to be considered

Name that artery

Just in the past few years, the arteries have joined the bones, teeth, and organs as routine subjects for medical radiography. Availability of injectible iodine compounds as contrast media has opened up arteriography. A funny little problem has arisen. Who can remember the names of all the above-charted arteries of the abdomen long after having passed one's anatomy exams? It can be embarrassing, now that there is so much more occasion to mention them. To help out, we have published a chart that gives the *Nomina Anatomica* names for all the numbers that can be scarcely read above. It is 27″ x 35″ and also charts the arteries of the pelvis and lower extremity. If you have real use for it, request Chart M4-2 from Eastman Kodak Company (Att.: D. L. Gilt), Rochester 4, N. Y. M4-2a is an 11″ x 16″ version folded for notebook.

The Sun play

Neutrons aren't much good by themselves for exposing photographic materials. Yet a mere few thousand thermal neutrons/mm^2 can give decent photographic images. We don't mean tracks, either. We mean continuous density, such as you might find useful for neutron radiography (read the wine level inside a lead amphora), neutron diffraction patterns, neutron flux measurements, etc. The topic of photographic detection of neutrons is too quiet for our liking. Let's have a little noise.

You do it by a triple play: thermal neutrons activate ^{10}B to emit alphas, which scintillate ZnS(Ag), which gives off visible light that exposes the film. For sharper images at the expense of longer exposure time, you can use a neutron activation technique involving an appreciable half-life. There are gadolinium, which works by an n,γ reaction at an optimum thickness of .074″, and dysprosium, which works by β decay at an optimum thickness of .023″. Expose such a neutron converter sheet without the film and then quickly pull it out of the neutron flux and put it in contact with the film.

As to which film, we suggest you first read J. App. Phys., 33, *48 and* Nucleonics, *July, 1962, pp. 60 and 61, and then ask for a film recommendation from Eastman Kodak Company, X-ray Division, Rochester 4, N. Y. Nice big sheets of .074″ gadolinium oxide are not stocked by most neighborhood hardware merchants nor by us. Maybe your best bet after all is the ^{10}B scintillator.*

A prominent role in all this has been played by a gentleman named Kuan-Han Sun, who once worked for us before his interest turned from non-silicate optical glasses to nucleonics. Married one of our x-ray researchers and took her off with him. Lovely gal whose name was Laura McGillivray.

Rigid, clear, machinable bearer of images

There are photographic plates that have their emulsions coated directly on clear methyl methacrylate .060″, .130″, or .250″ thick. We can make them as large as 30 inches wide by almost any length. The finished image-bearing plate can be conventionally sawed, drilled, threaded, or otherwise machined. It can be cemented. It doesn't shatter like glass.

Ask almost any camera shop for KODAK PHOTOPLAST Plates. If, now that you know, you want immediate action and can't wait while the dealer orders pamphlet P-34, it might be well to place a call to Rochester, Area Code 716, LO 2-6000, Ext. 2374.

The product has lately been revised to broaden latitude greatly. One can speak of latitude in an emulsion with a cliff-like density *vs.* log exposure curve because the cliff can be shifted parallel to itself by choice of development time. The development latitude gives exposure latitude (not in general but in this particular emulsion).

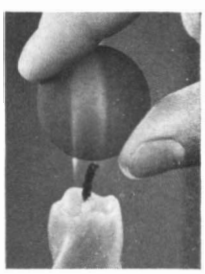
Uniquely polycrystalline facts

Since materials from which to make infrared-transmitting optical parts are selected by a mental process different from the one used in selecting a brand of shoe polish, a thin veil is hereby dropped:

KODAK IRTRAN 1 material is our unique polycrystalline magnesium fluoride. This transmits usefully from 2μ to 8μ, over which range the refractive index runs from 1.37 to 1.26. It therefore wastes little on reflection. It has good microwave characteristics and is comparable in general ruggedness with fused quartz, which is a great deal better than most optical glasses.

KODAK IRTRAN 2 material is our unique polycrystalline zinc sulfide; useful range, 1μ to 14μ; refractive index, 2.29 to 2.14. High index advantageous for lenses. Enjoying wide favor here and abroad among spectroscopists for its chemical and thermal ruggedness.

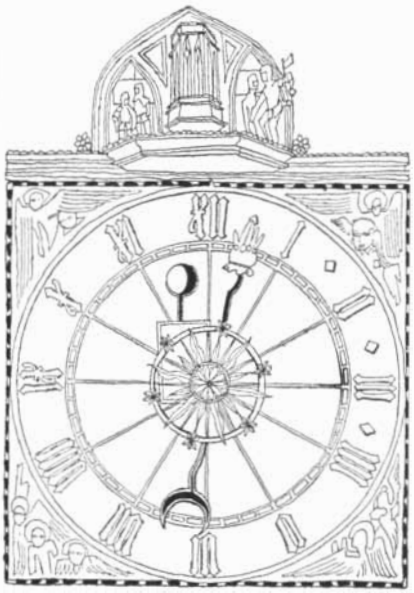
We now announce KODAK IRTRAN 3 optical material, unique polycrystalline calcium fluoride. It is clear enough in the visible so that you can see through it to line up your system. Transmits to 11μ. Having no cleavage planes, it trounces monocrystalline CaF_2 for shock survival, mechanical or thermal. True, the IRTRAN 1 material is even better against shock and water, but IRTRAN 3 takes the lead on withstanding a steady 900°C for 1 hour in air without forming any significant oxidation film. Index at 0.656μ, 1.4324; at 8.25μ, 1.3444. Maximum size at present: 5″ diameter x ¼″ thick.



The newest of all, KODAK IRTRAN 4 material, is our unique polycrystalline zinc selenide, a substance that transmits usefully from 1μ to 21μ. Still limited to a maximum diameter of 2″ and thickness of ¼″, which may suffice for your evaluation and planning purposes, should you have any. With a refractive index that descends from 2.5—much lower than that of germanium—optical homogeneity is less exasperatingly difficult to attain.

All these KODAK IRTRAN materials have very low emissivity because we have worked like dogs to get the absorption out. Discuss all this with Eastman Kodak Company, Special Products Division, Rochester 4, N. Y.

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



SCIENCE AND

The First Five Years

The space age began on October 4, 1957, with the launching of *Sputnik I.* Its fast-moving first half-decade ended on October 3, 1962, with the six-orbit flight of Walter M. Schirra, Jr. He was the seventh man to circumnavigate the earth in space, having been preceded by four Russians and two Americans. The Schirra flight was attended by impressive space-age activity: the radiation to which the pilot would be exposed was estimated on the basis of satellite data; landing conditions were forecast with the help of cloud photographs from the weather satellite *Tiros VI;* a television report of the launching was relayed to Europe by the communications satellite *Telstar I.* Within the week before the Schirra flight the U.S.S.R. had launched the ninth in its current series of large unmanned satellites and the U.S. had sent aloft two instrument packages: the first Canadian satellite, *Alouette,* in a nearly circular orbit and the radiation probe *Explorer XIV* in an elongated ellipse extending 61,000 miles from the earth at apogee. Meanwhile the U.S. space probe *Mariner II,* launched on August 27 and en route to a rendezvous some 20,000 miles from Venus on December 14, was filing its first reports on interplanetary space.

The data indicated that the flux of charged particles from the sun that had been detected by earlier space vehicles is apparently a steady "wind" that blows harder whenever such outbursts as solar flares occur on the surface of the sun. Although the solar wind is very tenuous indeed, it is apparently sufficiently dense and fast-moving to affect the "weather" in space: *Mariner's* instruments detected abrupt changes in magnetic fields that accompanied similar changes in the velocity and intensity of the solar wind.

The launching, orbital flight and landing of Schirra's *Sigma 7* capsule were marked by a degree of reliability and precision that brought the U.S. at least within range of the technique exhibited in the double satellite flight by Soviet cosmonauts in August. The only delay (15 minutes) in the countdown was caused by communication trouble downrange. In orbit Schirra concentrated on demonstrating the spaceworthiness of the Mercury capsule for a day-long flight, the objective for which it was designed. He repeatedly checked the attitude-control system, which had given earlier astronauts some trouble. He conserved power and fuel (as would be necessary in a longer flight) by letting the capsule drift about its pitch, yaw and roll axes for long periods. Like the Soviet cosmonauts, who spent several days in orbit, he reported no feelings of discomfort due to prolonged weightlessness. His re-entry was uneventful, and the landing only four miles from a waiting aircraft carrier in mid-Pacific was the most accurate to date.

The success of the *Sigma 7* flight will probably lead to the culmination of Project Mercury with a 24-hour, 18-orbit flight early next year. After that will come Project Gemini. The Gemini spaceship, a larger version of the Mercury capsule, is to be launched by the Titan II rocket now under development. It will carry two men in orbit for up to a week and will be genuinely maneuverable. Gemini is intended to develop the "docking" techniques and skills that will be central to Project Apollo, the effort to land a two-man capsule on the moon.

Infectious Vaccines?

The mass administration of the live (Sabin) vaccine against Type III poliomyelitis over the past summer in the U.S. was attended by the occurrence of 11 cases of paralytic infection with laboratory findings that, according to

THE CITIZEN

the U.S. Public Health Service, "could not exclude a possible relationship to the administration of the oral [live] vaccine." This untoward development brought conflicting advice from public health agencies.

The Surgeon General recommended the continuation of mass feeding of the vaccine to children, initiated with the licensing of the vaccine in March, but advised that the feeding of the vaccine to adults be stopped except in "epidemic emergencies." In New York, Michigan and Washington state health authorities called a halt to the administration of vaccine against Type III poliomyelitis in immunization campaigns under way in their communities.

The recommendation of the Surgeon General was predicated on the observation that the vaccine-associated cases were confined to adults and that the incidence of these cases was less than one per million persons vaccinated. Subsequently it was revealed that Federal health officials were investigating three possible cases in children—aged six, eight and 12—clustered in Nebraska. The Washington health authorities, coming to conclusions "not entirely in harmony with the Surgeon General's statement," cited the experience of Oregon, where "four cases occurred among 658,000 recipients of Type III oral vaccine, none among nonrecipients, none in 1962 prior to the vaccination program and none following the four . . . cases," yielding an incidence "closer to one case per 200,000 vaccinees."

In Canada, where seven vaccine-associated cases of Type III poliomyelitis —five in children and only two in adults— were recorded, the Dominion health authorities terminated their mass oral-vaccine immunization program. Reviewing his country's experience, a Canadian spokesman noted that none of the victims had been immunized with killed (Salk) vaccine. "In order to assess the risk of vaccine-induced polio," he declared, "it is necessary to exclude Salk-vaccinated individuals from the calculation. At the time we suspended the program, oral vaccine had been given to 3.7 million adults and children throughout Canada. Since all but one million had already been immunized against polio with killed vaccine, our rate was seven per

million—a figure about equal to the rate for 'natural' polio in North America in recent years."

Meanwhile officials of the National Foundation, which sponsored the development of both the Salk and the Sabin vaccines, questioned the continued mass administration of Type II live vaccine. This year, they observed, only one case of Type II poliomyelitis has occurred in the U.S.; last year there were only two. "It is apparent that Type II virus is practically extinct in the U.S. While Type II live vaccine is an effective immunizing agent, its use now carries a risk of reseeding the population with an extinct virus. The time may be at hand to confine Type II immunization to killed vaccine."

With 85 million U.S. citizens immunized by three or more inoculations with killed vaccine and seven million immunized by administration of all three live vaccines, the number of paralytic poliomyelitis cases in the 40th week of 1962 stood at 501. The estimated average annual incidence for the years 1949–1954 was 24,220 cases.

Regge Poles

A concept called Regge poles has had theoretical physicists in a ferment of excitement for the past year or two. In September two physicists published a paper suggesting that, although the concept does indeed have remarkable powers, it is actually implicit in the conventional field theory that has been in use for some 25 years.

Regge poles are named for Tullio Regge, an Italian mathematical physicist. The reason for the excitement they have caused is that some theoreticians think they see in Regge's ideas the first hint of a true theory of strong interactions (such as the force that holds particles of the atomic nucleus together). There are those who expect the theory to predict such quantities, totally unexplained at present, as the mass and spin of the particles that actually exist.

The Regge pole idea is intimately connected with another device of the theoretical particle physicist: the scattering matrix, or S-matrix. Scattering experiments, in which high-speed particles, usually from an accelerator, bombard other particles, are the meat and drink of particle physics. The observed results—that is, the numbers and kinds of particles that emerge at various angles, with their masses, spins, energies, momenta and so on—are both what theoretical physicists are trying to predict and the data on which their computations are based. About 25 years ago a mathematical device known as the S-matrix was introduced as a convenient way of describing such data.

A matrix is simply an array of numbers or other mathematical expressions, but these arrays, suitably defined, obey a complex set of mathematical rules. The elements of the S-matrix are various quantities that can be measured in scattering experiments. But the matrix itself has mathematical properties that can make it describe "unphysical" quantities such as negative kinetic energy. The physicist follows the matrix into these regions, calculating its behavior to see where it "re-emerges," so to speak, into the real world and to determine what predictions it makes.

About three years ago Regge pointed out that some elements of the S-matrix exhibited "poles"; that is, they became infinite at certain values of the variables. The quantity $1/(x-1)$, for example, has a pole at $x = 1$. A number of other physicists quickly followed up his suggestion and have come to the idea that particles are in a sense identifiable as Regge poles. The implication is that this point of view will allow a much better explanation of some experimental findings than was previously possible and even lead to a complete theory of the particles.

Throughout most of the period that physicists have been grappling with the particle problem they have been approaching it from the point of view of quantum field-theory, a method that has brilliantly accounted for the facts of electromagnetism but that has been largely defeated by the mathematical difficulties involved in dealing with stronger forces. A school of theoreticians led by Geoffrey F. Chew of the University of California has decided that the S-matrix-Regge-pole approach is a thing unto itself, derivable from separate postulates and totally independent of field theory. In fact, they feel that field theory offers no hope for understanding the strong interactions. Now Murray Gell-Mann of the California Institute of Technology and M. L. Goldberger of Princeton University have published a communication in *Physical Review Letters* calling into question this point of view. While not denying the power of the S-matrix-Regge-pole approach, they have made calculations suggesting, according to them, that it may be contained in field theory. The new approach can be used, they believe, whichever philosophical position is taken, but if they are right, the results of using it, whatever they may turn out

to be, will have been implicit in field theory.

Oil-troubled Waters

The fouling of the oceans with oil must be added to the list of pressing problems of environmental pollution, states a recent article in *Unesco Courier*, a publication of the United Nations Educational, Scientific and Cultural Organization. Any vacationer who has swum in oily waters or has stepped on a patch of tarry black stuff on a beach is familiar with one aspect of the problem. The effect on wildlife and on those who earn their livelihood from the sea is more serious. Fish brought up through oil slicks cannot be cleaned and are unusable as food; sea birds whose feathers are matted by oil die because they cannot swim or fly.

The consumption of fuel oil has increased some fiftyfold in the past 40 years. Most of the oil is transported by sea, and much of it is used as fuel for ships. The principal source of oil pollution is the sludge that remains in a tanker's compartments and is flushed into harbor waters after the ship unloads. Moreover, many oil-burning ships replace fuel consumed at sea with water ballast that becomes contaminated with oil and is later pumped out. Finally, oil tanks may be ruptured in accidents and oil may be jettisoned to lighten a ship. The combined effect of all these sources, it has been estimated, is to spread some 500,000 tons of oil on the waters of the world every year.

The oil does not disperse readily, of course, but stays on the surface, sometimes in great floating oil islands that travel hundreds of miles. When one such island came ashore in Denmark, attempts were made to attack it with flame throwers, but the oil survived and six miles of beach sand finally had to be bulldozed into open trenches. The Danes have also tried, without success, to adsorb floating oil on a powder that would later sink.

In 1954 an international convention on pollution of the sea was drawn up in an effort to encourage research and national legislation. At a meeting called last April by the Intergovernmental Maritime Consultative Organization, representatives of 40 nations signed a strengthened convention that forbids the discharge of oil anywhere in the Baltic Sea or North Sea, within 100 miles of the shore in certain other areas and within 50 miles anywhere else. The effectiveness of these steps will probably depend on the provision of alternative

means of disposal; that is, on the willingness of shipowners and port authorities to install "separators" aboard ships to remove oil from waste water and special plants ashore to process the sludge from tankers.

Polarized Cosmic Radio Waves

Many of the radio waves that reach the earth from outer space arrive with a considerable linear polarization. That is, their electric oscillations have maximum energy along some one direction and minimum energy in the perpendicular direction. The fact constitutes additional evidence that the source of much of the cosmic radio energy is "synchrotron radiation" produced by electrons accelerated in a magnetic field, because this type of radiation is linearly polarized. (The absence of polarization in waves arriving at the earth would not disprove the synchrotron radiation hypothesis; local differences in the magnetic fields of the sources might produce a jumble of different polarizations that would cancel.)

Over the past few years several radio observatories have detected varying degrees of linear polarization from various sources, but the effect was usually small and the measurements somewhat doubtful. In the past six months the effect has been confirmed with the new 210-foot, fully steerable radio telescope in Australia. This instrument, although not quite so large as the 250-foot reflector in England, is capable of working at shorter wavelengths and is in general the most versatile instrument now operating. Using the Australian reflector, F. F. Gardner and J. B. Whiteoak of the Commonwealth Scientific and Industrial Research Organisation (C.S.I.R.O.) have detected polarization in the radiation from nine different sources. Reporting their results in *Physical Review Letters,* they note that the greatest degree of polarization—38 per cent—was found for the nearest source: Centaurus A, which has an estimated distance of 13 million light-years. The stray magnetic fields of intergalactic space might act to depolarize an originally polarized train of waves, the astronomers point out, so that measured polarization might possibly be useful as a distance indicator. Polarization of the Centaurus source was also measured, and reported in *Nature,* by R. N. Bracewell, B. F. C. Cooper and T. E. Cousins of C.S.I.R.O.

After the large polarization of the Centaurus source was discovered, Cooper and R. M. Price studied the effect at a number of different wavelengths from 10 centimeters to about 30 centimeters, and they found that the direction of polarization varied in a regular way with the square of the wavelength. This would be expected if the waves had been subjected to Faraday rotation: a rotation of the direction of polarization produced when waves pass through a space containing free electrons and a magnetic field. For a given electron density and magnetic field the amount of Faraday rotation does vary with the square of the wavelength.

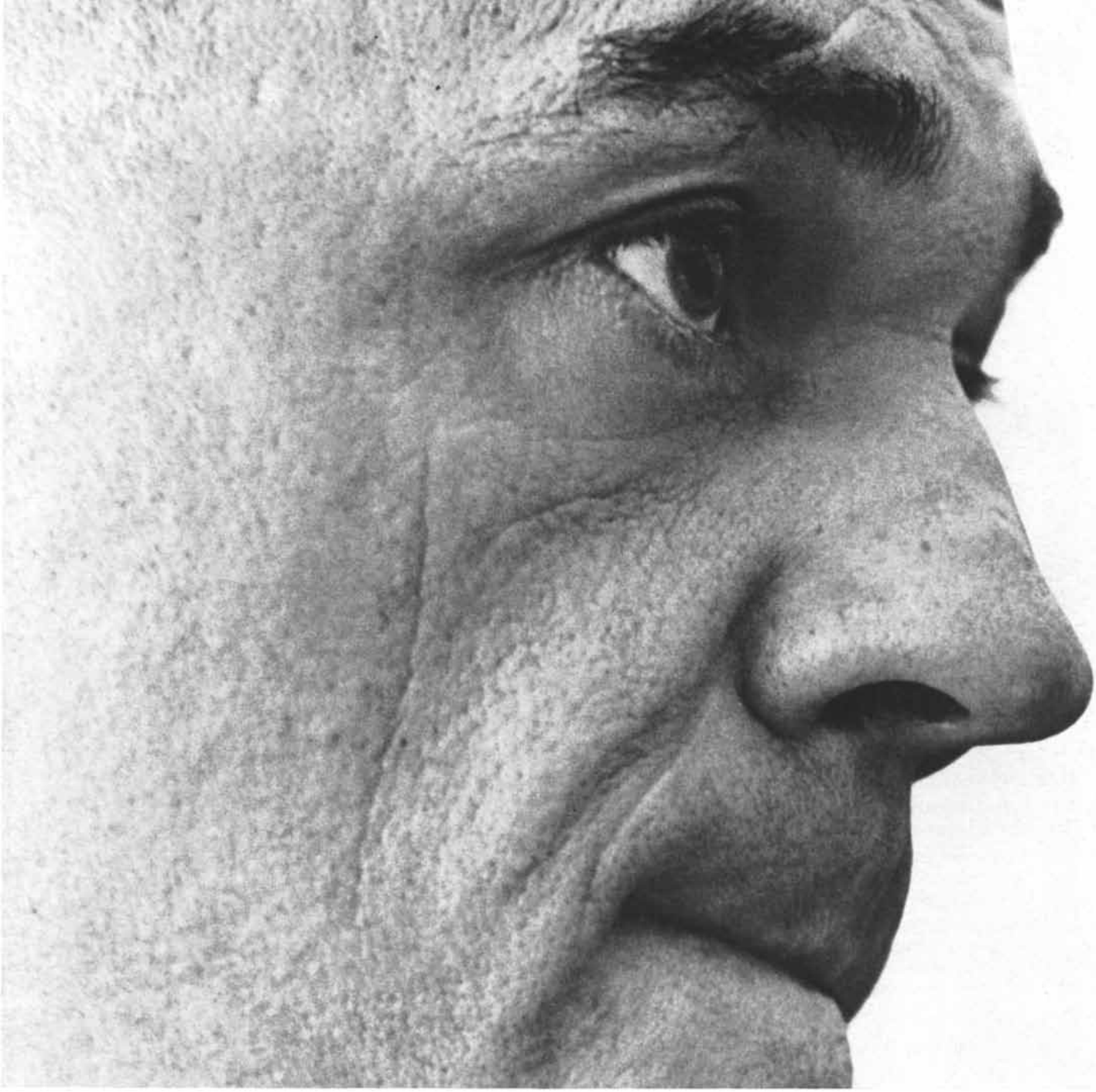
One place where the rotation could occur is the earth's ionosphere, which is pervaded by the geomagnetic field. Cooper and Price have calculated, however, that the effect they observed is much greater than can be ascribed to the ionosphere. They conclude that the rotation must take place either in the outer regions of Centaurus A or of our own galaxy. In either case the observed rotation implies the existence of uniform magnetic fields extending over immense reaches of space, a hitherto unsuspected phenomenon.

The Origin of Tektites (Contd.)

Hypotheses seeking to explain the origin of tektites—the oddly shaped, glassy objects found in "strewn fields" in several parts of the world—have been subjected to a new analysis by Ernst W. Adams and Robert M. Huffaker of the National Aeronautics and Space Administration. Their work appears to rule out the two hypotheses that had gained the most adherents. According to one of these hypotheses tektites are samples of material splashed into space by the impact of giant meteorites on the moon. According to the second hypothesis tektites are samples of terrestrial rock splashed high into the atmosphere by the impact of giant meteorites on the earth.

Adams and Huffaker accept the view that tektites have been shaped aerodynamically while traveling molten through the atmosphere. They argue, however, that if tektites originated as drops splashed from the moon, they would not be confined to the relatively limited corridors of the strewn fields. Terrestrial origin is ruled out, they believe, because it would require a violent event of such magnitude that it would "be very unlikely to have occurred."

They propose that "tektites were released as liquid droplets from the ablating surface of a hypothetical parent body in skipping flight through the Earth's atmosphere." The hypothetical body may have been a giant meteorite



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that entered the atmosphere at just the right angle to skip several times before making its final plunge.

The Bathtub Vortex

Everyone knows that when the water runs out of a bathtub, it develops a vorticity or swirling motion around the drain. Many people are under the impression that the rotation of the vortex is always counterclockwise in the Northern Hemisphere and clockwise in the Southern, and therefore that the effect is attributable to the rotation of the earth. Many other people are under the impression that this is a canard and that the rotation can and does go either way in either hemisphere. Now a report in the *Journal of Fluid Mechanics* indicates that both groups are right and that furthermore under certain circumstances the water goes *both* ways.

In the first place, water has an astonishingly long "memory" for the direction in which it rotated while the tub was being filled. (In a given bathtub the spout may be slightly angled, so as always to give the same circulation. In the laboratory, of course, the direction can be varied at will.) Water in a tub drained many hours after filling invariably swirls out the same way it swirled in. This fact led Ludwig Prandtl of the University of Göttingen, probably the world's greatest authority on fluid dynamics, to conclude that "in all such cases [that is, when a vortex developed] the moving fluid must previously have possessed circulation."

On the other hand, A. H. Shapiro of the Massachusetts Institute of Technology got a different result in a series of experiments in which he let the water settle for several days before emptying his tub. A vortex consistently developed in the counterclockwise direction. Evidently the earth's rotation was now producing the effect.

The new two-way rotation was discovered by Merwin Sibulkin of General Dynamics. Using a circular tub 12 inches in diameter with a drain in the center, he ran a number of tests at various fairly short settling times. Invariably the initial direction of rotation coincided with the direction of circulation during filling. But often, as the water got down to the last half-inch or less, its vortex direction reversed. This happened most frequently for settling times between five and 20 minutes. Sibulkin attributes the result to the development of a boundary layer at the bottom of the tub and a "radial component of vorticity" in the layer, which tends to make the

WHEN THE FLEET SAW RED

The flag as signal had a place in history as early as 480 B.C. In that year, at Salamis, the Greek navy met Xerxes, who had wiped out the Spartans at Thermopylae and overrun Greece. From his flagship, the Greek commander, Themistocles, ordered an improvised flag hoisted…a red cloak on an oar. At the signal, the Greek ships swung round together. Although outnumbered four to one, they bore down upon and routed the Persians, relieving the threat to Greece and European civilization.

Refinements of the signal flag system are still in use by navies of the world. This relatively slow means has limited use. Today, the speed of communications must often match that of missiles, its scope must match that of intercontinental wars. That's why REL's tropo scatter radio equipment—long the first choice for many military communications systems—is now beginning service with our own navy. Its messages move with the speed of light, lightly leap age-old barriers… mountains, desert sands, vast oceans, Arctic wastes. Such eminence must be deserved. Your telecommunications problems deserve consultation with REL.

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water change its direction of rotation. He admits, however, that his "heuristic arguments" may not be conclusive and invites other explanations.

Ignoble Gases

Because they disdain to react with other elements to form compounds, helium, neon, argon, krypton, xenon and radon have traditionally been called "noble" gases. Tradition was shattered early this year when Neil Bartlett of the University of British Columbia announced that he had combined xenon with platinum and fluorine to form xenon-platinum hexafluoride. Since the compound is fairly complicated, some investigators speculated that special forces made xenon behave as theory says it should not.

Now workers at the Argonne National Laboratory have reported the synthesis of a new and simpler xenon compound: xenon tetrafluoride. The compound was made by John G. Malm, Henry Selig and Howard H. Claassen. They sealed one part of xenon and five parts of fluorine in a container and heated it for one hour at 400 degrees centigrade. The container was then quickly chilled. Inside were colorless crystals of the new compound. The compound is surprisingly stable. It withstands heating to at least 400 degrees C. It reacts with water, but not so violently as many fluorine salts do. And it has about the same vapor pressure as ice.

The Argonne workers have also produced xenon difluoride, and their associates have found that radon, the noble gas next above xenon in atomic weight, will also combine with fluorine. However, the noble gas next below xenon, krypton, will not react under comparable conditions.

The noble gases had been thought to be inert because they contain a full complement of eight electrons in their outer shells. In other elements the outer shell contains anywhere from one to seven electrons. Compounds are commonly formed when an element containing only one or a few electrons in its outer shell shares these electrons with an element that is shy of a full set. Fluorine, which contains seven electrons in its outer shell, is the most electronegative of all elements, which means that it has the highest affinity for electrons. Evidently it is able to capture the tightly bound electrons of radon and xenon but not the still more tightly bound electrons of the other gases in the same family, which thus retain their nobility.

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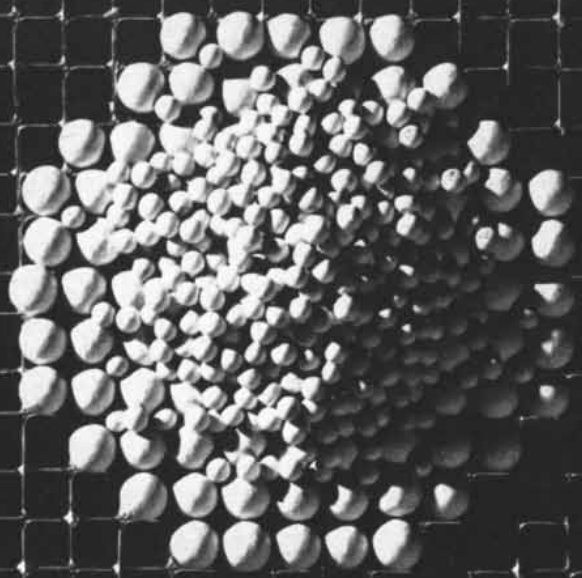

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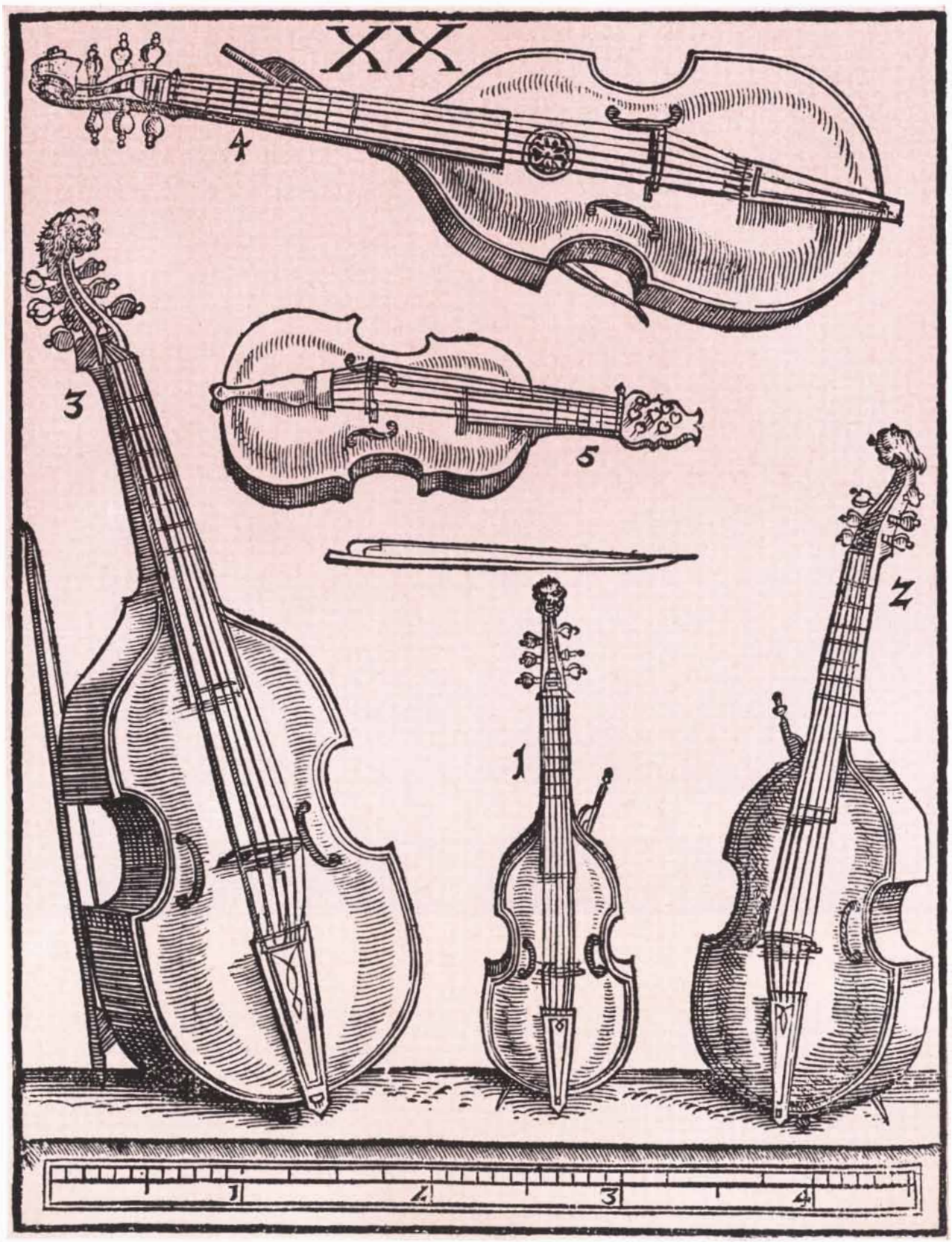


VIOL FAMILY, a somewhat earlier development than the violin family that eventually supplanted it, encompassed a large number of instruments of varying shapes and sizes. This drawing from the *Syntagmatis Musici* of Michael Praetorius (1619) shows three examples of the viola da gamba (*1, 2, 3*), a viola bastarda (*4*) and a viola da braccio (*5*). They have not all been drawn to the same scale.

The Physics of Violins

Modern acoustics is making it possible to account for the exquisite performance of the violins made by the Italian masters. The results promise a further evolution in the instruments of the violin family

by Carleen Maley Hutchins

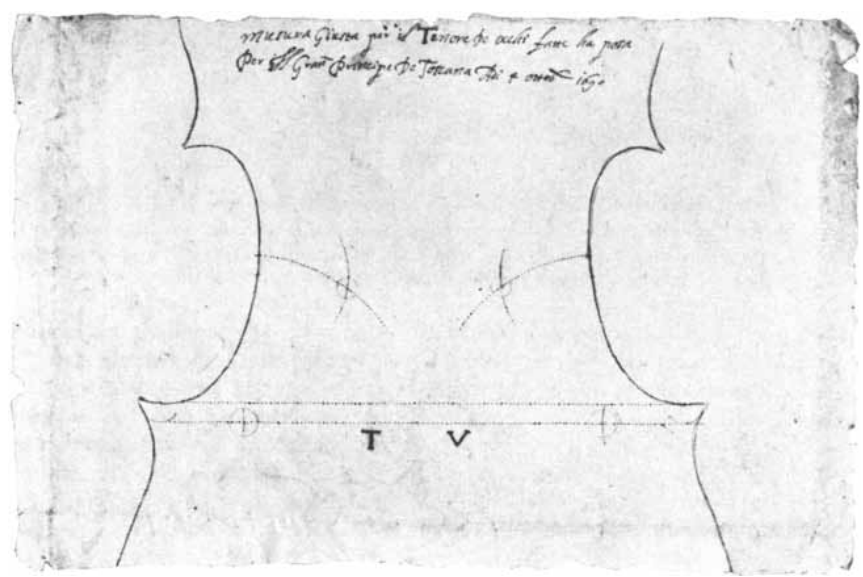
During the Renaissance there grew up in Italy two new families of musical instruments, both of them stemming from primitive stringed instruments of the Middle Ages such as the rebec and lute. The earlier of the two groups to emerge was the viols; the later, following about a century afterward, was the violins. The violin was not an outgrowth of the viol but a somewhat later development from similar sources, and the two were lively competitors for a long time. Composers wrote distinctive music for each kind of instrument, and each had its virtuoso performers. Eventually the violin family, having a richer and more powerful sound, supplanted the older group—except for the largest and lowest-pitched instrument, which survives as the bass viol.

As this story unfolds it will be clear that viols still have more than mere historical interest. For the moment I shall describe the viols briefly. They came in a variety of shapes and sizes [*see illustration on opposite page*], most of them having a flat back unlike the beautifully arched back plate of the violins. They had five, six or more strings, more slackly tuned than violin strings and supported on a flatter bridge. Often their finger boards were crossed by gut frets resembling the metal ridges on the finger board of a guitar. Their wooden sounding boards were lighter and more flexible than those of the violin family.

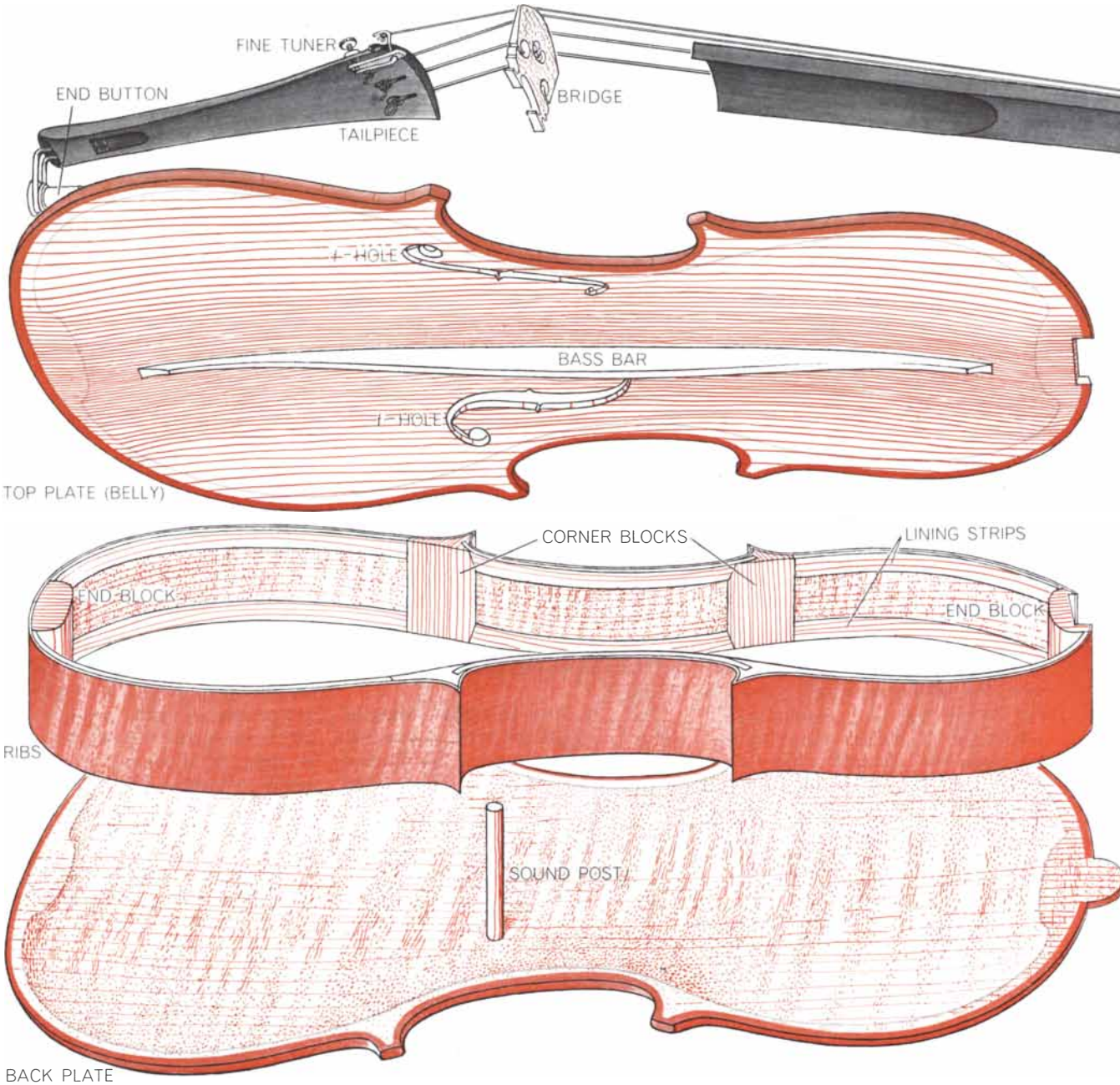
Exactly who invented the violin is not clear. It may have been Andrea Amati, who in any case founded the great Cremona school of violinmakers. Amati died around 1580; within 150 years or so his descendants and their pupils, particularly Antonio Stradivari and Giuseppe Guarneri, had brought the art of violinmaking to such an extraordinarily high level that it is only now that one dares to dream of equaling or surpassing it. These early masters must have had an open mind toward the little that was known in their time about the physics of sound. Their successors deserve credit for having lovingly preserved an art, but certainly not for advancing a science. In effect they have formed a cult that has been plagued with more peculiar notions and pseudo science than even medicine.

Today the well-developed science of acoustics is applicable to the understanding and making of violins. For the past 30 years or so a handful of interested physicists, chemists, musicians and some people who, like me, began as amateurs have been applying it. In fact, we have organized ourselves informally as the Catgut Acoustical Society. Much of what has been learned is still empirical, but it is nonetheless interesting and valuable. In this article I shall try to touch on at least the high spots of our studies.

In essence a violin—as well as its larger, deeper-voiced relatives, the viola and the cello (properly the violoncello)—is a set of strings mounted on a wooden box containing an almost closed air space. Some energy from the vibrations induced by drawing a bow across the strings (precious little energy, it turns out) is communicated to the box and the air space, in which are set up corresponding vibrations. These in turn set the air between the instrument and the listener into vibration; in other words, they produce the sound waves that reach his ears. That is the main story. The sound of a violin, putting aside the acoustics of



DRAWING BY ANTONIO STRADIVARI marks positions of the upper and lower ends of "f-holes" in a tenor viola. At top he has written: "Exact measurements for the sound holes of the tenor made expressly for the Grand Prince of Tuscany, the 4th day of October, 1690."



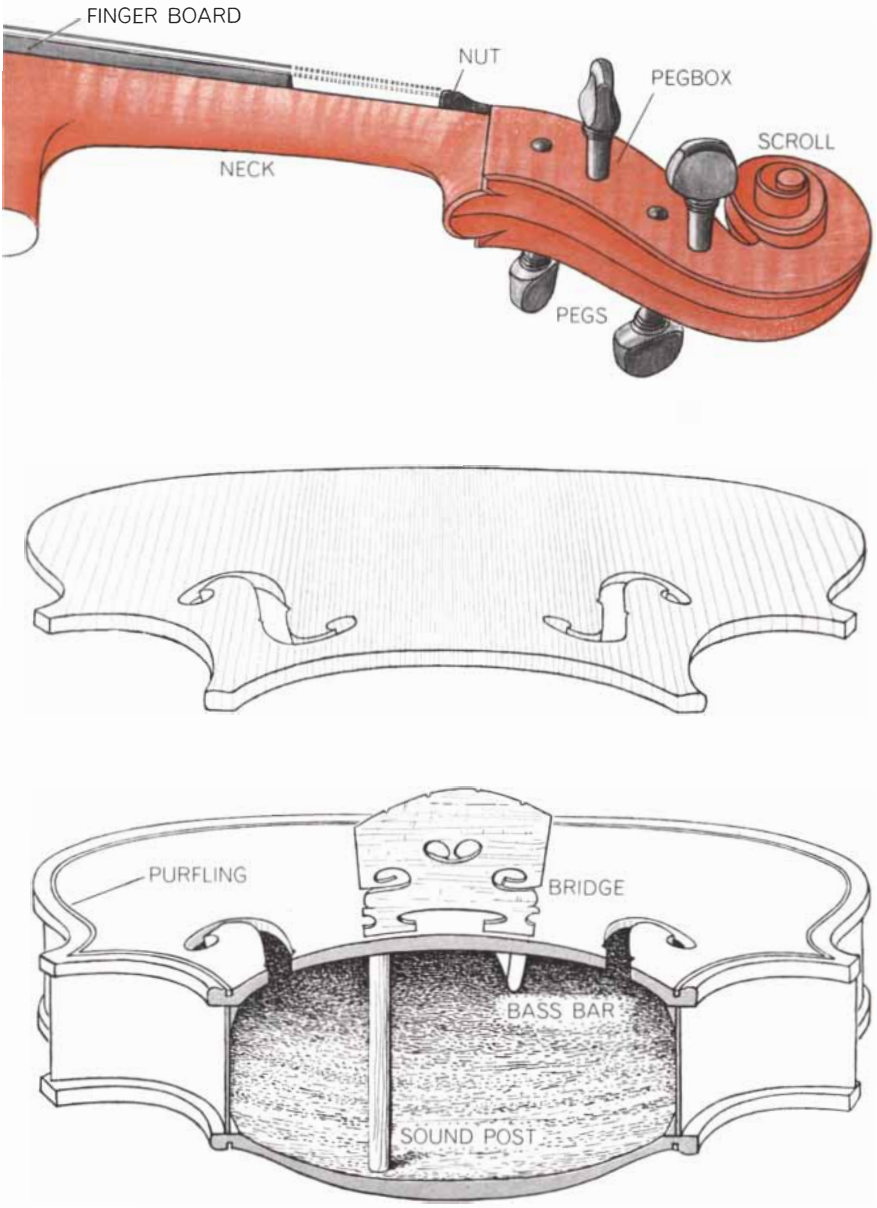
ANATOMY OF VIOLIN INSTRUMENTS is essentially the same for the violin, viola and cello. The exploded view of the viola on these two pages shows the top plate, ribs, back plate and devices for stringing at left, the neck, scroll and finger board at top right. Immediately below, a section of the top plate illustrates the bilateral symmetry of the grain of the spruce wood. At bottom

the room in which it is played and the skill of the player, depends on the transfer of vibration from string to sounding box to air.

The Basic Violin

Before getting into this apparently innocent problem, which turns out to be a veritable jungle of unknowns, it is worthwhile to pause for a moment to examine the instrument itself. Violin strings are usually made of metal, pig gut or gut wound with fine silver or aluminum wire. The sounding box consists of a front plate and a back plate, both arched slightly outward to form broad bell-like shapes, and the supporting ribs, or sides. The back plate is carved with chisel, plane and scraper, traditionally from a block of curly maple seasoned for at least 10 years and not kiln-dried. (Pear or sycamore wood are sometimes used.) It can be a single piece or two pieces carefully joined. In thickness the back plate varies from about six millimeters in the center to almost two millimeters just inside the edges (from 1/4 inch to 5/64 inch). The sides are pieces of matching curly maple, thinned down to a millimeter all over, bent into shape and glued to spruce or willow blocks set in the corners and at the forward and rear ends of the plates.

The top plate, usually spruce, is split lengthwise from a log and then joined so that the wood of the outside of the tree is in the center of the top, making the grain bilaterally symmetrical. In thickness the top plate ranges from two to three millimeters, and a pair of beautifully shaped "f-holes" are cut into each



right a cross section through the middle of the instrument shows the relative positions of the bridge, bass bar and sound post. The purfling consists of three very narrow strips of wood that are set in a shallow groove around the edge of both the top and back plates.

side of the plate. All around the outside of each plate, near the edge, is cut a shallow groove in which is inlaid the "purfling," consisting usually of two strips of black-dyed pearwood and a strip of white poplar.

Other materials may be mentioned: curly maple for the neck, ebony for the finger board, rosewood or ebony for the tuning pegs and tailpiece, hard maple for the bridge. The outside of the instrument is treated with filler and varnished. Filler, varnish and glue all contribute to the over-all characteristics of the violin, but there is no definite evidence to show that 300 years ago any of them was superior to the materials available now. In fact, the Catgut Acoustical Society is working to discover new substances that may be even more effective than the old. But it is a slow, painstaking search.

These were the general specifications for the Cremona fiddles and, with minor variations, for all good instruments since. Whether there is a mysteriously unique virtue in any of the woods or finishes, or whether some other types might not do as well for various purposes, is an open question. In a few years we hope to have some answers.

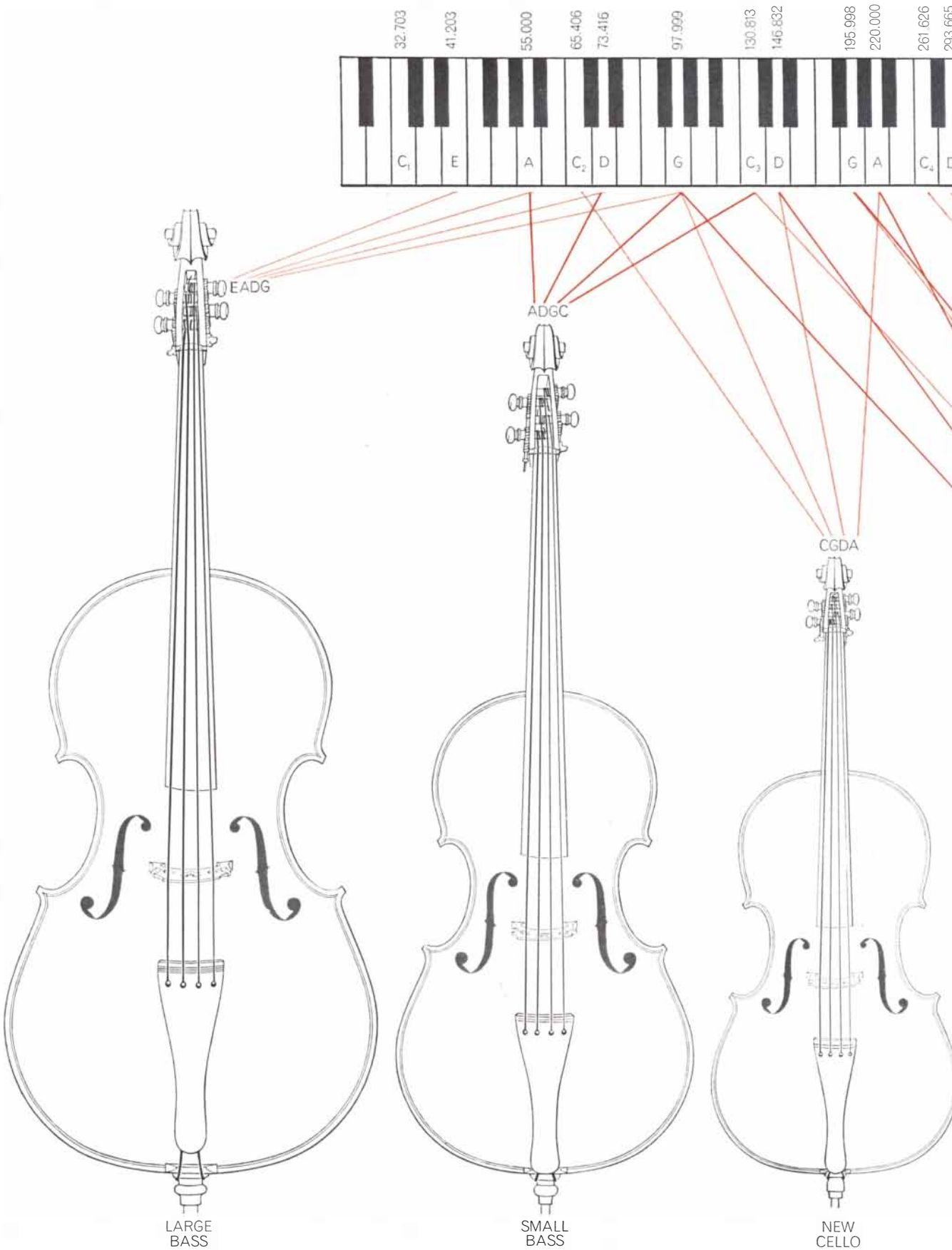
I might anticipate a bit here to mention a point that illustrates the subtlety of some of the problems in understanding the violin. Does the purfling serve any purpose other than decoration? It happens that the wood of the plates underneath the purfling is extremely thin. After years of playing, the glue that holds the purfling strips in their grooves begins to crack, in effect creating a vibrating plate with very thin edges. Frederick A. Saunders, professor emeritus of physics at Harvard University, has suggested that this may be a factor in the improved tone of an instrument that has been played for a long time.

The combined tension of the four strings of a properly tuned violin comes to around 50 pounds. As a result about 20 pounds is directed straight down through the bridge and against the delicate eggshell-like sounding box. To distribute the load and help the top plate withstand the downward component of string tension the viol makers glued to it a strip of wood running lengthwise down the middle. Whether by accident or by a stroke of genius, one of the earlier violinmakers moved the bar to one side so that one foot of the bridge rested above it. The strip, made of spruce, is now called the bass bar, since it is under the foot of the bridge on the side of the string of lowest tuning.

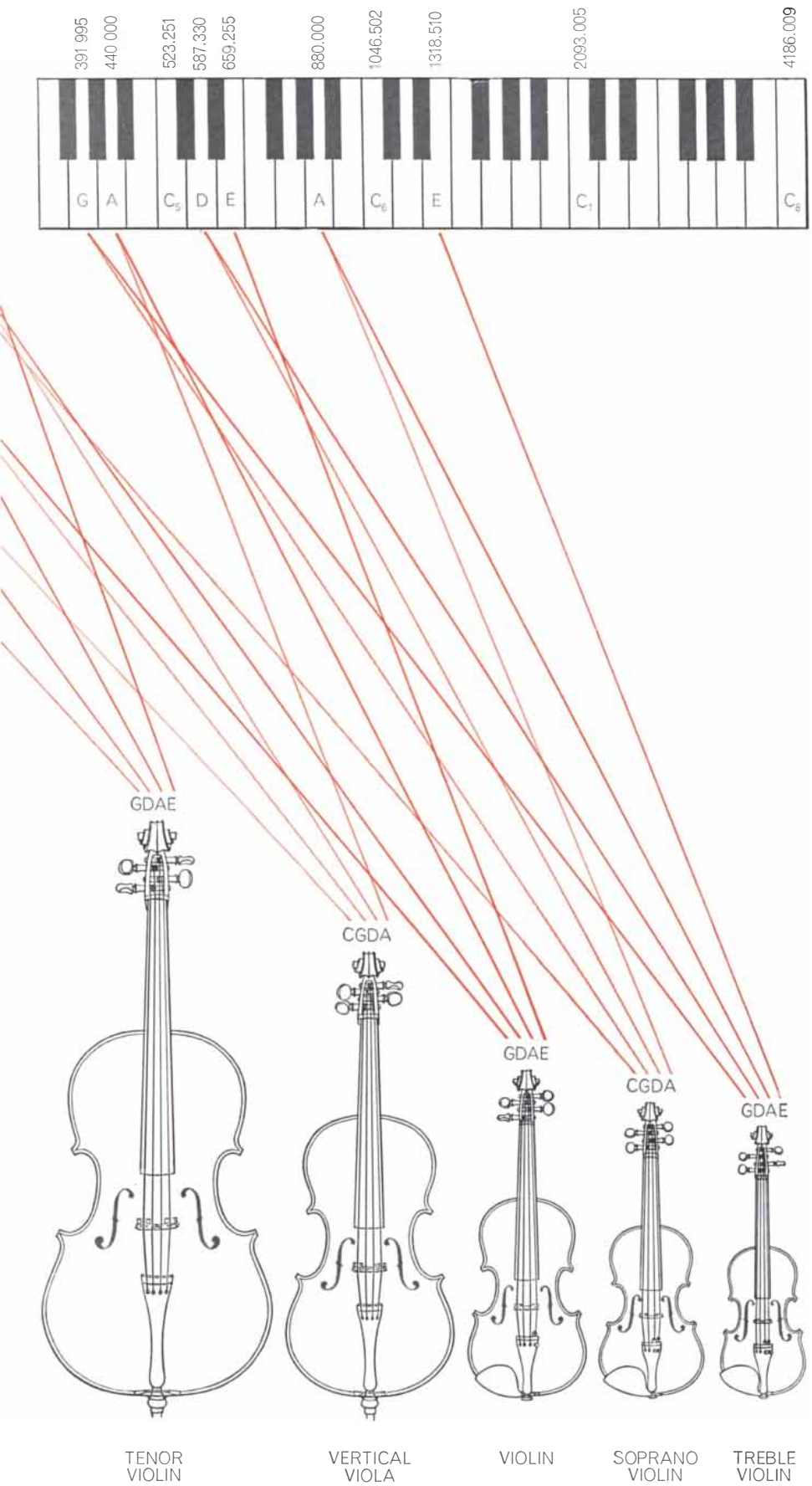
To support the other foot of the bridge there is placed approximately underneath it a vertical post, also made of spruce, called the sound post. It is carefully fitted and held in place between the front and back plates by friction. The acoustical function of the sound post has been a matter of debate for many years. The tone of a violin can be so greatly altered by small changes in the position, tightness and wood quality of the sound post that the French call it the soul (*l'âme*) of the instrument. Removing it altogether makes the violin sound rather like a guitar.

Although the modes of vibration of the plates exhibit great diversity throughout the frequency range, the bridge must always have some rocking motion to receive power from the string. In the important lower half of the range the sound post and the adjacent foot of the bridge have relatively little motion, thus providing in a sense a fulcrum that serves to transfer maximum travel to the bridge foot standing over the bass bar.

This too is getting a little ahead of the story, which begins when a bow is drawn across one or more of the strings of a violin. Vibrating strings have been stud-



NEW VIOLIN FAMILY will consist of eight instruments, twice the number of the present violin family. Of these the large bass and the treble violin are yet to be constructed; the small bass and the tenor and soprano violins are newly designed instruments; the new cello and vertical viola are rescaled instruments; the violin is the only member of the original family to be included in the new



group unchanged (*see illustration on next page*). The notes to which the four strings of each instrument are tuned can be read from the piano keyboard and the associated colored lines indicating the strings. The numbers at top show the frequencies in cycles per second.

ied since the time of Pythagoras. An early 19th-century French physicist, Félix Savart, showed that the bowed string has a multitude of harmonics; then the great German physicist Hermann von Helmholtz elucidated the types of vibration that distinguish the bowed string from the plucked string. In our own century the Indian physicist Sir C. V. Raman made an exhaustive investigation of the vibration of bowed violin and cello strings. It would be fair to say that the reaction of a string to a bow is quite thoroughly understood.

In spite of the vigorous vibration of the moving string, the sound from the string alone would be all but inaudible. It has too little surface area to set an appreciable amount of air in motion. Trying to make music with an unamplified string would be like trying to fan oneself with a toothpick. What happens is that some portion of the energy supplied by the player to the bow—perhaps 5 to 10 per cent—is communicated to the wooden body of the violin through the complex motions of the bridge. (Of all the energy that the player feeds into the violin, 1 or 2 per cent emerges as sound. The rest goes off as heat.) The vibrations of the bowed string at any instant include dozens of energetic harmonics with amplitudes falling off as frequency increases. Each of the frequencies present shakes the wooden box—"forces" it to vibrate—at its particular rate. Obviously the amplitude of vibration depends on the strength, or amplitude, of the forcing vibration.

The Resonant Box

If this were all there was to it, matters would be simple, and all tones would be amplified equally. But the wooden structure itself has scores of frequencies at which it tends to vibrate naturally. The coincidence of such a frequency of resonance in the wood with the frequency of a string harmonic will result in an enhanced transfer of energy from string to box and a correspondingly greater amplification of that particular tone. Therefore the actual response of a violin to the playing of various notes is an enormously complex affair, but a good violinist must unconsciously and automatically deal with it and compensate for it every time he plays.

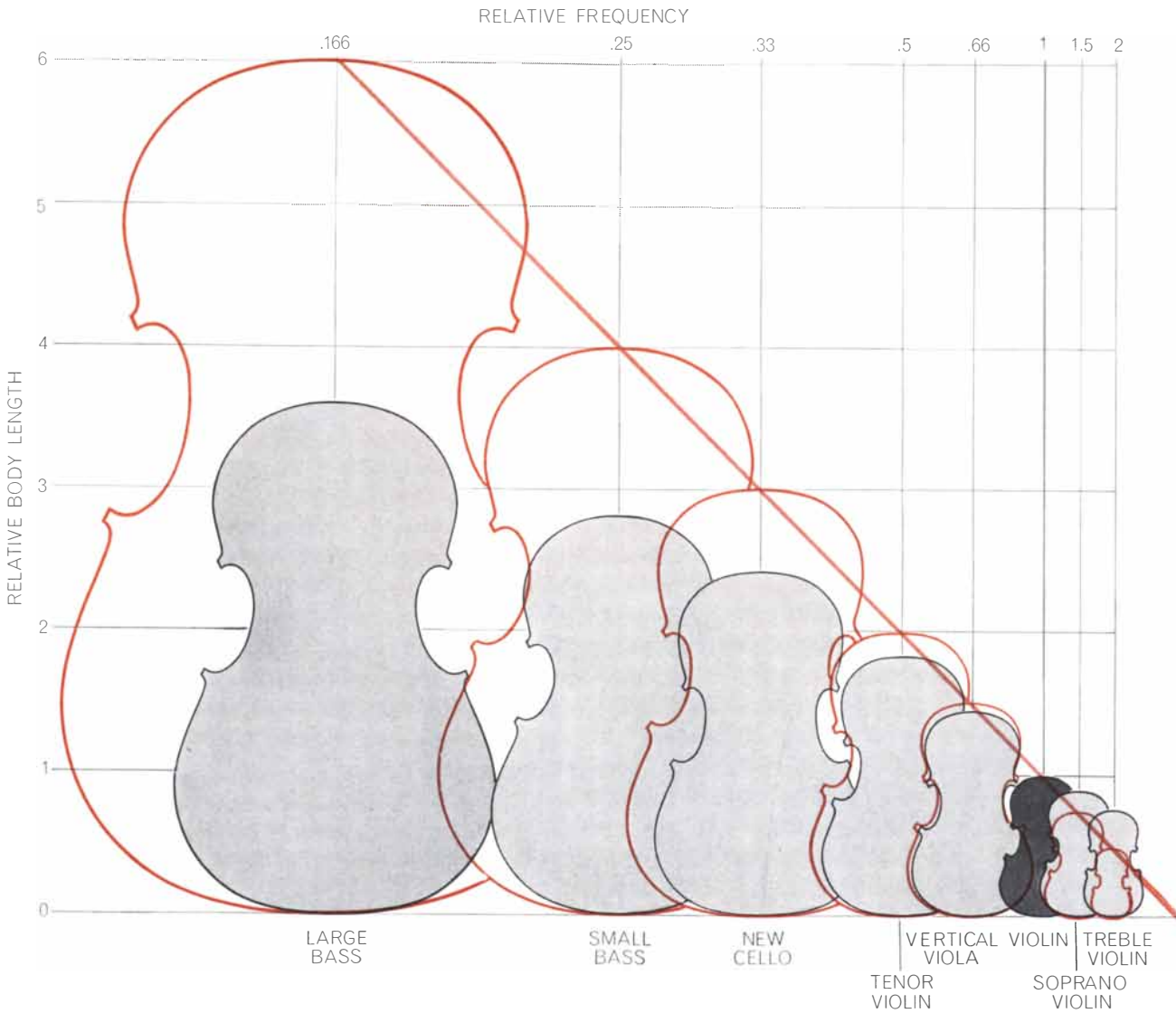
The scientific violinmaker is interested in all of these wood resonances, but he usually finds the resonance of lowest frequency an adequate guide during construction. This is called the main wood resonance. He is also interested in the lowest natural frequency (here only one

seems to have any measurable importance) of the enclosed air space, called the main air resonance. Tests show that a good violin usually has its main wood resonance within a whole note of 440 cycles per second: the note A, to which the second highest string of the instrument is tuned.

Some instruments have a "wolf note," almost always at the frequency of the main wood resonance. When this note is played on any string, the tone warbles unsteadily, often breaking by a whole octave somewhat as the voice of an adolescent boy does. The wolf note occurs when the string and the wood form a pair of mechanically coupled circuits; a beating action occurs because energy is cyclically shuttled back and forth between them. Violas and cellos are notoriously subject to wolf-note trouble. Even some of the finest cellos have bad wolf notes. It is possible to ameliorate this difficulty in a variety of ways, for example by tuning a length of string between the bridge and the tailpiece to the actual frequency of the wolf note. This absorbs enough energy to control the wolf. So far, however, the ideal method of control has not been found.

Inside the box of the violin is the air chamber, or resonating cavity, which communicates directly to the outside by means of the f-holes in the top of the instrument. As I have said, the enclosed air has so far been found to add measurable resonance to a range of tones surrounding one note on each instrument. The pitch of this main air resonance, or air tone, can be approximately located by blowing across the f-hole, as one might blow across the top of an empty bottle. (When one f-hole is covered lightly, this pitch is lowered.)

The frequency of the air tone is controlled by the volume of air enclosed by the box of the instrument and the combined area of its f-hole openings. The larger the air volume, the lower the frequency; the larger the f-hole area, the higher the frequency. These two variables can be calculated roughly. I have found that to raise the resonance of the enclosed air a whole tone requires approximately a 20 per cent reduction in air volume or a 59 per cent increase in f-hole area. Anyone looking at the handsomely shaped f-holes of a violin can appreciate that it is not practical to try to raise the frequency of the air



THEORETICAL AND ACTUAL SIZES of new instruments are compared. According to theory an instrument of a given relative frequency would have to be of the size represented by the colored outlines. In practice the size is that represented by the light gray areas. The relative frequency of an instrument (e.g., treble violin) is obtained by dividing the frequency of one of its strings (e.g., A) by the frequency of the corresponding string on the violin: 880 divided by 440 equals 2. The conventional viola, cello and double bass (*not shown in illustration*) have relative body lengths (using the violin as unity) of 1.17, 2.13 and 3.09 respectively.

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A man lies on the operating table, crippled with the exhausting tremors of Parkinson's disease. The surgeon guides a slender tube deep inside the patient's brain until it reaches the target area. Then liquid nitrogen, at 320 degrees below zero F., is fed to the end of the tube. Suddenly the trembling stops. The unearthly cold kills the diseased cells . . . and a once desperate human being has been given a new chance in life. ▶ Medical reports have indicated that not only Parkinson's disease but also other disorders causing tremor or rigidity have responded to this new technique in brain surgery. The operation has been described as easier on the patients than previous surgery, and they have been able to leave the hospital in a surprisingly short time. Also, encouraging results are reported on the use of cryosurgery, as it is called, to destroy diseased cells in other parts of the body. ▶ Through its division, Linde Company, Union Carbide was called upon by medical scientists for help in designing and making equipment to deliver and control the critical cold required in this new surgery. This dramatic use of cryogenics, the science of cold, is an example of how research by the people of Union Carbide helps lead to a better tomorrow.

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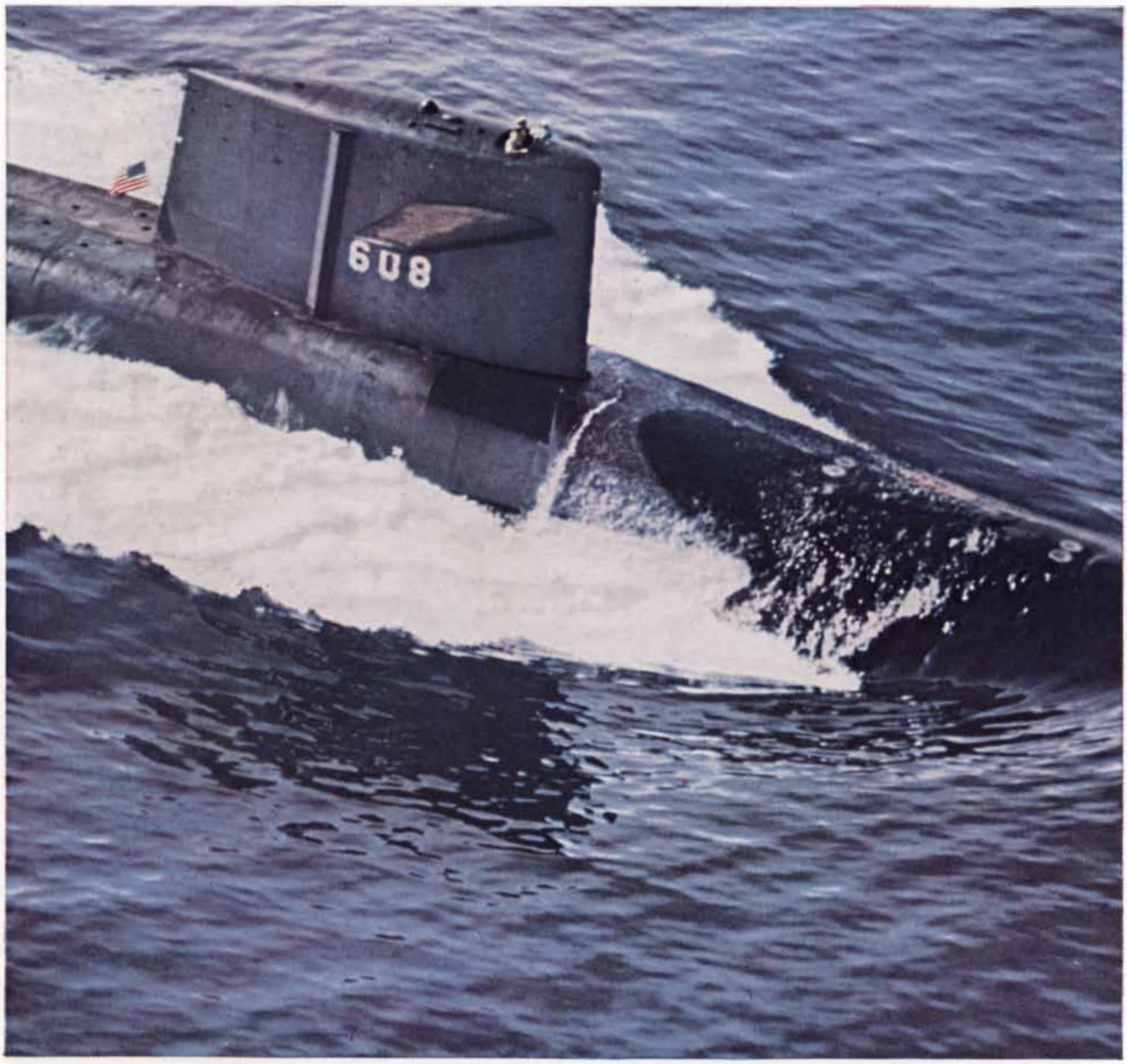

Photograph courtesy of General Dynamics

Quiet please – sub getting down to work

To men who go *under* the sea, avoiding detection by enemy listening devices can mean the difference between life and death. Many of the Navy's nuclear submarines (such as the Ethan Allen) run comfortably but quieter thanks to the whisper-quiet operation of air conditioning and refrigeration systems from York Division of Borg-Warner.

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resonance even a semitone by changing the size of the holes.

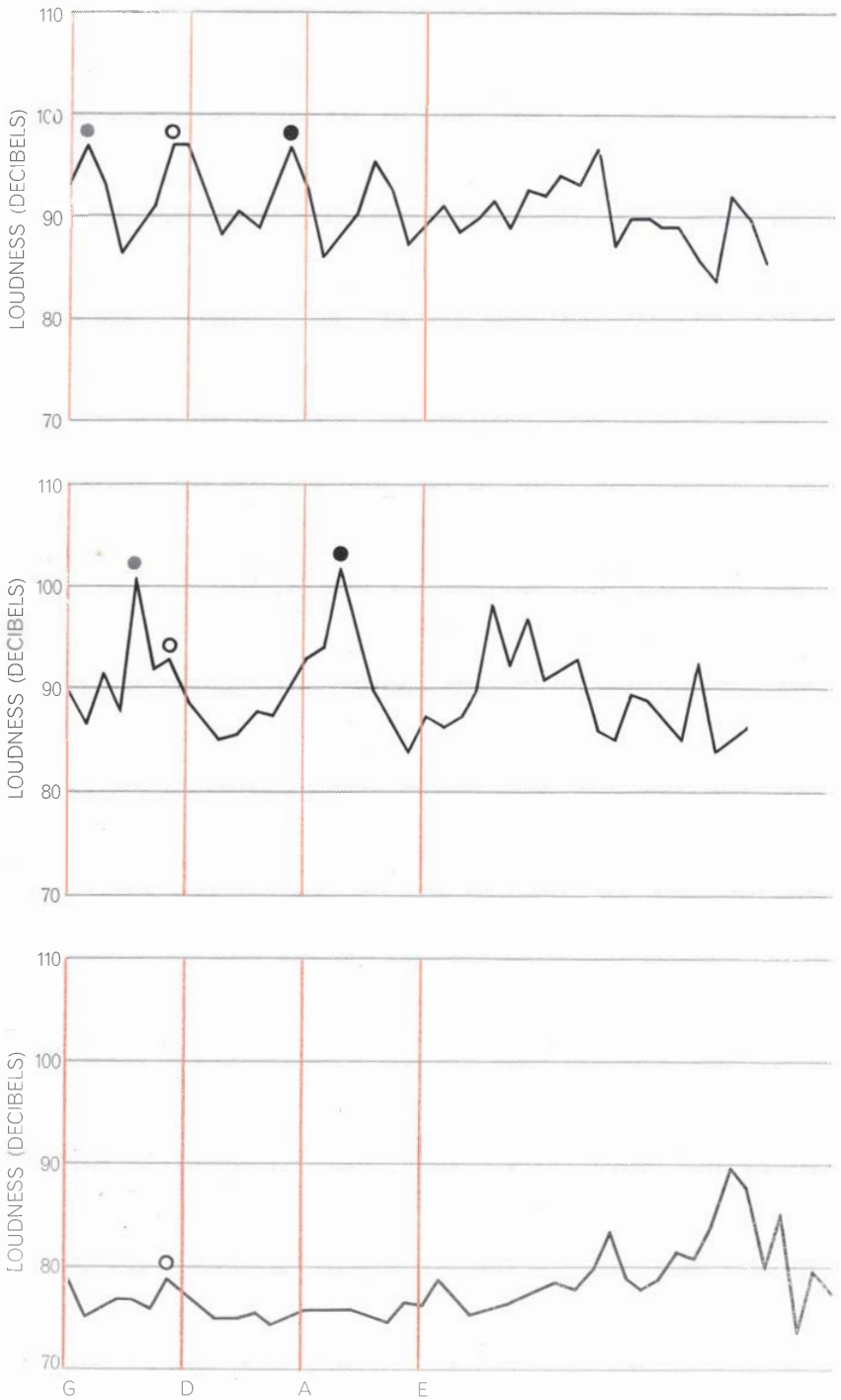
A number of workers—particularly Saunders, the late Hermann Backhaus of the Technische Hochschule in Karlsruhe, Hermann Meinel of Berlin, Gioacchino Pasqualini of Rome and E. Rohloff of the University of Greifswald—have developed methods of studying the resonances of violins. One of the most useful is the "loudness curve" originated by Saunders. It is also called the curve of total intensity, because it shows at each measured frequency the combined strengths of all the harmonics.

Loudness Curves

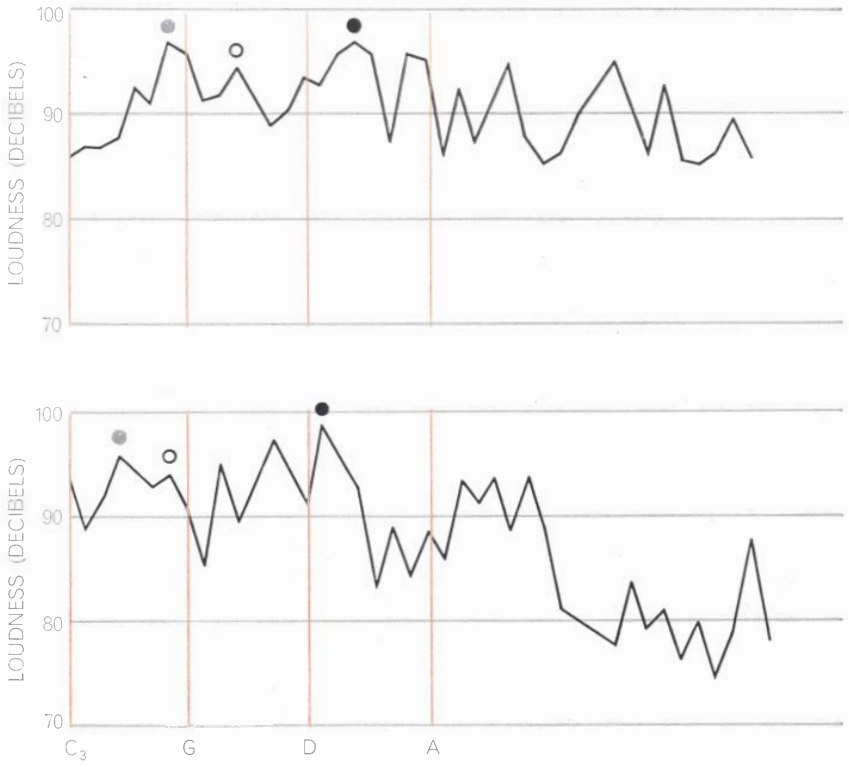
In making a loudness curve the violin is bowed normally, but without vibrato, at semitone intervals over its entire range to produce the loudest tone possible at each note. A General Radio sound-level meter, such as is used to measure levels of applause on television shows, records the loudness of each tone. It often comes as a shock to a musician to discover that his instrument is much louder at certain notes than at others. Try as he will he cannot possibly make them all register at an equally high level on the sound-level meter.

At the right are displayed loudness curves of a few violins, good and poor. In the good one the main wood resonance and the main air resonance fall approximately seven semitones, or a musical fifth, apart. (A fifth is the interval from "do" to "sol" on the diatonic scale. The frequency of each note is in the ratio of three to two for the note below it.) In some poor instruments the main wood and air resonances may be as much as 12 semitones, or an octave, apart (frequency ratio, two to one), giving two areas of strong resonance with a wide range of weak response between. The curve for one poor instrument shows only one area of strong resonance—the air resonance—with the wood contributing virtually nothing in the way of resonant reinforcement. A $5 violin with a curve almost as bad was used by Saunders for some time as his "standard" of badness. When I took the wretched thing apart and balanced it for good tone production, it showed an overall increase of loudness and an even spacing of peaks. At this point it was named Pygmalion. When it was played behind a screen in alternation with an excellent Cremona violin, the two were voted equal in tone by a college music department audience. In fairness it should be added that the skilled musician playing behind the screen was never in any doubt as to which was the superior instrument.

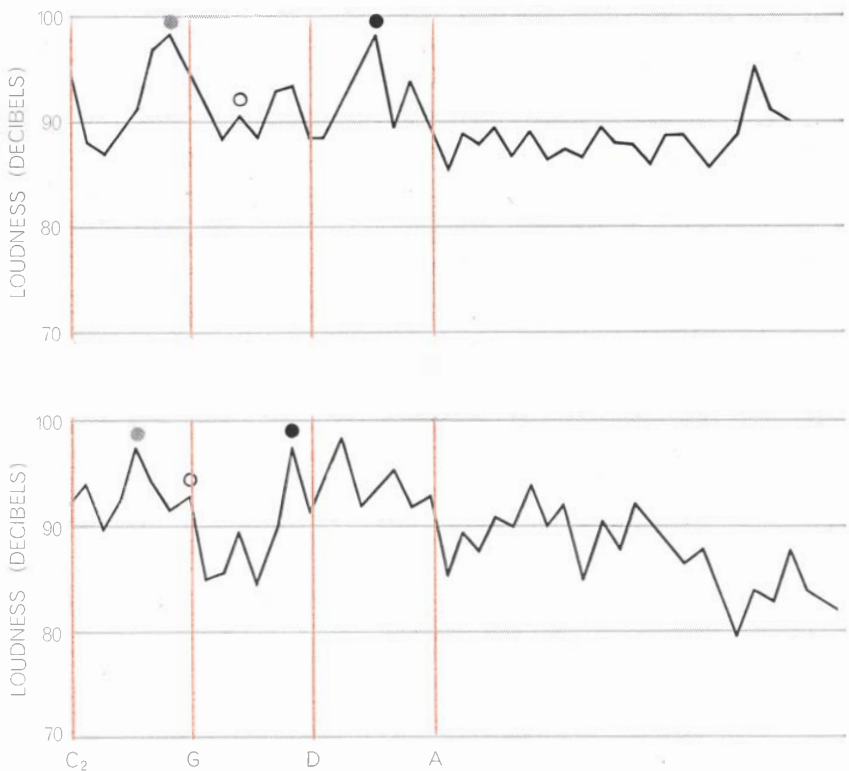
An octave below the main wood resonance there is almost always another strong peak of loudness that we label "wood prime." It can be called a subharmonic. It is well known in acoustics that if one harmonic of a complex tone is strengthened, the ear will hear an increase in loudness of the note as a whole with a slight change in quality but no change in pitch. By this process the wood peak is strengthened by the tone of the main wood resonance an octave above. The subharmonic of the main wood reso-



VIOLIN "LOUDNESS CURVES" compare maximum sound levels produced at semitone intervals by a good 1713 Stradivarius (*top*), a poor 250-year-old violin of doubtful origin (*middle*) and a poorer, somewhat older instrument credited to P. Guarneri (*bottom*). Only the first shows desirable spacing and strength of wood (*black dot*), "wood prime" (*gray dot*) and air resonances (*open circle*). Letters at bottom indicate tuning of open strings.



VIOLA LOUDNESS CURVES compare the responses of a conventional (*top*) and a vertical viola (*bottom*), both made by the author. The convention of dots and colored lines used in this illustration and that below is the same as in the illustration on preceding page.



CELLO LOUDNESS CURVES compare the responses of a conventional (*top*) and a new cello (*bottom*), both made by the author. Note that the main wood and air resonances of the new viola and cello are near the two open middle strings. The loudness curves on this and preceding page are based on tests performed by Frederick A. Saunders of Harvard University.

nance benefits the lower tones of the violin, viola and cello.

The subharmonic of the main air resonance does not show on curves of conventional instruments because it falls below the bottom notes of the instruments. Spacing the main wood and air resonances about a half-octave apart spreads these peaks so that the air-tone peak falls nicely in the middle of the octave between the wood resonance and its subharmonic. In hundreds of tests of violins, violas and cellos this arrangement of wood and air resonances emerges as one of the characteristics of the good instruments.

Experimental Instruments

I have built a series of experimental violins and violas to test the effect of moving the frequencies of the main resonances up or down the scale. In a pair of violas of similar pattern with identical f-holes, one was made with sides half an inch high to decrease the air volume; the other had sides two inches high, giving a large air volume. Normally the sides of a viola are about 1½ inches high, and the air tone is found to be in the range from B to B flat (233 cycles per second) on the G string. In the viola with the smaller air volume the air tone, as expected, moved up the scale to D sharp (300 cycles per second). In the one with the larger air volume the air tone moved downscale near A (220 cycles per second).

In both of these altered violas the normally strong tones of the B to B flat on the G string were missing, because the air resonance was no longer there to reinforce them. Musicians playing the instruments discovered interesting features. Neither one was suitable for playing the two-viola quintets composed by Mozart. The composer had written so well for the normally strong tones of the viola that the oustanding parts lacked their full expressive qualities when the experimental instruments were used. The strong resonance of the air tone was not where musicians expected to find strength, nor where Mozart had counted on it.

The most interesting feature of the two violas was that the thin, shallow instrument had a full, rich tone and a particularly strong, low C string, where the normal viola is notably weak. This was because the air tone had been shifted upscale enough so that its subharmonic came into useful range near 150 cycles per second on the low C string.

The thick viola with the two-inch ribs,

on the other hand, had a thin tone, and the lower range of its C string was weak, partly because the air tone had been moved from its normal position. Many musicians playing the two violas in alternation have remarked with astonishment at the full, rich tone of the thin one with the small air volume. Ribs half an inch high are structurally not very practical, but application of the principles involved has made possible the construction of good small violas.

In studying the resonances of violins I have discovered that in the best violins the main wood and air resonances invariably fall within a semitone or two of the frequency of the two open middle strings, the wood resonance corresponding to the higher-tuned string. When the early violinmakers hit on this arrangement, the muses must have been smiling. It is, quite simply, the way in which most good violins have been made ever since.

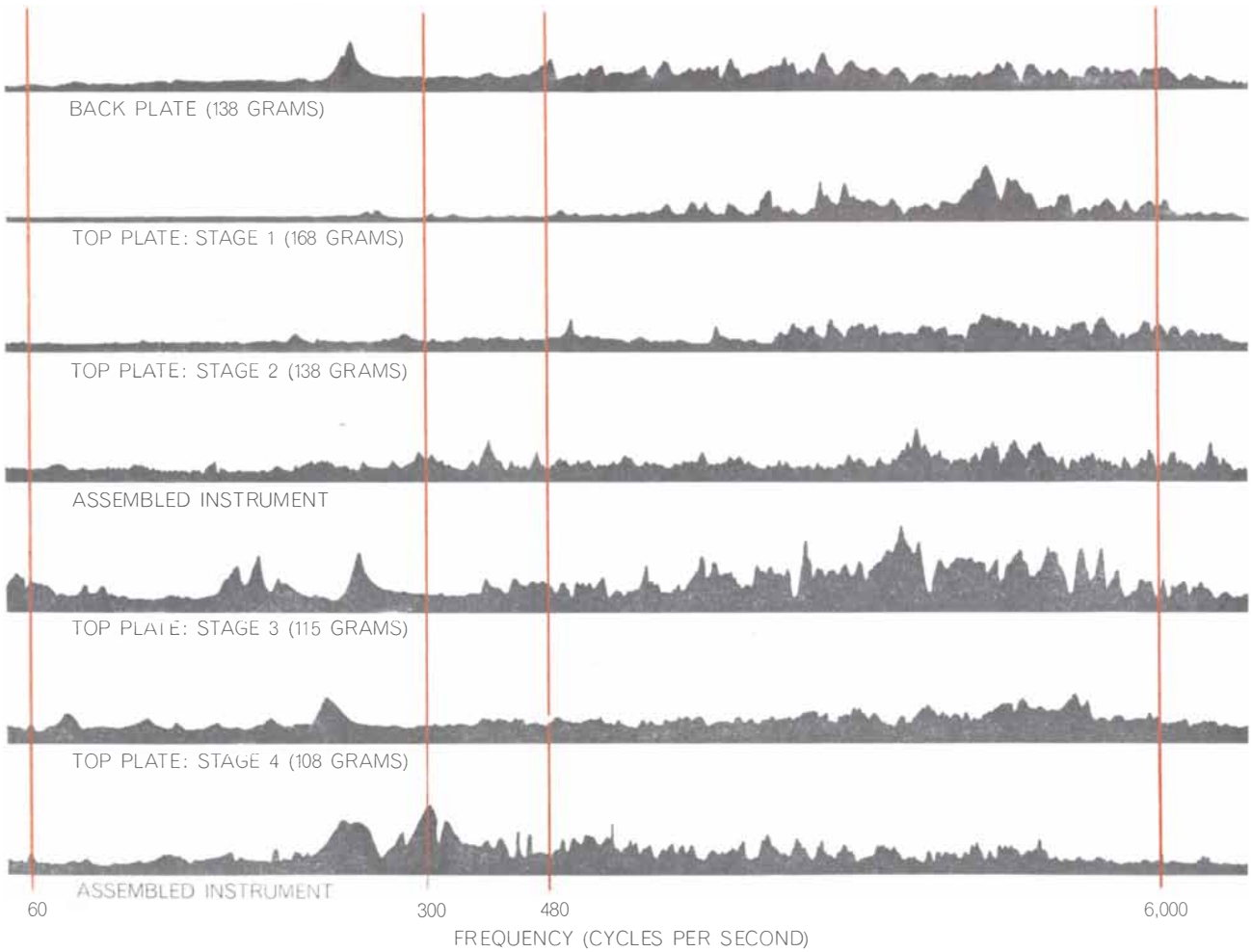
This is not true of the viola and cello. In these instruments as they are now built the wood and air resonances fall three to four semitones higher with respect to the frequencies of the open middle strings than they do in the violin. The reason is simple enough: the viola and cello are built smaller than optimum size to make them a convenient playing size. As a result the resonances are too far above the lower notes of the instruments, and these suffer in strength and quality. I shall have more to say about this matter later.

Tap Tones

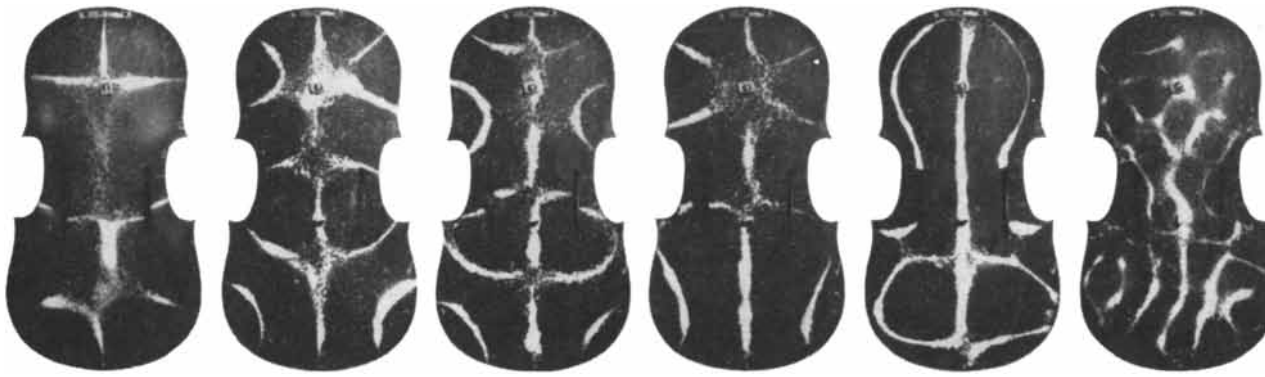
At the moment I should like to consider a different problem. Assuming one knows what the violin should be like when it is finished—where its resonances should fall and so on—how are these aims achieved in the process of construction? How does one make it come out the way one wants it? In addition to careful workmanship and accurate measurements the traditional method of the violinmaker has been to listen to the "tap tones" of the front and back plates.

In the final thinning and graduating of the top and back plates of a violin, the maker traditionally holds the plate near one end in his thumb and forefinger, taps it at various points with a knuckle and listens carefully to determine the pitch of the sounds he hears. These sounds are called the tap tones of the plates. The ability to judge the proper relation of tap tones of the free top and back plates in this manner is an important part of the art of violinmaking. With the ear alone it is extremely difficult to make out the frequencies of these tones, particularly in the case of the top plate, where the complicated structure with f-holes and bass bar creates at least two, and sometimes as many as five, strong natural resonances below 600 cycles per second.

Saunders and I, together with Alvin Hopping of Lake Hopatcong, N.J., have developed a method that makes it possible to determine the tap-tone frequencies in a free plate with considerable



FREQUENCY-RESPONSE CURVES of top and back plates of a viola and of the assembled instrument at various stages are depicted. Although the tests run from 20 to 20,000 cycles per second, most of the response to the magnetic driver used to vibrate the wood falls in the range of 60 to roughly 10,000 cycles per second. The four frequencies indicated here are those at which checks were made to ensure that the recording film was synchronized with the audio-generator. Height of peaks represents amplitude of response.

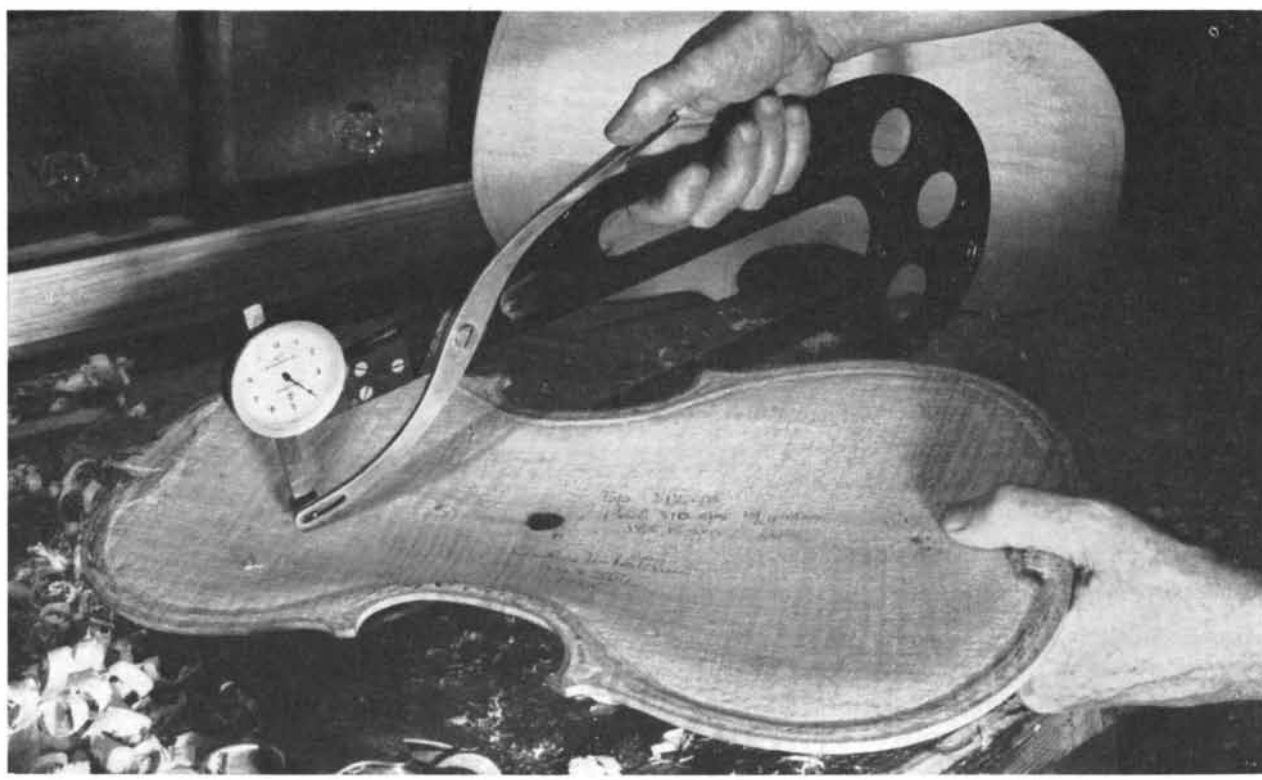


CHLADNI PATTERNS discussed in the text were made on a brass plate by Saunders at frequencies of 260, 340, 435, 520, 780 and 1,600 cycles per second. The plate is supported horizontally by a bolt at the center of its upper half; bottom end rests on a padded block.

accuracy. First we cut a flat brass plate in the shape of the violin plate. We dust it with powder and bow it at various points around the edge to set up different modes of vibration. Where the plate vibrates, the powder is bounced away, piling up along the nodal lines where there is no vibration. From these "Chladni" patterns on the brass [*see illustration above*] we are able to predict where a principal nodal point in the frequency test range will fall on the mid-line of a real violin plate. Since clamping on a nodal point does not affect the vibration pattern, we then clamp the violin plate at this point and set it into vibration at its exact center by means of a magnetic driver, activated by an audio-frequency generator, that can be varied from 20 to 20,000 cycles per second. The response of the wood plate to the input signal, which has variable frequency but constant amplitude, is picked up by a microphone and fed to an oscilloscope or a sound-level meter. The amplitude and frequency of the points of greatest response can be recorded manually. Better still, a "photostrip" can be made by pulling a film across the oscilloscope face at a speed synchronized with the sweep of the audio-frequency generator.

Once we had established the testing procedure we could address ourselves to a question that had been worried for several hundred years and that had been answered in a number of different ways: What sounds should the top and back plates of an instrument produce before they are joined?

In 1840 Savart reported that "a top of spruce and a back of maple tuned alike produced an instrument with a bad, weak tone." He took the plates off a number of Stradivarius and Guarnerius violins (imagine!) and tested them, finding that the tap tones varied "between C sharp 3 and D3 (in the octave above middle C) for the top, and D3 and D sharp 3 for the back, always one tone or one semitone difference, the



MEASURING PLATE THICKNESS makes it possible to determine where thinning can be done while maintaining a fairly uniform pattern of thickness. The measuring device, or caliper, consists of a dial gauge attached to one arm of an extended metal U.

back being higher than the top." Some violinmakers have held that the back should be a tone lower than the top; others, that the plates should be tuned to the same frequency.

My own findings are as follows: In the range of 120 to 600 cycles per second there may be one, two and possibly three peaks in the back plate and perhaps two or three more than that in the front. When the peaks of the front plate alternate with those of the back and the adjacent peaks are within about a semitone of one another, I get a good instrument. When the peaks coincide or are more than a tone apart, I get a bad one. Moreover, an average of the frequencies of the tap tones from front and back turns out to be just about seven semitones below the main wood frequency of the finished violin.

These conclusions are drawn from more than 400 photostrips of top and back plates of 35 instruments in the process of construction. After the plates were tested the instruments were assembled and then judged for tone quality by three criteria: (1) loudness test, (2) photostrips of the completed instrument and (3) actual playing by professionals. Then one plate, usually the top one, was removed and thinned, tested again and the instrument assembled for reappraisal. The back plate was thinned only when the top plate became so thin that it could no longer support string tension with safety. The entire thinning and testing process was sometimes repeated four or more times until each violin, viola or cello was judged to be good. So far I have spent six years on the program.

With our tap-tone test it is possible to follow the position of the main wood vibrations as they drift to lower frequencies when the wood is thinned and becomes more flexible. With a little practice one learns how to remove a few grams of wood from certain areas with a scraper or small plane and to estimate that the plate peaks (strong natural resonances) will move downscale, say 10 cycles per second. In some cases such a shift can make the difference between a good and a poor instrument.

As a kind of acid test of the theory I made a cello with the plate peaks matching; this is of course exactly wrong. During the next two years I gave the cello to several different cellists to play. All of them admired the workmanship and tried to be complimentary about the tone and playing qualities. The more forthright of them said that the tone was harsh and gritty in spots and weak in others and that the instrument was particularly hard to play softly.

Finally I took the plates off, tested them again and removed about 10 grams of wood from the edges of the top plate so that the peaks of the top alternated with those of the back. In this condition Mischa Schneider played the cello in a concert by the Budapest String Quartet and pronounced it to be *magnifico*.

The greatest difficulty with the tap-tone test on a finished instrument is that both the top and back plates must be off at the same time so that they can be tested under the same conditions and without the complication of drift in the measuring equipment. The removal of both plates is a touchy operation even for an expert. With the help of several co-operative violinmakers, however, we have been able to test the plates of a few good old violins. More such tests are needed for definitive comparisons.

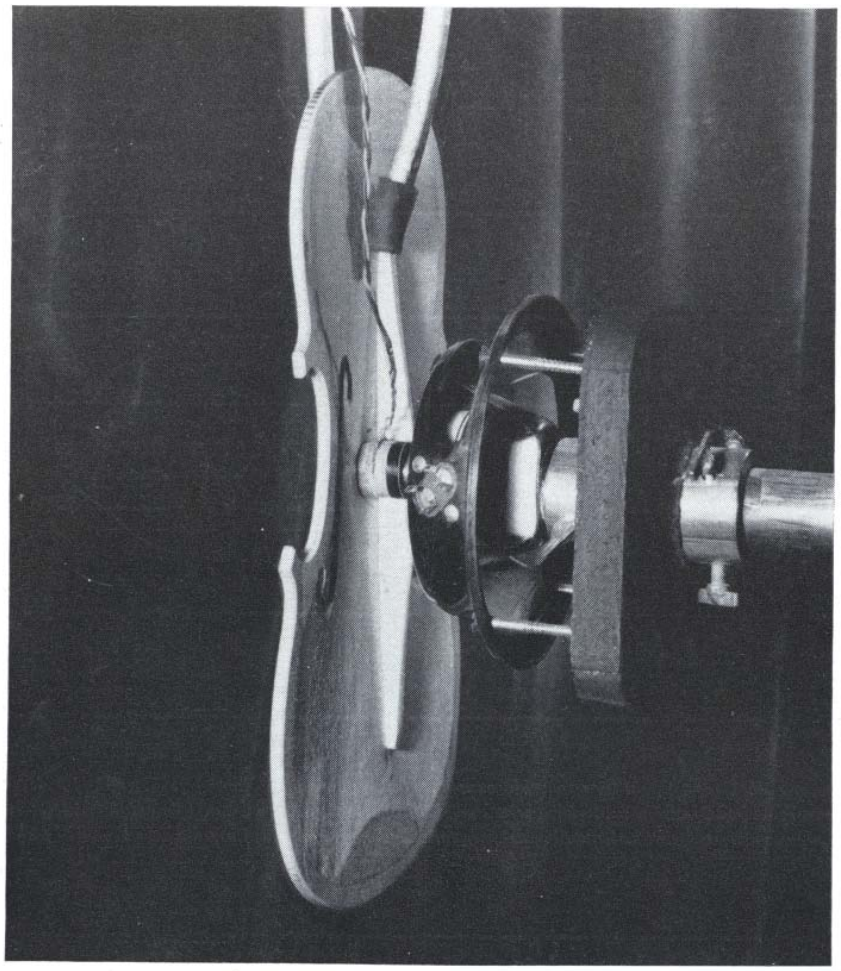
New Violins

It has been hundreds of years since the violin won its battle with the viols. The victory was not an unmitigated blessing. The variability of the shape of the viols, and particularly their flat back plate without a complicated set of resonances, meant that the instruments could be built in a variety of sizes that easily covered the entire range of pitch represented by the piano keyboard. On the other hand, the violin family leaves substantial gaps in coverage and, as has already been pointed out, its two deeper-voiced members do not have optimum musical characteristics.

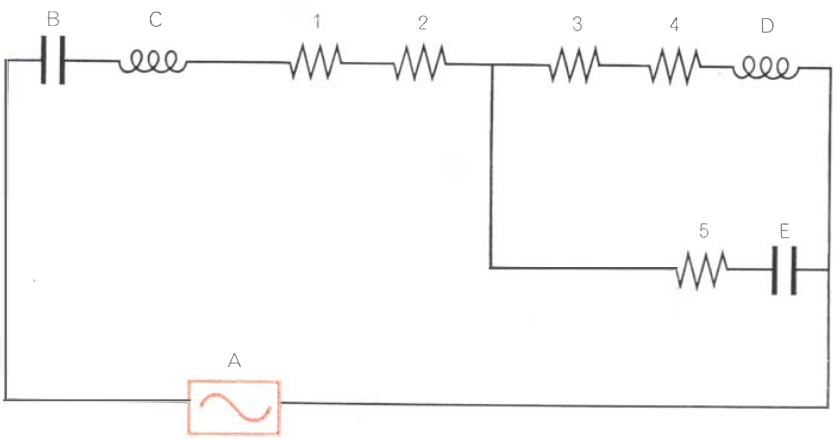
Buried in private collections and museums there is a neglected but rich repertoire of polyphonic string music from the Renaissance period written for viols. Their characteristically thin and nasal, but uniform and distinctive, timbre blended well with the clavichord and cembalo, which were played at the courts of Renaissance nobles. Many of these gentlemen kept a chest of viols, usually consisting of six instruments, two each of the treble, alto and tenor sizes.

For contemporary performance of the viol repertoire, however, the old instruments are unsuitable. They do not have the variety of timbre that the violin has taught the modern ear to expect, and they do not have nearly the power to satisfy the requirements of a concert hall of even moderate size. On the other hand, the present family of violin, viola and cello have too much inequality in timbre and too great gaps in pitch to play the music as it was written.

The need for new instruments of the



MAGNETIC DRIVER used in frequency-response tests is placed at the exact center of a top plate. The wires leading from the driver are connected to an audio-frequency generator that activates the driver over a range of frequencies from 20 to 20,000 cycles per second.



SIMPLIFIED ELECTRICAL CIRCUIT shows the nature of the two main resonances discussed in the text. The current from a constant-amplitude alternating-current generator (*A*) is analogous to the force applied by a given string to the bridge; this force is proportional to the string tension and amplitude of string vibration. The first capacitor (*B*) is analogous to a stiffness associated with the elasticity and dimensions of the wood: the first inductance coil (*C*) is analogous to a mass moving with the velocity of the bridge-string contact and having a kinetic energy equal to that in the wood. In instruments of the violin family the stiffness and mass of the wood largely determine its over-all response and the frequency of the main wood resonance. The main air resonance is determined largely by opposition of the air to compression when the f-holes are closed (*E*) and the mass of the air near the open f-holes (*D*). The five resistors in the circuit represent mechanical or acoustical resistances.

violin type has been considered by musicians and violinmakers for many years. The present work of developing the new instruments was initiated when Henry Brant, the composer-in-residence at Bennington College in Vermont, came to us with the problem. Brant felt that modern musicians, faced with the need to find an expressive language appropriate to the present day, are ever seeking to extend the powers of the bowed string instruments. The violin family remains the composer's most eloquent and expressive vehicle among all the instruments so far devised in Western music, but its members have been essentially unchanged for 200 years. More and more the need is being recognized for a gamut of graduated instruments of the violin type, with each member well enough developed to meet the test of solo as well as ensemble playing.

Changing the classical dimensions of the violin to create instruments of varied sizes and tunings has been tried many times without success. Now the necessary knowledge is at hand. I have indicated that the variables in the design of the violin are close to optimum. The object is to keep the two main resonances on the two open middle strings in spite of changes in size and tuning. It can readily be appreciated that it is no mean task to arrive at the correct proportions among physical variables—size, thickness and stiffness of wood, tightness of stringing and so on—that will produce the desired result in the resonance. For me it has meant years of literal cut and try, but with the help of scaling theory I am now close to having a set of empirical rules for making a genuinely complete family of instruments of the violin type. In doing this I have drawn heavily on the knowledge gained by other violinmakers who have tackled the same problem but without success because they did not have the benefit of modern acoustical physics. I have already built revised versions of the viola and cello, enlarging them somewhat to bring the resonances down to the frequencies of the open middle strings. As a result my viola has to have a peg at the bottom, like a cello, and is played between the knees. In addition I have added two new instruments to the family (one replaces the bass). This past January the six scaled members of the violin family were tried out at an informal concert, which a number of professional musicians found interesting and challenging as well as aesthetically pleasing. The smallest and the largest of the new instruments have not yet been finished and are giving the most trouble. Although scaling theory

tells us what to do, we are up against the limits of available materials and the human physique. For the smallest instrument, which is tuned an octave above the violin, material of sufficient tensile strength for strings is the major problem. Few materials have the strength to vibrate within the requisite range of frequencies and still provide strings long enough to allow the player to finger consecutive semitones. In the largest instrument the designer faces the mechanical problem of making it possible for the musician to bow and finger simultaneously.

Other violinmakers have experimented with instrument size. In the 19th century Jean Baptiste Vuillaume introduced a new model of the viola with an exceptionally large air volume, constructed on the scientific principles of Savart. He also developed a huge double bass, known as the *octobasse*, that was tuned by means of levers. Fred Dautrich of Torrington, Conn., spent much of his time during the 1920's and 1930's working on a graded series of instruments of the violin type that he called the vilonia, the vilon and the vilono. I have been fortunate enough to obtain a set of these. They are of such excellent workmanship and proportions that it has been possible to modify them slightly by applying scaling theory and adapt them to our present series of instruments.

In the past few years J. C. Schelleng, formerly of the Bell Telephone Laboratories, has been studying the violin as a circuit, one of the standard techniques of acoustics in which the various mechanically vibrating parts are treated in a manner analogous to the elements of an electrical circuit. Although the violin is exceedingly complicated, it possesses many simplicities not usually recognized. These, along with the fundamental physics of the instrument, permit the definition of "circuit elements" and lead to relations difficult to find empirically. This circuit concept is already being of great help in perfecting the new instruments, defining such problems as string tension, the mass of the box and the stiffness of the plates.

To sum up, I believe that, without ignoring the precious heritage of centuries, the violinmaker should become more conscious of the science of his instrument, and that the acoustical physicist should see that here is a real challenge to his discipline. We really ought to learn how to make consistently better instruments than the old masters did. If that challenge cannot be fulfilled, we should at the very least find out the reasons for our limitations.

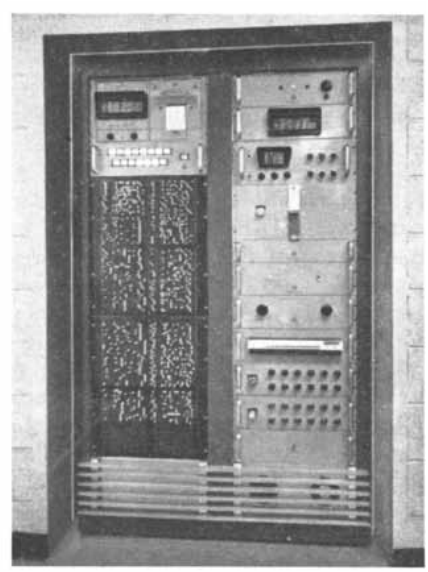
"Computing" data logger simplifies complex test problem

By WILLIAM KIEVIT
District Manager, Nutley, N.J., Office, Non-Linear Systems, Inc.
MILTON BAXTER, Group Leader, Product Development Laboratory
Cities Service Research and Development Co., Cranbury, N.J.

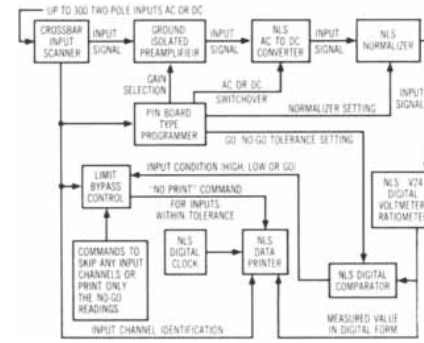
PROBLEM: In comparing the performance of fuels and lubricants under actual operating conditions, Cities Service Research and Development Company faced a problem. In short, it was to monitor the operation of many internal combustion engines running simultaneously to ensure uniform test conditions.

TO BE SPECIFIC: Engineers of Cities Service and Non-Linear Systems, Inc., worked together to meet these requirements:

- Collect, measure and record large amounts of data quickly, accurately and reliably.
- Automatically evaluate each measurement as it is made and, when desired, record only data deviating from preset limits.
- Optionally present measurements in several ways: (1) voltage, (2) percentage (with 100% "normal"), (3) per cent deviation from "normal," or (4) engineering units such as pressure, temperature, etc.
- Provide unattended, uninterrupted testing.
- Sound an alarm for abnormal conditions.
- Provide for fast, simple change of system programming.



This universal data logger features simple programming, as illustrated by the pin-type Sealectro programmer board (left portion of system).



Simplified functional chart showing versatility of the system.

SOLUTION: A versatile, computing data logger formed of a time-proven NLS V24 Digital Voltmeter and other standard instruments was the answer. In 15 seconds, the system makes, evaluates and records 20 measurements of temperature, fuel flow, speed, torque and pressure from any of 15 engines running simultaneously. A digital comparator can activate an alarm when measurements vary from pre-set limits. Or an operator can easily program the system to record only abnormal values, eliminating tedious data sorting.

Rearranging pins on the Sealectro programmer board (left section) programs amplifier gain, selection of AC or DC measurement (depending on the transducer type used), normalizer setting and go/no-go limits for each input channel — over 3 billion settings in all. A digital clock provides unattended testing.

To eliminate manual data computation, the system's preamplifier and normalizer can act as computing elements to convert data to engineering units or percentages. Or, the system can check an engine two ways during each test, once in engineering units and once in percentage.

FOR MORE INFORMATION: For competent advice on digital techniques as utilized in this system, contact one of 19 NLS factory offices or Non-Linear Systems, Inc., Del Mar, Calif.

CHEMICAL TOPOLOGY

Although molecular rings are quite familiar, it has only recently been demonstrated that two such rings can be linked. It may even be possible to synthesize molecules in the form of knotted rings

by Edel Wasserman

Organic molecules, having a great range of sizes, also have a rich variety of architectural forms. These days chemists are increasingly interested in the three-dimensional arrangement of the atoms of a molecule; this spatial structure is often an important element in determining the properties of a substance. In the past few years some of us at the Bell Telephone Laboratories have been examining a novel aspect of the organic structure problem, involving what might be called chemical topology.

What we have done, in brief, is to prepare and identify a structure we call a catenane (after *catena*, the Latin word for "chain"), which consists of two closed-ring molecules that are linked more mechanically than chemically, each simply threading the other. In one chemical sense a pair of closed rings constitutes the same structure, threaded or not. Each ring can be described independently of the other. Chemically they share no bonds and are in this sense independent. Topologically the cases differ, in the sense that two unjoined rings cannot be converted to a joined pair, or vice versa, without breaking one ring. A macroscopic pair of unjoined rings can lie flat on a table; a joined pair cannot.

What about the chemical properties of catenanes? That is what we are looking into. Certainly the breaking of a chemical bond in one of the rings is required to convert one form to the other. Therefore the two can be called topological isomers. (Isomers are molecules containing the same atoms in different configurations.) The chemical significance of topological isomers is a large, unexplored field that we and a few others are just beginning to investigate.

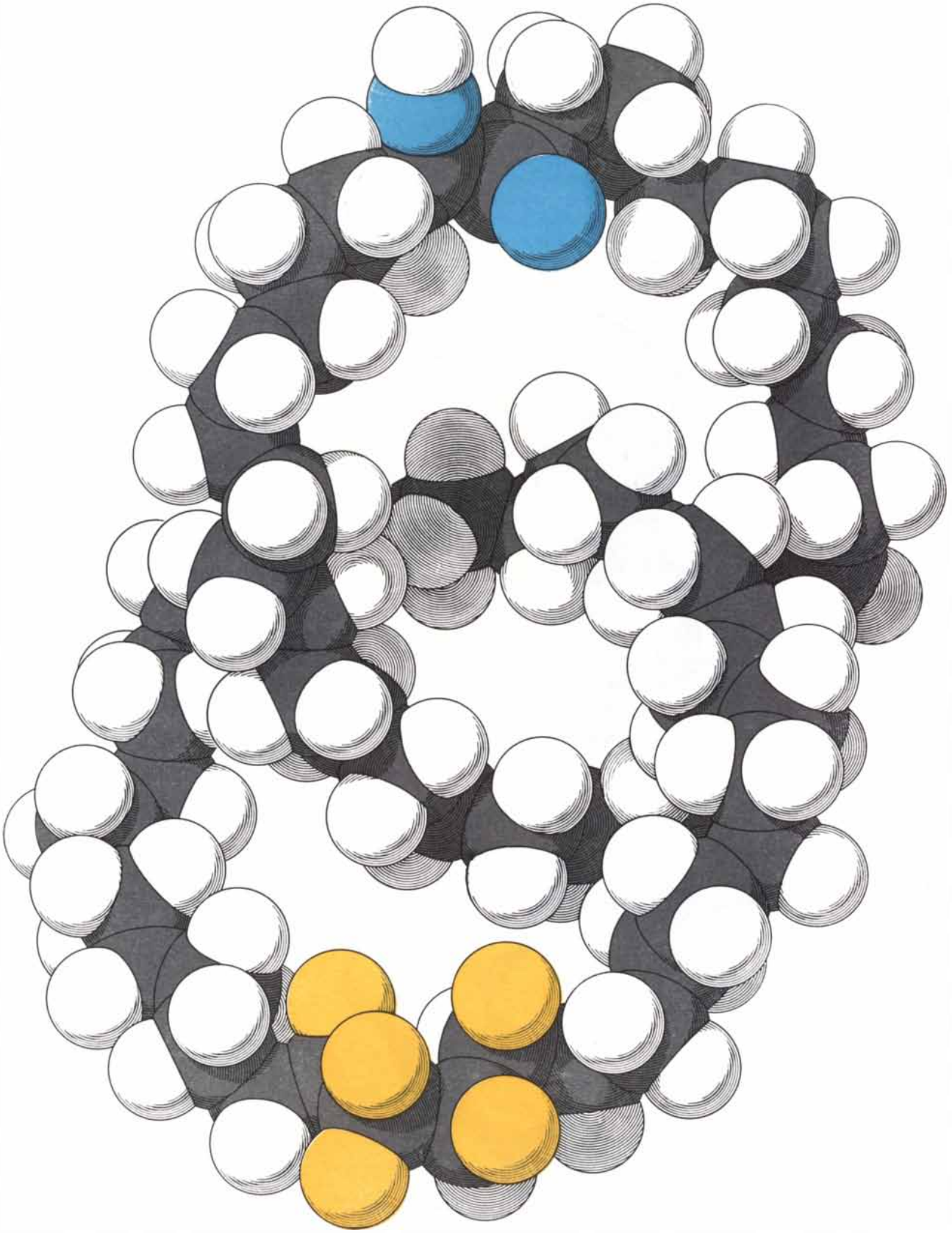
Most readers, in thinking of ring molecules, probably will envisage the six-carbon benzene ring and others of about the same size that appear so profusely in structural formulas of organic compounds. These are not the kind of rings with which we are dealing. Their structure resembles that of a doughnut swollen to such an extent that the space in the middle has almost disappeared. With the addition of more carbon atoms to the straight molecule whose ends are to be joined to form a ring, some empty space appears. Not until the hole is big enough to admit a second straight segment is it possible to form a catenane.

Working with accurately scaled models of CH_2 groups, the chief units in the precursor straight molecules, we were able to determine that a ring would have to contain 20 CH_2 units before another unit could thread it without having to overcome large repulsive forces from the ring molecules, as would be the case in a tight fit [*see illustration on page 96*]. Anything bigger, of course, would make the threading easier, but larger molecules are harder to make and harder to handle because of their decreased solubility. Our compromise was a 34-carbon ring, which makes what we designated a 34, 34 catenane. It should be mentioned that our rings, and most large rings, have no double bonds between carbon atoms as the benzene ring does.

We were by no means the first to think of making linked-ring compounds. More than 50 years ago the German chemist Richard Willstätter considered the possibility. The ring molecules known at the time, however, were too small. In the 1920's the Swiss chemist Leopold Ruzicka developed methods for making rings with as many as 34 carbon atoms, but these methods yielded only a tiny proportion of large rings. Finally in 1947 two other Swiss chemists, V. Prelog and M. Stoll, independently developed a general method of making large rings in quantity. Any of the several methods available today for producing large rings must also yield some catenanes, and by the same process as ours. We do not push straight molecules through rings; we simply rely on the law of averages to do it for us a small percentage of the time when rings and straight molecules are mixed. According to calculations by H. L. Frisch of the Bell Laboratories a few per cent of the 34-carbon rings can be expected to interlock.

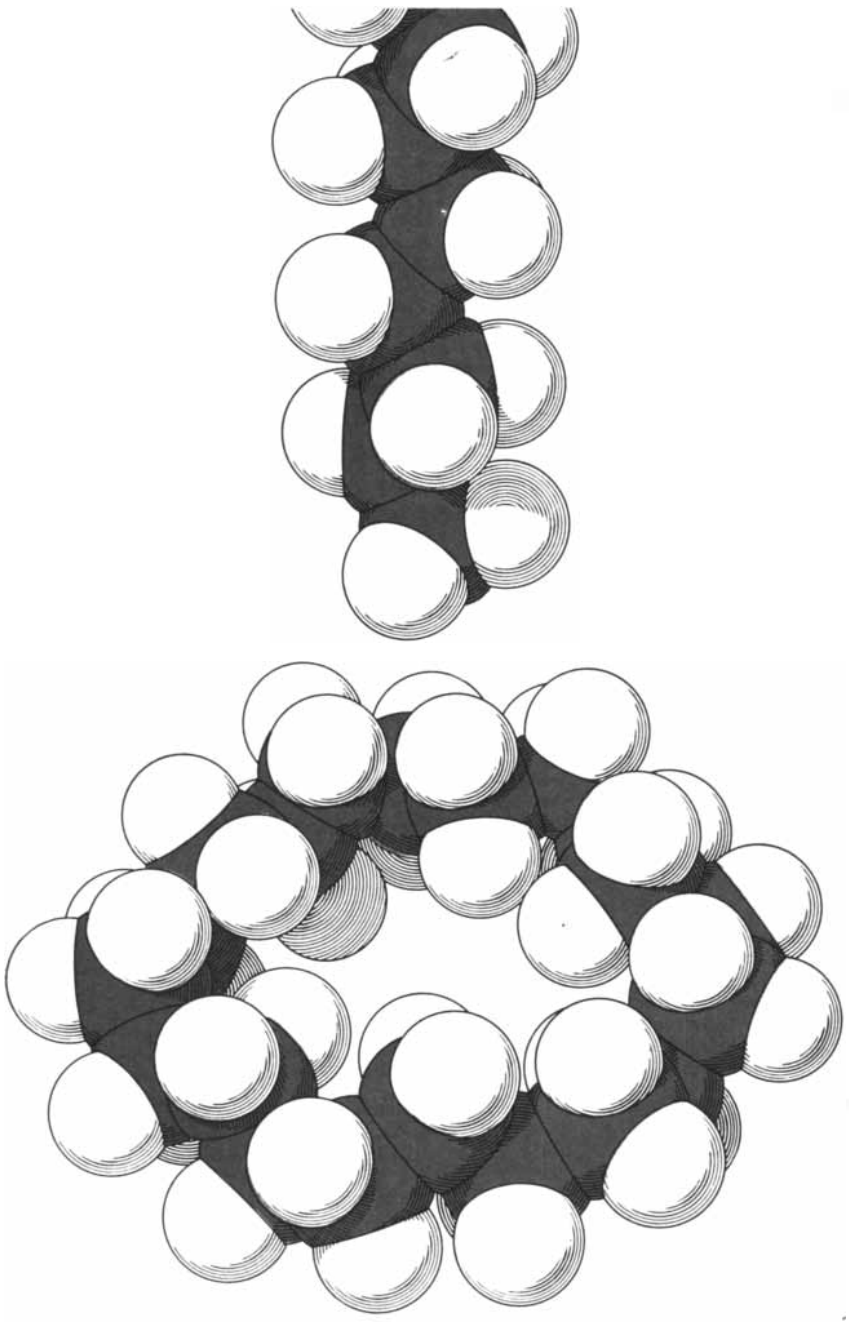
What we feel we have done is to increase the yield of catenanes to a detectable amount and, for the first time, to prove that such interlocked rings are present. Our method for forming rings is the same as that of Prelog and Stoll. In principle we start with a string of carbon atoms that has an acid group (COOH) at each end. This string is combined with methyl alcohol to convert each end group to form a $COOCH_3$, making what is known as a diester [*see illustration on page 97*]. Then in an atmosphere of inert gas the diester is slowly added to liquid xylene (a nonreactive solvent) that contains finely divided sodium. Now acetic acid is added and reacts to produce a circular molecule called an acyloin. This molecule has a hydroxyl group (OH) and an oxygen atom (O) on the two carbon atoms that were the ends of the linear molecule. The rest of the molecule consists of carbon and hydrogen. There are several ways to prove that the molecules have in fact formed rings, such as cleaving them once and showing that the number of molecules remains the same.

Every solution of acyloin rings un-



TWO LINKED RING MOLECULES are topological isomers of an unlinked but otherwise identical molecular pair. The two shown here each contain 34 carbon atoms (*gray*). Ring A (*the lower*) is a paraffin, a relatively inert compound consisting of carbon and hydrogen (*white*) including five atoms of heavy hydrogen, or deuterium (*color*). Ring B (*the upper*) is an acyloin, an active compound that has two oxygen atoms (*color*). This 34, 34 catenane is the compound that the author has constructed, identified and isolated. The rings are not rigid. They change shape constantly, and most of the time the holes are not so large as those shown here.

doubtedly contains some that have accidentally linked, but they would be very difficult to detect. What one needs is a pair of slightly different rings that can be identified when they become linked. To this end we prepare a batch of acyloin rings and then alter all of them, keeping the rings intact. We treat them with hydrochloric acid in which the hydrogen has been replaced by heavy hydrogen, or deuterium. The result is both the removal of the oxygen atoms from the acyloin ring and the substitution of deuterium for approximately five of the 68 hydrogen atoms in the ring. We call the altered rings A rings; the acyloin rings we call B. The removal of oxygen turns the ring into a comparatively inert compound known as a cycloparaffin. The deuterium content of the A ring means that it responds somewhat differently to infrared radiation than does an ordinary all-hydrogen cycloparaffin ring. Because the deuterium atom is heavier than the hydrogen atom, it vibrates more slowly in response to infrared rays, which means that the carbon-deuterium bonds absorb infrared radiation of lower frequency (longer wavelength) than do carbon-hydrogen bonds. The difference in activity is revealed clearly by a spectrograph [*see illustrations on page 100*].



SMALLEST RING that can be threaded by another hydrocarbon molecule, when hole is wide open, contains 20 carbon atoms. As part of his investigations, the author builds such models, in which the "atoms" have the same relative sizes as in the chemical compounds.

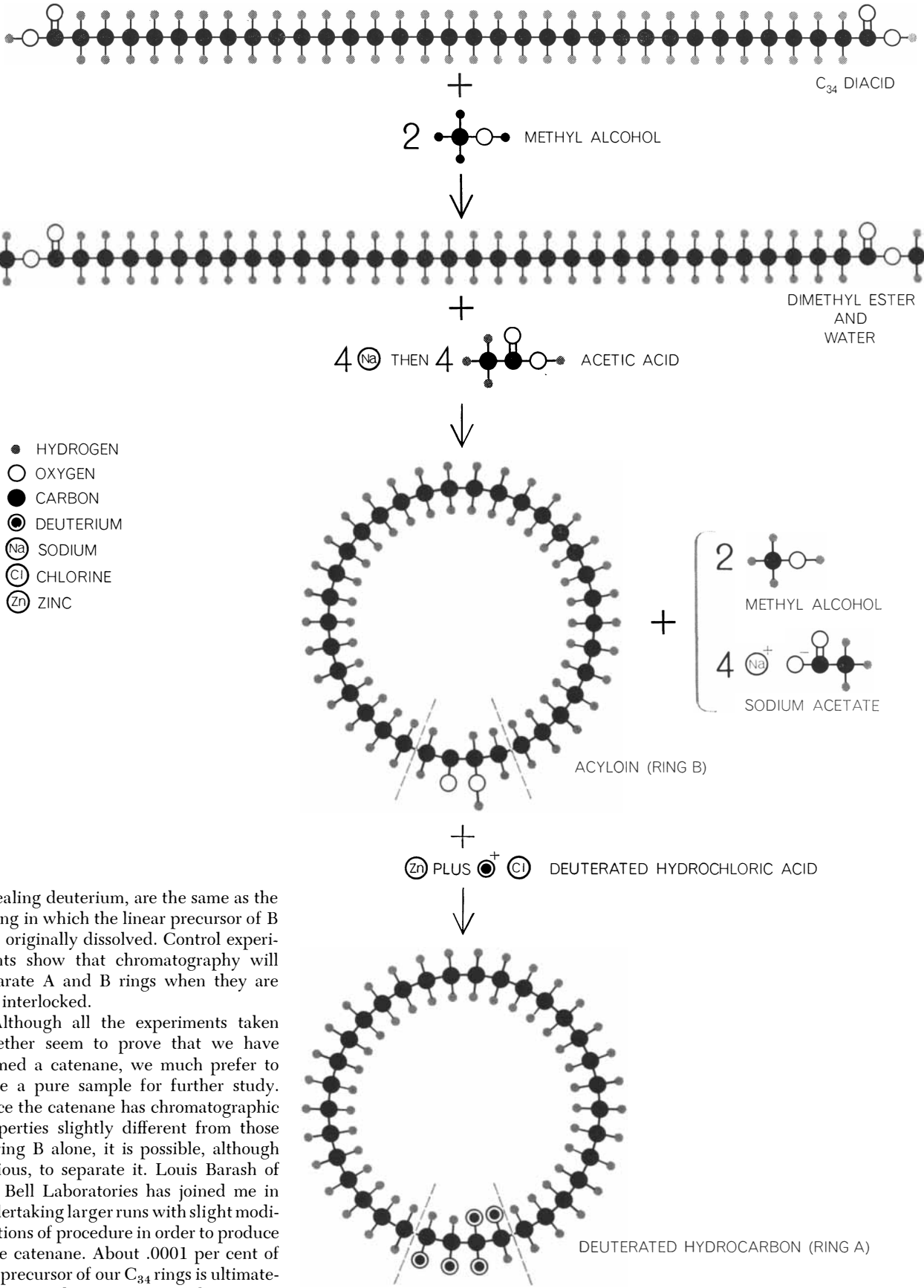
Having formed the deuterated A rings, we use them to replace much of the xylene as the solvent, add more of our linear C_{34} diester to this solution and convert the diester to B rings. Some of the linear molecules thread A rings before we change them into acyloin rings. These B rings contain oxygen atoms, of which A has been deprived. The final product of the reaction consists of the deuterated ring A, ring B and the A, B catenane.

We separate the A, B catenane from the other molecules by the chromatographic process of passing the solution containing the various rings through a glass tube filled with a powdered solid, such as alumina or silica gel. Ring A has only carbon and hydrogen atoms (including the deuterium), and these are not attracted to the solid. The ring washes out of the tube when we pour pentane, an inert solvent, through. The oxygen atoms on ring B, however, attach themselves to the particles of powder, and B (including A, B catenane) remains in the column. Now we pour into the column an active solvent, such as ether or methyl alcohol, that contains oxygen. This displaces B (and A, B catenane) and carries it out of the column in solution [*see illustrations on page 98*]. The infrared spectrum of this second solution indicates the presence of deuterium. The amount suggests that of the 10 grams of A in the original reaction mixture, about one milligram (.01 per cent) is associated with the 100 milligrams of ring B that were formed.

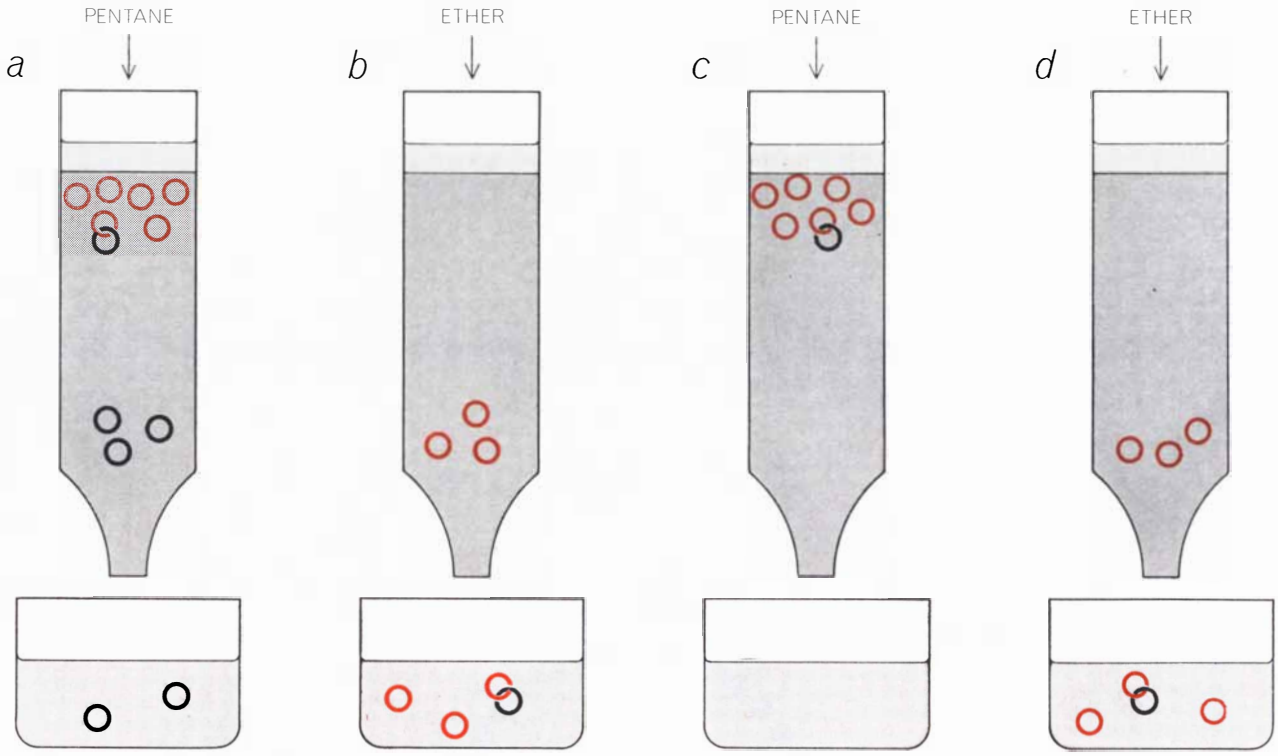
The presence of deuterium along with B rings is consistent with the presence of an A, B catenane. Other possibilities, however, must be excluded. For example, some A may have been oxidized by air (although this is a very slow process), during the chromatographic separation. Addition of oxygen in this way would make A stick to the powder. To test this possibility we unlock the B rings by chemical reactions that yield the linear diacid from which ring B originally came. The reactions have no effect on ring A; it is simply freed from the catenane. Chromatography of the solution produces free ring A that, further testing shows, contains no oxygen atoms. Its melting point and infrared spectrum,

revealing deuterium, are the same as the A ring in which the linear precursor of B was originally dissolved. Control experiments show that chromatography will separate A and B rings when they are not interlocked.

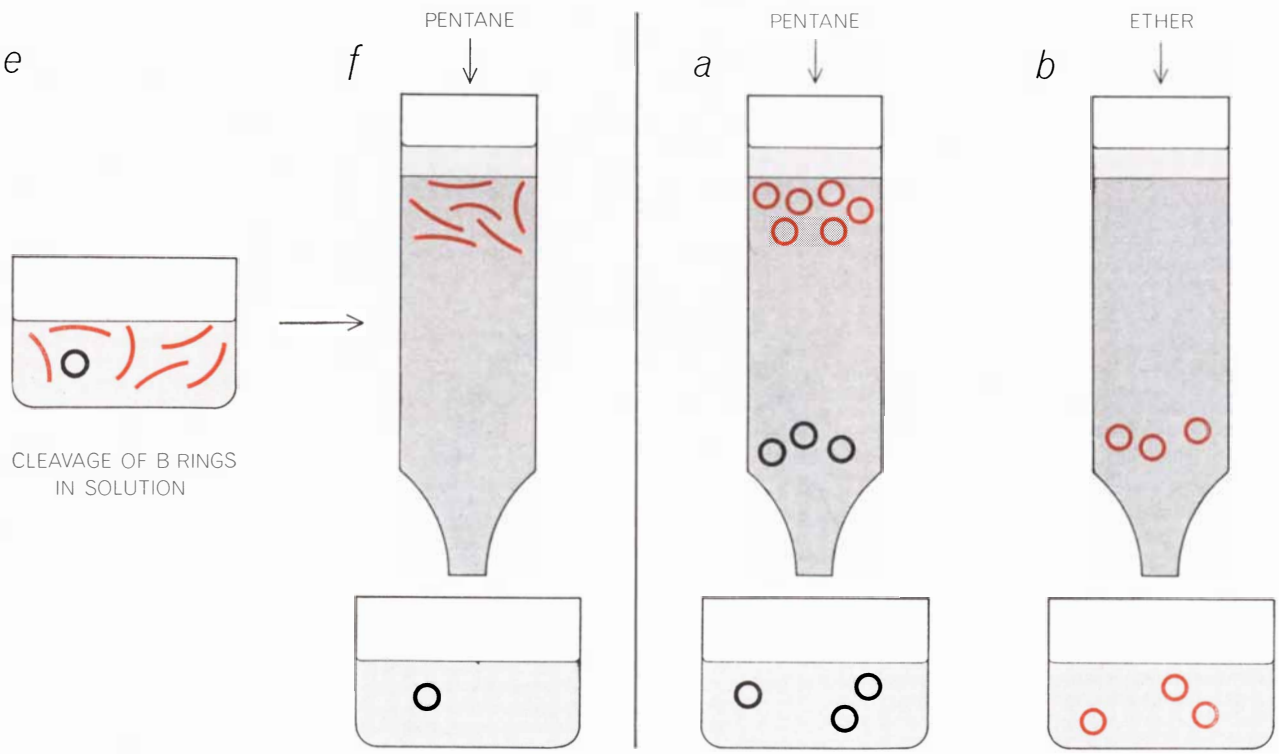
Although all the experiments taken together seem to prove that we have formed a catenane, we much prefer to have a pure sample for further study. Since the catenane has chromatographic properties slightly different from those of ring B alone, it is possible, although tedious, to separate it. Louis Barash of the Bell Laboratories has joined me in undertaking larger runs with slight modifications of procedure in order to produce pure catenane. About .0001 per cent of the precursor of our C_{34} rings is ultimately converted to catenane. At this writing we have a few milligrams (totaling perhaps a 5,000th of an ounce) of isolated catenane. About all we can say of it is that it seems to be an oil. In the near



CHEMICAL REACTIONS that produce ring molecules begin with a linear molecule that has an acid group at each end (*top*). The broken lines in the two rings mark small reactive regions that were previously the ends of the linear molecules. Other chemical reactions can turn the upper ring back into linear diacid. Schematic diagrams on this page do not show true appearance of the molecules. Holes in the real ring molecules are much smaller.



CHROMATOGRAPHIC PROCESS is used to separate the A, B catenane from free A rings. Solution of catenane (*linked rings*), A rings (*black*) and B rings (*color*) is poured (*a*) into glass tube packed with powdered alumina (*darker gray*). An inert solvent, pentane, washes out A rings but leaves catenane and B rings, which contain oxygen atoms and are held by the alumina. Ether, an active solvent, displaces the B rings and the catenane and carries them out of the column (*b*). Process is repeated, using only molecules removed by ether. Pentane comes out free of ring molecules (*c*), while ether again takes rings out of column (*d*). Infrared spectrometry (not illustrated here) proves presence of deuterium, which is in A ring only. Obviously some A rings are locked to B rings.



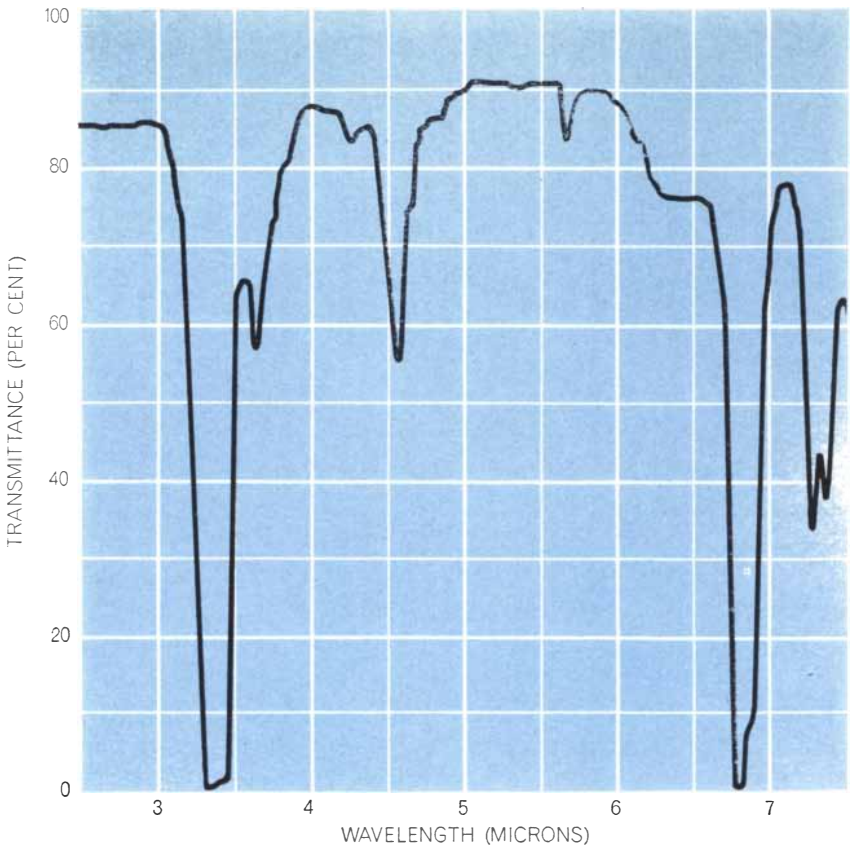
TEST CONTINUES with unlocking of B rings (*e*), which frees A ring from catenane. Pentane then washes the molecule containing deuterium (A ring) out of the chromatographic column, leaving linear diacid that resulted from the cleavage of the B rings (*f*).

CONTROL TEST shows that inert solvent, pentane, removes A rings from mixture of A and B rings (*a*). No catenane is present. Then the active solvent, ether, removes the B rings from the column (*b*). This experiment works under a variety of conditions.

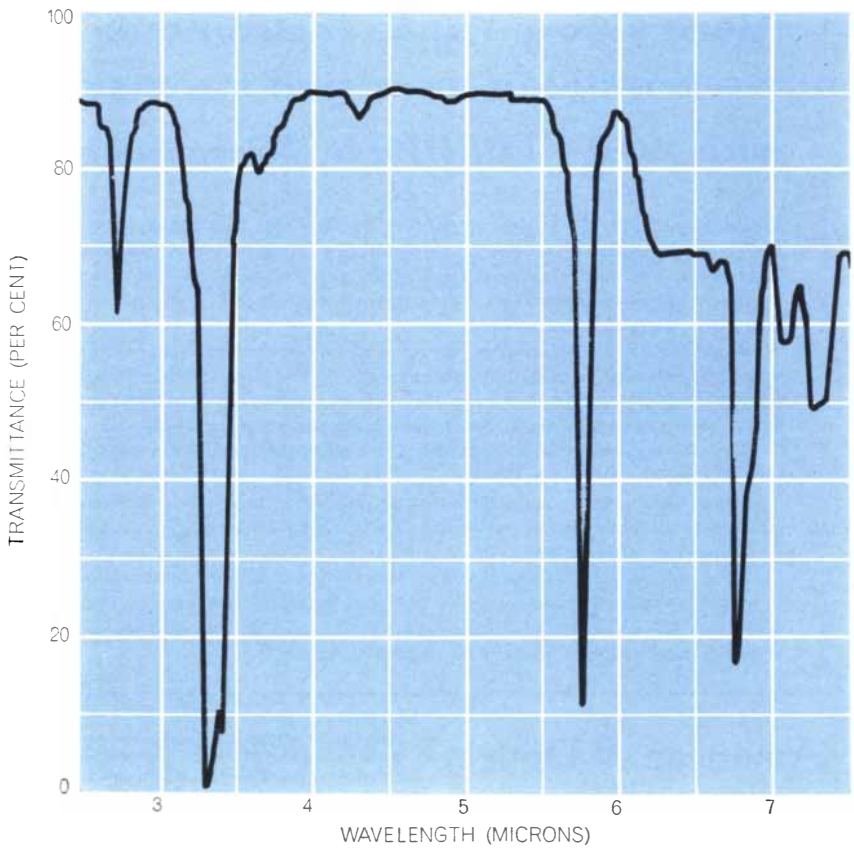
future we should be able to learn something about its properties. (It may be possible to produce much higher yields by other methods. David M. Lemal of the University of Wisconsin and Lester Friedman of the Case Institute of Technology are trying to synthesize a molecule in which both rings are attached to a central core in such a way that when the core is removed by chemical reactions, a pair of interlocked rings remains.) When we have enough catenane, we will be able to perform some interesting tests. One thing we will do is to convert the B ring in the combination into another inert A ring, so that our two links will be identical except for the deuterium in one, which should have no appreciable effect. Then we can compare the properties of an A, A catenane with a solution of unlinked A rings. The differences, if any, that we find will be solely due to the linking in the catenane. It will be much easier to make a valid comparison when all the rings are of one type than it is when we compare the more complex A, B catenane with a mixture of unlinked A and B rings.

In addition to the two interlocked rings, other forms of catenane are possible. One would arise if the precursor of ring B threads A twice before closing. Molecular scale models indicate that the minimum size for this structure would be a C_{33} molecule, only one less than the C_{34} we have been using. Therefore the amount of double-threaded form we actually get should be minute compared with that of the simple chain. If the linear diester threads two rings before closure, a three-link chain will form. Since only about 1 per cent of B joins in a catenane, less than .01 per cent should thread two A rings. Borromean rings, in which all three rings are joined but no two of them [*see top illustration on page 102*], require a minimum string of 30 carbons and involve a considerable restriction on the motion of the loops—both unfavorable for the construction of such a complex form. Other possibilities are even more unlikely. We believe that our linked rings are more than 99 per cent simple two-link catenane.

One interesting question about the catenane is whether it is one molecule or two. In ordinary "geometrical" chemistry a molecule consists of atoms interconnected by chemical bonds. This is not the case with our material. We must nonetheless break a chemical bond to split the catenane apart. Perhaps it is best to say that a "topological bond" exists between the rings. The bond is not the property of any pair of atoms but of



INFRARED SPECTRUM shows amount of infrared radiation transmitted at different wavelengths by solution of ring A. Deuterium in the ring absorbs at wavelength near 4.6 microns.



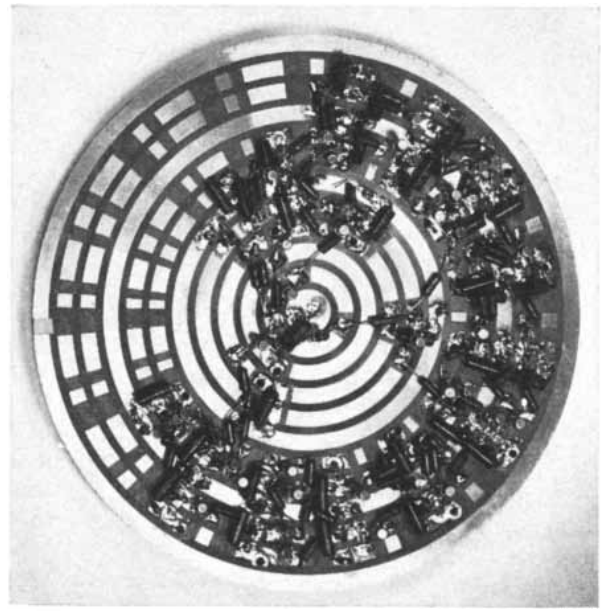
ANOTHER SPECTRUM is obtained from solution containing only ring B, which has no deuterium. This compound absorbs not at 4.6 microns but rather at 2.7 and 5.8 microns.

the two complete rings. It breaks when any carbon-carbon bond is cleaved. Since the topological bond is as strong as an ordinary chemical bond, we prefer to regard our catenane as a single molecule. Determination of its molecular weight and other properties, such as its rate of diffusion in solution, will show whether or not we are right in thinking of it as a single molecule.

Catenanes and combinations of three or more linked rings are not the only examples of the possibilities of chemical topology. H. L. Frisch of the Bell Laboratories and Norman Martin Van Gulick of E. I. du Pont de Nemours and Company have independently pointed out that a single large molecule, ring or otherwise, can have a knot in it. Only a ring, however, would have to be cut to be untied, and so only a ring is topologically different from the unknotted form. Scale models show the size of ring needed for various knots. Rings with 50 or more carbon atoms can have a simple overhand knot, or trefoil (so named because it has three crossover points). No other knot is possible until the molecule has 74 carbons, when a figure eight, the only four-fold knot, may appear. There are four different six-fold knots, 21 eight-fold knots and 133 10-fold knots. To figure out the minimum number of carbons required for each knot requires only patience and enough atomic models.

Although the probability of forming knots increases with ring size, separation of the different kinds of knots in a mixture and their identification is a nightmare we prefer to avoid. In order to have only one alternative to the simple ring, we have prepared a C_{66} linear diester for a knot test. We guess that statistically about .1 per cent of these "string" molecules may have overhand knots in them after conversion to rings. Separation and identification is going to be difficult. We have no analogue of the deuterium label and the unlocking reaction that we use on our A and B rings. Cleavage of a plain C_{66} ring and of a C_{66} ring with a knot in it would lead to topologically identical products (because an unknotted string is topologically equivalent to a knotted one).

The trefoil knot possesses one property that single rings do not: it can exist in two forms. One is a "right-hand" knot and the other a "left-hand" knot. They are mirror images of each other and have the same sort of relation as right and left hands. Left-handed and right-handed molecules are optically active: in solution they rotate the plane of polarized light in opposite directions. This rota-



Pseudo-random sequence generator employing tunnel diodes. The symmetrical arrangement contributes to the extremely high operating speed of the circuit (100+ megacycles).

Ultra-High Speed Logic Via The Tunnel Diode

The pattern of enthusiasm for the tunnel diode coincides curiously with the shape of the characteristic N-curve of the diode itself. Interest among computer engineers quickly rose to a peak, almost as quickly dropped away, and is again on the rise. The reason is obvious. Many of the problems which arose in the early development of high-speed tunnel diode circuitry have been overcome, and practical applications are increasing. Take the work of the Bendix Digital Research Group.

A most interesting device is an experimental tunnel diode computer which operates at a clock rate of 100 megacycles. This is probably today's most capable digital device operating at this speed, in terms of complexity of logical operations handled.

Containing 160 tunnel diodes, the computer embodies over 80 logic gates, including AND, OR, NOT and MAJORITY. It has been programmed, for example, to solve a second-order differential equation at the rate of more than 4,000,000 points per second.

Since this computer is an experimental system built primarily to demonstrate the feasibility of using high-speed tunnel diode logic circuits in large combinations, it contains only two integrators. It is not designed to be used as a general purpose data processing system, but it clearly demonstrates the feasibility of producing such a system.

Another tunnel diode system is the pseudo-random sequence generator (pictured above). This generates a series of pulses which, over a specific interval of time, appear to be randomly distributed. To the properly keyed receptor, however, the pulse pattern is *not* random, but rather, informational. Extremely high operating frequencies are involved. The present sequence generator operates at 100 megacycles, and higher frequencies appear within reach, perhaps several times as high.

In another area, tunnel diode memory development, we've found a way to simplify the circuit configuration and at the same time provide operational capability over a wide temperature range. At present, one experimental model operates on a cycle time as short as 50 nanoseconds.

Bendix research embraces a complete range of disciplines including acoustics, nuclear, data processing, microwave, fluid power, lasers and masers, guidance, electronics, solid state physics, and mechanics. Motivation: to develop new techniques and hardware for producing complete, integrated, advanced systems for defense, industrial and commercial applications. Inquiries are invited. We also invite engineers and scientists to discuss career position opportunities with us. An equal opportunity employer. Write Director, Bendix Research Laboratories Division, Southfield, Michigan.

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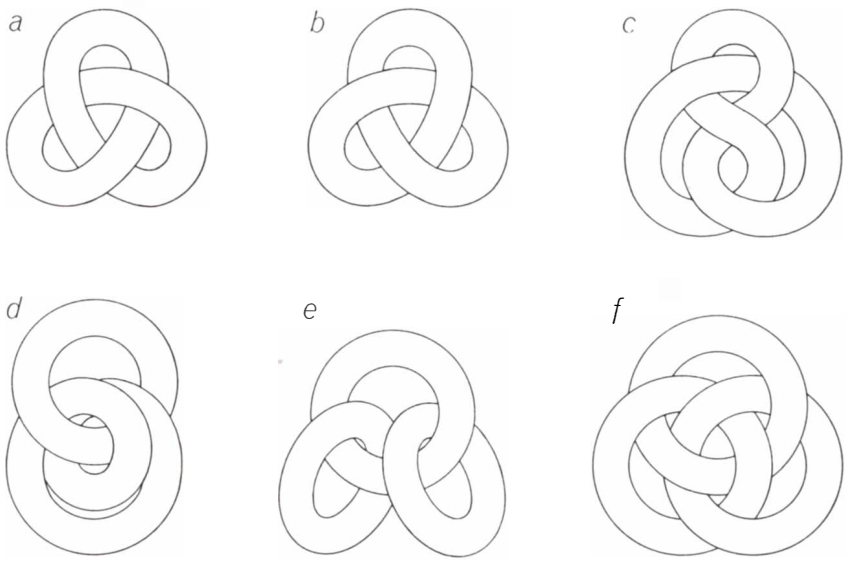


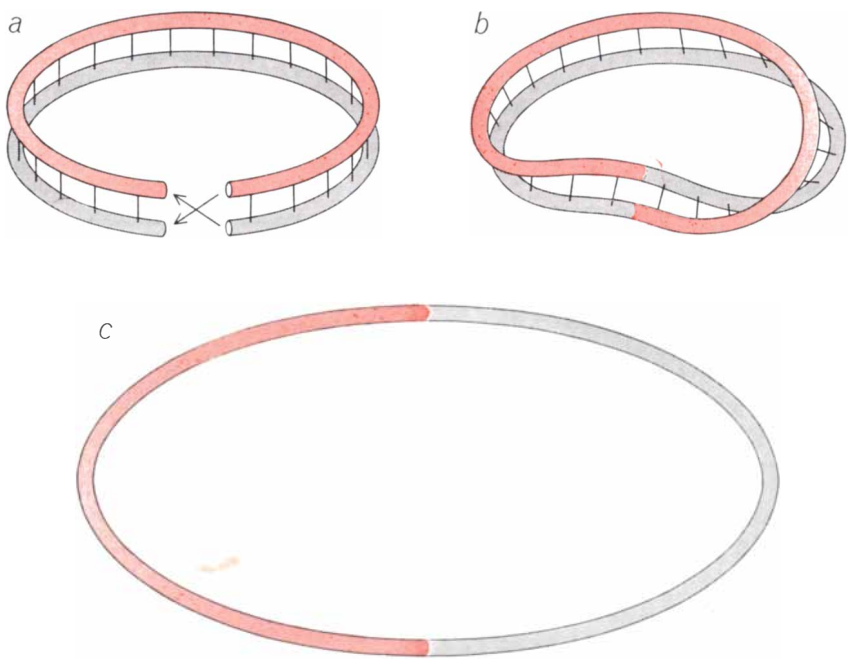
TOPOLOGICAL ISOMERS when ends of linear molecules are joined to form a ring could include "left-hand" and "right-hand" trefoil knots (*a and b*), figure eight knot (*c*), linked rings with one threading the other twice (*d*), one ring threading two others (*e*) and Borromean rings (a well-known brewer's symbol), in which three rings are joined but no two (*f*).

tion of light should serve as a tracer for the knot.

Unfortunately our solution of C_{66} rings, including the knotted rings, will contain equal numbers of left and right forms and will produce no net rotation of polarized light. We hope to separate out at least some of one type of knot by introducing another optically active compound that will absorb or hold one of the knots rather than the other (somewhat as a right hand clasps a left hand but not another right). Then we may be able to separate one type from the mixture by chromatography and to show its presence through the use of polarized light.

Some circular compounds are found in living organisms and may exhibit topological isomerism. These rings, however, do not arise at random. They are synthesized in close proximity to the surface of an enzyme and are unlikely to be interlocked or knotted unless nature "intends" them to be so. One unusual material is a virus deoxyribonucleic acid (DNA) molecule that appears to be circular [see "Single-stranded DNA," by Robert L. Sinsheimer; SCIENTIFIC AMERICAN, July]. The ring contains 5,500 carbon-oxygen-phosphorus-oxygen groups, for a total of 22,000 atoms in the loop itself. The possibilities for knotting are great. The natural ring may even have one or more knots, but there is no evidence to support this speculation.

Topological chemistry is not restricted to the single-stranded molecules considered so far. Parallel strings of atoms can be cross-linked to produce a "surface," which can then be transformed in many ways. The first example has already been prepared by John F. Brown, Jr., and his co-workers at the General Electric Research Laboratory. They have synthesized a double-stranded silicone. (In silicones the atoms of the main chain are silicon and oxygen, not carbon.) A particularly interesting possibility is the conversion of a roughly rectangular surface into a Möbius strip by a half-twist about the long axis before the ends are joined to form a ring. Subsequent cleavage of the cross-links in such a two-stranded strip would lead to a large single ring, since there is only one edge to the surface [*see bottom illustration at left*]. A three-stranded strip would produce a pair of interlocked rings. Knots may be formed also: separation of a two-stranded strip that has three half-twists will yield a trefoil.



DOUBLE-STRANDED MOLECULES with cross-links (like rungs of a ladder) might be joined as in *a* to produce a molecular Möbius strip (*b*) with half-twist about the long axis. Cleavage of all the cross-links would produce the large single-ring molecule shown in *c*.

Whether or not catenanes and knots will have any properties of special interest can only be determined after considerably more experiment. One possibility, suggested by Herman F. Mark of the Polytechnic Institute of Brooklyn, is based on the preference of some inorganic compounds for existing in small ring forms instead of linear structures of high molecular weight. To take advantage of their stability at high temperatures and to obtain long polymeric structures, similar to those now found only among carbon compounds, many loops might be interlinked. The statistical methods that we have employed for our catenanes would not be suitable because of their small yield; other methods might be developed if the properties of the simplest inorganic catenanes were promising.

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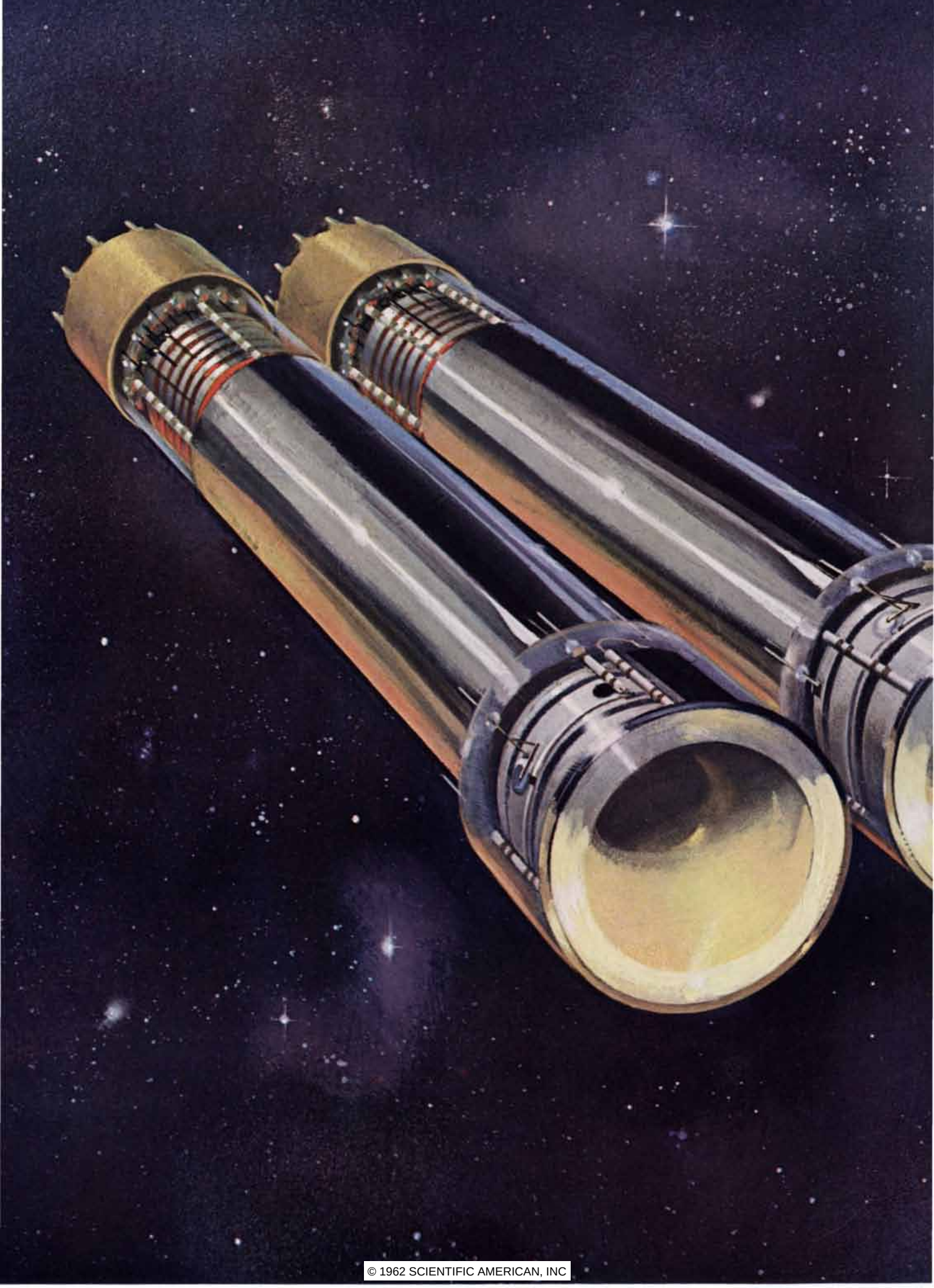

ORTHICON

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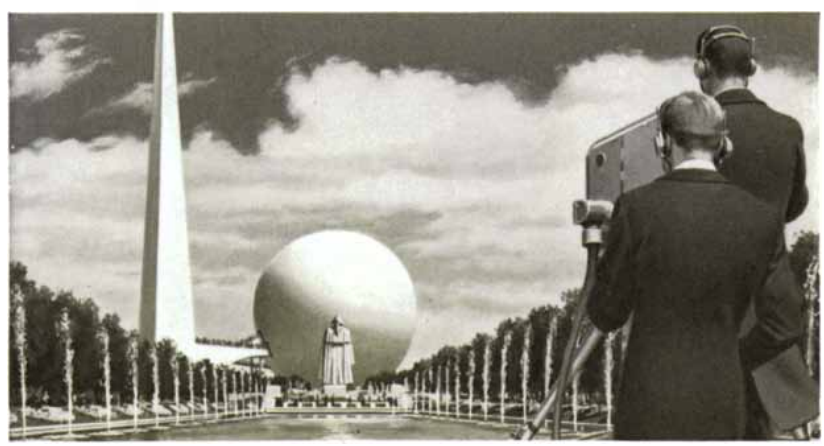

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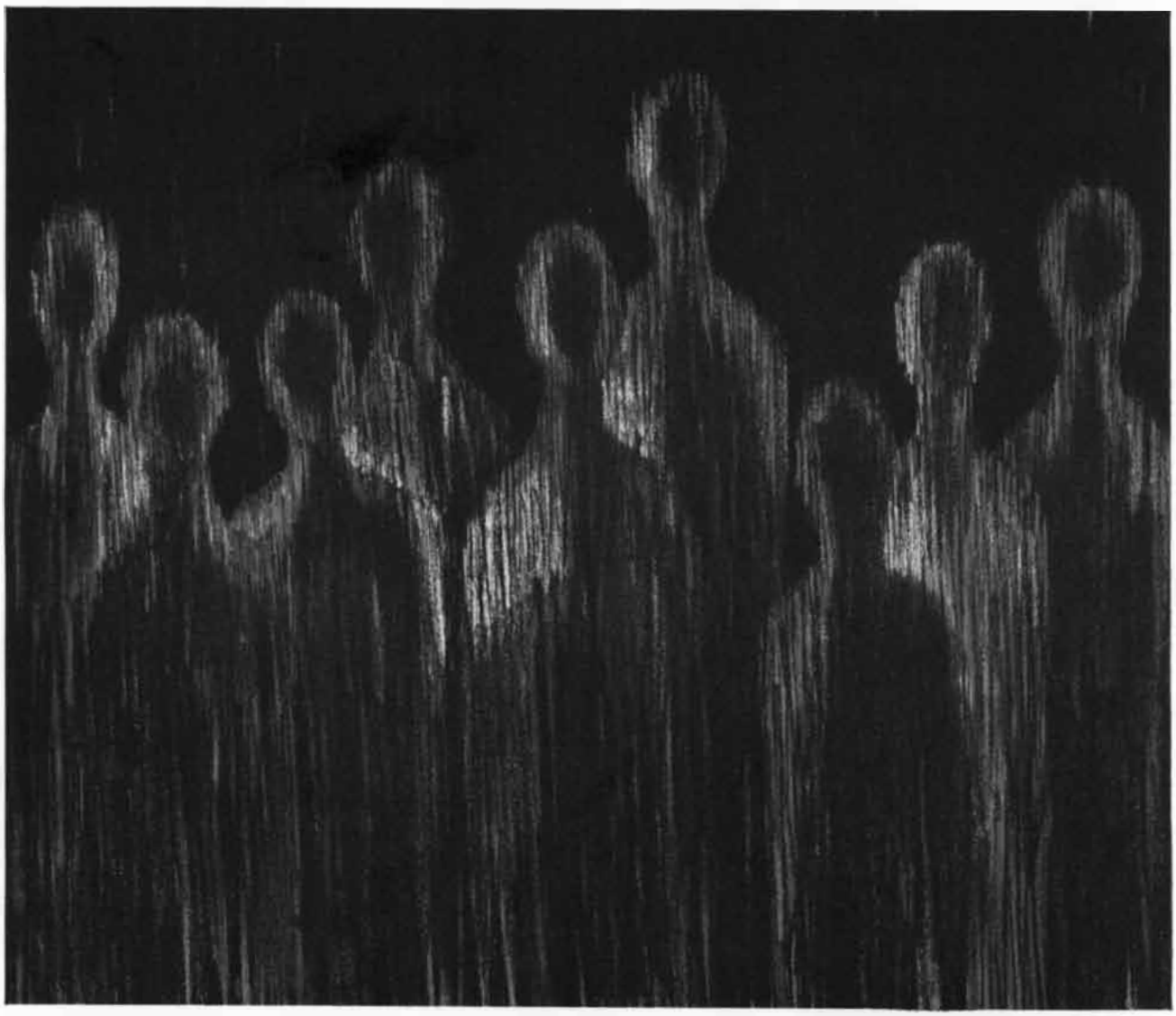


Development of improved man-machine relationships and detailed planning of the giant vehicle systems that are involved in space exploration are among more than 500 research and development programs now under way at Douglas.

DOUGLAS

NEUTRON RADIOGRAPHY

Pictures made by slow neutrons disclose many things that cannot easily be seen in pictures made by X rays. New detection methods are making it attractive to use neutrons as an inspection tool

by Harold Berger

The value of radiography in medicine and industry is so firmly established that today the amount of photosensitive film used for making X-ray pictures greatly exceeds the amount of black-and-white film used by amateur photographers. With X rays of sufficient energy and intensity it is possible to make pictures through objects of any material and of almost any thickness. It has been known virtually from the time the neutron was discovered, 30 years ago, that neutrons might also be used to make pictures through objects. But since neutrons in a form useful for imaging purposes are harder to produce than X rays, one may wonder what advantage is to be gained by making neutron radiographs. The answer is that neutrons make it possible to see things that X rays do not reveal at all, or reveal only with difficulty.

Neutron radiography has become practical with the advent of nuclear reactors and particle accelerators, which can provide a source of neutrons of the required intensity. Nuclear reactors produce neutrons directly, as a by-product of nuclear fission. Accelerators produce beams of high-energy charged particles, usually protons, which can give rise to neutrons if they are directed against a suitable target material, such as lithium or beryllium. The high-energy neutrons produced by an accelerator are absorbed about equally by different materials. To be most useful in radiography neutrons must be slowed down until their velocity is simply the velocity imparted to them by the random movement of atoms at ordinary temperatures. Such low-energy neutrons, called thermal neutrons, can be obtained directly from nuclear reactors.

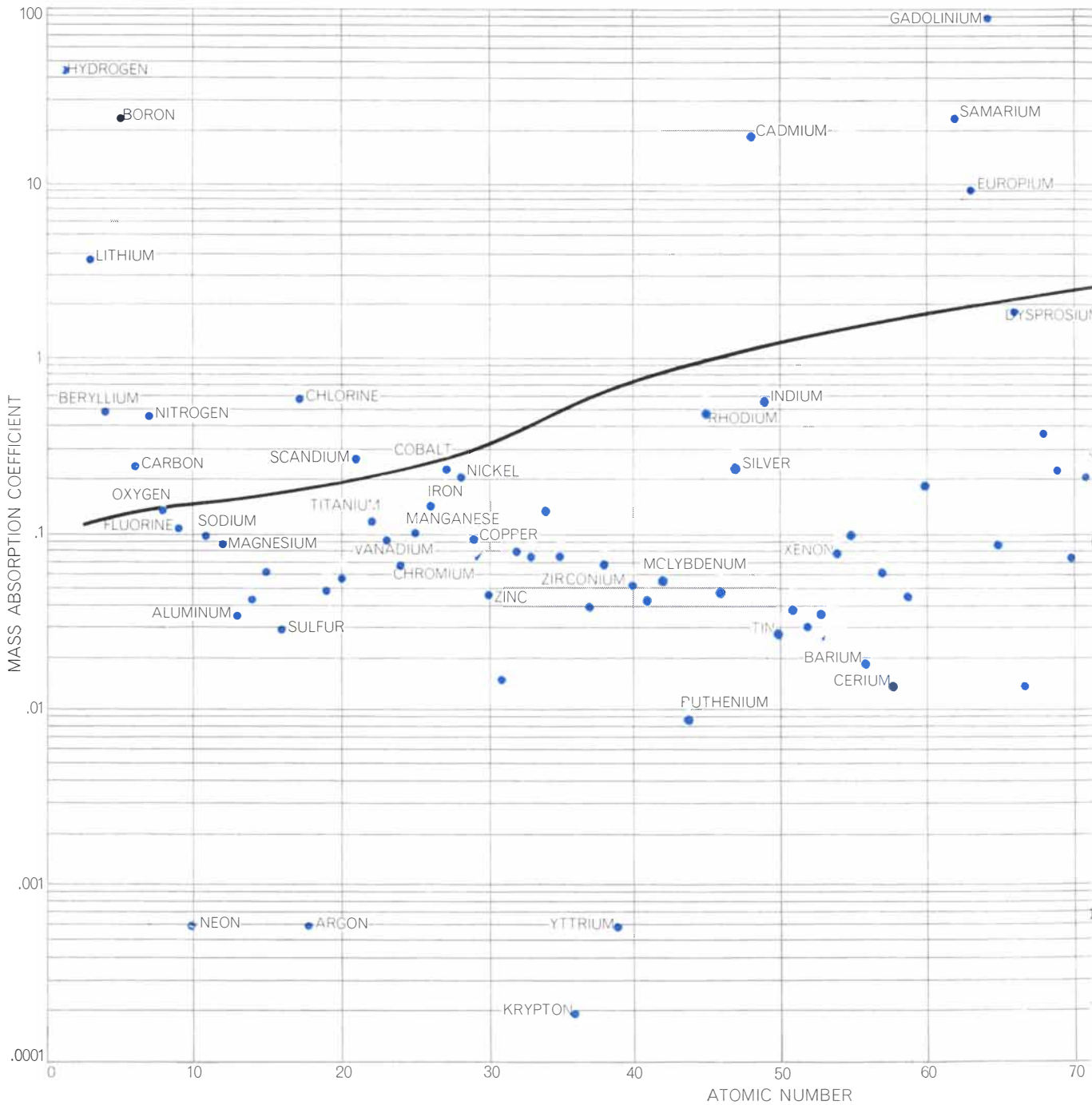
The value of thermal neutrons in radiography is that their absorption characteristics are quite different from those of X rays. For elements at either end of the periodic table the absorption characteristics of thermal neutrons and X rays are essentially reversed [*see illustration on next two pages*]. Heavy elements such as lead, bismuth and uranium are practically transparent to thermal neutrons,

NEUTRON RADIOGRAPH OF GRASSHOPPER gives information that would be difficult to obtain in an X-ray picture. Tissue components absorb X rays about equally. Neutrons, however, are heavily absorbed by hydrogen. Thus white areas here are hydrogen-rich.

whereas they absorb X radiation strongly. Conversely, hydrogen, lithium, boron and other light elements strongly absorb thermal neutrons but allow X rays to pass freely. For example, with neutron radiography it would be an easy matter to record the height of a column of water in a lead tube. Neutrons would have no difficulty penetrating the lead but would be strongly absorbed by the hydrogen in the water. X rays would be so readily absorbed by the lead that the slight additional absorption due to water would be difficult to observe.

In general, various materials stop X rays in direct proportion to their mass. For this reason it is difficult to distinguish between elements that lie near each other on the periodic table. Neutron absorption, on the other hand, is not related directly to atomic number or mass; neighboring elements such as cadmium and tin or boron and carbon can differ in neutron "transparency" by factors of 100 or 1,000.

A neutron radiograph is made in much the same way as an X radiograph. The object to be inspected is simply placed between a source of radiation and a radiation detector. If the source produces fast neutrons, they can be slowed down by allowing them to diffuse through a medium containing light elements, such



ABSORPTION CAPACITY OF ELEMENTS is plotted for X rays (*black curve*) and for thermal, or low-energy, neutrons (*colored dots*). The higher the mass-absorption coefficient, the more absorbing the material. In general the coefficient for X rays increases steadily with atomic number. The coefficient for neutrons is much more random, but there is a tendency for absorption to be the

as hydrogen or carbon. Since a great many fast neutrons are absorbed in the thermalizing process, the original source must produce on the order of 10 billion neutrons per second to yield a thermal-neutron beam of useful intensity. We have found at the Argonne National Laboratory that an intensity of at least 100,000 thermal neutrons per square centimeter per second appears desirable. Even low-power reactors, however, can produce beams 100 times more intense.

A number of commercially available accelerators can produce thermal-neutron beams of adequate intensity at a price competitive with high-energy X-ray equipment. Recently Edward J. Hennelly of the Savannah River Laboratory operated by E. I. du Pont de Nemours and Company has described a low-cost radioactive source of thermal neutrons. The source consists of radioactive antimony 124, which has a half life of 60 days, and beryllium. Neutrons are produced when the beryllium atoms are struck by gamma rays from the antimony 124. The initial cost of the source has been estimated at $3,500, and the cost of maintaining the source at a high output should be less than $5,000 a year.

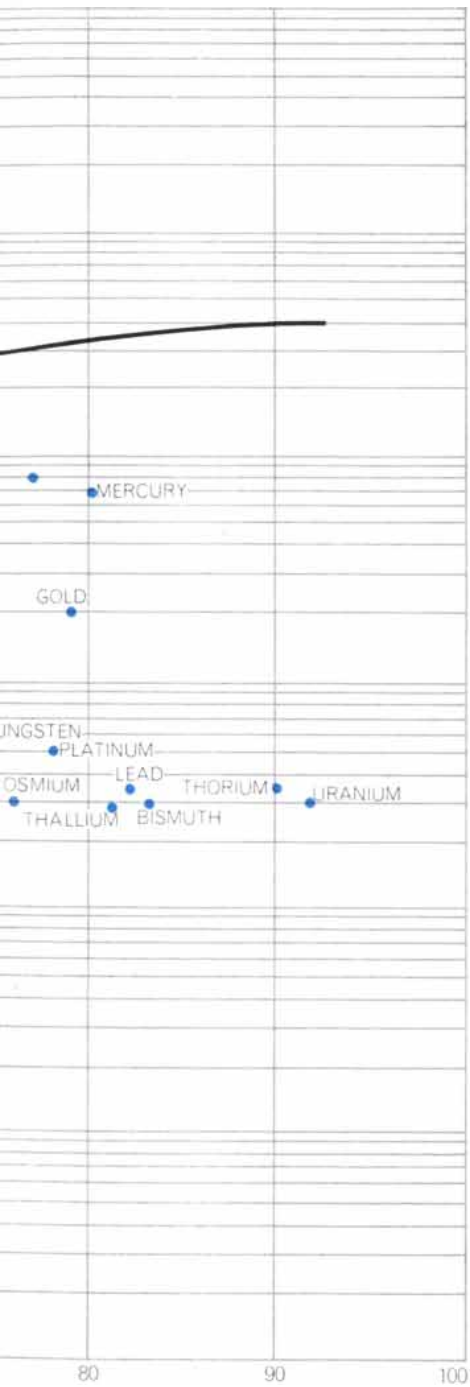
One problem associated with fast-neutron sources is that the thermalized neutron beam also contains high-intensity gamma radiation. If the neutron beam were being used to inspect uranium or some other heavy metal, the gamma rays might even contribute usefully to the image. In other cases, however, gamma radiation may confuse the radiographic picture. One answer to the problem is to remove the gamma rays by means of a filter, consisting of an element such as bismuth, that has high absorption for gamma radiation but low absorption for thermal neutrons. Another approach is to allow the neutrons to strike a crystal and form a reflected beam that contains thermal neutrons but little or no gamma radiation. Such an arrangement is called a neutron spectrometer; it not only reduces gamma rays but also fractionates the neutrons into beams of different energies, or wavelengths. By selecting only neutrons reflected at a certain angle one can obtain a "monochromatic" beam in which all the neutrons have about the same energy. It happens that most of our radiographic studies at Argonne have been done with monochromatic beams, but such beams offer no advantage for most applications.

Still another way to combat the problem of gamma-ray contamination is to use detectors that do not respond to gamma rays. I shall therefore broadly describe the various methods of detecting neutrons. In the transfer method the neutrons are allowed to strike a metal screen that becomes radioactive in proportion to the intensity of the neutrons at each point. The screen thus contains a radioactive image of the test object. To make this image visible the screen is placed against photographic film, and the radiation arising from radioactive decay exposes the film. Since the photographic film is not exposed to the neutron beam itself, the gamma rays in the neutron beam are made ineffective.

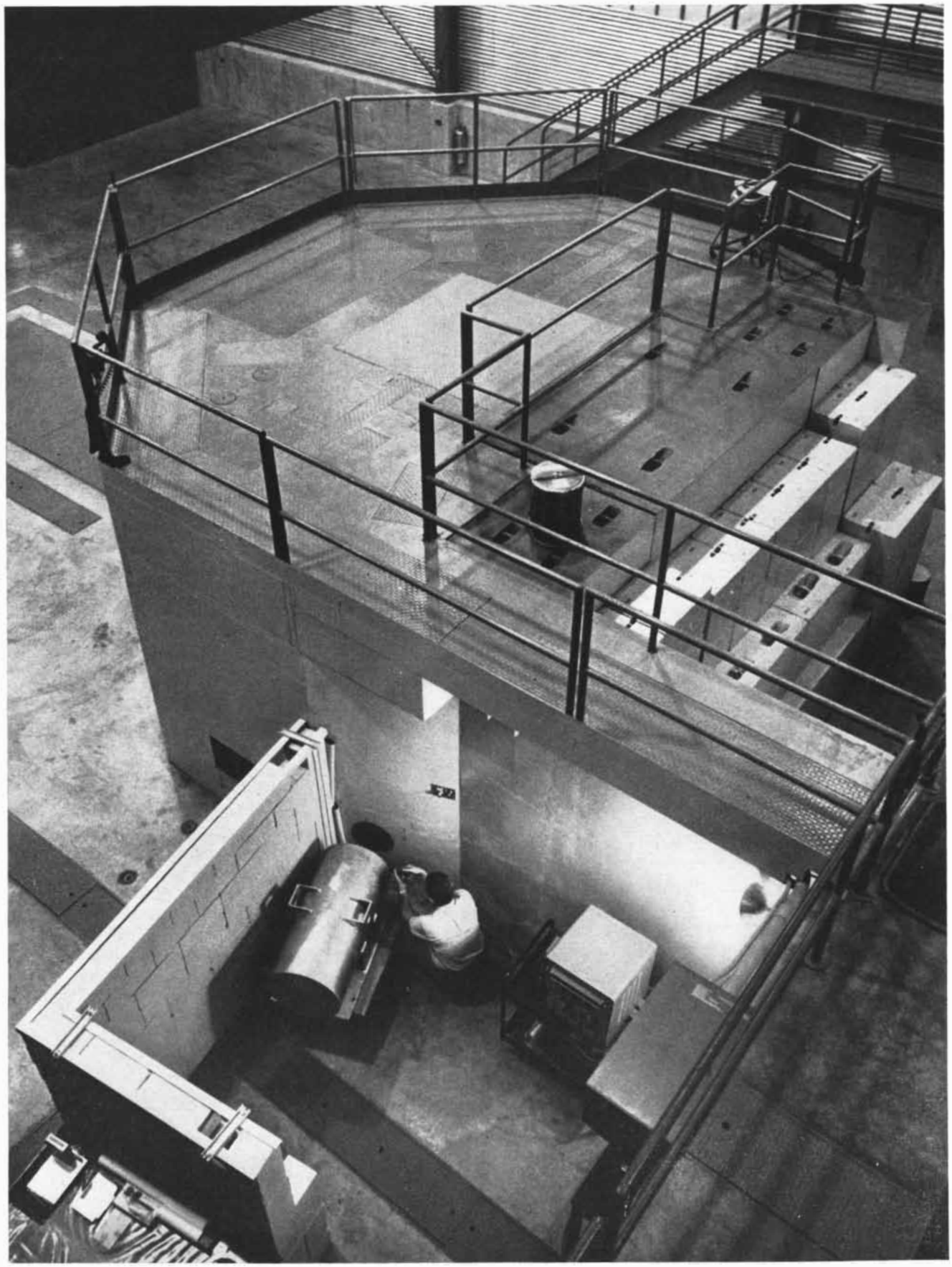
Metal screens for the transfer method incorporate isotopes that have a conveniently short half life. Examples are gold 198 (half life, 2.7 days), dysprosium 165 (2.3 hours), indium 116 (54 minutes), rhodium 104 (4.4 minutes) and silver 108 (2.3 minutes). Even with saturation exposure the Argonne neutron beam with an intensity of 100,000 neutrons per square centimeter per second yields a barely detectable transfer image when short-lived rhodium and silver are used in conjunction with a fast X-ray film. The image cannot be strengthened by lengthening the exposure because after a certain time—equal to about three half lives of the isotope in the screen—the number of atoms decaying begin to match the number of new radioactive atoms being produced. To achieve a stronger image with very short-lived isotopes it is necessary to increase the intensity of the neutron beam. As it is increased more radioactive atoms are created per unit of exposure time, and the level of radioactivity in the screen is increased correspondingly. As a result rhodium and silver isotopes, as well as many others, can be used to make transfer radiographs with beams that have an intensity greater than 100,000 neutrons per square centimeter per second.

Another neutron-detection method can employ a wide range of screen materials, including some that do not actually become radioactive; it also responds, however, to the gamma radiation in the beam. In this technique, which we have termed the direct-exposure method, the screen and the film are exposed to the neutron beam together. The neutrons have little direct effect on the film, but the film now accumulates all the radiation emitted from the screen during the exposure. In addition to collecting all the radioactive-decay radiation, the screen also collects "prompt emission" radiation, which can consist of either gamma rays or charged particles (usually alpha particles, or helium nuclei) produced almost instantaneously by neutron bombardment. This prompt emission combines with the decay emission to allow much shorter exposures with the direct-exposure method than with the transfer method.

Several materials that have only a negligible tendency to become radioactive make excellent direct-exposure screens. These materials include cadmium and gadolinium, which are prompt gamma-emitters, and certain isotopes of boron and lithium that emit alpha particles when they are struck by slow neu-



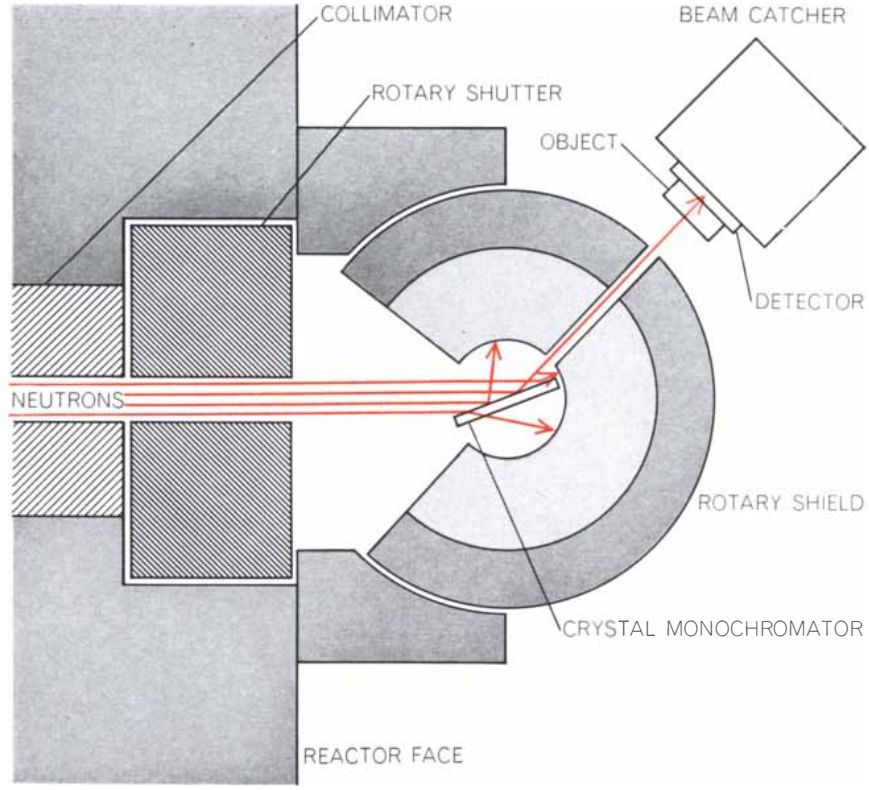
reverse of that for X rays. Values are based on those given by James Thewlis of the Atomic Research Establishment at Harwell.



"JUGGERNAUT" RESEARCH REACTOR at the Argonne National Laboratory provides an intense beam of neutrons useful for radiography. The beam leaves the reactor through a slot opposite the horizontal cylinder. The object to be radiographed is mounted in front of the cylinder, which stops the beam. A close-up of the cylinder and the neutron exit port appears at the top of page 112.

trons. The most sensitive detectors are made by combining the alpha-emitters boron 10 and lithium 6 with a phosphor, such as silver-activated zinc sulfide, which gives off flashes of light when it is struck by alpha particles. These scintillations expose the film more effectively than alpha particles themselves do. Such detectors produce good images when struck by only a few hundred neutrons per square millimeter. This is at least an order of magnitude more sensitive than any other neutron detector that seems useful for radiography.

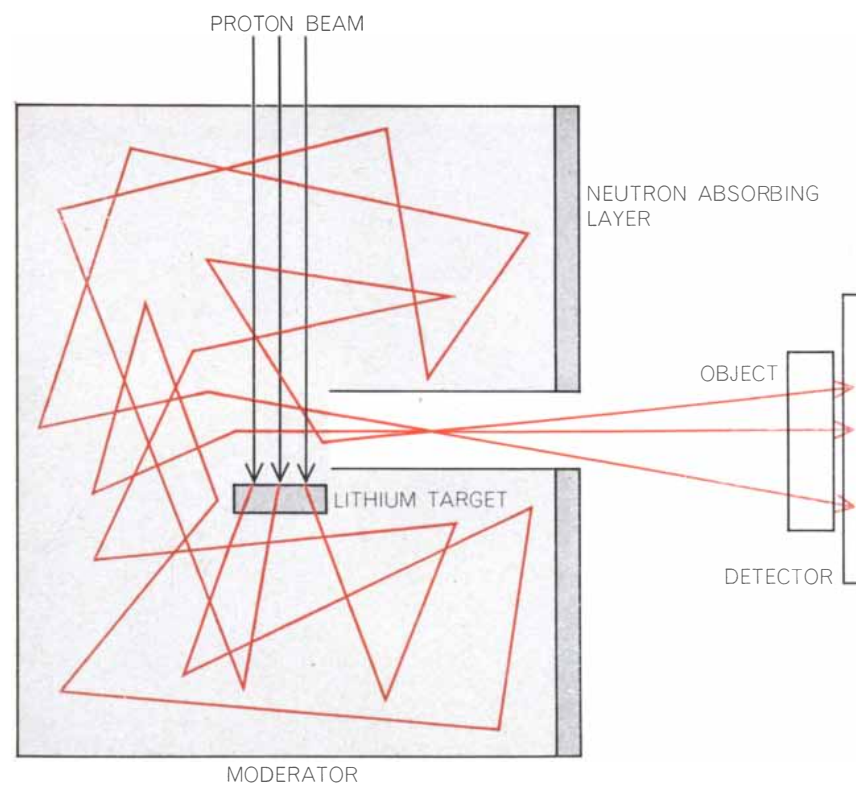
The over-all sensitivity of the detector depends, of course, on the speed of the film employed. Until recently the shortest exposures were obtained with scintillators placed in direct contact with blue-sensitive X-ray films, such as Kodak Type F, or with the Polaroid film that has a speed rating of 3,000. The newly available Polaroid film with a rating of 10,000 has cut exposure times still further. It is possible to detect neutrons directly in ordinary photographic film, without the need for screens, and one can also use special emulsions loaded with boron 10 or other elements that produce radiation when struck by neutrons, but the speeds are still below those obtainable by converter-screen methods.



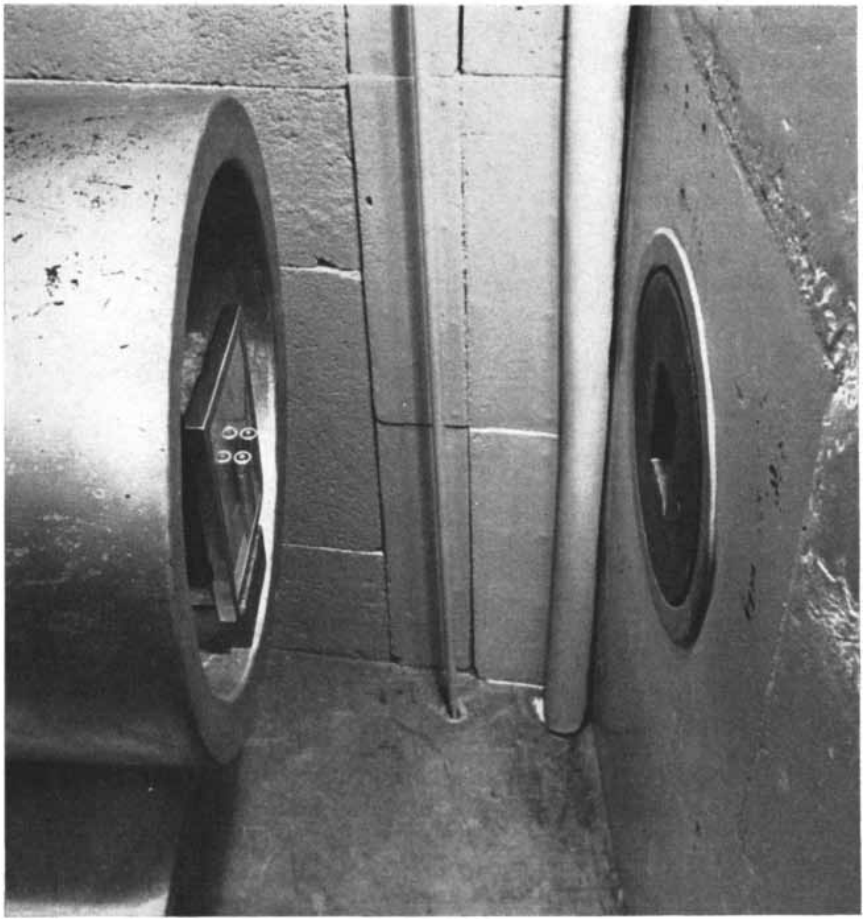
REACTOR NEUTRON SOURCE is of the type used by the author in experiments at the Argonne National Laboratory. After leaving the reactor (*left*) the neutrons strike a large single crystal, where they are deflected at various angles depending on their energies. For most radiographic purposes the neutron beam could be used just as it leaves the reactor.

The various detection methods differ not only in speed but also in image sharpness. To examine sharpness, or resolving power, we have made many neutron radiographs of test objects containing small holes. We find the highest resolution is obtained with thin gadolinium screens in a direct-exposure method. Test films made by this method produced distinct images of tiny holes that are appreciably closer than 1,000th of an inch. The sharpness can evidently be attributed to the fact that gadolinium, when struck by thermal neutrons, emits low-energy electrons that travel only a short distance in the photographic emulsion. Next in order of image sharpness are most of the transfer methods and the direct exposures using scintillators. Other direct-exposure methods, using screens of such materials as cadmium, silver and indium, yield somewhat poorer images.

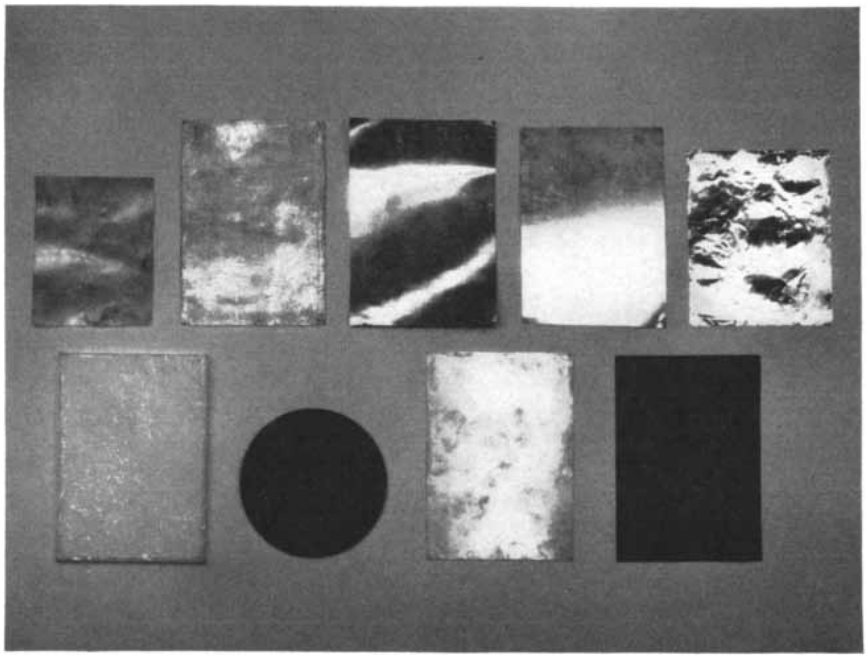
Another important property of a radiographic image is contrast, which makes it possible to distinguish different thicknesses of material in the test object. In examining the heavy metals, for example, we find that we can usually detect thickness variations of the order of 1 per cent with any of the detection methods, except when a scintillator is employed. In



ACCELERATOR NEUTRON SOURCE yields high-speed neutrons when high-energy protons strike lithium or some other suitable target. The neutrons are slowed down by diffusing through a moderator, which contains light elements such as hydrogen or carbon.



SETUP FOR NEUTRON RADIOGRAPHY is demonstrated at the Argonne National Laboratory. The neutron beam emerges from the Juggernaut reactor through the port at the right. Objects to be examined (small dry batteries) are mounted on a detector screen. Neutron radiographs of the batteries are compared with X radiographs at bottom of page 116.



RADIOGRAPHIC SCREENS convert neutron radiation into radiation that exposes photographic film. When struck by neutrons, the screens in the top row (dysprosium, indium, rhodium, silver and gold) become radioactive; the two screens at right in the bottom row (cadmium, gadolinium) emit gamma rays; the other two (boron scintillators) give off light.

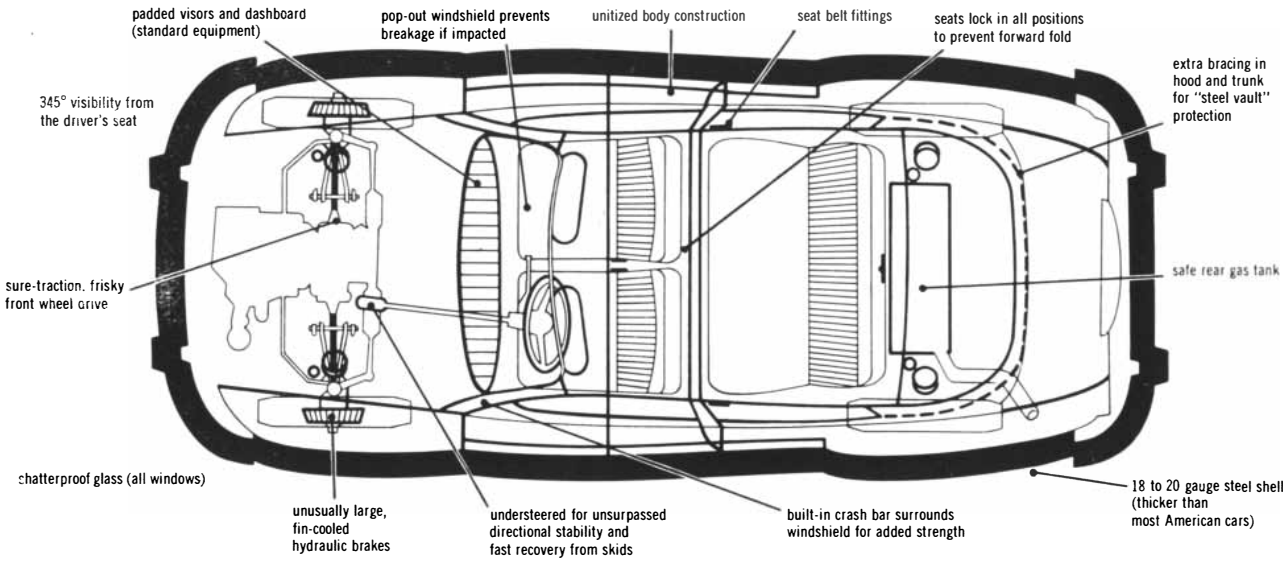
images produced by a scintillator the smallest detectable thickness variation runs from about 5 to 15 per cent. Although the scintillator methods leave something to be desired, we have found them useful for a quick look at a new test object. Speed and convenience are particularly good when the scintillator image is recorded on the high-speed Polaroid film, which develops in only 10 seconds.

Generally speaking, the resolution and contrast of the better radiographic methods compare favorably with those commonly obtained with conventional X-ray and gamma-ray equipment, but they do not yet measure up to the best results obtainable with X rays. Nevertheless, the quality of present neutron radiographic methods is high enough to suggest many industrial and technical applications, particularly where neutrons can provide distinctive information.

In metallurgy, for example, neutron radiography could be used to observe concentrations of light elements such as hydrogen, lithium or boron contained within various kinds of materials or objects. The top illustration on page 116 is a neutron radiograph of a zirconium bar containing sintered boron carbide, used to control the neutron intensity in portions of a nuclear reactor. A critical component in the bar is boron, placed there because of its capacity for absorbing neutrons. One would like to have an inspection method that would show whether or not the boron is distributed uniformly. An X radiograph is not much help because boron carbide and zirconium absorb X rays about equally. Neutrons, however, are absorbed several hundred times more readily by boron than they are by zirconium; thus the distribution of the boron shows up clearly in a neutron radiograph. Going through the periodic table, one can find many other combinations of substances that are easily distinguished by neutron absorption but not by X-ray absorption.

Another metallurgical use for neutron radiography is in the inspection of objects containing heavy metals such as uranium, lead and bismuth, which are much more transparent to neutrons than they are to X rays. When the thickness of such metals runs beyond a few inches, the exposure time for a neutron radiograph can become significantly less than for an X radiograph [*see illustration on page 119*]. Even the low-intensity neutron beam at Argonne can be used, with high-resolution techniques, to inspect a sample of uranium two inches thick in about an hour. This is only a small fraction of the comparable exposure that

1963 SAAB . . . built so well that it has a 24,000-mile/24-month written warranty*



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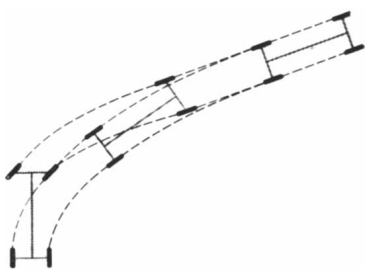

SAAB FRONT WHEEL DRIVE, carefully calculated understeering, low center of gravity, and advanced suspension design work together to optimize roadholding ability and safety in motion. Self-centering action of directly driven front wheels (see diagram) provides best possible roadholding ability at high speeds. Positive traction of front wheel drive at lower speeds makes cornering easier, dangerous skids virtually impossible. Front wheel drive pulls SAAB safely—on any road, at any speed, through ice, snow, and mud.

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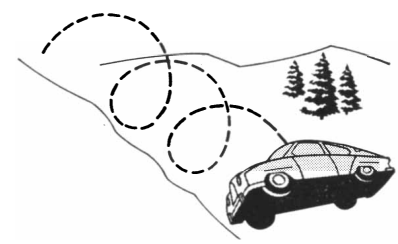

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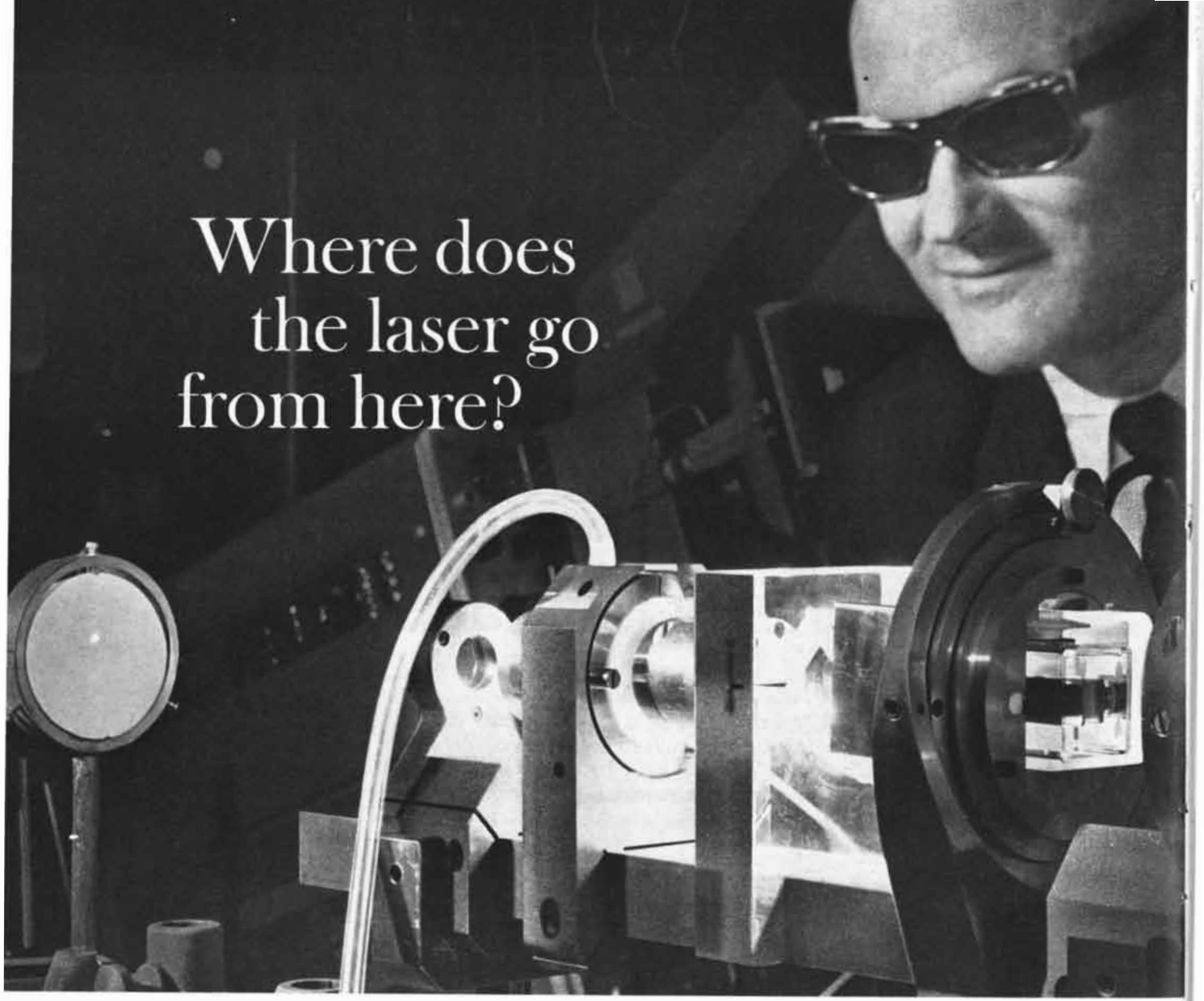
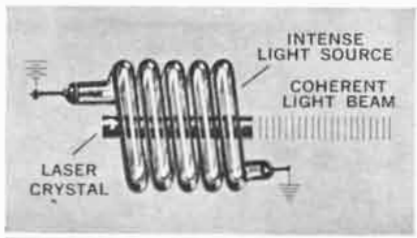


This tiny spot of light—produced by an advanced Hughes laser—is the symbol of a "quiet revolution" now rising in the electronics sciences.

The laser's product is *coherent* light. A basic phenomenon which stirs the imagination with its potential. First, coherent light beams are almost perfectly parallel—much like monochromatic "pipes of light." Hughes scientists and engineers, developing this unique characteristic, have already demonstrated a coherent light radar—Colidar—which predicts radar systems capable of discriminating between button-size objects at several miles range. Applying these beams to space communications systems could extend man's intelligence far into unknown space.

Second, coherent light can generate equivalent temperatures in the order of millions of suns. Hughes studies show laser beams could transmit energy—for example, to a satellite's power source. Hughes welding specialists are developing new laser fusion techniques for tomorrow's microminiature circuits.



Significant as they are, these accomplishments only hint at the scope of the laser. In 1960, Hughes demonstrated the first laser to produce coherent light. Today, Hughes researchers are probing deep into all three types of lasers—solid state (e.g. ruby and others), gas, and most recently,

Inside the laser—A crystal (or other material) exposed to an intense light source has its electrons "pumped up." As they relax, they emit photons. These stimulate a chain reaction to amplify the light pulse millions of times—producing a coherent light beam. Hence the acronym, "laser"—Light Amplification by Stimulated Emission of Radiation.

Demonstrated at a recent electronics convention, this Hughes Model 200 laser produces more than 20kW peak power for general laboratory and industrial use. For more details please write to address at right.

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liquid. While uncovering the basic secrets of each of these lasers, they are also developing new techniques and materials.

Characteristically, these discoveries are shared with Hughes systems and applications engineers. Together, their efforts are pacing entirely new laser technologies—in the service of our Armed Forces and NASA, and for civilian needs.

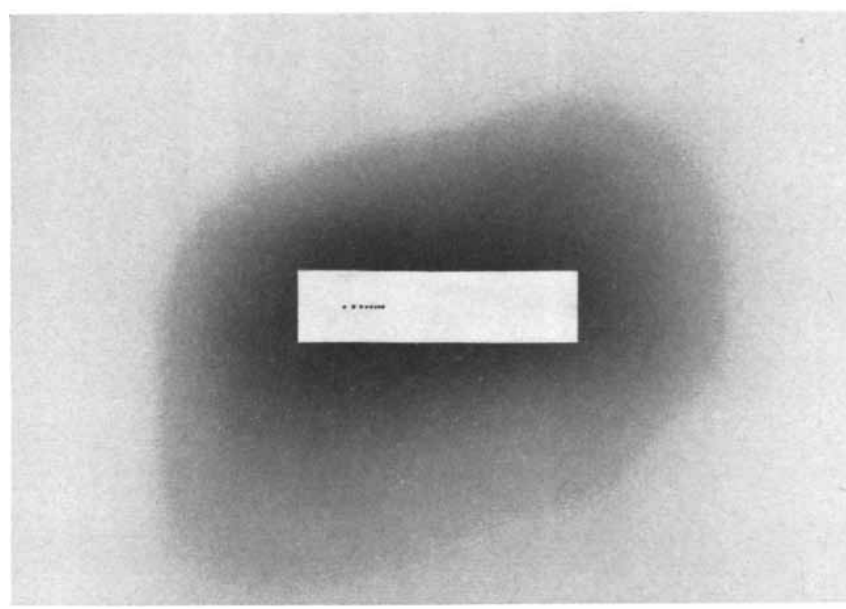
These kinds of advances do not just happen. They are the products of imaginative people working in an environment uniquely suited to stimulating achievement. Engineers, scientists and others interested in these Hughes activities are invited to write Hughes Aircraft Company, Department 05-22, Culver City 1, California.

would be required with a standard one-million-volt X-ray generator or with gamma rays from a cobalt-60 source of fair intensity. With neutron beams of greater intensity than our original Argonne beam, which should not be difficult to achieve, the exposure time could be cut to less than a minute. In comparison, the 22-billion-volt X rays from a betatron would require several minutes to produce a comparable radiograph through two inches of uranium. Actually with the fast scintillator technique the Argonne beam could produce a neutron radiograph of such a sample in less than 30 seconds, but the quality of the picture, as I have explained, would be substantially below X-ray quality.

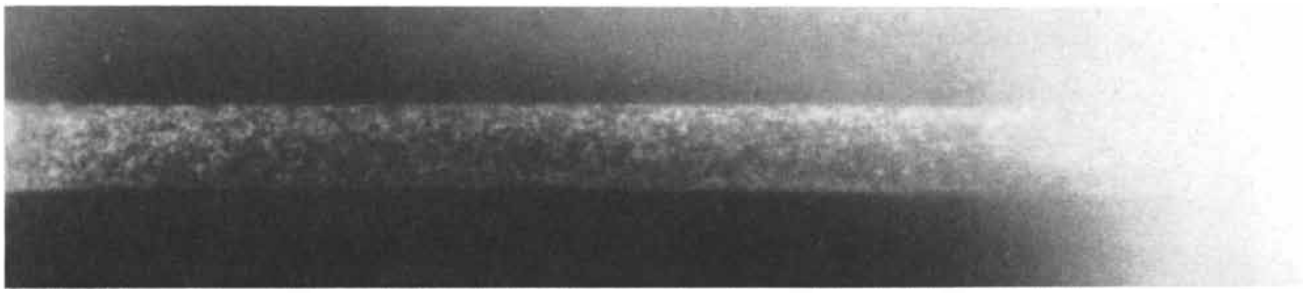
One of the fascinating things about thermal neutrons is that the same neutron beam used to inspect several inches of uranium or lead can be used to inspect specimens such as leaves, insects and thinner biological specimens. The neutron picture of a grasshopper on page 107 illustrates the possibility of applying neutron radiography in biological studies. I do not mean to suggest that neutron radiography of living animals or humans is feasible, much less desirable. Quite the contrary; the rich hydrogen content of animal tissue would make it difficult for the neutron beam to penetrate, and the exposures needed might induce enough radioactivity in the tissue to harm the organism. Neutron inspection of thin biological specimens may nonetheless offer advantages, particularly if the purpose of the inspection is to locate the position of hydrogen or other neutron-absorbing materials. For such biological applications the exposures required for neutron radiography are not excessive. With the use of metal screens and fast X-ray films, a radiograph of reasonable quality can be obtained with a total exposure of 10 million thermal neutrons per square centimeter of detector. This can be translated into an exposure of about 10 milliroentgens, a figure comparable to that required by fast X-radiographic methods.

The strong neutron absorption of hydrogen also makes inviting the possibility of neutron-radiographic inspection of such hydrogen-containing materials as paper, rubber, wood, plastics and adhesives. Small differences in the hydrogen content or the thickness of such substances, as well as the location of the substances in objects primarily made up of other materials, should be comparatively easy to observe with neutron radiography. The radiographs of the small batteries at the bottom of page 116 show the different responses of neutrons and X rays to objects containing various substances, including hydrogen. The pictures are X radiographs and neutron radiographs of new and used batteries. One can see first of all that the waxy material in the top seal of the battery—a material rich in hydrogen—completely absorbs the neutrons but transmits much of the X radiation.

A second and more interesting difference in response can be found if one



RESOLUTION TEST shows that neutron radiography can record fine detail. The test object is a piece of cadmium containing eight holes .02 inch in diameter. The picture was made with a thin gadolinium screen by the direct-exposure method described in text. The irregular blackened area around the object shows the actual dimensions of the neutron beam.



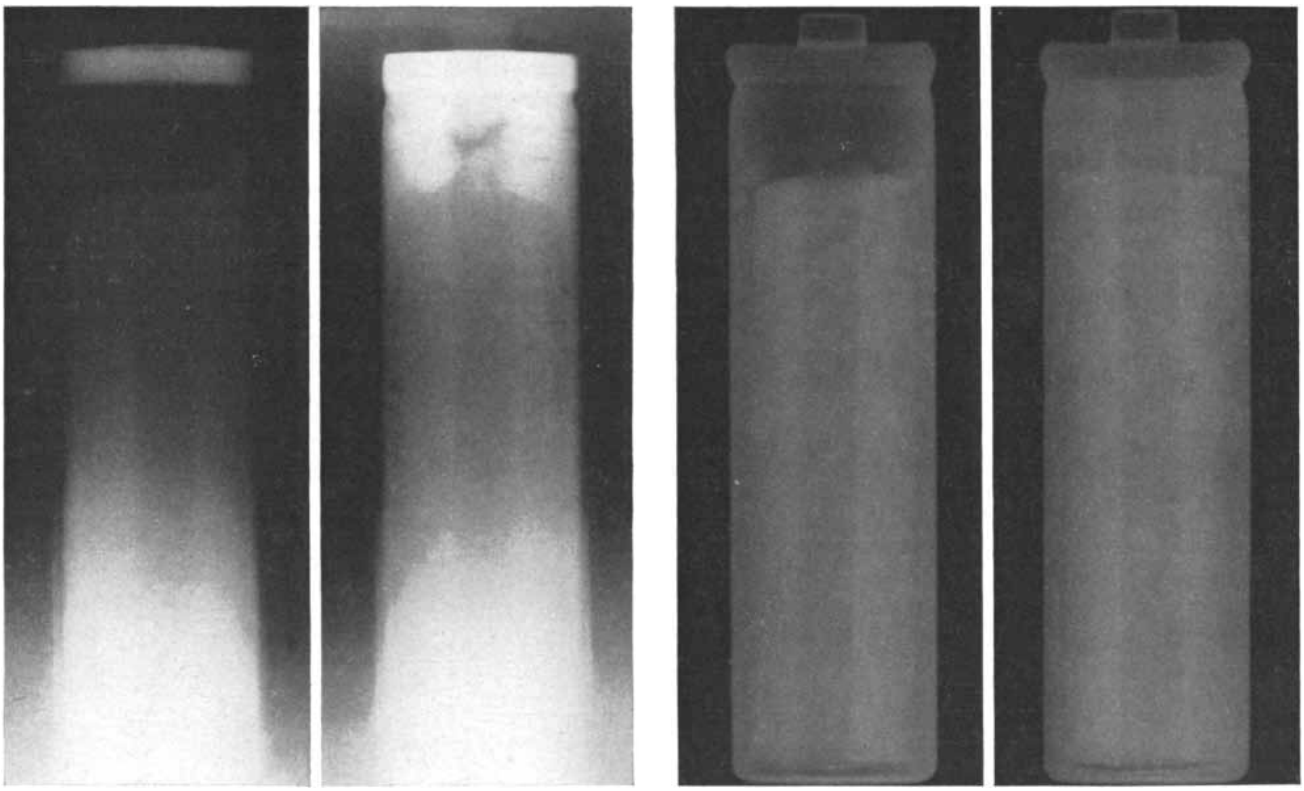
ZIRCONIUM BAR containing boron carbide makes a good test object for neutron radiography. Since boron carbide and zirconium have about the same absorption for X rays, an X radiograph would not tell much about boron carbide distribution. Boron, however, is one of the strongest absorbers of neutrons, whereas zirconium is only an average absorber. Hence boron carbide shows up as white.

compares the new and the used batteries. This difference is most evident in the expansion chamber near the top of the battery. In a new battery the expansion chamber is empty; both neutrons and X rays pass through it easily. In a used battery the expansion chamber has become filled with a paste-like material of high hydrogen content. The material consequently absorbs neutrons strongly but for X rays is only slightly more absorbent than empty space.

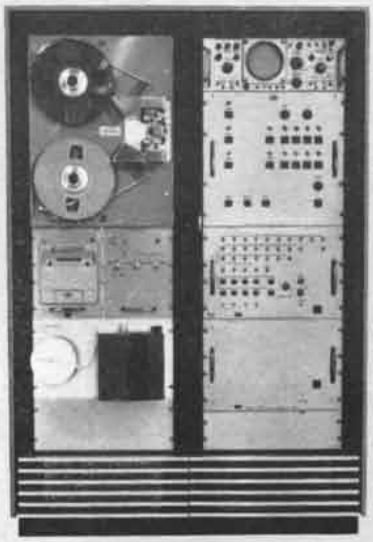
These neutron and X radiographs of the same samples demonstrate how the two techniques complement each other and how they broaden the usefulness of radiographic inspection when they are used together. Still, in spite of the many potential advantages to be gained using neutron radiography, and in spite of the fact that some of the original work on neutron radiography was reported in the technical literature more than 15 years ago, little use has been made of this inspection method to date.

This is perhaps not too surprising; the availability of neutron sources that have characteristics useful for radiography is still not very great. It is also true that until recently the quality of inspection possible with neutron radiography was not widely known, nor was much known about the many useful detection methods that could be employed for neutron imaging. As a result anyone wishing to try neutron radiography for a special inspection problem had the task of finding suitable equipment and of working out his own exposure methods. Even now, with many of these difficulties much diminished, there are still problems standing in the way of the routine application of neutron radiography.

In order to inspect large objects, or to view many small objects in one exposure, it would be desirable to have a larger beam of radiation than any now available. Most of our experiments were done with a neutron beam that covered an area only about three inches in diameter. The beam from the recently completed



RADIOGRAPHS OF SMALL DRY BATTERIES were made with neutrons (*pair at left*) and X rays (*pair at right*). In each set of pictures the battery on the right is a used one, hence the expansion chamber near the top is filled with an ammonia-containing material. This material produces a strong increase in neutron absorption but only a modest increase in X-ray absorption.



New approaches to problems in technical measurement

Nuclear structure studies can now be made in greater detail than ever, by physicists using the TMC 4096-channel time-of-flight analyzer. As the target material is bombarded by neutrons, nuclear particles may be displaced and scattered hither and yon. The time-of-flight analyzer detects these particles, measures their flight time from target to detector and stores the information in an appropriate channel of the unit's computer memory. With a capacity of 4096 channels* each storing 10^5 "bits" of data and ability to record flight times in the nanosecond range, this new analyzer provides resolution that permits more critical research analyses than ever before. In addition, the instrument can be set up to make pulse height analyses of gamma radiation simultaneously with time-of-flight studies.

This is one of many TMC innovations in nuclear physics research instrumentation. And TMC subsidiaries are equally important in their fields . . . Mnemotron Corporation in medical and industrial research; Telemetrics, Inc. in advanced ground station telemetry. For details on TMC capabilities in solving your technical measurement problems, write Technical Measurement Corp., 441 Washington Avenue, North Haven, Connecticut.

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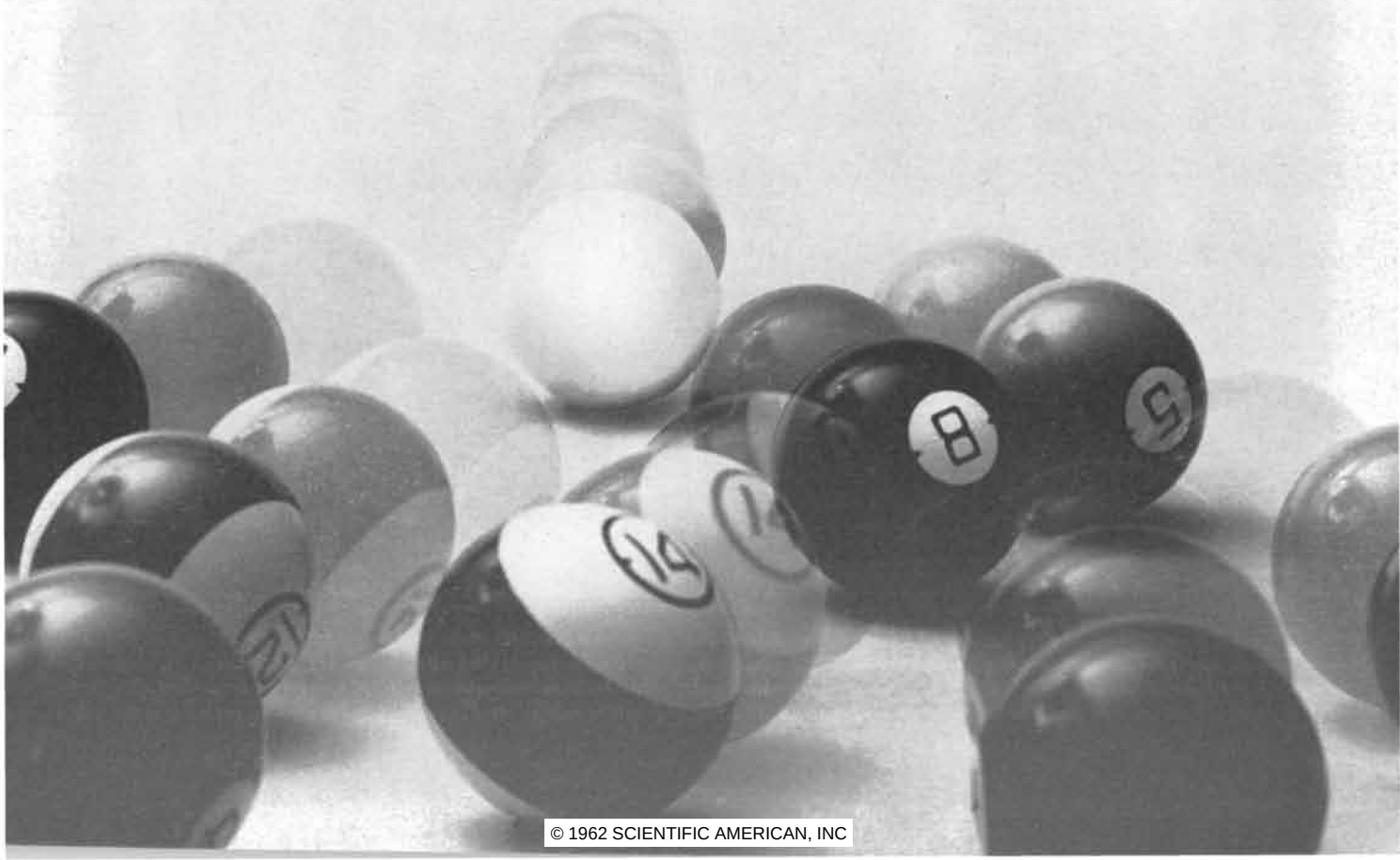

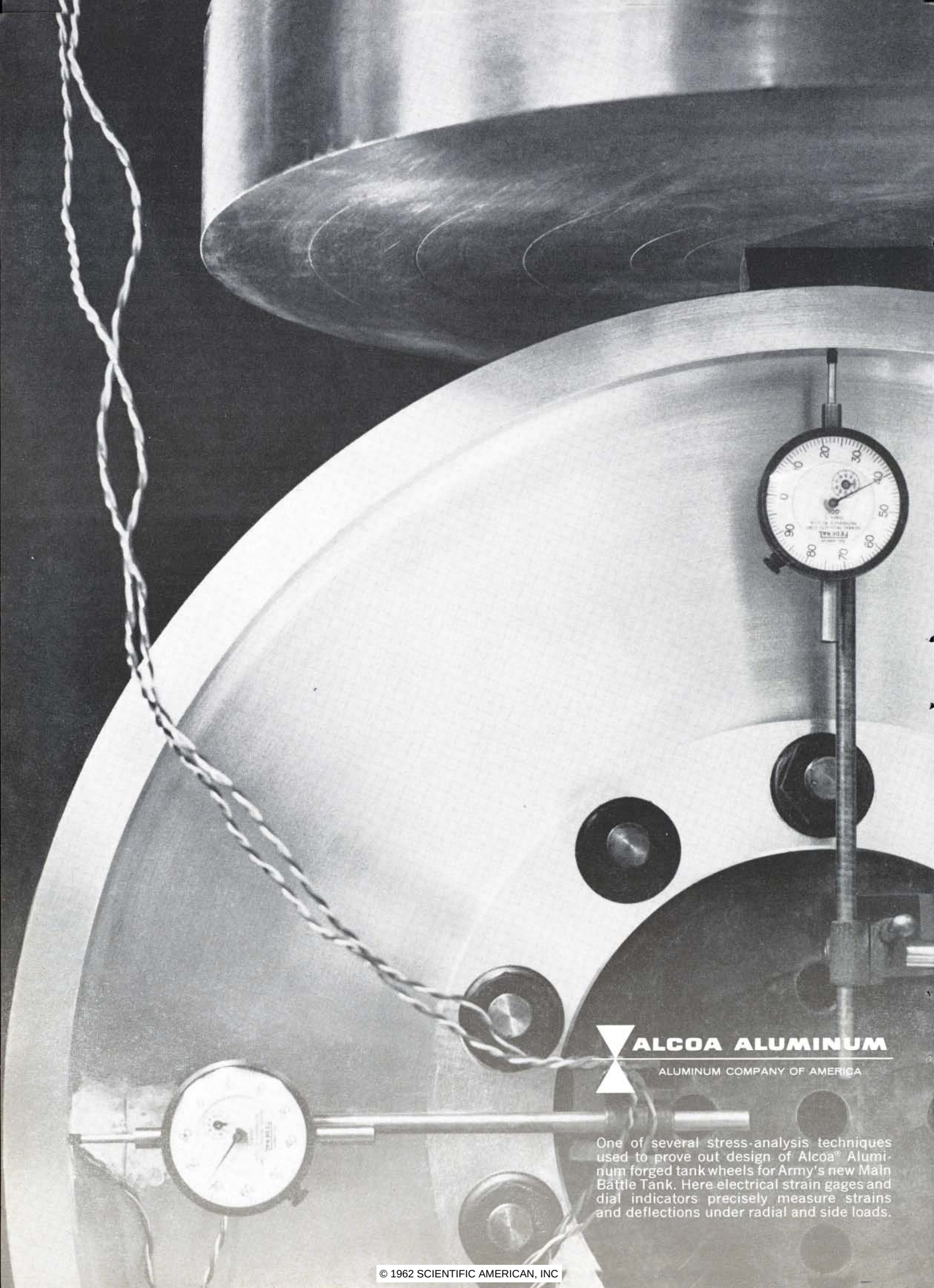

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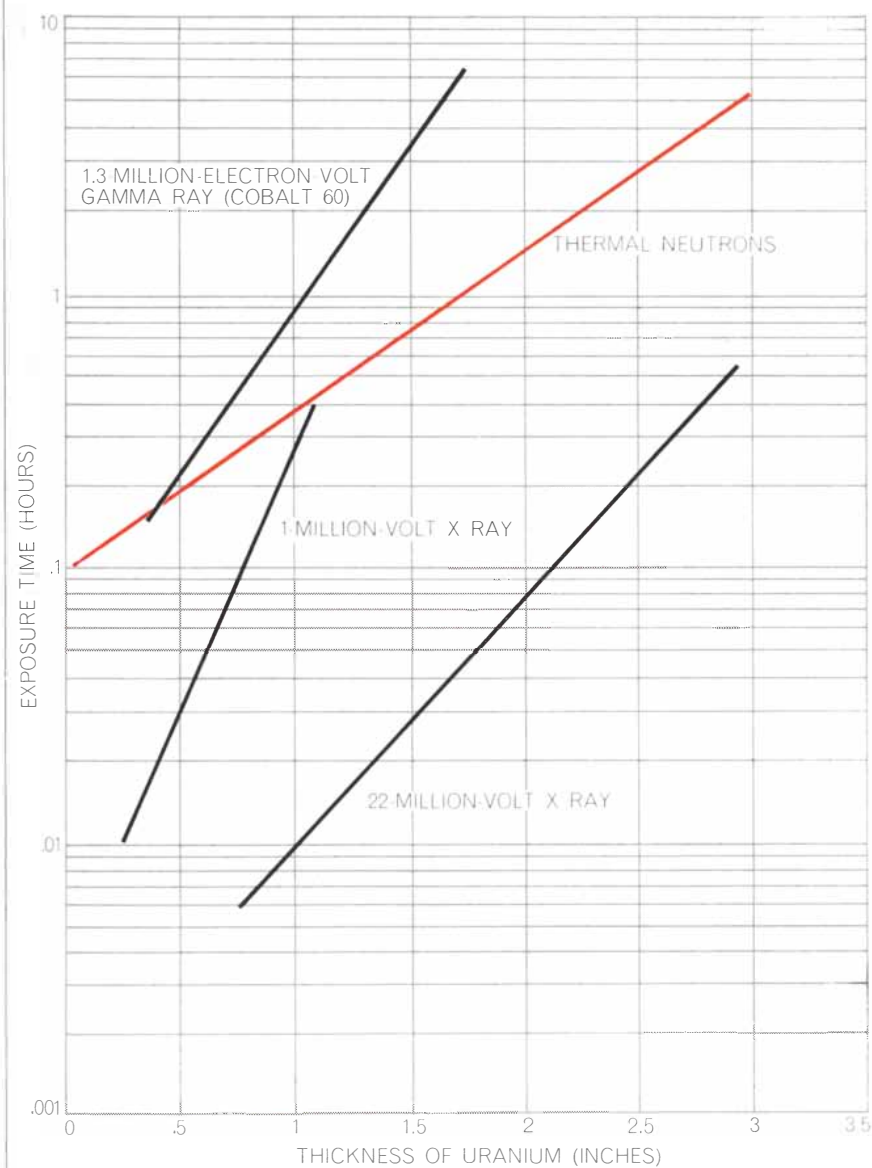
One of several stress-analysis techniques used to prove out design of Alcoa® Aluminum forged tank wheels for Army's new Main Battle Tank. Here electrical strain gages and dial indicators precisely measure strains and deflections under radial and side loads.

Juggernaut reactor at Argonne, shown on page 110, will produce radiographs 2.5 by four inches and will eventually supply a neutron beam six inches in diameter. It is possible, of course, to radiograph large objects section by section with small beams, but obviously this is slow and cumbersome. In short, the difficulty of obtaining large, uniform neutron beams of high intensity is still a major deterrent to the widespread application of neutron radiography.

For many purposes, particularly scientific ones, it would also be valuable to have a well-defined diverging beam of neutrons. Such a beam would in effect constitute a neutron microscope. It could be used, for example, to observe hydride precipitation in single crystals of metal or to observe the diffusion of boron or lithium in semiconductor materials. A diverging neutron beam would also have many uses in biology.

Better neutron sources are therefore needed to help neutron radiography realize its full potential. Even now, however, the capabilities and potential advantages of neutron radiography recommend its consideration for a variety of inspection problems. There is not much doubt that it will eventually become a routine inspection tool.



RADIOGRAPHIC EXPOSURE TIMES are shown for neutrons, for gamma rays from cobalt 60 and for X rays of two levels of energy. Gamma rays and X rays, of course, are both high-energy photons and carry different names only by custom. Exposure times reflect typical values for X-ray and gamma-ray sources and are based on the work of Gerold H. Tenney of the Los Alamos Scientific Laboratory. Neutron exposures are for an intensity of 100,000 neutrons per square centimeter per second, using a gadolinium screen and direct exposure.

Visual Pigments in Man

One pigment records images in black and white when the light level is low; two other pigments distinguish between green and red when the level is raised. The blue-sensitive pigment is yet to be found

by W. A. H. Rushton

Everyone knows that the eye is a camera—more properly a television camera—that not only forms a picture but also transmits it in code via the optic nerves to the brain. In this article I shall not discuss how the lens forms an image on the retina; it does so in virtually the same way that the lens of a photographic camera forms an image on a piece of film, and the process needs no explanation here. Nor shall I treat of the encoding of nerve messages in the eye, still less of their decoding in the brain, because on those topics reliable information remains extremely scanty. I shall deal rather with the light-sensitive constituents of the retina of the eye—the "silver bromide" of vision—and their relation to the perception of light and color.

It is no use taking a snapshot with color film if the illumination is poor; the only hope of getting a picture is to use sensitive black-and-white film. If the light signal is only sufficient to silhouette outlines, it cannot provide additional information for the discrimination of color. Thus for a camera to be well equipped to extract the maximum information from any kind of scene it must be provided with sensitive black-and-white film for twilight and color film for full daylight. The eye is furnished with a retina having precisely this dual purpose. The saying goes, "In the twilight all cats are gray," but by day some cats are tortoise-shell.

We cannot slip off our daylight retina and wind on the twilight roll; the two films must remain in place all the time. They are not situated one behind the other but are mixed together, the grains of the two "emulsions" lying side by side. The color grains are too insensitive to contribute to the twilight picture, which is therefore formed entirely by the black-and-white grains; these, on the other hand, give only a rather faint picture, which in daylight is quite overpowered by the color grains.

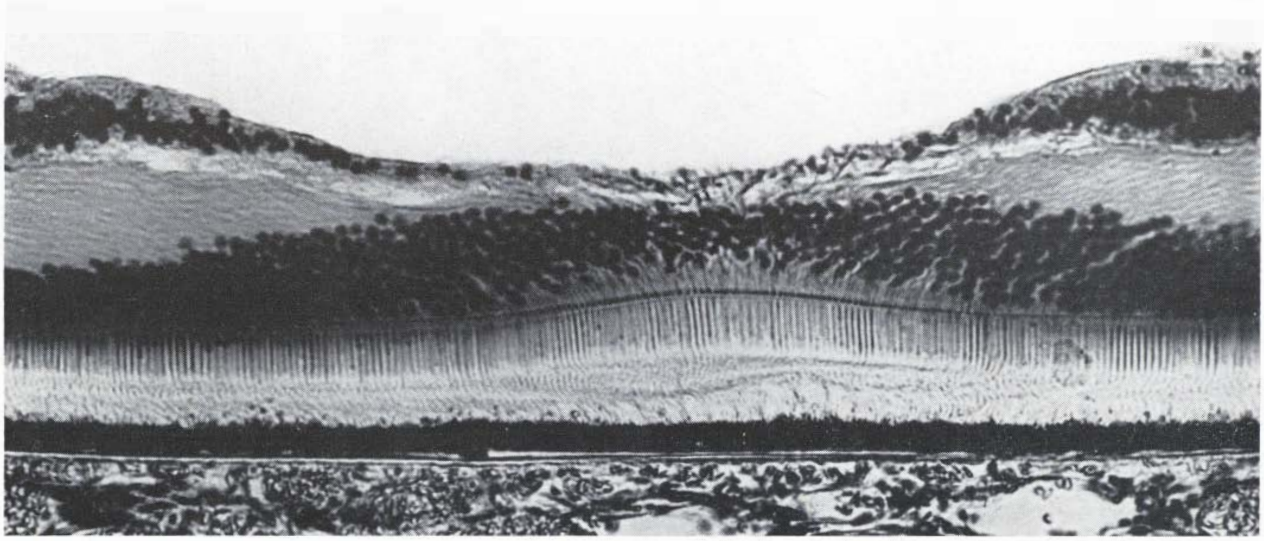
Of course the actual grains in the retina are not inorganic crystals such as silver bromide but are the specialized body cells known as rods and cones. The rods and cones do, however, contain a photosensitive pigment that is laid down in a molecular array so well ordered as to be quasi-crystalline. The rods are the grains responsible for twilight vision, and their photosensitive pigment is rhodopsin, often called visual purple. The cones are the grains of daylight vision, and the photosensitive pigments they contain will be one of the topics of this article.

It was first noticed almost a century ago that if a frog's eye was dissected in dim light and if the excised retina was then brought out into diffuse daylight, the initial rose-pink color of the retina would gradually fade and become almost transparent. The fading of the retina was the more rapid the stronger the light to which it was exposed; hence the term "bleaching" is used to describe the chemical change brought about when light falls on the photosensitive constituents of the rods and cones. If a microscope is employed to observe the retina as it bleaches, one can see that the pink color resides only in the rods. The cones appear to possess no colored pigment at all.

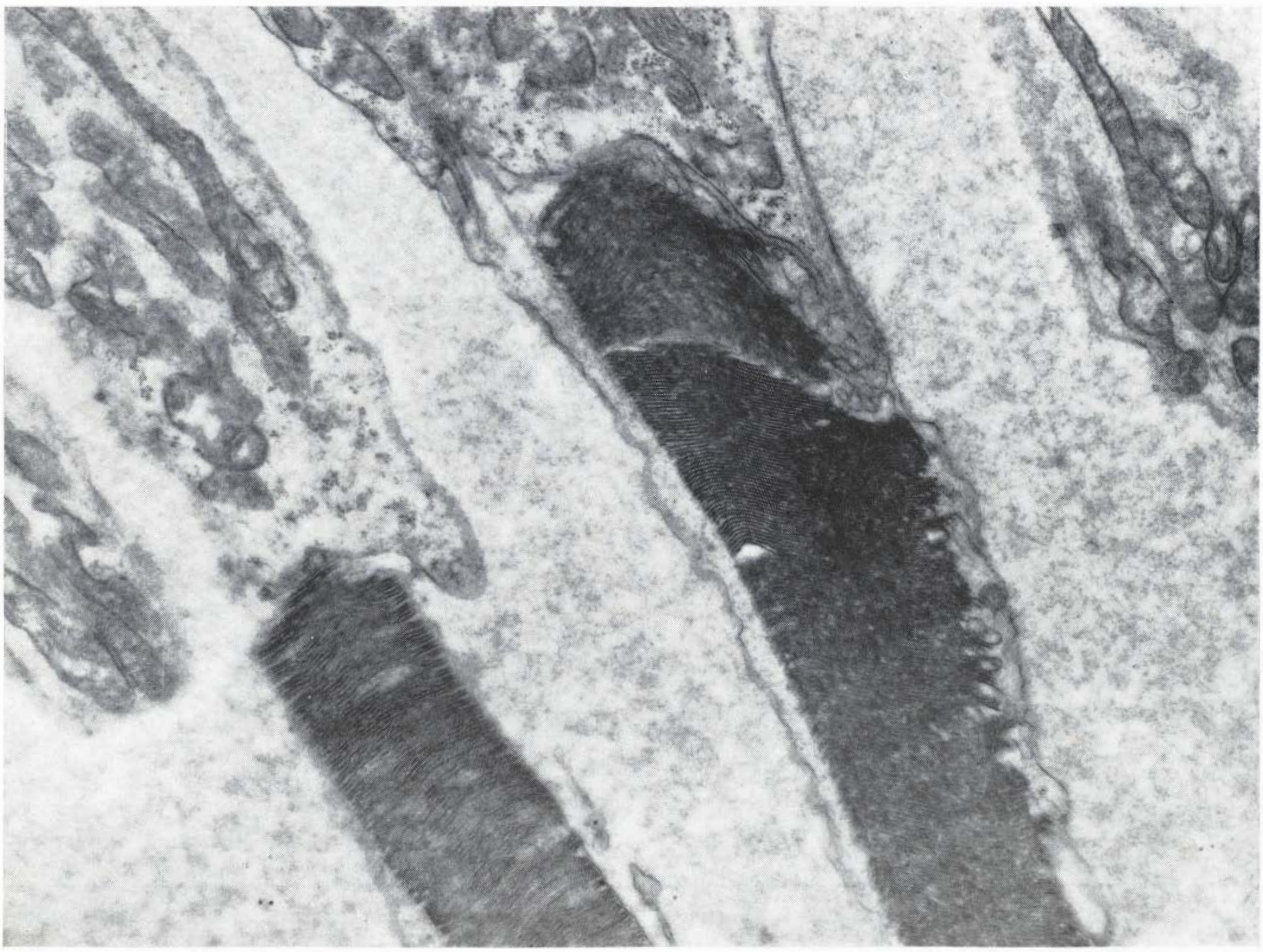
The presence of a photosensitive pigment in the rods does not prove that this is the chemical that catches the light with which we see; the pigment may be doing something quite different. There is one rather strict test that must be satisfied if rhodopsin, the pink pigment, is the starting point of vision. Since the pigment looks pink by transmitted light, it obviously absorbs green and transmits red (and some blue). With a spectrophotometer it is quite easy to measure the absorption of a rhodopsin solution at various wavelengths. When this is done, one obtains a bell-shaped curve with a peak close to a wavelength of 500 millimicrons, in the blue-green region of the spectrum. If rhodopsin catches the light we see in twilight, we should see best precisely those wavelengths that are best caught. In other words, the spectral absorption curve of rhodopsin should coincide with the spectral sensitivity curve of human twilight vision. Actual measurements of the twilight sensitivity of the eye at various wavelengths leave no doubt that rhodopsin is indeed the pigment that enables us to see at night [*see illustration on page 125*].

The eye is able to discriminate differences in brightness efficiently over a range in which the brightest light is a billion times more intense than the dimmest. Any instrument that can do that must have a variable "gain," or sensitivity-multiplying factor, and some means of adjusting the gain to match the level of signal to be discriminated. It is common experience that the eye adjusts its gain so smoothly that when the sun goes behind a cloud, the details of the scene appear just as distinct as before, and indeed we have so little clue to the eye's automatic compensation that when (as in photography) we want an estimate of the light intensity, it is safer to use a photoelectric meter. The change in gain of the eye is called visual adaptation.

It is plain that visual adaptation adjusts itself automatically to the prevailing brightness. To explain how this could occur Selig Hecht of Columbia Uni-



HUMAN RETINA, magnified about 370 diameters, is shown sectioned through the fovea, the tiny central region responsible for acute vision. The rods and cones, the photoreceptor cells containing the visual pigments, are the closely packed vertical stalks extending across the picture. Above the rods and cones are several layers composed chiefly of nerve cells that relay signals from the retina to the brain. At the fovea, which contains few if any rods, these layers are much thinned out to expose the light-sensitive part of the cones to incident light. This micrograph was made by C. M. H. Pedler of the Institute of Ophthalmology at University of London.



HUMAN ROD AND CONE are magnified about 20,000 diameters in this electron micrograph. The rod is on the left; the cone, on the right. The lamellated structures are the photoreceptor segments, believed to contain the visual pigments. These segments are joined at their base to the inner segments filled with mitochondria, which supply the cell with energy. The inner segments are positioned nearest the incoming light. The picture was made by Ben S. Fine of the Armed Forces Institute of Pathology in Washington.

versity 40 years ago drew attention to the visual pigments and suggested that their color intensity seems to vary with the level of light. He hypothesized that in bright light these pigments are somewhat bleached and that in the dark they are regenerated from precursors stored in the eye or conveyed by the blood. Under steady illumination a balance will be struck between these two processes, and the equilibrium level of rhodopsin will be lower the stronger the bleaching light is. Hecht suggested that the level of rod adaptation is controlled by the level of the rhodopsin in the rods.

One difficulty in accepting this rather plausible suggestion is that until one can measure the actual rhodopsin level in the eye and correlate it with the corresponding state of visual adaptation, the idea remains speculative and very insecure. This indeed was the situation for some 30 years, but now it is possible to measure rhodopsin and cone pigments in the normal human eye by a procedure requiring only about seven seconds. As a result one can now follow the time course of bleaching and regeneration and test Hecht's suggestion.

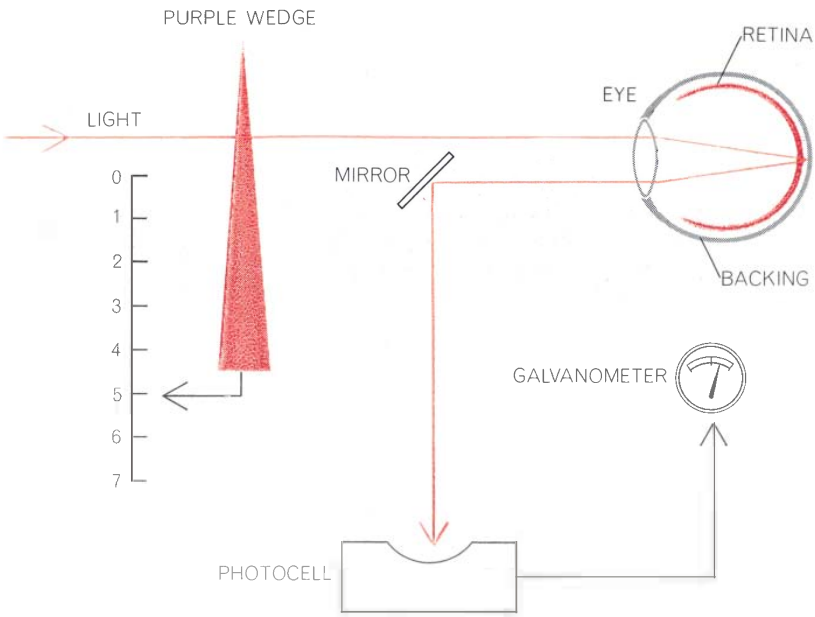
Most people have at one time or another seen the eyes of a cat in the glare of an automobile headlight. The brilliant yellow-green eyes shining out of the darkness are a striking sight. The effect is caused simply by the reflection of light from the back of the cat's eye. What is important for our purpose is that these rays are reflected from behind the cat's retina and have therefore passed twice through the retina and the rhodopsin contained in the retina. This by itself would make the eye look pink, as it does in the case of the dissected frog retina. The cat, however, has a brilliant green backing to its retina and it is this backing that colors the returning light. To see the color of rhodopsin itself we need an animal whose retina has a white backing. If instead of a cat there were an alligator in the road, we should see the eye-shine colored pink by rhodopsin.

By using a photocell to analyze the returning light one can measure the rhodopsin no matter whether the eye is backed by green as it is in the cat, by white as in the alligator or even by black as in man. Regardless of its color, the reflectivity of the rear surface is unchanging, whereas the rhodopsin lying in front can be bleached away by strong light. It follows that if one measures not the color but the intensity of the returning light, one can find how much of the light was absorbed by rhodopsin.

The illustration on this page shows schematically the instrument used to measure the bleaching of human eye pigments in my laboratory at the University of Cambridge. Light enters the eye through the upper half of the pupil, which has been dilated by a drug to allow more light to pass. It returns after reflection from the black rear surface, having twice traversed the retina. A small mirror intercepts the light from the lower half of the pupil and deflects it into a photomultiplier tube, which provides a measure of the light absorbed by the retinal pigments. If a powerful light is shined into the eye, the light bleaches away some of the pigment. This leaves less pigment to absorb the light traversing the retina; consequently the photocell output will be greater than before. The output can be returned to its former value by reduction of the measuring light. This is done by interposing a purple wedge in the beam of light entering the eye. The initial photocell output is restored when the amount of purple added by the wedge exactly matches the visual purple—the rhodopsin—removed by bleaching. The change in rhodopsin is thus measured simply by the change in wedge thickness that replaces it. The wedge scale is calibrated so that the reading is zero when all the rhodopsin is bleached away. Therefore the wedge setting for constant photocell output gives the rhodopsin density at that moment.

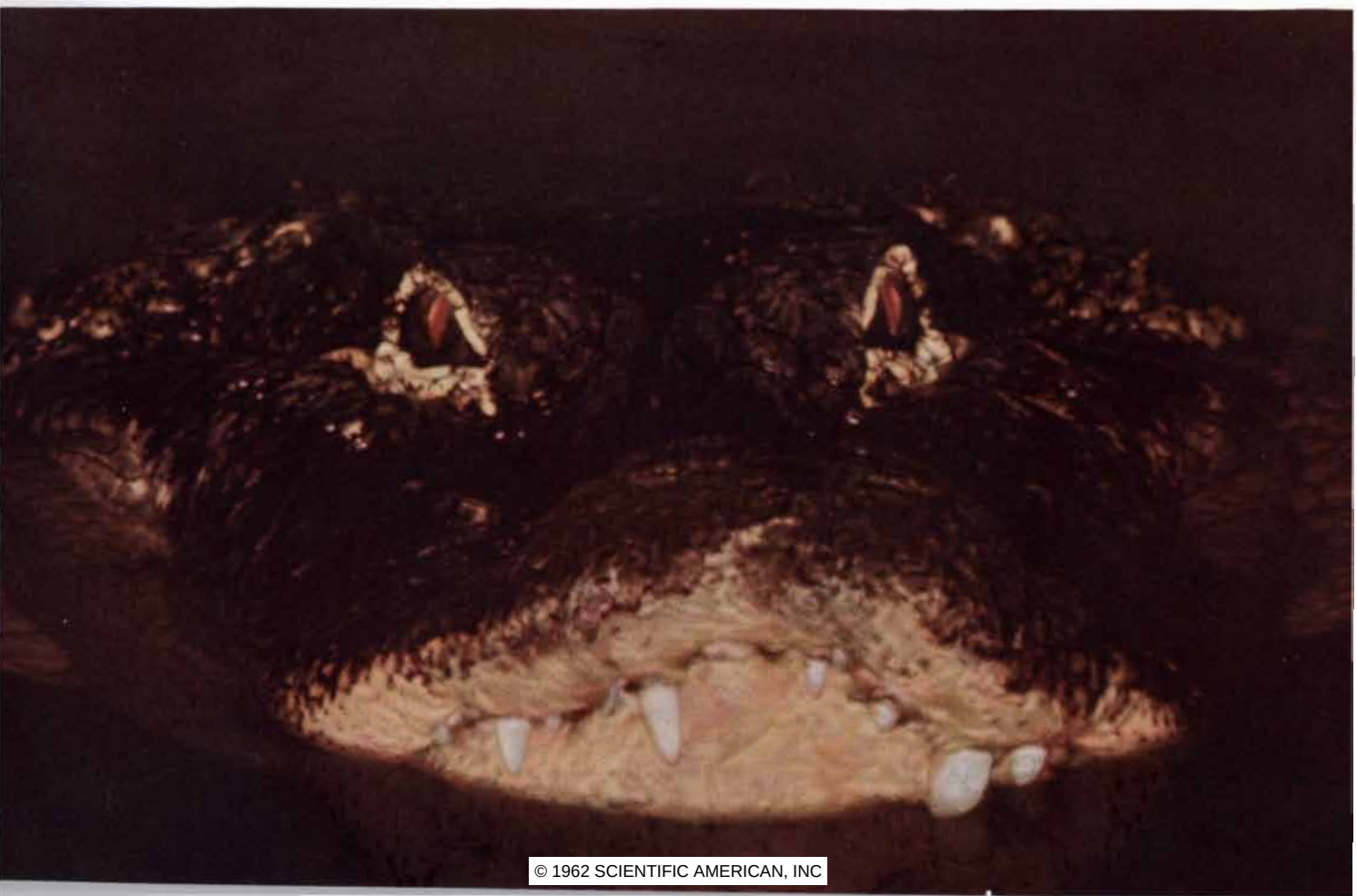
The intensity of the light reaching the photocell is only about a 20,000th of that falling on the eye, and the light striking the eye has to be so weak that it will not appreciably bleach the pigment it measures. Thus the equipment needs some rather careful compensations if measurements are to be reliable. We are not concerned here, however, with the technique of measurement but with the results in relation to the physiology of vision, and in particular with the question of the relation of rhodopsin level to visual adaptation.

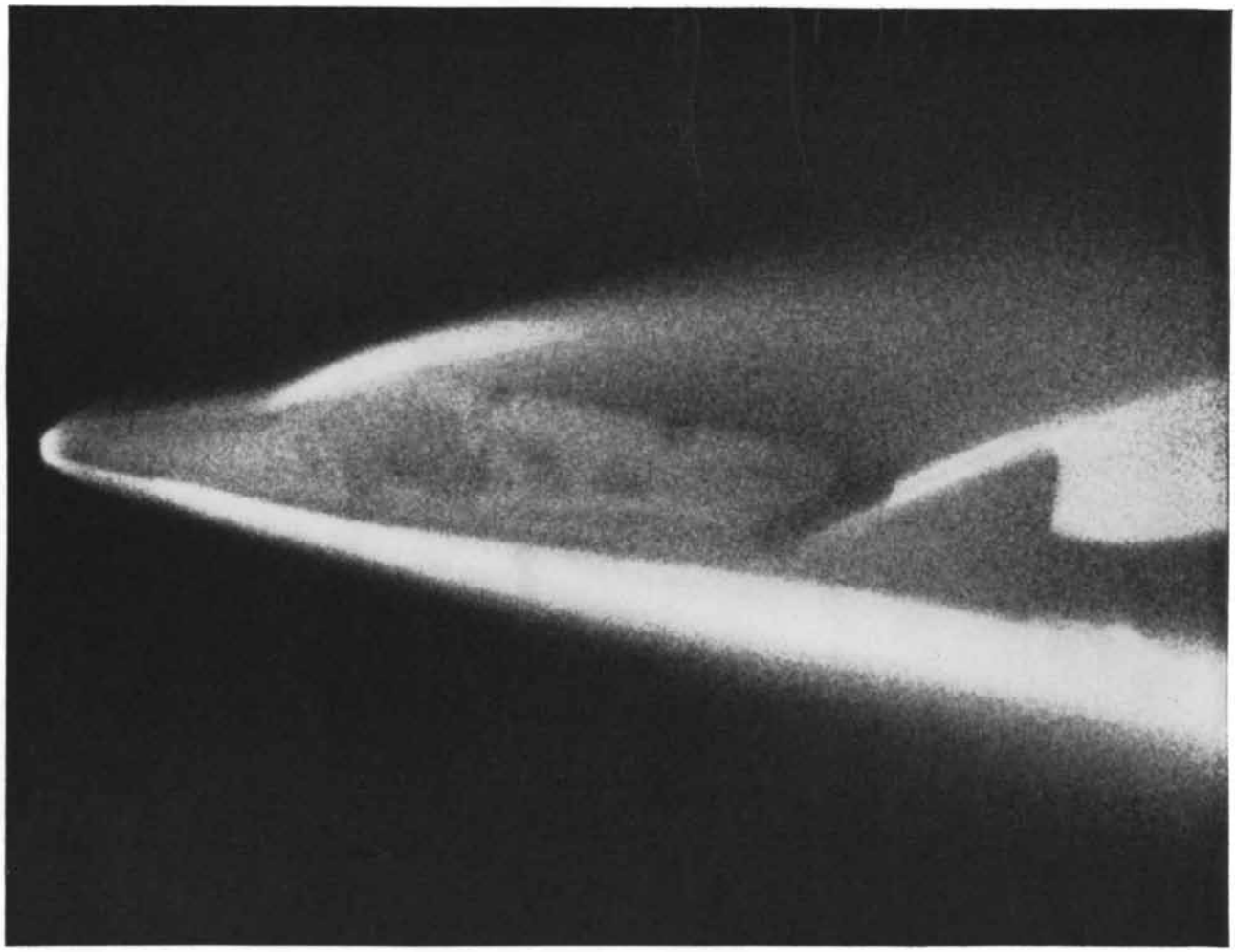
The top illustration on page 126 shows the first measurements of this kind. They were made on my eye by F. W. Campbell at the University of Cambridge in 1955. The black dots show the wedge readings when a moderately bright bleaching light (one "bleaching unit") was applied to the dark-adapted eye. The pigment at first bleaches fast, then more slowly, and in five minutes it levels out, either because all the pigment is now bleached or because bleaching is just counterbalanced by the regeneration



METHOD OF MEASURING VISUAL PIGMENTS depends on the bleaching produced by light. Light enters the eye through a purple wedge, and the amount reflected is measured by a photocell. When the pigment rhodopsin, or "visual purple," is bleached from the retina, an equivalent amount of wedge is inserted in the light beam to keep the electric output the same after bleaching as before. The change in pigment is measured by the wedge displacement; a change of one unit means reflectivity of the eye has changed by a factor of 10.

EYE OF THE ALLIGATOR, which has a white reflecting layer behind the retina, illustrates how rhodopsin bleaches in the light and regenerates in the dark. The eye of the alligator above is light-adapted; the light of a stroboscopic-flash lamp, reflected from the white layer through the retina, is essentially colorless. The eyes of the alligator below are dark-adapted; the light reflected is red. The photographs were made at the New York Zoological Park with the kind assistance of Herndon G. Dowling and Stephen Spencook.





12,000 MPH. Space vehicle research model glows with heat during 12,000 mph test in Boeing hot-shot wind tunnel. Providing highest velocities of any privately-owned facility of its kind in the world, this Boeing wind tunnel can simulate orbital speeds up to 18,000 miles an hour, altitude conditions into space and temperatures to 14,000° F. Used extensively in Boeing's U.S. Air Force X-20 (Dyna-Soar) and Minuteman ICBM research, this hypervelocity tunnel helps solve problems of space re-entry.

Capability has many faces at Boeing

THREE-ENGINE 727. Scale model shows Boeing 727 short-range jetliner. First flight is scheduled for this winter. Deliveries begin in 1963. American, Eastern, Lufthansa, TWA and United airlines have ordered 127 Boeing 727s.

ADVANCED SATURN in drawing, right, will be world's largest rocket, some 350 feet high. Boeing holds NASA contract to develop, build and test S-IC first-stage booster, developing thrust equal to about 160,000,000 horse power.

SEA SIMULATOR. Boeing-built electronic device tests autopilot Boeing is designing and manufacturing for high-speed U.S. Navy hydrofoil vessels. The hydrofoil, its dynamics, and the sea are simulated by a computer. The system can simulate anything from flat calm to a hurricane, with all results observed and tabulated.

BOEING

process. The latter is obviously the correct explanation, since by increasing the intensity of the bleaching light fivefold, further bleaching occurs and a lower level of equilibrium is achieved. In fact, a further increase of a hundredfold is needed to bleach the pigment entirely. The rate of pigment regeneration in the dark following total bleaching is plotted by the colored dots in the illustration. The regeneration follows an exponential curve and is about 90 per cent complete in 15 minutes.

Let us now examine Hecht's suggestion that it is the level of rhodopsin in the rods that defines the state of adaptation in twilight vision. But before doing so we must distinguish two quite different visual processes that are often designated by the word "adaptation." One process is exemplified by the quick changes in sensitivity that occur at night when the moon is fitfully obscured by passing clouds. This can be called field adaptation. When, on the other hand, we have got well adapted to bright light and then go into the dark—from sunlight into a theater, for instance—a different process occurs, which can be called adaptation of bleaching.

Now, field adaptation has nothing to do with the level of rhodopsin in the rods (or of visual pigments in the cones); the light intensity involved is only about a 100,000th of the bleaching unit referred to earlier, so that no appreciable bleaching can have occurred. Moreover, the time of adjustment to the new light level when the moon pops in and out of cloud is of the order of two seconds, rather than the 1,000 seconds required for the regeneration of rhodopsin. This rapid change of gain is in all likelihood produced entirely by the activity of nerve cells. Conceivably a feedback mechanism in the neural system maintains a constant signal strength by exchanging sensitivity for space-time discrimination. The adaptation of bleaching, on the other hand, turns out to be tightly linked to the level of rhodopsin in the rods.

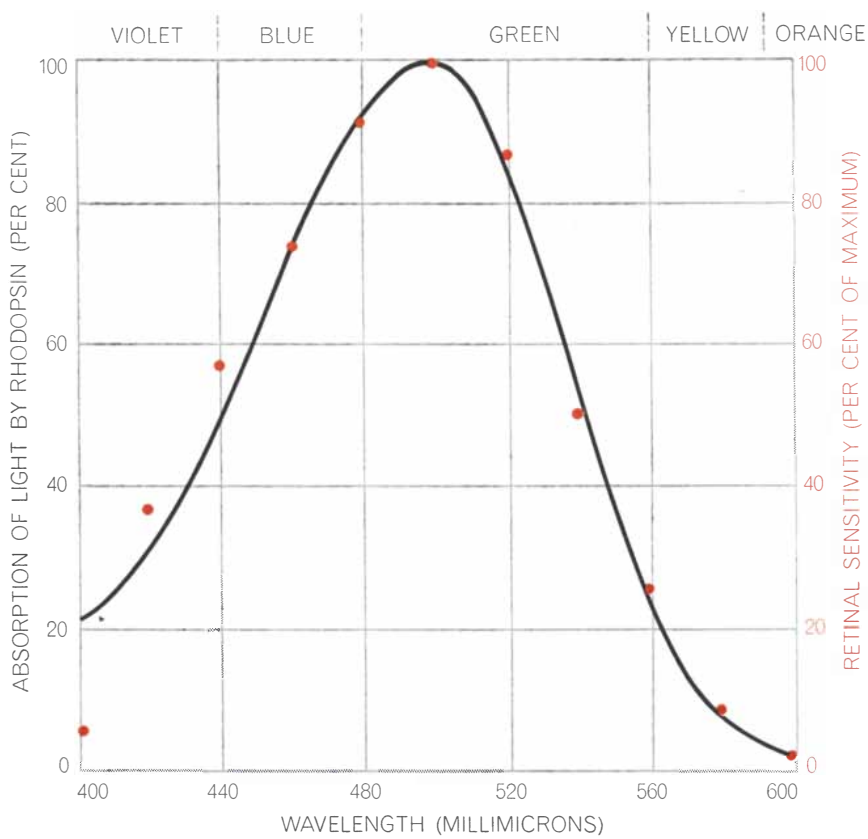
The simplest way to examine this relation is to illuminate the eye with a powerful beam of light, a beam having an intensity of 100 bleaching units. After a minute or two all the rhodopsin will be bleached away and the course of pigment regeneration can be followed. The experiment is now repeated, but instead of measuring rhodopsin we determine the threshold of the eye by finding what is the weakest flash that can be detected at various intervals as the pigment regenerates. This is conveniently done by inserting a gray wedge to reduce the flash to threshold strength. The wedge displacement will now give the threshold directly on a logarithmic scale. A plot of this threshold yields the well-known dark-adaptation curve, shown in the bottom illustration on the next page.

As can be seen, the curve for the normal eye consists of two branches, the first of which corresponds to the log threshold of cones; the second, to the log threshold of rods. Only the rod threshold is related to rhodopsin, and it is a serious drawback that so much of this curve is hidden by the cone branch. Fortunately the complete rod curve can be obtained by using test subjects with a rare congenital abnormality in which rods are normal but cones entirely lack function. The dark-adaptation curve for such a subject is the black curve in the bottom illustration on the next page. It can be seen that the curve exactly follows the time course of the regeneration of rhodopsin, whether measured in the same subject or in a normal subject. It is therefore plain that the increase in light sensitivity of the rods waits precisely on the return of rhodopsin in the rods. What is far from plain, however, is what the increase in sensitivity waits for.

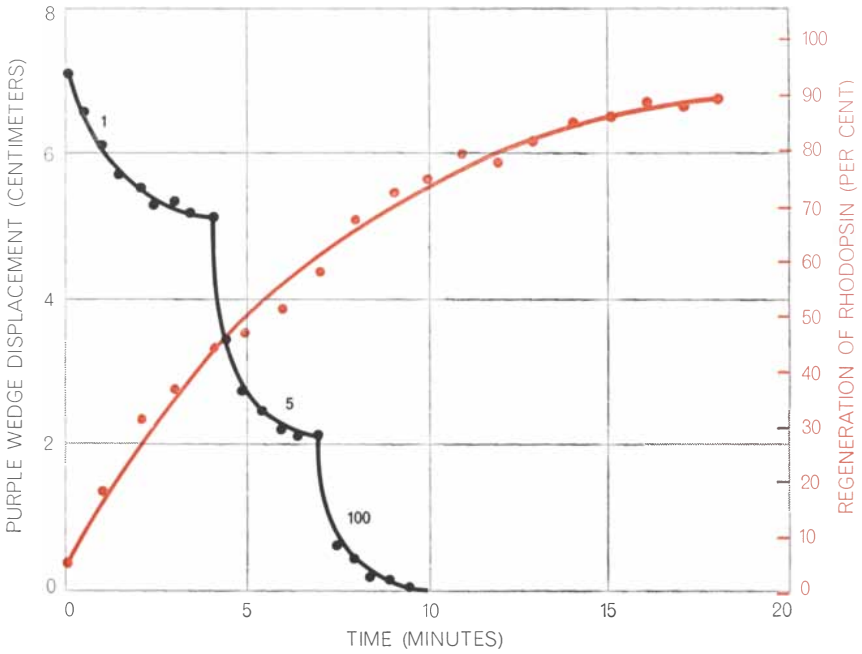
The change of sensitivity gain by nerve feedback in field adaptation is purposeful and efficient. The coupling of gain to the regeneration of rhodopsin in the adaptation of bleaching seems both pointless and clumsy. I have a far greater faith in nature, however, than in myself. I am sure that someone with deeper insight will eventually show that the deficiencies in dark adaptation, which to me seem unnecessary, are in fact inevitable.

The rapid and unconscious change of gain that makes absolute levels of light intensity hard to judge applies to cones as well as to rods, but in cones there is also the appreciation of color, which has its own adaptations. In judging brightness we estimate the brightness of parts with respect to the mean brightness of the whole. Thus the actual intensity of light reflected from black print in the noonday sun is far greater than that from white paper after sunset, yet the first looks black and the second white.

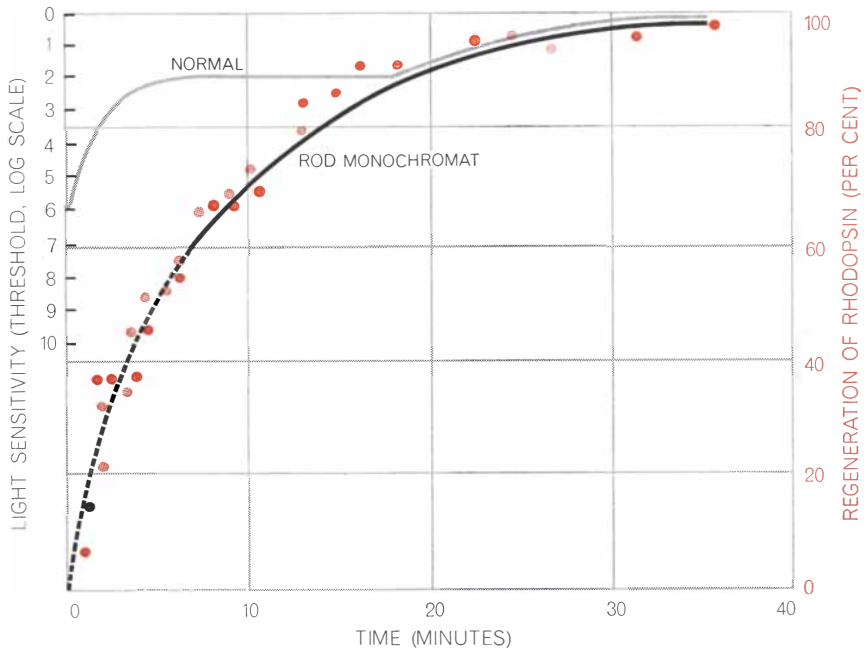
In color judgments wavelengths en-



MEASUREMENTS OF RHODOPSIN show it to be the pigment responsible for twilight vision. The black curve indicates how a solution of rhodopsin, obtained from retinal rods, absorbs light of various wavelengths. Dots show sensitivity of the eye in twilight.



BLEACHING AND REGENERATION OF RHODOPSIN are shown in the two curves obtained by the method illustrated on page 122. The black curve records the time course of bleaching for a light of moderate intensity (*1*) and for lights five and 100 times brighter. In the dark, rhodopsin regenerates as shown by the colored curve. The measurements were made on the eye of the author by F. W. Campbell at the University of Cambridge.

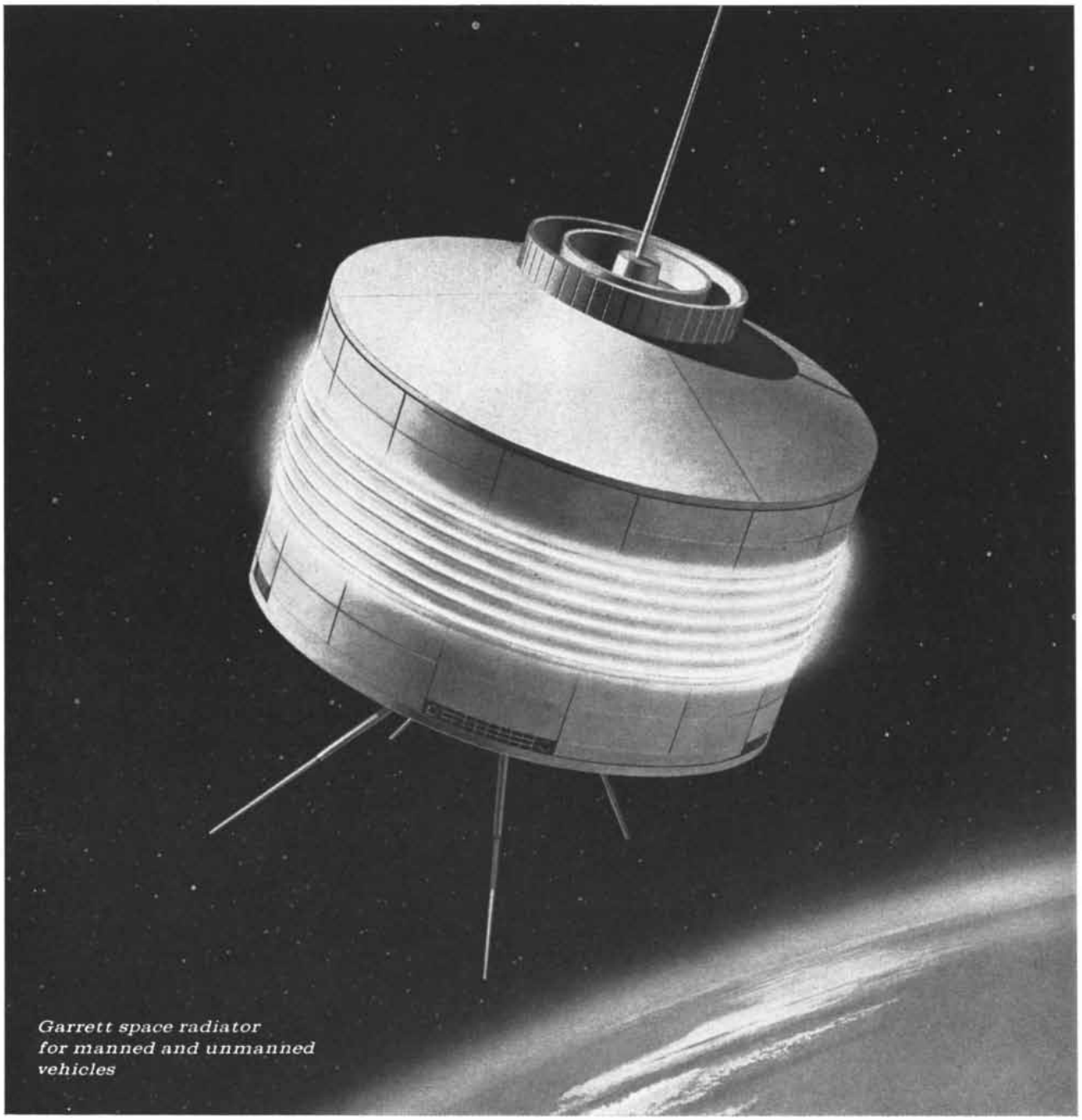


ROD AND CONE LIGHT SENSITIVITY can be distinguished by comparing a normal eye with that of a "rod monochromat," a person whose retinal cones do not function. The rhodopsin is fully bleached and the weakest detectable flash of light is measured. As the rhodopsin regenerates, the eye detects flashes that are weaker and weaker. The light sensitivity of the normal eye follows a discontinuous curve. The initial sensitivity increase is due to cones; the final increase is due to rods. In the rod monochromat the sensitivity rises more slowly but in a smooth curve. Independent measurements with the purple-wedge technique show that rhodopsin regeneration goes hand in hand with increased light sensitivity in the rod monochromat (*dark-colored dots*). In the normal eye, however, rhodopsin regeneration (*light-colored dots*) follows only the rod branch of the light-sensitivity curve.

ter in, and we estimate the color of parts of a scene in relation to the mean wavelength of the whole. The fact that our perceptions of color can be independent of wavelength to a surprising degree has been brought into great prominence by the striking demonstrations of Edwin H. Land of the Polaroid Corporation [see "Experiments in Color Vision," by Edwin H. Land; SCIENTIFIC AMERICAN, May, 1959]. Land has shown, for example, that two superimposed images of a scene, made on black-and-white film through different filters, will appear to contain a large range of color when one image is projected by red light and the other by white light. To say that the eye uses the average wavelength of such a red-and-white projection to judge the color of its parts is not meant to "explain" the Land phenomena, still less to suggest that no explanation is needed. It is merely a reminder that owing to some sort of adaptation—which Land has recently shown to be instantaneous—the eye is almost as bad at making absolute judgments of color as it is of brightness.

What the eye can do very well, however, is to make color *matches*, and these remain good even in the conditions of Land's projections. For instance, if monochromatic beams of red and green light are superimposed by projection on a screen, they can be made to match the yellow of a sodium lamp exactly, just by suitably adjusting the intensity of the red and of the green. If this red-green mixture is now substituted for the sodium yellow in one of Land's two-color projections, the colored picture resulting is exactly what it was before. Although many strange things appear in Land's pictures, one thing is clear: If red and green match yellow in one situation, they will match it in every other situation. Why, we may ask, are color matches stable under conditions where color appearance changes so greatly, and what colors can be matched by a mixture of others? A century ago James Clerk Maxwell showed that all colors could be matched by a suitable mixture of red, green and blue primaries, and indeed that any three colors could be chosen as primaries provided that no one of them could be matched by a mixture of the other two. The trichromaticity of color implies that the cones have three and only three ways of catching light. It seems reasonable, therefore, that there may be three and only three different cone pigments.

Since the rods have only one pigment,



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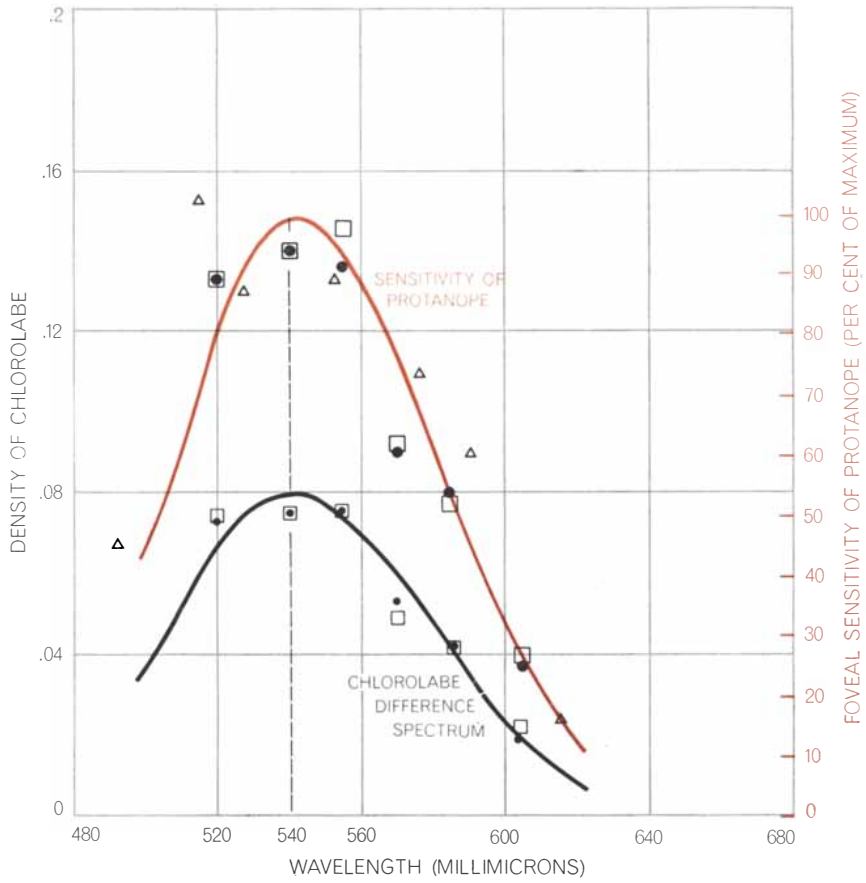
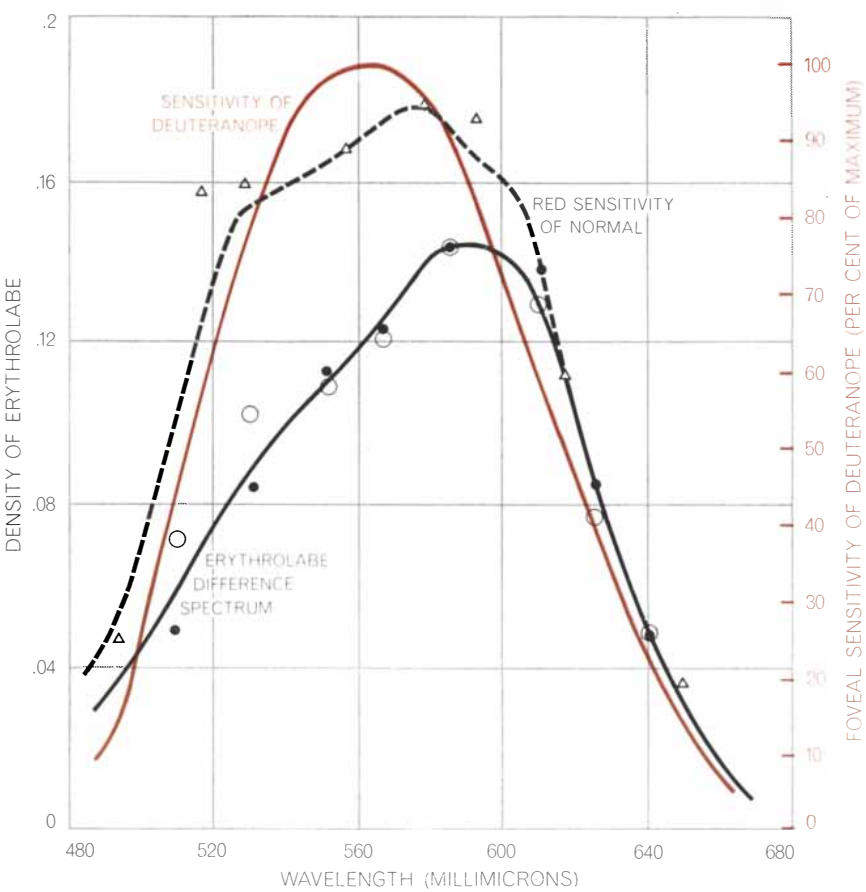


GREEN-CATCHING PIGMENT, called chlorolabe, can be measured in the eye of a protanope, the name given to a person who is red-blind. The pigment in the fovea of a protanope is partially bleached with red light and the change in reflectivity is measured at six wavelengths (*small dots*). The reflectivity change is then measured after partial bleaching with blue-green light (*small squares*). Since the protanope's fovea responds in the same way to both bleaches, it evidently contains only one pigment. The two sets of measurements define the difference spectrum of chlorolabe. Bleaching with white light, which shows total pigment present, shifts the foveal reflectivity upward at each wavelength (*larger squares and dots*). White-bleaching measurements coincide well with measurements of the protanope's sensitivity to white light (*colored curve*), made by F. H. G. Pitt of Imperial College. Still another way to measure bleaching, described in text, defines the "action spectrum" (*triangles*). It also supports the view that cones of the protanope contain one pigment.



RED-CATCHING PIGMENT, erythrolabe, can be measured in the eye of a deuteranope, a person who is green-blind. The experiments are similar to those performed on the protanope. The black dots show the change in reflectivity of the fovea after partial bleaching with red light, the open circles after partial bleaching with blue-green light. The curve fitted to the two sets of circles is the difference spectrum of erythrolabe, the single visual pigment in the foveal cones of the deuteranope. The erythrolabe difference spectrum, however, does not coincide well with measurements by Pitt showing the deuteranope's sensitivity to white light (*colored curve*). This suggests that erythrolabe forms a colored photoproduct when bleached, which reduces foveal reflectivity below the values expected. The efficacy of bleaching as measured by the action spectrum comes closer to matching the deuteranope's visual sensitivity. It also agrees well with the sensitivity of the normal eye to red light alone (*broken curve*).

two lights of different wavelength composition will appear identical if they are scaled in intensity so that both are equally absorbed by rhodopsin. By the same token it should be possible to scale the intensity of two lights of different composition so that they will be absorbed equally by any one cone pigment. To that pigment the two lights would appear to have the same color. The scaling that will deceive the red pigment, however, will be detected by the green and blue pigments. It needs rather careful adjustment of two different color mixtures if they are to match; that is, if they are to deceive all three cone pigments at the same time. When this is achieved, the two inputs to the eye are in fact identical, and no one—not even Land—has the magic to show as different what all three cone pigments agree is the same.

Now we see why color matches are stable although color appearances change. Matches depend simply on the wavelength and intensity of light striking the three pigments and on the absorption spectra of these three chemicals. But appearances are subject to the whole complex of nervous interaction not only between cone and cone in the retina but also between sensation and preconception in the mind. Let us therefore leave the rarefied atmosphere of color appearance and return to the solid ground of cone pigments.

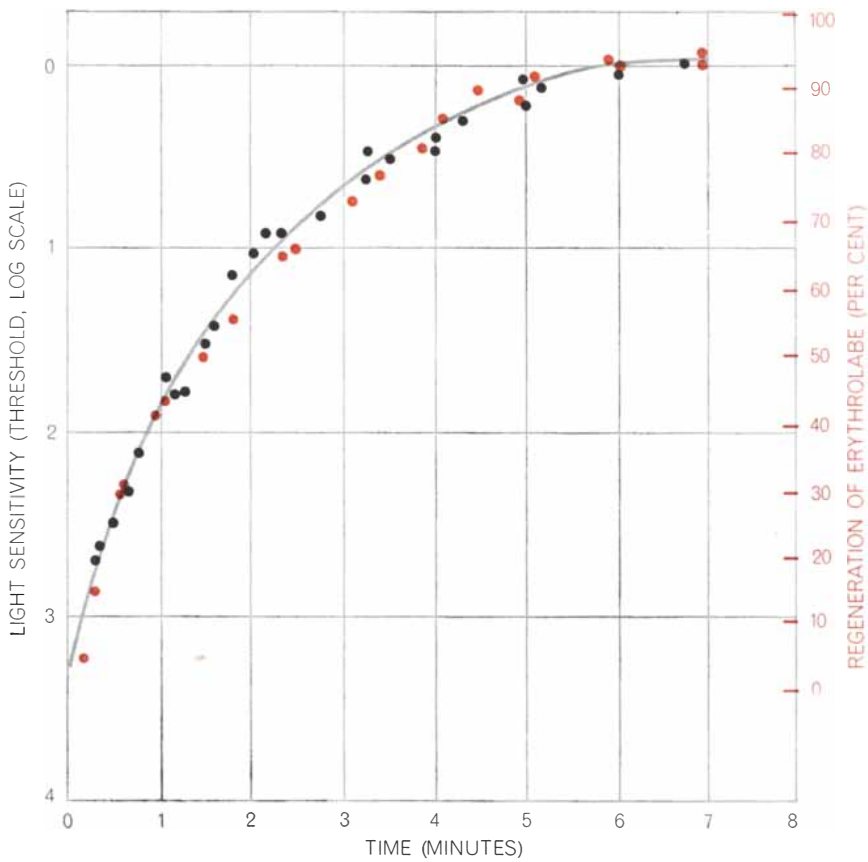
If the cones contain three visual pigments, it should be possible to detect them and measure some of their properties by the method described for rhodopsin. To be sure, the human retina, like that of the frog, contains such a preponderance of rhodopsin that it is hard to measure anything else. Fortunately the fovea, that precious central square millimeter of the retina that we use for reading, contains no rods. It is also deficient in blue cones. Therefore if pigment-absorption measurements are confined to this tiny area, they should reveal the properties of just the red and green cones. One can simplify even further.

The common red-green color blindness is of two kinds: in one the colorblind individual is red-blind, in the other he is not. It turns out that the first individual lacks the red-sensitive pigment and that the second lacks the green-sensitive pigment. Therefore by measuring the fovea of the red-blind person, or protanope, we obtain information about the green-sensitive pigment only. The results of an analysis of this kind are

set forth in the top illustration on page 128.

It will be recollected that what we do is to adjust the wedge so that the output of the photocell is the same after bleaching as it was before. For the protanope experiment we use a gray wedge and express this displacement in terms of the corresponding change in optical density of the cone pigment. Since light passes through the pigment twice, once on entering and once on returning, measurements indicate a "double density" of pigment. Such measurements, made in lights of six wavelengths, are shown by the squares and dots in the illustration. The change in the reflectivity of the fovea, caused by bleaching, is maximal when measured with light that has a wavelength of 540 millimicrons and diminishes on each side. The small squares represent change in the reflectivity after bleaching with blue-green light; the small dots, after bleaching with very bright red light. These changes define a curve that we call a difference spectrum. The fact that both curves coincide means that there is only one pigment present. If there had been a mixture, the more red-sensitive of the two would have shown a greater change after bleaching with red light; the other, after bleaching with blue-green light. A second series of measurements made after bleaching with a bright white light shows the total pigment present.

To discover whether or not this photosensitive pigment is indeed the basis of cone vision in the protanope we apply the test discussed earlier for rhodopsin. We simply ask: Does the spectral absorption coincide with the spectral sensitivity? The colored curve in the top illustration on page 128 shows how the cone sensitivity of the protanope does in fact correspond to the absorption measurements. We may conclude, therefore, that the protanope in daylight sees by this pigment, which is called chlorolabe, after the Greek words for "green-catching."



LIGHT SENSITIVITY AND REGENERATION OF ERYTHROLABE follow the same time course. The black dots show how the deuteranope's fovea becomes increasingly sensitive to brief flashes of light as the eye becomes dark-adapted. The colored dots are separate measurements made after the erythrolabe has been fully bleached. They show that the foveal pigment regenerates in seven minutes. The coincidence of the two sets of measurements implies that cones, like rods, have dark adaptation linked to pigment regeneration.

The other type of color-blind person, lacking chlorolabe, is known as a deuteranope. That he also has a single foveal pigment is established by the similar change in foveal reflectivity produced by either deep red light or blue-green light, as shown in the bottom illustration on page 128. It is plain that this pigment, which is called erythrolabe ("red-catching"), has a difference spectrum extending much further into the red than chlorolabe. If erythrolabe is the pigment that catches the light by which the deuteranope sees, he ought to be able to see further into the red end of the spectrum than the protanope can. This indeed is the case, but it is also apparent that the difference spectrum of chlorolabe does not coincide too well with the spectral sensitivity of the deuteranope, shown by the colored curve. Therefore the matter needs to be studied further.

If erythrolabe is the cone pigment of the deuteranope, lights of various wavelengths adjusted in intensity so that each appears equally bright to the deuteranope ought also to prove equivalent in the rate at which they bleach erythrolabe. Measurements of bleaching efficacy for lights of various wavelengths produce an "action spectrum," shown by triangles in the two illustrations on page 128. It can be seen in the bottom illustration that the action spectrum coincides reasonably well with the sensitivity of the deuteranope and also with the sensitivity of the red mechanism in the normal eye, shown by the broken curve. Thus there is fair agreement between sensitivity and bleaching power, and erythrolabe has a strong claim as the visual pigment of the deuteranope and of the normal red color mechanism.

It is also possible to measure the time required for the erythrolabe in the deuteranope's fovea to regenerate after bleaching. The curve in the illustration at the left resembles that for rhodopsin but rises about four times faster. It can be seen that the light sensitivity of the deuteranope, also plotted, increases precisely in step with the return of erythrolabe. So we are reasonably confident that erythrolabe is the pigment with which the deuteranope catches light.

Now we are in a position to prove that the normal fovea contains both green-sensitive chlorolabe and red-sensitive erythrolabe. The pertinent measurements are shown in the illustration on page 132. The black dots show the bleaching produced by deep red light, and it is evident that they define a curve

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In 1932, a surprise in a dilatometer

The research chemist put the bar of test glass inside the chamber to measure its coefficient of thermal expansion. He threw a switch and the temperature in the chamber rose to nearly 600°C.

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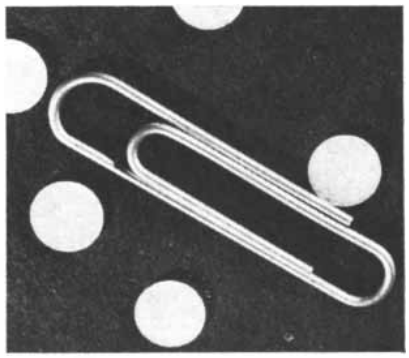

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VYCOR brand glassware will work continuously at 900°C., and will function without damage on occasional excursions to 1300°C. It can be heated cherry-red and then plunged into ice water without breaking.

It gets stronger as it gets hotter. Its modulus of rupture at 800°C. is 28% higher than at room temperature.

Indifference to high temperature, heat shock, and chemicals makes VYCOR brand glassware ideal for tough sight glass and labware applications.

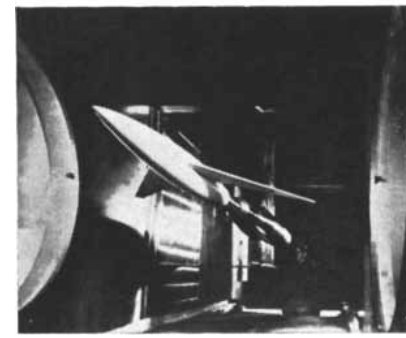
Acids, water, and steam won't affect it measurably at low or high temperatures.

Compared to ceramics and glasses in general, it has higher electrical resistivity and lower dielectric loss.

Its transmission of ultraviolet and infrared is exceptional.

Nose cones on heat-seeking missiles are VYCOR brand domes that transmit better than 90% of the useful infrared.

Singly and in combination, these properties make VYCOR brand glassware the answer to many problems.



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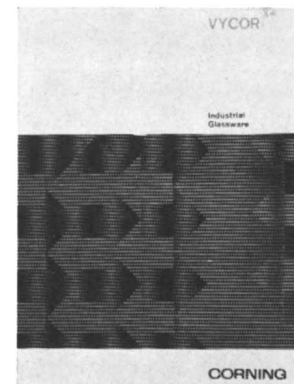


Corning Glass Works, Industrial Components Department, 4911 Crystal St., Corning, N. Y.

CORNING

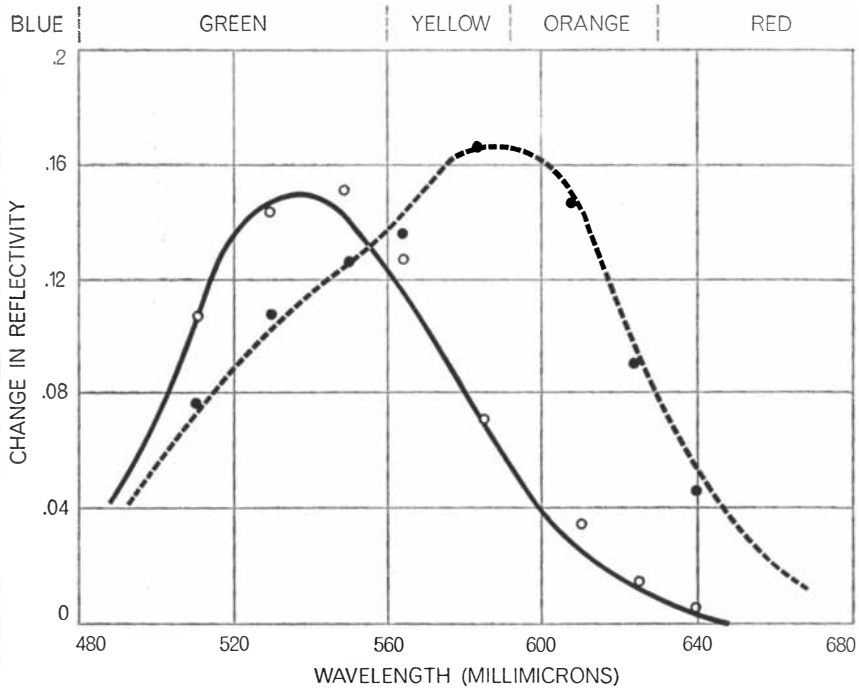
identical to the difference spectrum of erythrolabe, as measured in the deuteranope.

If in the deuteranope we changed the bleaching light from red to blue-green, no alteration would occur, since both lights bleach the deuteranope's single pigment equally. But when blue-green light is used to bleach the normal eye, one discovers that additional bleaching takes place, which cannot be attributed to erythrolabe. This additional bleaching is shown by the open circles in the illustration. Since no change in erythrolabe can contribute to this increment, it must represent the pure change in a second pigment in the normal eye. To see if this pigment is chlorolabe we draw on the same chart the difference spectrum of chlorolabe, as measured in the protanope, and we find that it closely follows the open circles. Thus the normal fovea is seen to contain both erythrolabe and chlorolabe.

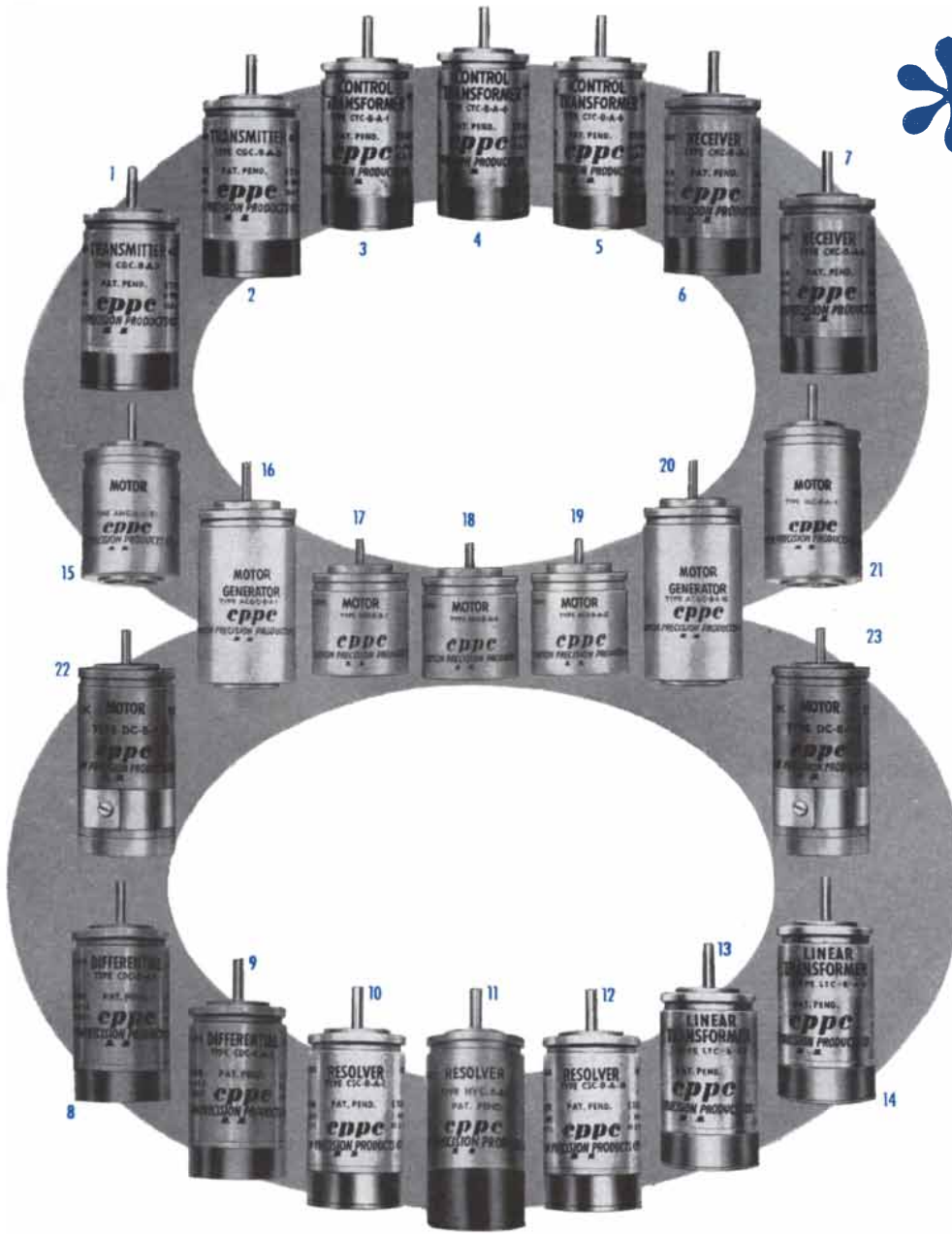
A person with normal color vision can distinguish colors in the red-orange-yellow-green range of the spectrum because all of these colors affect the pigments erythrolabe and chlorolabe in different proportions. In this range protanopes and deuteranopes have only the one, or only the other, of these pigments; hence they have no more means of distinguishing these colors by day than a person with normal vision has by night. They can see only one color because they have only one pigment.

The reader will ask: What about the blues? Is there a "blue-catcher"—a cyanolabe—to complete the triad of cone pigments? I think there is, but it is much harder than the others to measure and there is not much at present to be said about it.

Practically all the ideas in this article have been entertained long ago by acute investigators; they have also often been disputed. What the measurement of pigments in man has done is to bring some degree of exactness and security to ideas that were enticing but speculative. The precision of measurement, however, lies not in the investigator who turns the knobs but in the subjects who sit with clamped head and fixed eye gazing steadfastly 20 minutes at a time through flashing and gloom. These are my students, some normal, some color-blind—volunteers from the classes in physiology in the University of Cambridge.



TWO PIGMENTS IN NORMAL CONES are demonstrated by bleaching the eye with deep red light, then with blue-green light and recording the change in reflectivity of the fovea at eight wavelengths. Bleaching with red light gives the results shown by black dots and coincides with the erythrolabe difference spectrum (*broken curve*) found in the deuteranope (*see bottom illustration on page 128*). When the bleaching light is blue-green, the reflectivity of the fovea increases beyond that observed when the bleach is red. The additional reflectivity is shown by open circles and conforms to the difference spectrum of chlorolabe (*solid curve*), as measured in the protanope (*see top illustration on page 128*).



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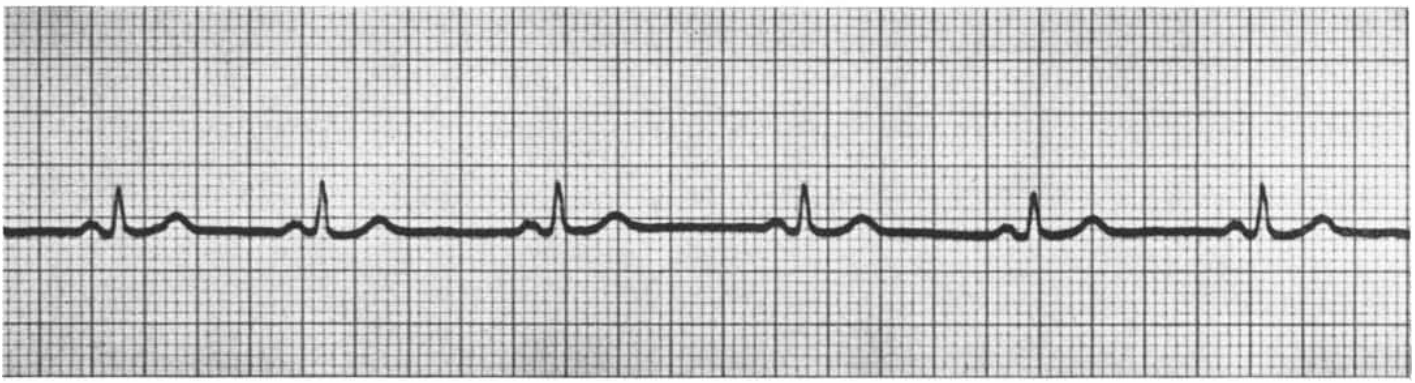

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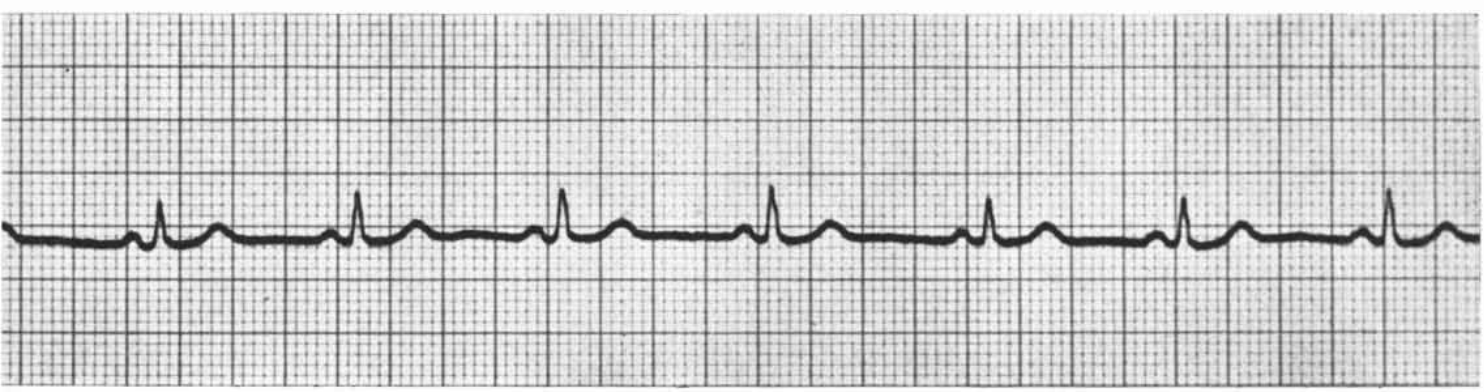

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NORMAL MOTHER-INFANT RELATION among monkeys involves close bodily contact between the two. This pair and three similar pairs were used in a study of the relative importance of maternal and peer relations in the social development of the young. Each pair was housed alone, but the infants had access to a common playpen. In this situation the young developed normally.

Social Deprivation in Monkeys

Maternal care has long been known to influence the emotional development of infants. New studies with rhesus monkeys suggest that peer relations may play an even more decisive role

by Harry F. and Margaret Kuenne Harlow

In *An Outline of Psychoanalysis,* published posthumously in 1940, Sigmund Freud was able to refer to "the common assertion that the child is psychologically the father of the man and that the events of his first years are of paramount importance for his whole subsequent life." It was, of course, Freud's own historic investigations, begun a half-century before, that first elucidated the role of infantile experiences in the development of the personality and its disorders. The "central experience of this period of childhood," he found, is the infant's relation to his mother. Freud's ideas have now shaped the thinking of two generations of psychologists, psychiatrists and psychoanalysts. Much evidence in support of his deep insights has been accumulated, particularly from clinical studies of the mentally ill. Contemporary writers stress inadequate or inconsistent mothering as a basic cause of later disorders such as withdrawal, hostility, anxiety, sexual maladjustment, alcoholism and, significantly, inadequate maternal behavior!

The evidence from clinical studies for this or any other view of human personality development is qualified, however, by an inherent defect. These studies are necessarily retrospective: they start with the disorder and work backward in time, retracing the experiences of the individual as he and his relatives and associates recall them. Inevitably details are lost or distorted, and the story is often so confounded as to require a generous exercise of intuition on the part of the investigator. Nor does evidence obtained in this manner exclude other possible causes of personality disorder. Against arguments in favor of a biochemical or neurological causation of mental illness, for example, there is no way to show that the patient began life with full potentiality for normal development. Given the decisive influence ascribed to the mother-infant relation, there may be a tendency in the reconstruction of the past to overlook or suppress evidence for the influence of other significant early relations, such as the bonds of interaction with other children. Little attention has been given, in fact, to child-to-child relations in the study of personality development. Yet it can be supposed that these play a significant part in determining the peer relations and the sexual role of the adult. Plainly there is a need to study the development of per-

ABNORMAL MOTHER, raised with a cloth surrogate instead of her mother, rejects her infant, refusing to let it nurse. Infants of four such mothers, raised under same conditions as infants of good mothers, developed relatively normally in spite of poor maternal care.

INFANTS PLAY in one of the playpens used in experiments described in two preceding illustrations. Both infants, photographed when they were six months old, had normal mothers.

sonality forward in time from infancy. Ideally the study should be conducted under controlled laboratory conditions so that the effects of single variables or combinations of variables can be traced.

Acceding to the moral and physical impossibility of conducting such an investigation with human subjects, we have been observing the development of social behavior in large numbers of rhesus monkeys at the Primate Laboratory of the University of Wisconsin. Apart from this primate's kinship to man, it offers a reasonable experimental substitute because it undergoes a relatively long period of development analogous to that of the human child and involving intimate attachment to its mother and social interaction with its age-mates. With these animals we have been able to observe the consequences of the deprivation of all social contact for various lengths of time. We have also raised them without mothers but in the company of age-mates and with mothers but without age-mates.

We have thereby been able to make some estimate of the contribution of each of these primary affectional systems to the integrated adult personality. Our observations sustain the significance of the maternal relation, particularly in facilitating the interaction of the infant with other infants. But at the same time we have found compelling evidence that opportunity for infant-infant interaction under optimal conditions may fully compensate for lack of mothering, at least in so far as infant-infant social and heterosexual relations are concerned. It seems possible—even likely—that the infant-mother affectional system is dispensable, whereas the infant-infant system is the *sine qua non* for later adjustment in all spheres of monkey life. In line with the "paramount importance" that Freud assigned to experience in the first years of life, our experiments indicate that there is a critical period somewhere between the third and sixth months of life during which social deprivation, particularly deprivation of the company of its peers, irreversibly blights the animal's capacity for social adjustment.

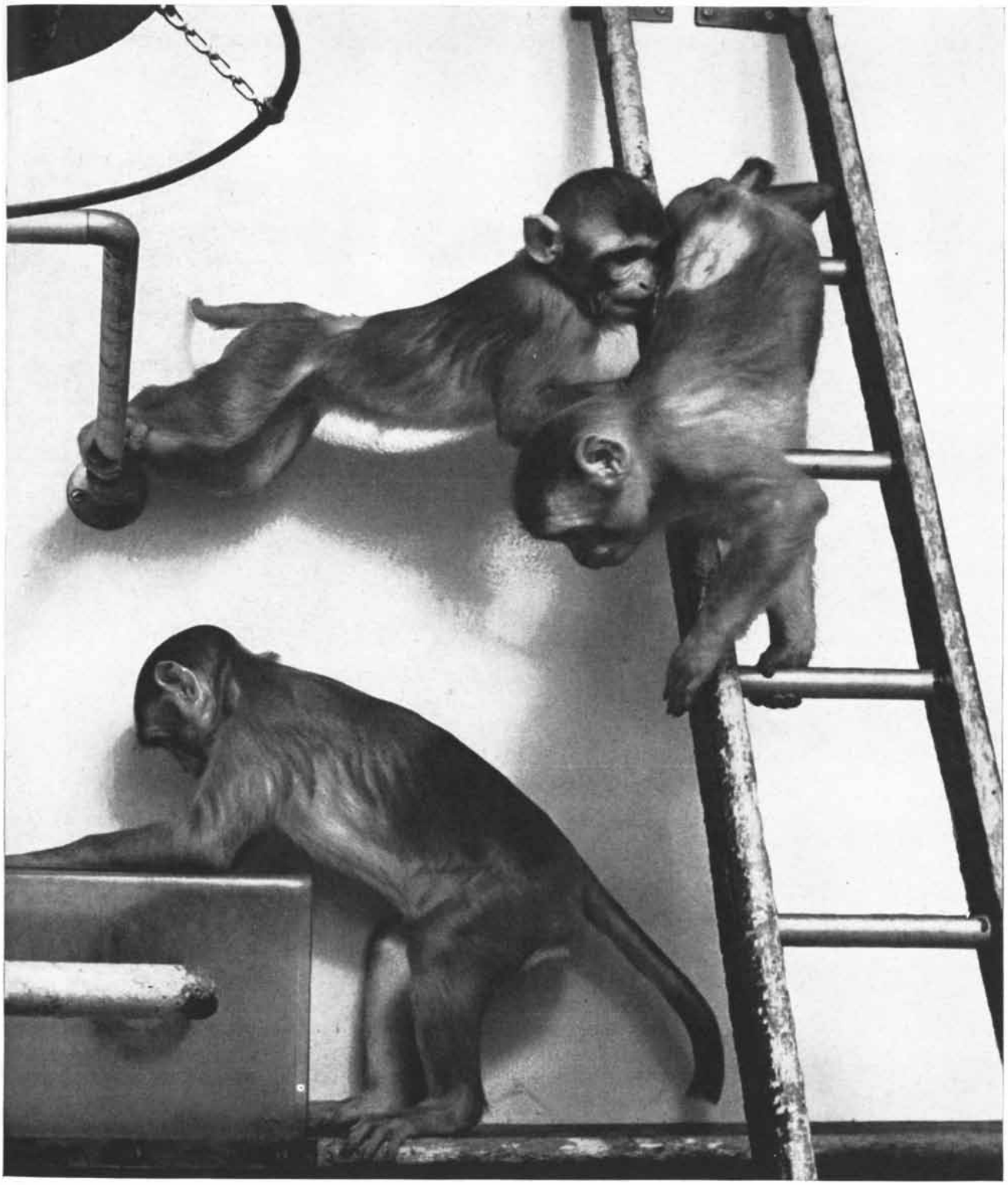
Our investigations of the emotional development of our subjects grew out of the effort to produce and maintain a colony of sturdy, disease-free young animals for use in various research programs. By separating them from their mothers a few hours after birth and placing them in a more fully controlled regimen of nurture and physical care we were able both to achieve a higher rate of survival and to remove the animals for testing without maternal protest. Only later did we realize that our monkeys were emotionally disturbed as well as sturdy and disease-free. Some of our researches are therefore retrospective. Others are in part exploratory, representing attempts to set up new experimental situations or to find new techniques for measurement. Most are incomplete because investigations of social and behavioral development are long-term. In a sense, they can never end, because the problems of one generation must be traced into the next.

Having separated the infant from its mother, our procedure was to keep it alone in a bare wire cage in a large room with other infants so housed. Thus each little monkey could see and hear others of its kind, although it could not make direct physical contact with them. The 56 animals raised in this manner now range in age from five to eight years. As a group they exhibit abnormalities of behavior rarely seen in animals born in the wild and brought to the laboratory as preadolescents or adolescents, even after the latter have been housed in individual cages for many years. The laboratory-born monkeys sit in their cages and stare fixedly into space, circle their cages in a repetitive stereotyped manner and clasp their heads in their hands or arms and rock for long periods of time. They often develop compulsive habits, such as pinching precisely the same patch of skin on the chest between the same fingers hundreds of times a day; occasionally such behavior may become punitive and the animal may chew and tear at its body until it bleeds. Often the approach of a human being becomes the stimulus to self-aggression. This behavior constitutes a complete breakdown and reversal of the normal defensive response; a monkey born in the wild will direct such threats and aggression at the approaching person, not at itself. Similar symptoms of emotional pathology are observed in deprived children in orphanages and in withdrawn adolescents and adults in mental hospitals.

William A. Mason, now at the Yerkes Laboratories of Primate Biology, compared the behavior of six of these animals, which were then two years old and had been housed all their lives in individual cages, with a matched group of rhesus monkeys that had been captured in the wild during their first year of life and housed together in captivity for a while before being individually housed in the laboratory. The most striking difference was that all the animals that had been born in the wild—and not one of the laboratory-born animals—displayed normal sex behavior. That the laboratory-born animals were not lacking in sex drive was indicated by the fact that the males frequently approached the females and the females displayed part of the pattern of sexual presentation. But they did not orient themselves correctly and they did not succeed in mating. Moreover, the monkeys born in the wild had apparently learned to live with others in a stable hierarchy of dominance, or "pecking order"; consequently in the pairing test they fought one another less and engaged more often in social grooming. They would also release a companion from a locked cage more frequently than did the laboratory-

born animals, which usually ignored their caged partner's plight.

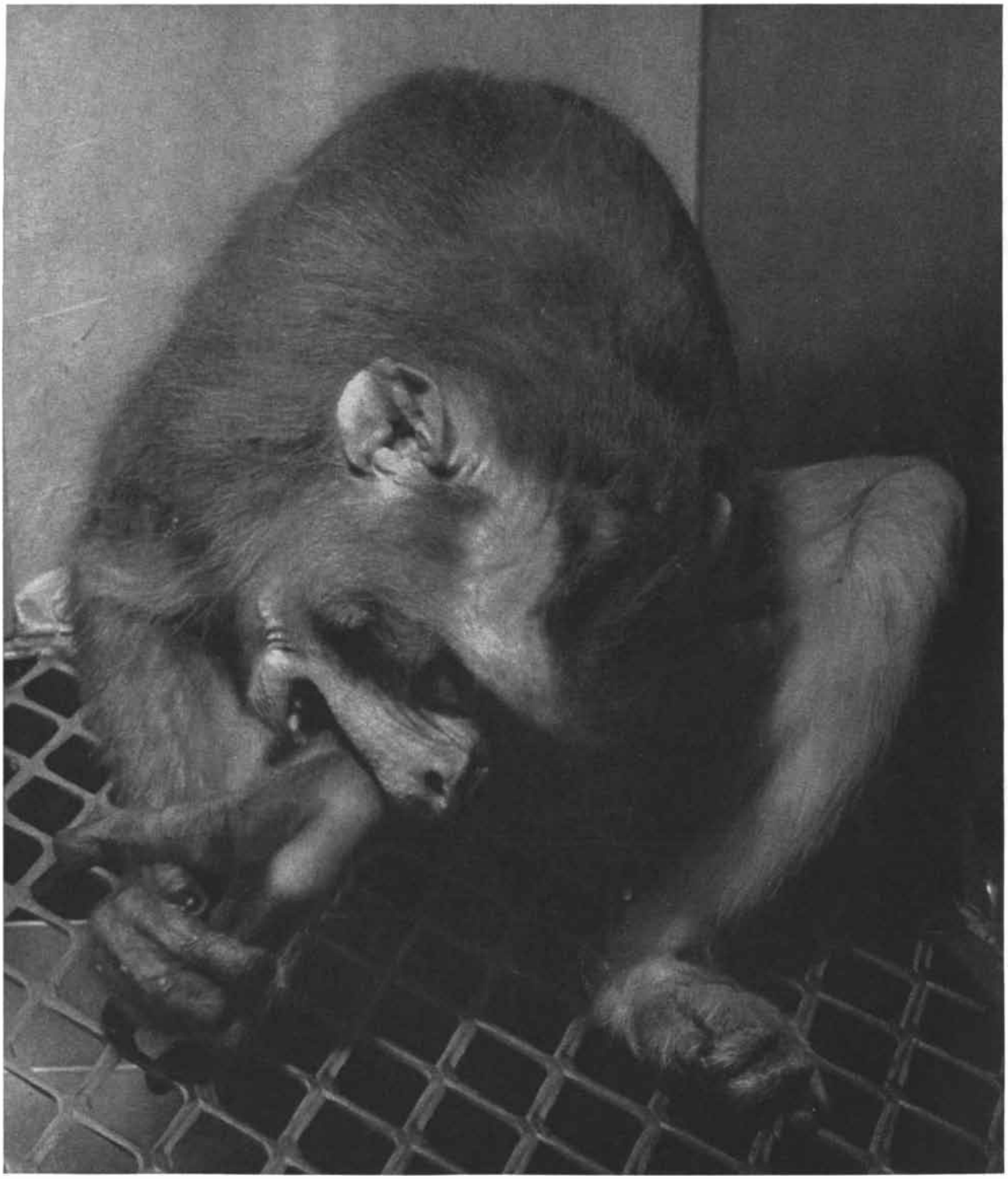
The severity of the affliction that grips these monkeys raised in the partial isolation of individual wire cages has become more apparent as they have grown older. They pay little or no attention to animals in neighboring cages; those caged with companions sit in opposite corners with only rare interaction. No heterosexual behavior has ever been observed between male and female cagemates, even between those that have lived together for as long as seven years. When efforts have been made to bring about matings, by pairing animals during the female's estrus, they have sometimes fought so viciously that they have had to be parted. Attempts to mate the socially deprived animals with sexually adequate and experienced monkeys from



MOTHERLESS INFANTS, raised from birth by cloth surrogates, play in a specially constructed playroom supplied with equipment for climbing and swinging. These animals, plus one other not seen in this photograph, were kept in individual cages and brought together in the playroom for 20 minutes a day. Although they had no maternal care whatever, they developed normally in every respect.

the breeding colony have been similarly frustrated.

In the summer of 1960 we undertook to devise a group-psychotherapy situation for 19 of these animals—nine males and 10 females—by using them to stock the monkey island in the municipal zoo in Madison, Wis. This was their first experience outside the laboratory, and they had much to learn in order to survive. They had to learn to drink water from an open trough instead of from a tube in the wall of a cage, to compete for food in a communal feeding situation, to huddle together or find shelter from inclement weather, to climb rocks and avoid the water surrounding the island. Most difficult of all, they had to learn to live together. Within the first few days they made all the necessary physical adjustments. The three casualties—a male that



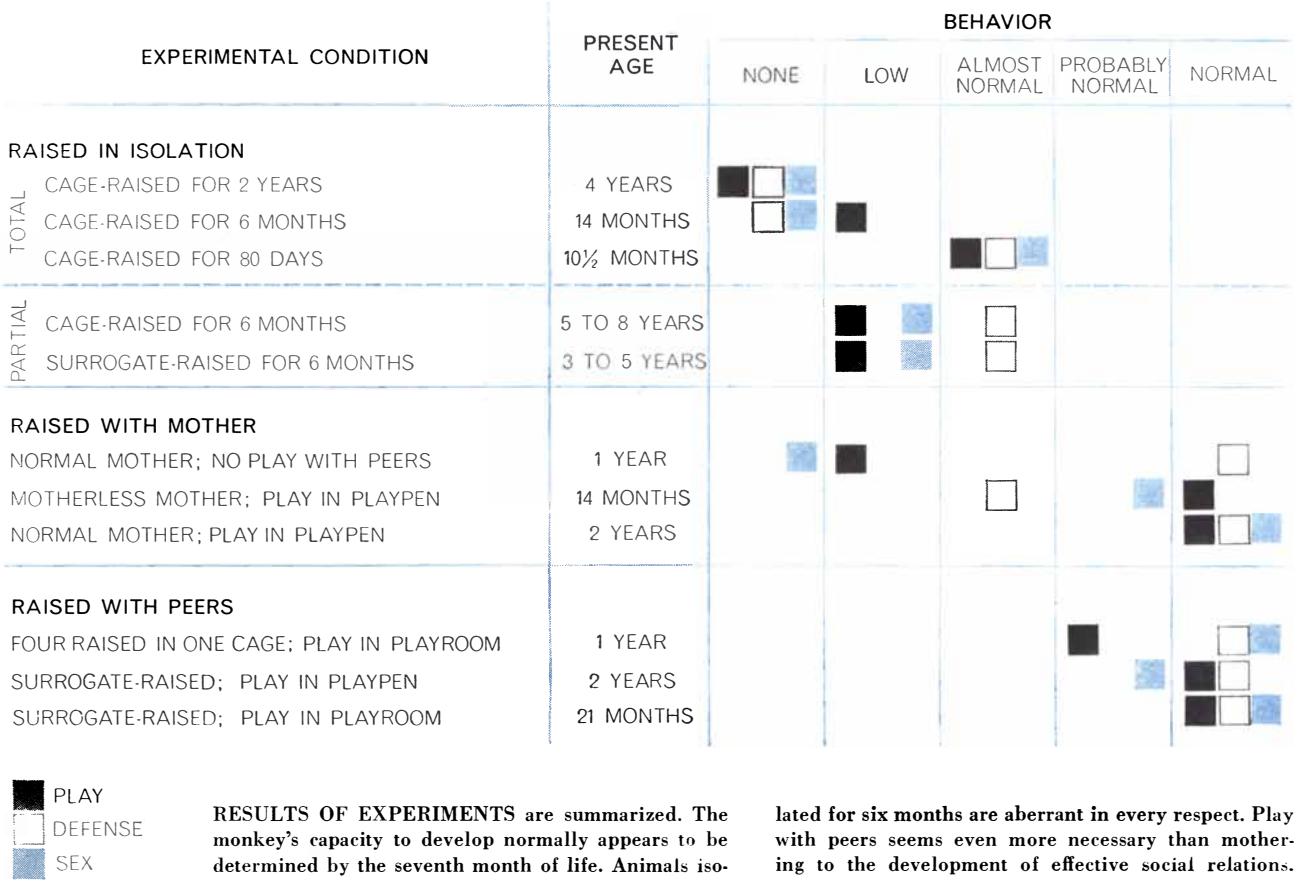
MONKEYS RAISED IN PARTIAL ISOLATION from birth to six months develop severe abnormalities of behavior. This animal, now full-grown, bites itself at the approach of the photographer. Animals raised in isolation often display such self-punishing behavior when a human being appears. They defend themselves adequately, however, against other monkeys and are often extremely aggressive.

drowned and two females that were injured and had to be returned to the laboratory—resulted from the stress of social adjustment. Fighting was severe at first; it decreased as effective dominance relations were established and friendship pairs formed. Grooming appeared in normal style and with almost normal frequency. A limited amount of sex behavior was observed, but it was infantile in form, with inadequate posturing by both females and males. In the hope of promoting therapy along this line we introduced our largest, strongest and most effective breeding-colony male to the island around the middle of summer. He immediately established himself at the head of the dominance order. But in spite of his considerable persistence and patience he did not succeed in starting a single pregnancy.

Back in the laboratory these animals ceased to groom and fought more frequently. In pairings with breeding-colony monkeys, not one male has achieved a normal mount or intromission and only one female has become pregnant. After two years we have had to conclude that the island experience was of no lasting value.

As the effects of the separation of these monkeys from their mothers in infancy were first becoming apparent in 1957 we were prompted to undertake a study of the mother-infant affectional bond. To each of one group of four animals separated from their mothers at birth we furnished a surrogate mother: a welded wire cylindrical form with the nipple of the feeding bottle protruding from its "breast" and with a wooden head surmounting it. The majority of the animals, 60 in all, were raised with cozier surrogate mothers covered by terry cloth. In connection with certain experiments some of these individuals have had both a bare-wire and a cloth-covered mother. The infants developed a strong attachment to the cloth mothers and little or none to the wire mothers, regardless of which one provided milk In fright-inducing situations the infants showed that they derived a strong sense of security from the presence of their cloth mothers [see "Love in Infant Monkeys," by Harry F. Harlow; SCIENTIFIC AMERICAN, June, 1959]. Even after two years of separation they exhibit a persistent attachment to the effigies.

In almost all other respects, however, the behavior of these monkeys at ages ranging from three to five years is indistinguishable from that of monkeys raised in bare wire cages with no source of con-



RESULTS OF EXPERIMENTS are summarized. The monkey's capacity to develop normally appears to be determined by the seventh month of life. Animals isolated for six months are aberrant in every respect. Play with peers seems even more necessary than mothering to the development of effective social relations.

tact comfort other than a gauze diaper pad. They are without question socially and sexually aberrant. No normal sex behavior has been observed in the living cages of any of the animals that have been housed with a companion of the opposite sex. In exposure to monkeys from the breeding colony not one male and only one female has shown normal mating behavior and only four females have been successfully impregnated. Compared with the cage-raised monkeys, the surrogate-raised animals seem to be less aggressive, whether toward themselves or other monkeys. But they are also younger on the average, and their better dispositions can be attributed to their lesser age.

Thus the nourishment and contact comfort provided by the nursing cloth-covered mother in infancy does not produce a normal adolescent or adult. The surrogate cannot cradle the baby or communicate monkey sounds and gestures. It cannot punish for misbehavior or attempt to break the infant's bodily attachment before it becomes a fixation. The entire group of animals separated from their mothers at birth and raised in individual wire cages, with or without surrogate, must be written off as potential breeding stock. Apparently their early social deprivation permanently impairs their ability to form effective relations with other monkeys, whether the opportunity was offered to them in the second six months of life or in the second to the fifth year of life.

One may correctly assume that total social isolation, compared with the partial isolation in which these subjects were reared, would produce even more devastating effects on later personality development. Such disastrous effects have been reported in the rare cases of children who have been liberated after months or years of lonely confinement in a darkened room. We have submitted a few monkeys to total isolation. Our purpose was to establish the maximum of social deprivation that would allow survival and also to determine whether or not there is a critical period in which social deprivation may have irreversible effects.

In our first study a male and a female were housed alone from birth for a period of two years, each one in its own cubicle with solid walls. Their behavior could be observed through one-way vision screens and tested by remote control. The animals adapted to solid food slowly, but they had normal weight and good coats when they were removed from the isolation boxes at the end of two years. Throughout this period neither animal had seen any living being other than itself.

They responded to their liberation by the crouching posture with which monkeys typically react to extreme threat. When placed together, each one crouched and made no further response to the other. Paired with younger monkeys from the group raised in partial isolation, they froze or fled when approached and made no effort to defend themselves from aggressive assaults. After another two years, in which they were kept together in a single large cage in the colony room, they showed the same abnormal fear of the sight or sound of other monkeys.

We are now engaged in studying the effects of six months of total social isolation. The first pair of monkeys, both males, has been out of isolation for eight months. They are housed, each monkey in its own cage, in racks with other monkeys of their age that were raised in the partial isolation of individual wire cages. For 20 minutes a day, five days a week, they are tested with a pair of these monkeys in the "playroom" of the laboratory. This room we designed to stimulate the

young monkeys to a maximum of activity. It was not until the 12th and 27th week respectively that the two totally deprived monkeys began to move and climb about. They now circulate freely but not as actively as the control animals. Although frequently attacked by the controls, neither one has attempted to defend itself or fight back; they either accept abuse or flee. One must be characterized as extremely disturbed and almost devoid of social behavior. The other resembles a normal two-month-old rhesus infant in its play and social behavior, and the indications are that it will never be able to make mature contacts with its peers.

A considerably more hopeful prognosis is indicated for two groups of four monkeys raised in total isolation for the much shorter period of 80 days. In their cubicles these animals had the contact comfort of a cloth-covered surrogate. They were deficient in social behavior during the first test periods in the playroom. But they made rapid gains; now, eight months later, we rate them as "almost normal" in play, defense and sex behavior. At least seven of the eight seem to bear no permanent scars as the result of early isolation.

Our first few experiments in the total isolation of these animals would thus appear to have bracketed what may be the critical period of development during which social experience is necessary for normal behavior in later life. We have additional experiments in progress, involving a second pair that will have been isolated for six months and a first pair that will have been isolated for a full year. The indications are that six months of isolation will render the animals permanently inadequate. Since the rhesus monkey is more mature than the human infant at birth and grows four times more rapidly, this is equivalent to two or three years for the human child. On the other hand, there is reason to believe that the effects of shorter periods of early isolation, perhaps 60 to 90 days or even more, are clearly reversible. This would be equivalent to about six months in the development of the human infant. The time probably varies with the individual and with the experiences to which it is exposed once it is removed from isolation. Beyond a brief period of neonatal grace, however, the evidence suggests that every additional week or month of social deprivation increasingly imperils social development in the rhesus monkey. Case studies of children reared in impersonal institutions or in homes with indifferent mothers or nurses show a frightening comparability. The child

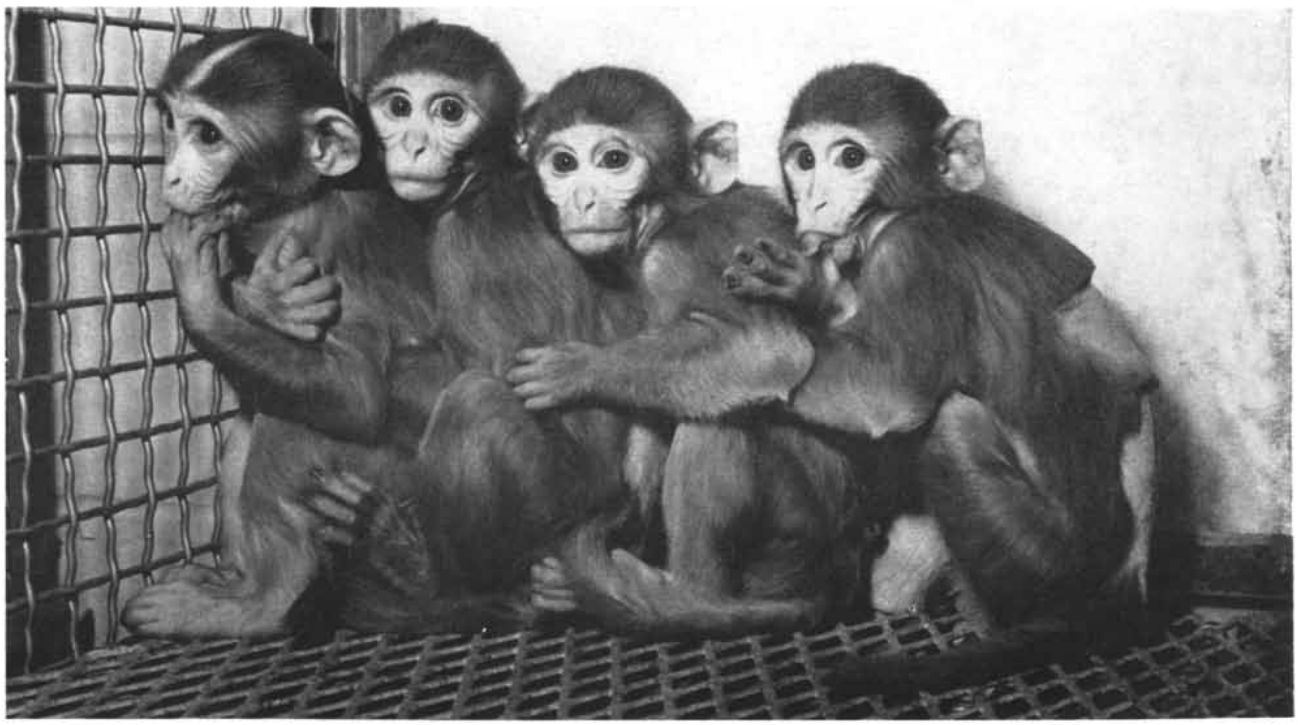
may remain relatively unharmed through the first six months of life. But from this time on the damage is progressive and cumulative. By one year of age he may sustain enduring emotional scars and by two years many children have reached the point of no return.

In all of these experiments in partial and total isolation, whether unwitting or deliberate, our animals were deprived of the company of their peers as well as of their mothers. We accordingly undertook a series of experiments designed to distinguish and compare the roles of mother-infant and infant-infant relations in the maturation of rhesus monkey behavior. Our most privileged subjects are two groups of four monkeys each, now two years old, that were raised with their mothers during the first 18 and 21 months respectively and with peers from the first weeks. Each mother-infant pair occupied a large cage that gave the infant access to one cell of a four-unit playpen. By removing the screens between the playpens we enabled the infants to play together in pairs or as foursomes during scheduled observation periods each day. In parallel with these two groups we raised another group of four in a playpen setup without their mothers but with a terrycloth surrogate in each home cage.

From the time the mothers let them leave their home cages, after 20 or 30 days, the mothered infants entered into more lively and consistent relations with one another than did the four motherless ones. Their behavior evolved more rapidly through the sequence of increasingly complex play patterns that reflects the maturation and learning of the infant monkey and is observed in a community of normal infants. The older they grew and the more complex the play patterns became, the greater became the observable difference between the mothered and the motherless monkeys. Now, at the end of the second year, the 12 animals are living together in one playpen setup, with each original group occupying one living cage and its adjoining playpen. All are observed in daily interaction without the dividing panels. The early differences between them have all but disappeared. Seven of the eight mothered animals engage in normal sexual activity and assume correct posture. The deviant is a male, and this animal was the social reject in its all-male group of four. Of the two motherless males, one has recently achieved full adult sexual posture and the other is approaching it. The two motherless females appear normal, but it remains to be seen whether or not their maternal behavior will reflect their lack of mothering.

Observation of infants with their mothers suggests reasons for the differences in the early social and sexual behavior of these playpen groups. From early in life on the infant monkey shows a strong tendency to imitate its mother; this responding to another monkey's behavior carries over to interaction with its peers. It is apparent also that sexual activity is stimulated by the mother's grooming of the infant. Finally, as the mother begins occasionally to reject its offspring in the third or fourth month, the infant is propelled into closer relations with its peers. These observations underlie the self-evident fact that the mother-infant relation plays a positive role in the normal development of the infant-infant and heterosexual relations of the young monkey.

That the mother-infant relation can also play a disruptive role was demonstrated in another experiment. Four females that had been raised in the partial isolation of individual wire cages—and successfully impregnated in spite of the inadequacy of their sexual behavior—delivered infants within three weeks of one another. This made it possible to set up a playpen group composed of these "motherless" mothers and their infants. The maternal behavior of all four mothers was completely abnormal, ranging from indifference to outright abuse. Whereas it usually requires more than one person to separate an infant from its mother, these mothers paid no attention when their infants were removed from the cages for the hand-feeding necessitated by the mothers' refusal to nurse.



"TOGETHER-TOGETHER" EXPERIMENT involved raising four motherless infants in one cage and giving them 20 minutes a day in the playroom. At one year of age they are normal, but during their early months they spent most of the time huddled in this position.

Two of the mothers did eventually permit fairly frequent nursing, but their apparently closer maternal relations were accompanied by more violent abuse. The infants were persistent in seeking contact with their mothers and climbed on their backs when they were repulsed at the breast. In play with one another during the first six months, the infants were close to the normally mothered animals in maturity of play, but they played less. In sexual activity, however, they were far more precocious. During the eight months since they have been separated from their mothers, they have exhibited more aggression and day-to-day variability in their behavior than have the members of other playpen groups. The two male offspring of the most abusive mothers have become disinterested in the female and occupy the subordinate position in all activities.

More study of more babies from motherless mothers is needed to determine whether or not the interrelations that characterize this pilot group will characterize others of the same composition. There is no question about the motherless mothers themselves. The aberration of their maternal behavior would have ensured the early demise of their infants outside the laboratory. As for the infants, the extremes of sexuality and aggressiveness observed in their behavior evoke all too vivid parallels in the behavior of disturbed human children and adolescents in psychiatric clinics and institutions for delinquents.

Another pilot experiment has shown that even normal mothering is not enough to produce socially adequate offspring. We isolated two infants in the exclusive company of their mothers to the age of seven months and then brought the mother-infant pairs together in a playpen unit. The female infant took full advantage of the play apparatus provided, but in three months the male was never seen to leave its home cage, and its mother would not permit the female to come within arm's reach. Social interaction of the infants was limited to an occasional exchange of tentative threats. For the past two months they have been separated from their mothers, housed in individual cages and brought together in the playroom for 15 minutes each day. In this normally stimulating environment they have so far shown no disposition to play together. Next to the infants that have been raised in total isolation, these are the most retarded of the infants tested in the playroom.

It is to the play-exciting stimulus of the playroom that we owe the unex-

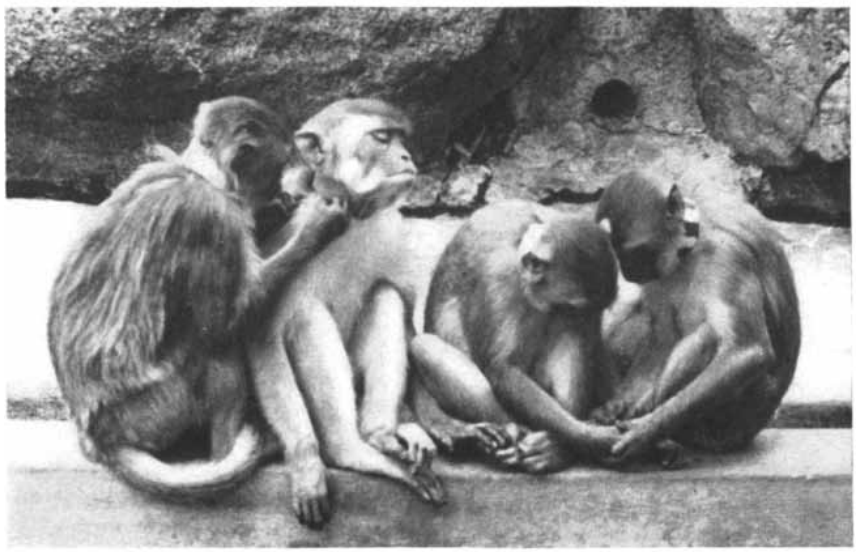
pected outcome of our most suggestive experiment. The room is a relatively spacious one, with an eight-foot ceiling and 40 square feet of floor space. It is equipped with movable and stationary toys and a wealth of climbing devices, including an artificial tree, a ladder and a burlap-covered climbing ramp that leads to a platform. Our purpose in constructing the playroom was to provide the monkeys with opportunities to move about in the three-dimensional world to which, as arboreal animals, they are much more highly adapted than man. To assess the effects of different histories of early social experience we customarily turn the animals loose in the room in groups of four for regularly scheduled periods of observation each day.

The opportunities afforded by the playroom were most fully exploited by two groups of four infants that otherwise spent their days housed alone in their cages with a cloth surrogate. In terms of "mothering," therefore, these monkeys were most closely comparable to the four that were raised with surrogates in the playpen situation. These animals were released in the playroom for 20 minutes a day from the first month of life through the 11th, in the case of one group, and through the second year in the case of the other. In contrast with all the other groups observed in the playroom, therefore, they did their "growing up" in this environment. Even though their exposure to the room and to one another was limited to 20 minutes a day, they enacted with great spirit the entire growth pattern of rhesus-monkey play behavior.

They began by exploring the room and each other. Gradually over the next two or three months they developed a game of rough-and-tumble play, with jumping, scuffling, wrestling, hair-pulling and a little nipping, but with no real damage, and then an associated game of flight and pursuit in which the participants are alternately the threateners and the threatened. While these group activities evolved, so did the capacity for individual play exploits, with the animals running, leaping, swinging and climbing, heedless of one another and apparently caught up in the sheer joy of action. As their skill and strength grew, their social play involved shorter but brisker episodes of free-for-all action, with longer chases between bouts. Subsequently they developed an even more complex pattern of violent activity, performed with blinding speed and integrating all objects, animate and inanimate, in the room. Along with social play, and possibly as a result or by-product, they began to exhibit sexual posturing—immature and fleeting in the first six months and more frequent and adult in form by the end of the year. The differences in play activity that distinguish males and females became evident in the first two or three months, with the females threatening and initiating rough contact far less frequently than the males and withdrawing from threats and approaches far more frequently.

Thus in spite of the relatively limited opportunity for contact afforded by their daily schedule, all the individuals in these two groups developed effective infant-infant play relations. Those observed into the second year have shown the full repertory of adult sexual behavior. At the same chronological age these motherless monkeys have attained as full a maturity in these respects as the infants raised with their mothers in the playpen.

Another group of four motherless animals raised together in a single large cage from the age of two weeks is yielding similar evidence of the effectiveness of the infant-infant affectional bond. During their first two months these animals spent much of their time clinging together, each animal clutching the back of the one just ahead of it in "choo-choo" fashion. They moved about as a group of three or four; when one of them broke away, it was soon clutched by another to form the nucleus of a new line. In the playroom the choo-choo linkage gave way to individual exploratory expeditions. During periods of observation, whether in their home cage or in the playroom, these animals have consistently scored lower in play activity than the most playful groups. We think this is explained, however, by the fact that they are able to spread their play over a 24-hour period. At the age of one year they live amicably together. In sex behavior they are more mature than the mother-raised playpen babies. No member of the group shows any sign of damage by mother-deprivation.



GROUP PSYCHOTHERAPY for monkeys raised in isolation in the laboratory was attempted by removing them to the semiwild conditions of the zoo after they reached maturity. Here their behavior improved; they began to play together and groom one another. But when they were returned to the laboratory, they reverted to their earlier abnormal behavior.

Our observations of the three groups of motherless infants raised in close association with one another therefore indicate that opportunity for optimal infant-infant interaction may compensate for lack of mothering. This is true at least in so far as infant-infant and sexual relations are concerned. Whether or not maternal behavior or later social adjustment will be affected remains to be seen.

Of course research on nonhuman animals, even monkeys, will never resolve the baffling complex roles of various kinds of early experience in the development of human personality. It is clear, however, that important theoretical and practical questions in this realm of interest can be resolved by the use of monkeys. The close behavioral resemblance of our disturbed infants to disturbed human beings gives us the confidence that we are working with significant variables and the hope that we can point the way to reducing the toll of psychosocial trauma in human society.

The Honeywell Visicorder watches a bolt do the twist

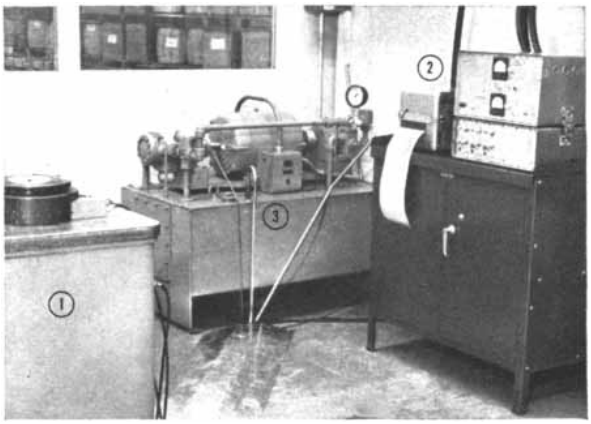
When measuring the dynamic effects of torque and load on a bolt fastener, Lamson and Sessions found that fast rise-time was the most essential characteristic of the measuring instrument.

The high frequency response of the Visicorder Oscillograph (DC to 5000 cps) thus made it the choice for measuring these sudden loads applied by an impact wrench. The test set-up is a load analyzer consisting of a Model 906 Visicorder, a Model 119 Honeywell Amplifier, an hydraulic pump unit, a test block, and a load cell.

The Visicorder is extremely reliable in an application of this kind, since the light-beam galvanometers eliminate recording pens and the large mechanical systems that pens and styli require. And a wide range of chart speeds assures the desired degree of data resolution.

The Lamson and Sessions studies have charted the complex relationships of joint components under load. Some of these relationships are fastener strength; relaxation properties; optimum clamping load for a given size and strength of fastener; bearing areas adequate to prevent embedding; the number, size, and strength of fasteners consistent with the greatest strength, lightest weight, and lowest cost; and proper assembly techniques.

The Visicorder recordings have provided enough new knowledge of these factors to point the way to new fastener specifications and designs. There are five models of the Honeywell Visicorder Oscillograph, each designed to meet your specific test program requirements. Different models provide record capacity from 1 to 6 up to 1 to 36 data channels. Paper speeds from .1 inch per hour to 13 feet per second in the different models mean that data can be presented on the time base most meaningful to your test.



The Lamson and Sessions Load Analyzer: (1) Test block with load cell included, (2) Honeywell Model 906 Visicorder and 112 Amplifier, (3) Hydraulic pump unit.

For full specifications on all Visicorder Oscillographs, write Minneapolis-Honeywell, Heiland Division, 4800 E. Dry Creek Road, Denver 10, Colorado. Or phone 303-794-4311.

Honeywell

First in Control

Hardware?

Maybe connectors were "hardware" twenty years ago.

That's when the P-38 was the hottest fighter plane we had. Pilots were proud when they could hit 300 MPH and go up to 50 or 60 thousand feet. With this kind of performance requirement, most connectors worked without a hitch. You just connected them and forgot about them, like nuts and bolts.

HOW TIMES HAVE CHANGED

Now we're up around Mach 5 and altitude has been pushed into outer space. Nose cones light up like giant soldering irons and components have to operate in a near vacuum.

Fortunately, Amphenol engineers saw that the old "hardware" concept was headed out the window. Programs coming up were going to need connectors that could put up with terrific environmental conditions of heat and altitude cycling. For example, at high temperatures most of the elastomers used as insert materials or connector seals either melt into a puddle, turn into a cinder, or set-up and lose compression.

What's more, connectors now have to keep on functioning *all* the time, with no allowance for failure. So—Amphenol designers went to work developing a connector to meet the new space-age standards.

DISSECTING MOLECULES

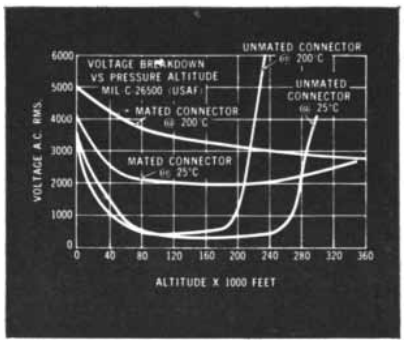
The Amphenol Materials Lab, with the help of a shiny new infra-red photospectrometer, began dissecting elastomer molecules. They were able to pinpoint the weak spots in molecular structure where breakdowns begin. Then they were able to plan and build new molecules, with built-in "armor" to protect against failure. Result: an exclusive silicone rubber compound that maintains its integrity and elasticity under severe temperature extremes and also withstands exposure to violent new propellants like hydrazine and nitrogen tetroxide.

At the same time, Amphenol design engineers were hard at work perfecting metal-to-metal shouldering of mating shells that allowed precision control over compression of the sealing ring. In addition, the metal-to-metal design damped vibrational stress nine times more effectively than resilient damping. Finally, they incorporated a semi-rigid anti-deflection disc to control insert expansion under thermal stress.

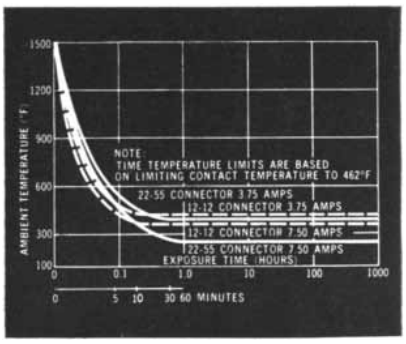
Having all the pieces, we put them together, called it the Amphenol 48 Series, and started testing. In the vacuum chamber, 48 Series connectors operate very nicely at a simulated altitude of 500,000 feet. They are quite comfortable in the hot box at 200°C ambient, *carrying full rated current*. They don't even mind going up to 600°C, if they don't have to stay too long. In short, Amphenol 48's can take almost anything you throw at them.

PROJECTS WANTED

Amphenol designers have established criteria for determining connector time-temperature-current capability. This information will be especially valuable to engineers presently engaged in "exotic" projects, perhaps the kind of project where previous connectors have failed to measure up to the new space-age standards. If this is the case, contact an Amphenol sales engineer. He's a "space-age hardware" expert. Or, write directly to Bob Dorrell, Vice President, Engineering, Amphenol Connector Division, 1830 South 54th Avenue, Chicago 50, Illinois.



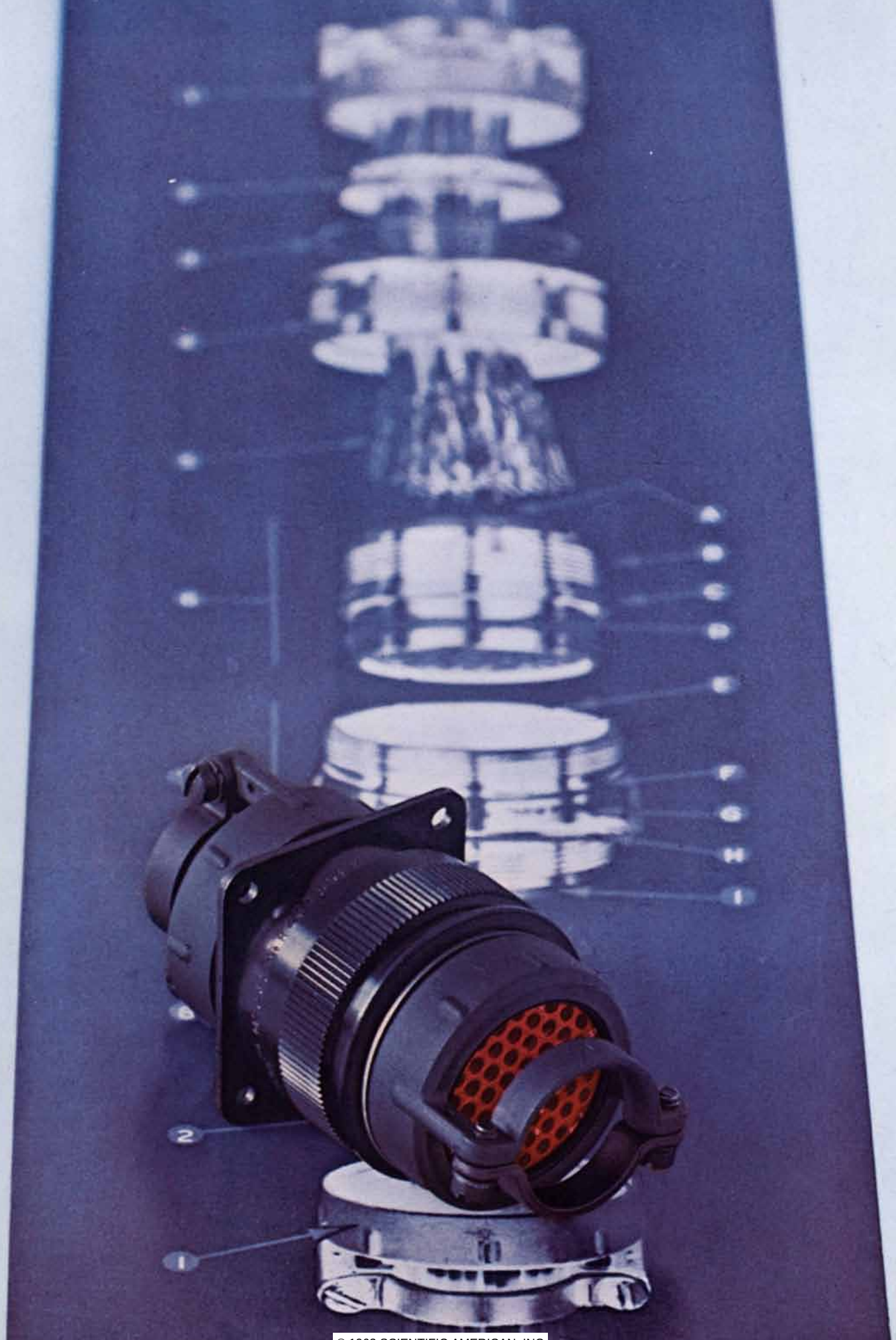
High altitude air has low dielectric strength. By maintaining an air-tight seal 48 Series Connectors enjoy extremely high voltage safety factors.

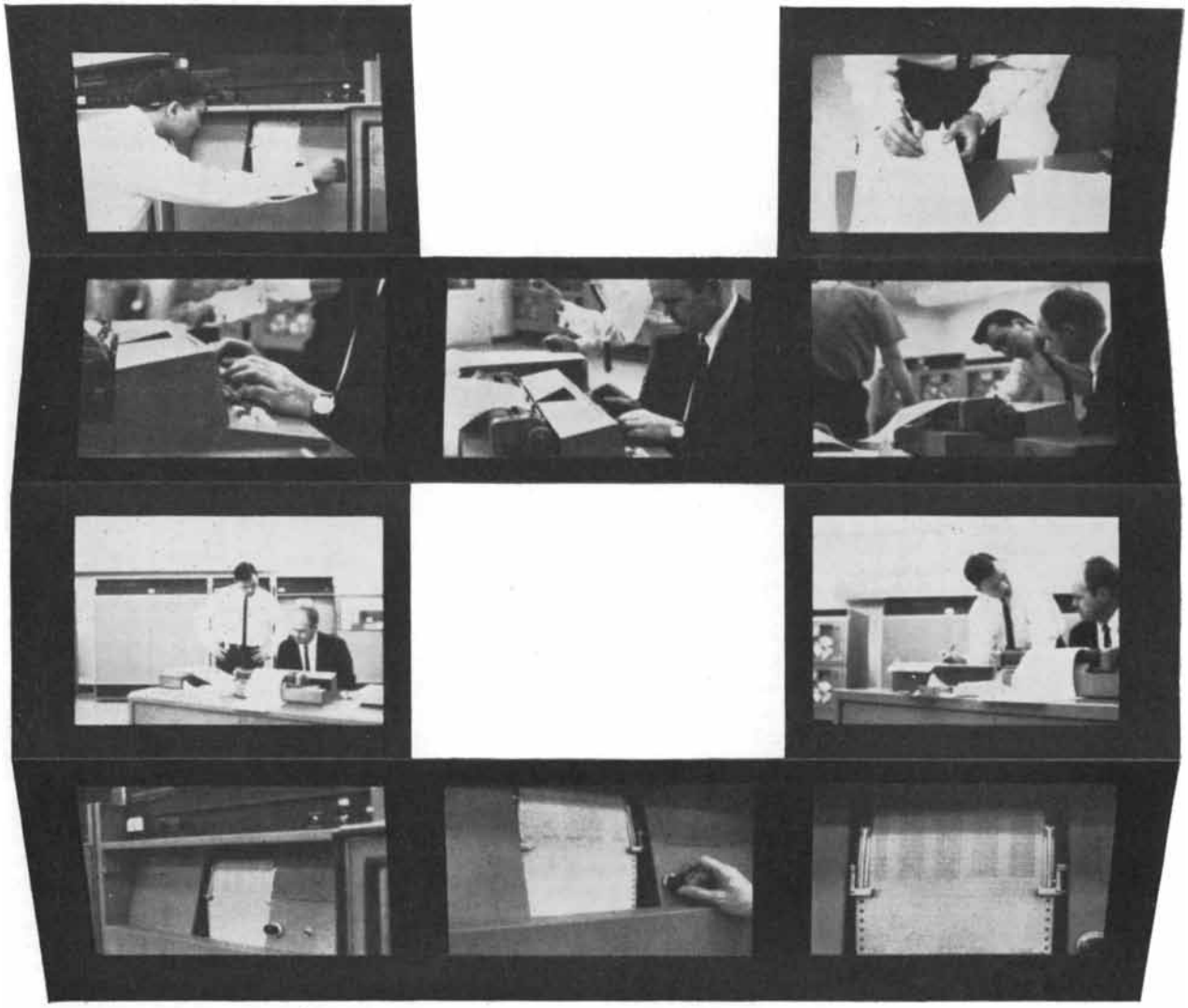


While Amphenol 48 Series Connectors are nominally rated at 200° C, they can also withstand considerably higher short-time temperature exposures.

Amphenol 48 Series Meets Mil C 26500 (USAF).

AMPHENOL **Connector Division** / Amphenol-Borg Electronics Corporation





FROM EVERY POINT OF VIEW...

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MATHEMATICAL GAMES

Some puzzles based on checkerboards, and answers to last month's problems

by Martin Gardner

Pennypacker's office still smelled of linoleum, a clean, sad scent that seemed to lift from the checkerboard floor in squares of alternating intensity; this pattern had given Clyde as a boy a funny nervous feeling of intersection, and now he stood crisscrossed by a double sense of himself . . .

—JOHN UPDIKE, *Pigeon Feathers*

The crisscrossing of a checked pattern may give some people a "nervous feeling," but when a recreational mathematician sees a checkerboard floor his mind leaps happily toward almost innumerable puzzle possibilities. It is safe to say that no other geometrical pattern has been so thoroughly exploited for recreational purposes. I am not referring now to games such as checkers, chess and go, which use the checked pattern as a board, but to an endless variety of puzzles that derive from the metric and topological properties of the pattern itself.

Consider for a moment a problem that appeared in this department five years ago and is now well known. If two diagonally opposite corner squares of an 8×8 checkerboard are removed, can the remaining 62 cells be completely covered by 31 dominoes? Since each domino is assumed to cover two adjacent squares, one black and one white, 31 dominoes must cover 31 black squares and 31 white squares. But diagonally opposite corner squares are the same color, so the mutilated board will have 32 squares of one color and 30 of another and clearly cannot be covered by 31 dominoes. This proof of impossibility is a classic illustration of how the coloring of a checkerboard, far from merely making the pattern more pleasing aesthetically or more convenient for plotting checker and chess moves, provides a powerful tool for analyzing many types of checkerboard problem.

Instead of removing two squares of the same color, suppose we remove two squares of opposite colors. They may be taken from any two spots on the board. Is it always possible to cover the remaining 62 squares with 31 dominoes? The answer is yes, but is there a simple way to prove it? One could, of course, test all possible combinations of missing squares, but that would be tedious and inelegant. Dana Scott, a mathematician at the University of California, has called to my attention a beautiful proof discovered by his friend Ralph Gomory, a research mathematician. Heavy lines are drawn on the board as shown in the illustration on the next page, forming a closed path along which the cells lie like beads of alternating colors on a necklace. The removal of two squares of opposite colors from any two spots along this path will cut the path into two open-ended segments (or one segment if the removed squares are adjacent on the path). Since each segment must consist of an even number of squares, each segment (and therefore the entire board) can be completely covered by dominoes.

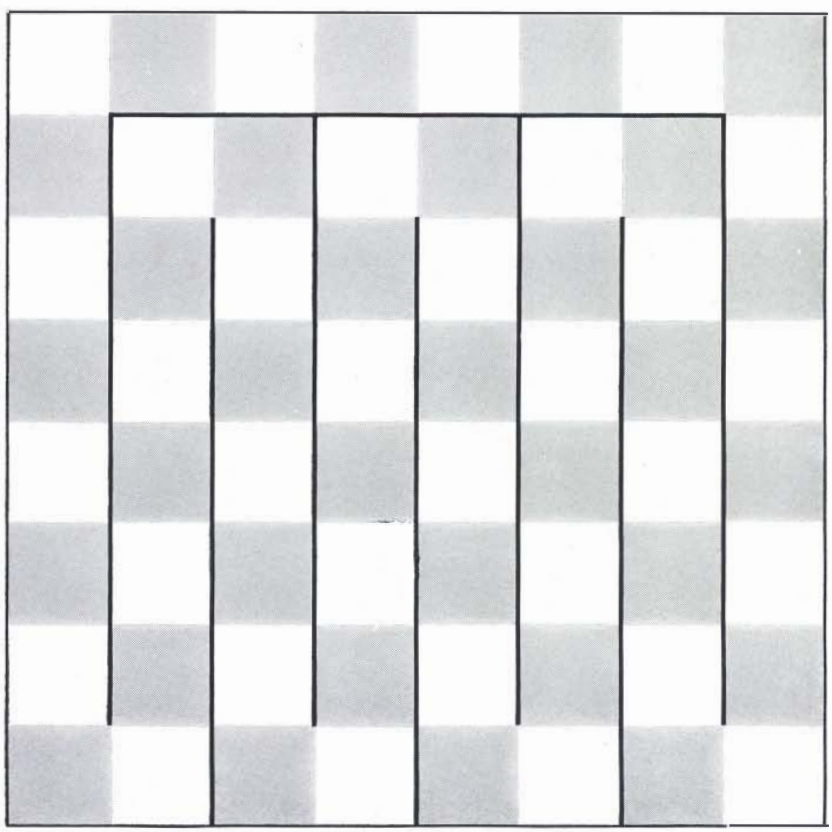
Instead of trying to cover a mutilated checkerboard with dominoes, suppose we mutilate it in such a way that *no* domino can be placed on it. What is the smallest number of squares that must be taken away in order to make it impossible to place a single domino on what remains? It is easy to see that 32 squares, all of one color, must be removed. But the problem is not so easy to solve if we substitute for the domino one of the higher "polyominoes." (A polyomino is any figure formed by checkerboard squares that are connected along their edges.) Solomon W. Golomb, a mathematician at the Jet Propulsion Laboratory of the California Institute of Technology whose name often appears in these columns, has recently proposed this type of problem and answered it for every type of polyomino up through the 12 pentominoes (five-square figures). The pentomino shaped like a Greek cross provides a pretty problem. Assume that the 8×8 checkerboard is

made of paper. If 16 squares are shaded as shown in the illustration on page 154, it obviously is not possible to cut a Greek cross from the unshaded squares. But 16 is not the minimum. What *is* the minimum? Readers may enjoy working on this until the solution is given in this space next month.

A fascinating checkerboard-cutting problem, as yet unsolved, is that of determining the number of different ways the 8×8 board can be cut in half along the solid lines that form the cells. The two halves must be the same size and shape so that one can be fitted on top of the other without flopping either one over. Henry Ernest Dudeney, the English puzzlist, first posed this problem some 60 years ago and reported that he found it "bristling with difficulties." He was unable to make a full tabulation of patterns. It is obvious that a 2×2 board can be cut in half in only one way. The 3×3 cannot be divided into identical parts (because it contains an odd number of cells), but if the central cell is considered a hole, it also can be bisected in only one way.

The 4×4 takes a bit of thinking, but it is not hard to discover that there are just six solutions [*see illustration on page 156*]. These can be rotated and reflected in various ways, but patterns so obtained are not considered "different." Dudeney was able to show that the 5×5 (with missing center cell) has 15 solutions and that the 6×6 has 255. There he stopped. The 7×7 and 8×8 problems should lend themselves easily to solution by a modern computer, but I am not aware that anyone has yet harnessed a computer for either task.

A closely related problem, first posed by Howard Grossman, a New York mathematics teacher, is that of cutting a square checkerboard into congruent quarters. As before, the four pieces must be the same size and shape and have the same "handedness." The coloring of the board is ignored. The 2×2 obviously can be quartered in only one way; the same is true of the 3×3 with the center hole. What about the 4×4? How many fundamentally different ways can it be quartered, not counting rotations and reflections? Readers should have little difficulty in drawing all the patterns, which will be illustrated here next month. More ambitious readers may wish to go on to the 5×5 (with center

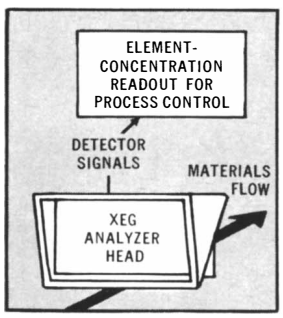


Gomory's proof of a domino-and-checkerboard theorem

Why lose hours just learning you're wrong ...when you can "sense" you're right from the start

Sampling and testing of material as it courses through processing presents formidable problems: In making cement, for example, wet chemical methods provide control information on tons of material only after delays of hours; yield historical data, rather than fresh "trend-analyses."

Swift and continuous trend-analysis is essential in detecting any drifts away from production specifications, if corrections are to be made sufficiently early.



Here's exactly where the General Electric "XEG" Materials Analyzer fits in. It checks elemental composition on the line (see block diagram).

In the cement industry, XEG opens up opportunities for start-to-finish automation. Already, gains include getting control data where it counts at once; more economic use of raw material; savings on kiln maintenance; increased production from existing machinery.

General Electric XEG capitalizes on the fact that elements emit known wavelengths of secondary radiation when bombarded by an x-ray beam. The character and strength of this secondary radiation provides an accurate measure of materials composition instantaneously.

With XEG, you can conduct continuous qualitative and quantitative checks. You get accurate trend-analysis so rapidly that control corrections can be made before serious, costly spoilages occur.

Materials can be dry or moist powders, slurries, liquids, sheets, wires or rods. XEG can "watch" up to six elements simultaneously. It's like an instantaneous, automatic laboratory, right on the production line.

XEG's output signal can be used in turn, to operate indicators, recorders, process computers, or control drives. Where full automation is needed, General Electric process engineers can provide the added value available through overall systems planning.

Accent on VALUE

Process control with XEG already extends into petroleum, steel, chemicals, pharmaceuticals, electronics, mining, and other processing fields.

For example:

- In metal mining: XEG permits more complete extraction of valuable metals; copper, molybdenum, iron, lead and zinc.
- In producing solid rocket propellant, XEG provides swift, precise measurement of elements to meet extremely critical standards.
- In steel making, XEG guides the right balance of ingredients for increased quality and savings in materials.
- In cement processing, XEG is regulating quality within close tolerances, making better use of raw materials and increasing process efficiency.

PROCESS CONTROL

Have a General Electric representative explore your own potential application for XEG. Contact him immediately; or write directly to X-Ray Department, General Electric Company, Milwaukee 1, Wisconsin, Room TT-114.

Progress Is Our Most Important Product

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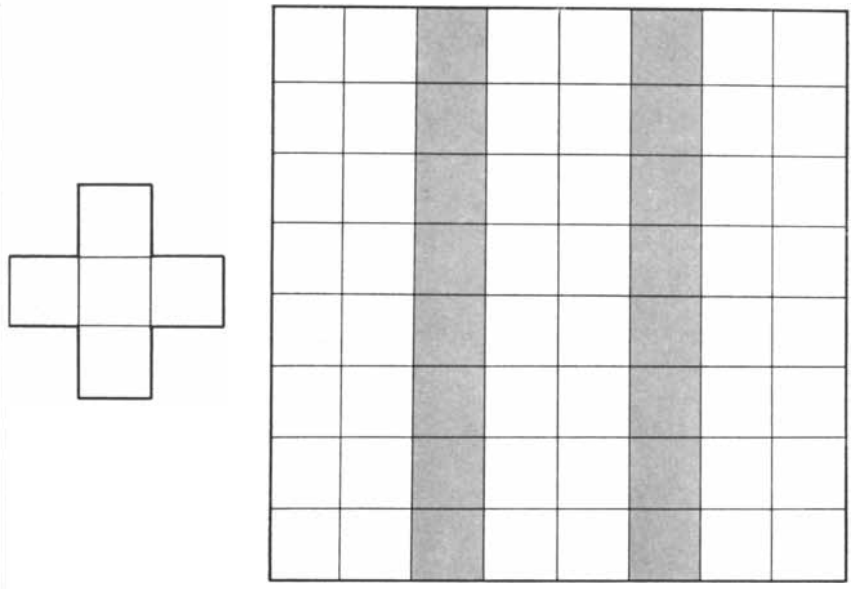


Golomb's Greek-cross problem

hole), which has seven patterns. Even the 6×6 is easily solved without computer aid, although the number of patterns rises to 37. As in the previous problem, solutions for the 7×7 and 8×8 are not known, unless somewhere a computer has devoted a few minutes during off hours to the contemplation of these problems.

Both the halving and the quartering of square checkerboards have their analogues in three dimensions, where the analysis is considerably more complex. Even the lowly $2 \times 2 \times 2$ is tricky. Many people guess that there is but one way to halve such a cube (cutting only along planes that divide the cubical cells) when in fact there are three. (Can the reader visualize them?) It can be quartered in two ways. As for the $4 \times 4 \times 4$, as far as I know no one has the slightest notion of how many different ways it can be halved or quartered.

When counters of various sorts are added to the board, an infinite variety of puzzle possibilities open up. For example, given a checkerboard of order n (the order is the number of cells on a side), what is the largest number of chess queens that can be placed on the board in such a way that no queen is attacked by another? Since a queen moves an unlimited distance up and down, left and right and diagonally, the task is the same as that of placing a maximum number of counters so that no two lie in the same row, column or diagonal. It is easy to see that the maximum cannot exceed the order of the board, and it has been shown that on any board of order n, where n is greater than 3, n queens can be placed to meet the problem's conditions.

Not counting rotations and reflections as being different, there is only one way to place the queens on the 4×4 board, two ways on the 5×5, one way on the 6×6. (The reader may enjoy finding these patterns. The 6×6 problem has often been sold as a peg-and-board puzzle.) A 7×7 board has six solutions, the 8×8 has twelve, the 9×9 has 46, the 10×10 has 92, the 11×11 has 341 and the 12×12 has 1,784. (There is no known formula by which the number of solutions on a board of order n can be determined.) When the order of the board is not divisible by 2 or 3, it is possible to superimpose n solutions that completely fill all the cells. Thus on the 5×5 one can place 25 queens—five of each of five colors—in such a way that no queen attacks another of the same color.

The 12 fundamental patterns for the standard 8×8 chessboard are shown on page 158. An enormous literature has grown up around this problem—usually called "the problem of the eight queens"—since it was first proposed in 1848. It is not easy to prove that the 12 patterns exhaust all possibilities. Such a proof, by way of determinants, was finally obtained by the English mathematician J. W. L. Glaisher and published in *Philosophical Magazine* for December, 1874.

Each of the 12 basic solutions can be rotated and reflected to give seven other patterns, except for Solution 10, which, because of its symmetry, yields only three other patterns. Thus there are 92

A Report On Research At Sun Oil Company

Of the many and varied research activities conducted by Sun Oil Company, the following two major programs are under way:

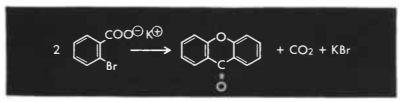
One program, at the company's Marcus Hook, Pa. research center near Philadelphia, puts primary emphasis on chemical research, as related to the profitable utilization of hydrocarbons. The other, at the company's Richardson, Texas laboratories near Dallas, is concerned primarily with fluid flow investigations, as related to the development of improved oil and gas recovery techniques.

A report on a typical project in each program is presented here.

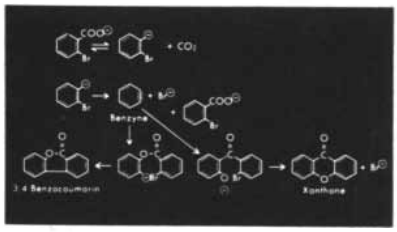
Discovering The True Mechanisms Of Known Chemical Reactions

Challenged by the fact that the true mechanisms of many known chemical reactions are still in doubt, Sun R&D personnel have the opportunity to undertake, in the scouting time available to them, comprehensive investigations into this area.

A typical project brought to a significant conclusion is the following reaction-path investigation conducted by Dr. Edward J. McNelis of Sun's R&D Division, Marcus Hook, Pa. Dr. McNelis sought to determine the mechanism of the reaction in which certain salts of o-halobenzoic acids yield xanthone when heated:



The mechanism of this interesting reaction has been in doubt for some time, with some workers favoring an initial step involving displacement on halogen by o-halobenzoate. Dr. McNelis, on the other hand, envisioned the reaction as proceeding through a benzyne intermediate, as follows:



Using tetraphenylcyclopentadienone as a trapping agent, Dr. McNelis isolated 1, 2, 3, 4-tetraphenylnaphthalene in 11 per cent yield. This could have arisen only by the sequence:

In addition, two isomeric xanthones were isolated during the pyrolysis of potassium 2, 4-dichlorobenzoate. The displacement path would predict only one isomer. Consequently, xanthone must arise, at least in part, by a path involving benzyne as an intermediate.

Work with the proposed intermediates has given some proof for a concerted addition of carboxylate to benzyne. Other interesting side reactions, such as the formation of 3, 4-benzocoumarin, were uncovered during the course of this investigation.

Recovery Research

At Sun Oil Company's Richardson, Texas laboratories, extensive study of fluid flow in various underground formations has led to the successful development of mathematical models and new engineering techniques, all of which are increasing the recovery of oil and gas from reservoirs.

One particularly interesting and productive technique arising out of this work is known as "thermal recovery." Thermal recovery is used to particular advantage in reservoirs where other methods, such as the injection into the well of gas, water or other fluids, cannot be used efficiently.

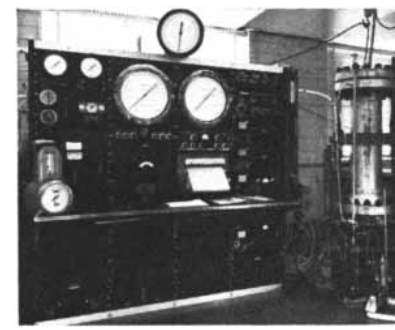
This technique supplies energy in the form of heat to displace the oil through the reservoir. This is done by injecting air into a well in which an igniter has been placed. When ignition occurs, the igniter is removed and air injection is continued. The resulting fire front moves slowly through the reservoir, consuming coked material as fuel and displacing the lighter, more valuable hydrocarbons toward the producing wells. This work was carried out under the direction of Carey Hardy of the Richardson laboratory.

After the initial development work, Sun researchers felt that thermal recovery would have great promise as a truly efficient production technique if the problem of flow restriction which often arises during the process could be solved.

Additional study revealed that the movement of the fire front from an injection well to one or several producing wells gives rise to several recognizable zones, one of which is the condensation zone. It was further found that flow restriction occurs in this zone, and is caused by the condensation of water of combustion which restricts both liquid and gas permeability.

It was discovered that liquid permeability is restored by reducing the pressure in the system. This is done by discontinuing air injection into the injection well while continuing to remove gas and liquids from the producing wells. By this method, the condensation process is reversed and the liquid products are vaporized. The increase in gas saturation restores the gas permeability and the removal of water droplets restores liquid permeability.

This finding is considered to be a significant advance in the technique and makes thermal recovery a truly efficient method for recovering large quantities of oil from reservoirs previously considered non-productive. Patents have been applied for.



Laboratory equipment used in thermal recovery research permits monitoring and recording of pertinent variables as fire front is moved slowly through vertical tube containing sand and oil.

The Opportunity At Sun

Research people seeking challenging work and the opportunity for self expression thrive at Sun Oil Company. They work in an atmosphere conducive to research. They associate with some of the industry's leading scientists. A wide variety of research activities are offered. R&D personnel are encouraged to spend about 15 per cent of their time exploring their own ideas. Facilities include the latest in laboratory equipment and apparatus. And the research function is constantly being expanded.

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PROMOTING PROGRESS THROUGH RESEARCH

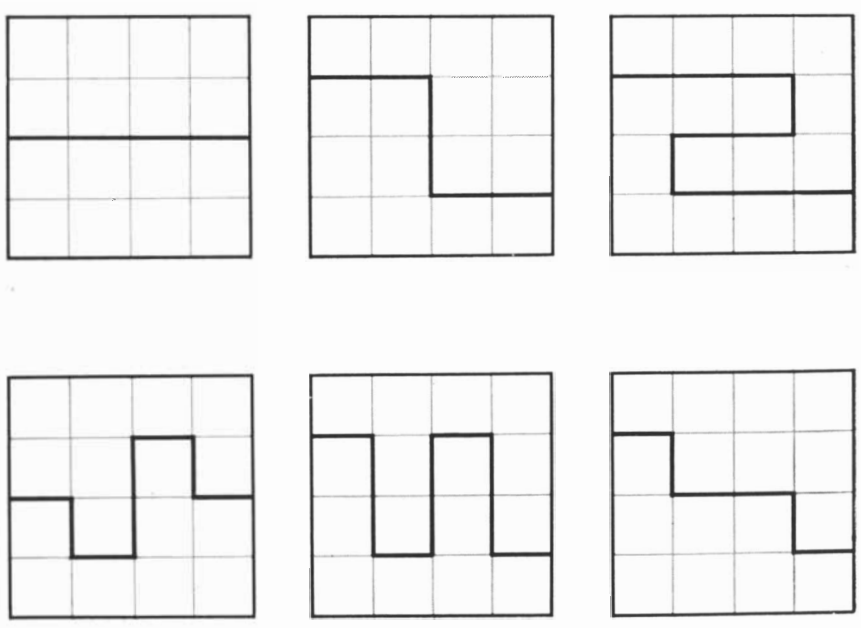
solutions altogether. Solution 10 is unique in having no queens on its 16 central squares. It shares with Solution 1 the lack of queens along both main diagonals. Solution 7 is the most interesting of all: it is the only pattern in which no three queens (considered as points at the center of their cells) lie on a straight line. The reader may enjoy verifying this by finding straight lines on all the other patterns that pass through three or four queens. (The reference here is not to diagonals of squares on the board but to geometrical straight lines of any orientation.) Every now and then a puzzlist announces that he has found a second pattern that also avoids three-in-a-line, but on closer inspection it always turns out that there has been an oversight or that his second pattern is merely a rotation or reflection of Solution 7. Incidentally, it is sometimes maintained that the eight-queen problem has no solution with a queen on a corner cell; as the illustration shows, there are actually two such solutions.

Other chess pieces can, of course, be substituted for queens. In the case of rooks it is obvious that, like the queens, a maximum of n rooks can be placed on a board of order n; more would put at least two rooks in one of the rows. A method that applies to a board of any size is simply to line the rooks up along a main diagonal. The number of ways this can be done is $n!$ (that is, $1 \times 2 \times 3 \ldots n$), but the task of eliminating rotation and reflection duplicates is so difficult that it is not known how many essentially different solutions exist even on as low-order a board as the 8×8.

For bishops the maximum is $2n - 2$. To prove this, note that the number of diagonals running in one direction is $2n - 1$. No diagonal can have more than one bishop on it; in addition, the two end diagonals (that is, the two opposite corner squares) cannot both contain a bishop. This reduces the maximum to $2n - 2$. Thus on the standard board no more than 14 bishops can be placed so that no two attack each other. Dudeney has shown that this can be done in 36 essentially different ways. The total number of ways on a board of order n is 2^n, but (as with the rooks) it is not easy to winnow out the rotation and reflection duplicates. A method of placing the maximum number of bishops on a board of any size is to fill one edge row with n bishops and center $n - 2$ bishops along the opposite edge.

The maximum for kings is $\frac{1}{4}n^2$ on even-order boards, $\frac{1}{4}(n + 1)^2$ on odd-order boards. There is only one pattern: the kings are arranged in a square lattice, each separated by one cell from all neighbors.

The knight, which Dudeney calls the "irresponsible low comedian of the chessboard" because of its odd way of hopping, is perhaps less easy to analyze than the other pieces. What is the largest number of knights that can be placed on the 8×8 board in such a way that no knight attacks another? And in how many different ways can it be done? The reader will be surprised and amused to



Six ways to halve a 4 × 4 board

SILICOLOGY

REPORTING ON:

An Innovation in Silicone Technology

New OrganoFunctional Silicone Forms a Super-Thin Finish, Prevents Metal Corrosion

A new silicone metal protectant that *really* protects, without affecting dimensional tolerances or surface appearance, has been developed by Union Carbide scientists. Effective on all metals between magnesium and gold in the electromotive series, the new material prevents corrosion and tarnish indefinitely under a variety of service conditions.

Called UCAR 101 Silicone Metal Protectant, it is one of a whole family of OrganoFunctional Silicones that show unusually tenacious adhesion to metal surfaces when applied as films only 1/10,000 of an inch thin.

A copper conductive circuit board has been half-treated with UCAR 101 and then exposed to a sulphide atmosphere. While the unprotected half of the circuit board is greatly discolored, the treated portion retains its characteristic copper color.

SPECIAL PROPERTIES

The UCAR 101 film offers greater protection than common commercial lacquers because it is absolutely free of pinholes that may become hidden sites for corrosive attack. And, because it is a truly non-porous coating that prevents moisture and oxygen from penetrating to the substrate metal, it is superior to plated coatings. It even surpasses the natural corrosion resistance of oxide films found on such metals as aluminum and stainless steel.

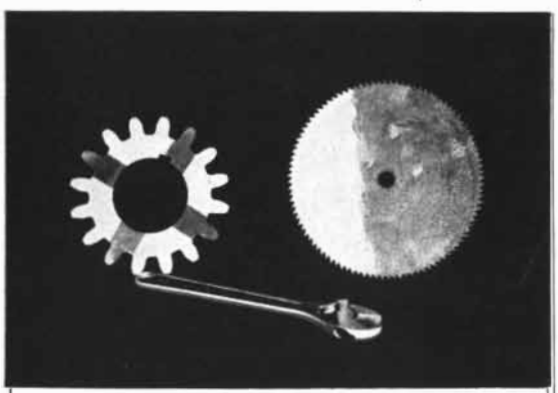
These benefits of UCAR 101 result from its extreme adhesion and exceptional continuity as an inert film. The bond it forms with a metal surface is far stronger than any organic film-to-metal bond observed previously. The bonding mechanism itself seems to be a form of chemisorption or hydrogen bonding that falls somewhere between a mechanical bond and a true chemical bond.

Although in the test tube UCAR 101 appears as an amber colored liquid, when it is applied to a metal surface its extreme and uniform thinness makes it virtually colorless. Since the film has no appreciable effect on dimensional characteristics, it is particularly useful on expensive parts machined to close tolerances. A corollary benefit of this thinness is high surface coverage, approximately 1,000 sq. ft. per gallon.

PERFORMANCE IS EXCEPTIONAL

Five years of laboratory testing show that UCAR 101 provides long-lasting protection against attack by environmental atmospheres containing sulphides and other corrosive materials in liquid, solid or gaseous form.

Copper, aluminum, brass, bronze, gold and other metals were coated with UCAR 101, immersed in hot detergents, and exposed to sodium sulphide. They showed no change in appearance. Yet similarly tested items, treated only with a common nitrocellulose lacquer, became tarnished and discolored. Other tests proved UCAR 101's ability to withstand continuous heat below 200°F and intermittent heat up to 250°F. UCAR 104, another version of this new silicone material, has been developed for use at higher temperatures.



Steel saw and gear, each half-treated with UCAR 101, show signs of corrosion on untreated portions after exposure for only 12 hours in an 85% relative humidity atmosphere.

VARIOUS WAYS TO APPLY

Application of UCAR 101 is simple. It can be sprayed, dipped, or wiped on. After 5 or 10 minutes of air drying, the treated object can be safely handled. Seven days of air drying, or 15 minutes of heating at 250°F, will completely cure the film. Immediate applications seem to be such items as electronics components, jewelry, hardware, household utensils, and machine parts.

Union Carbide is the leading innovator in silicones technology. New products, such as this metal protectant, are constantly developing. One reason for this is the great resource of technical capacities available within Union Carbide Corporation. To find out what's being done in silicones today (and tomorrow), contact your Silicones Man. He represents thousands of scientists and their coordinated abilities. Send in the coupon below for further information.

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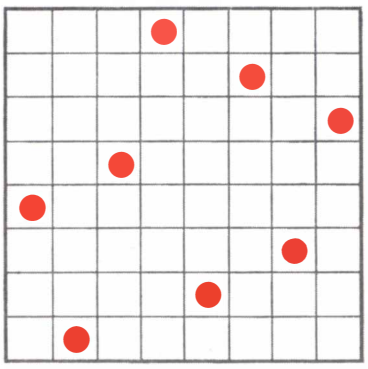

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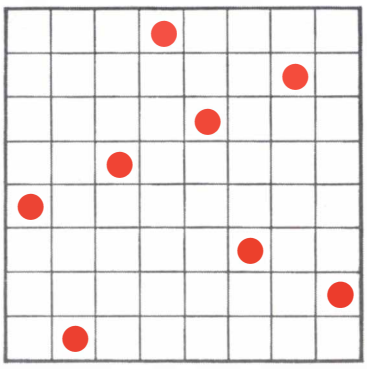

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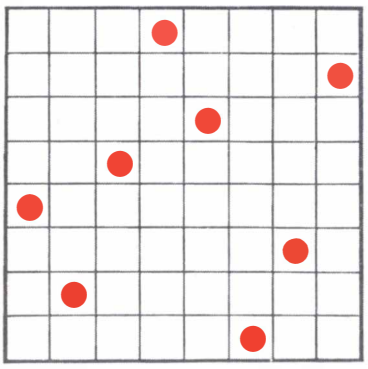

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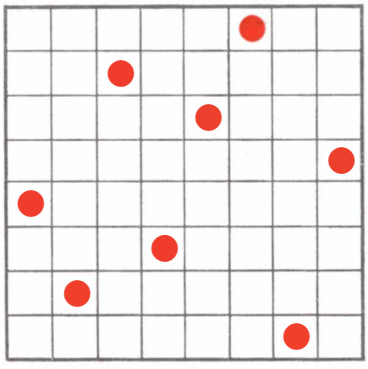

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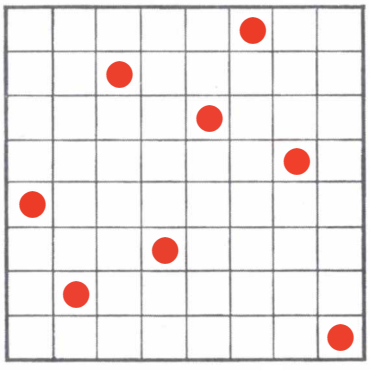

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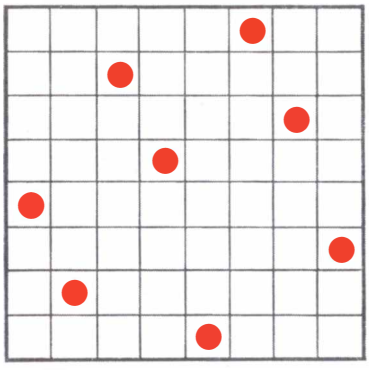

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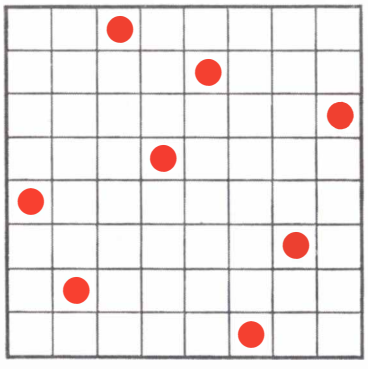

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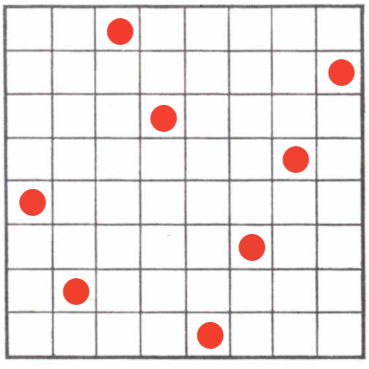

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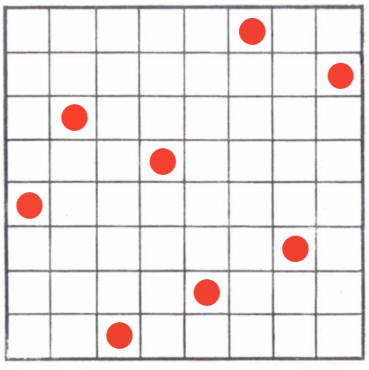

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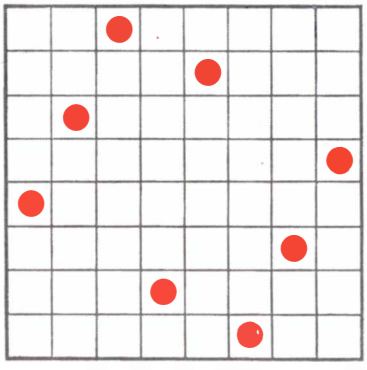

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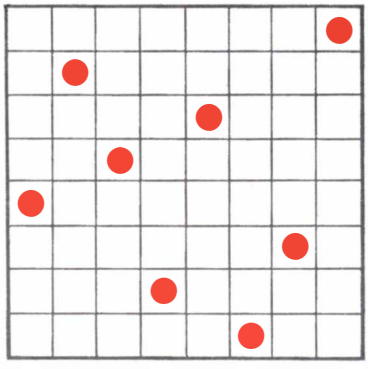

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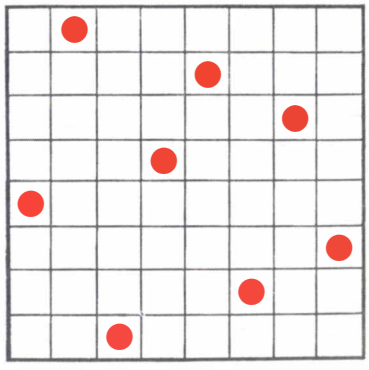


12

The 12 solutions to the classic problem of eight queens

discover the answers for himself, so I am withholding them until next month.

The short problems presented in this department last month are answered as follows:

1.

There are many different ways in which seven three-by-five-inch file cards can be placed on a sheet of legal-sized paper (8½ by 12½ inches) so that exactly 100 square inches are covered. One such method is shown in the top illustration on the next page. But, as Stephen Barr of Woodstock, N.Y., has discovered, if the central card is tilted slightly, as in the bottom illustration on the next page, the covered area is increased by a tiny fraction of a square inch.

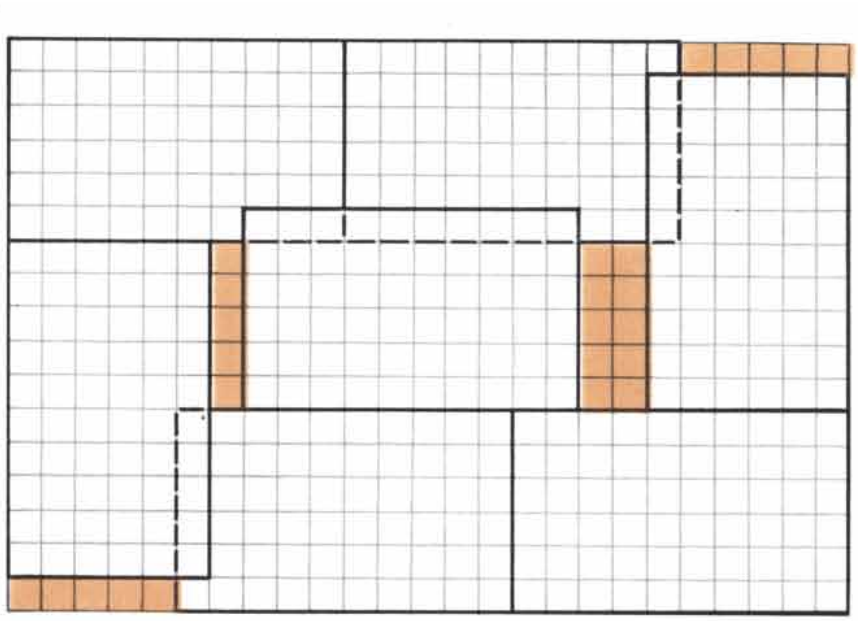
By exactly how much is it increased? This turns out to be equivalent to a problem often encountered in puzzle literature. It usually takes the form of a diagonal road that cuts across a rectangular plot of land. Given the dimensions of the rectangle and the width of the road, what is the road's area? In this case the rectangle is the three-by-five file card and the road is the 2½-inch-wide strip over which the card is placed. Exactly how much of the strip is covered by the tilted file card? Readers may enjoy answering this before next month, when the solution will be given.

2.

Every two people in a set of six people either mutually love or mutually hate each other, and there is no set of three who mutually love one another. The problem is to prove that there is a set of three who mutually hate one another.

The problem is easily solved by a graph technique. Six dots represent the six individuals [*see upper illustration on page 163*]. All possible pairs are connected by a broken line that stands for either mutual love or mutual hate. Let blue lines symbolize love and red lines symbolize hate.

Consider dot *A*. Of the five lines radiating from it, at least three must be of the same color. The argument is the same regardless of which color or which three lines we pick, so let us assume that three lines are red as shown in the illustration. If the lines forming triangle *BCE* are all blue, then we have a set of three people who mutually love one another. We are told no such set exists; therefore at least one side of this tri-

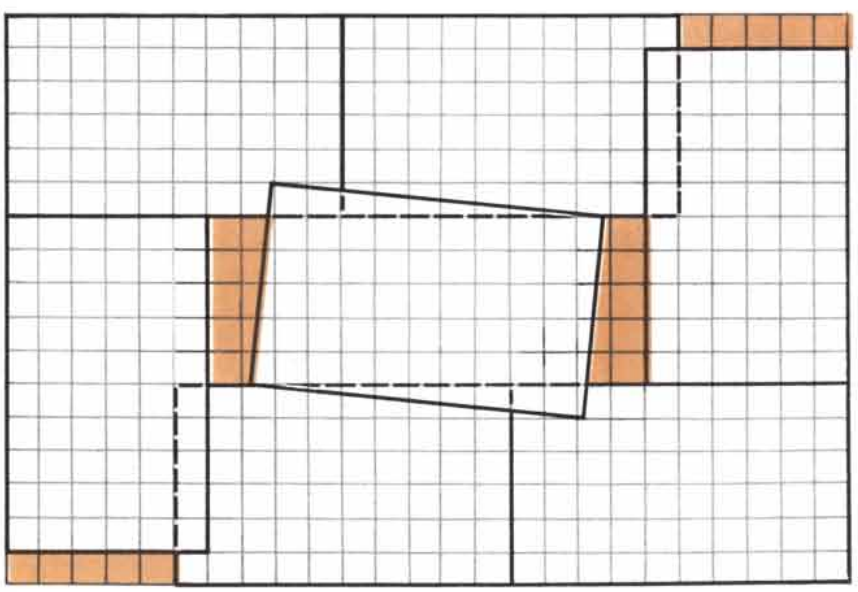


Seven file cards arranged to cover 100 square inches

angle must be red. No matter which side we pick for red, we are sure to form an all-red triangle (i.e., three people who mutually hate one another). The same result is obtained if we choose to make the first three lines blue instead of red. In that case the sides of triangle *BCE* must all be red; otherwise a blue side would form an all-blue triangle. In brief, there must be at least one triangle that is either all-blue or all-red. The problem rules out an all-blue triangle, so there must be an all-red one.

Actually, a stronger conclusion is obtainable. If there is no all-blue triangle, it can be shown (by more complicated reasoning) that there are at least *two* all-red triangles. In graph theory, a two-color graph of this sort, with no blue triangles, is called a blue-empty chromatic graph. If the number of points is six, as in this problem, the minimum number of red triangles is two.

When the number of points in a blue-empty graph is less than six, it is easy to draw such graphs with no red triangles. When the number of points is seven, there must be at least four red triangles. For an eight-point blue-empty graph the minimum number of red triangles is eight; for a nine-point graph it is 13. Anyone wishing to go deeper into the



The file cards arranged to cover a fraction of an inch more

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theory should consult Gary Lorden's excellent paper on "Blue-Empty Chromatic Graphs" in the February 1962 issue of *The American Mathematical Monthly.*

3.

A plays a stronger chess game than *B.* If your object is to win two games in a row, which is better: to play against *A*, then *B*, then *A;* or to play *B*, then *A*, then *B?*

Let P_1 be the probability of your defeating *A* and P_2 the probability of your defeating *B.* The probability of your *not* winning against *A* will then be $1 - P_1$ and the probability of your *not* winning against *B* will be $1 - P_2$.

If you play your opponents in the order *ABA*, there are three different ways you can win two games in a row:

1. You can win all three games. The probability of this occurring is $P_1 \times P_2 \times P_1 = P_1^2P_2$.

2. You can win the first two games only. The probability of this is $P_1 \times P_2 \times (1 - P_1) = P_1P_2 - P_1^2P_2$.

3. You can win the last two games only. The probability is $(1 - P_1) \times P_2 \times P_1 = P_1P_2 - P_1^2P_2$.

The three probabilities are now added to obtain $P_1P_2(2 - P_1)$. This is the probability that you will win twice in a row if you play in the order *ABA.*

If the order is *BAB*, a similar calculation will show that the probability of winning all three games is $P_1P_2^2$, of winning the first two games is $P_1P_2 - P_1P_2^2$, and of winning the last two games is $P_1P_2 - P_1P_2^2$. The sum of the three probabilities is $P_1P_2(2 - P_2)$. This is the probability of winning two games in a row if you play in the order *BAB.*

We know that P_2, which is the probability of your winning against *B*, is greater than P_1, the probability of your winning against *A*, so it is apparent that $P_1P_2(2 - P_1)$ must be greater than $P_1P_2(2 - P_2)$. In other words, you stand a better chance of winning twice in succession if you play *ABA:* first the stronger player, then the weaker, then the stronger.

4.

Fitch Cheney's cryptarithm has the unique answer

$$\begin{array}{r} 285 \\ 39 \\ \hline 2565 \\ 855 \\ \hline 11115 \end{array}.$$

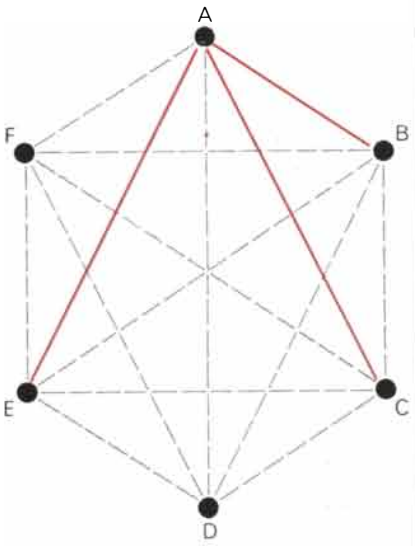
The unique answer to Joseph Ellis Trevor's cryptarithm is

$$\begin{array}{r} 775 \\ 33 \\ \hline 2325 \\ 2325 \\ \hline 25575 \end{array}.$$

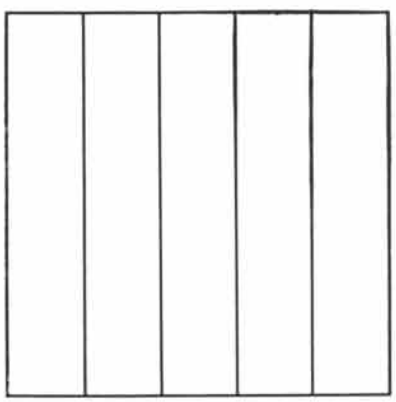
Trevor's problem, the more difficult of the two, is perhaps best approached by searching first for all three-digit numbers composed of prime digits that yield four prime digits when multiplied by a prime. There are only four:

$$775 \times 3 = 2325,$$
$$555 \times 5 = 2775,$$
$$755 \times 5 = 3775,$$
$$325 \times 7 = 2275.$$

No three-digit number has more than one multiplier, therefore the multiplier



Graph solution for Problem 2



Solution for Problem 5

in the problem must consist of two identical digits. Thus there are only four possibilities that need to be tested.

5.

A square can be dissected into five congruent parts only in the manner shown at the bottom of the preceding page. The consternation of those who find themselves unable to solve this problem is equaled only by their feeling of foolishness when shown the answer.

6.

To drive through Floyd's Knob without a traffic violation, take the following directions at each successive intersection (the letters stand for North, South, East, West): E-E-S-S-E-N-N-N-E-S-W-S-E-S-S-W-W-W-W-N-N-E-S-W-S-E-E-E-E-N-E.

7.

"However little French I know," says J. E. Littlewood (in explaining why he was not obliged to write an infinite regress of footnotes to an article that a friend translated), "I am capable of *copying* a French sentence."

8.

To form an expression equal to 100, plus and minus signs can be inserted between the digits, taken in reverse order, as follows:

$$98 - 76 + 54 + 3 + 21 = 100 .$$

Did any reader manage to do it with fewer signs?

9.

Two circular cylinders of unit radius intersect at right angles. What is the volume common to both cylinders? The problem is solved easily, without the use of calculus, by the following elegant method:

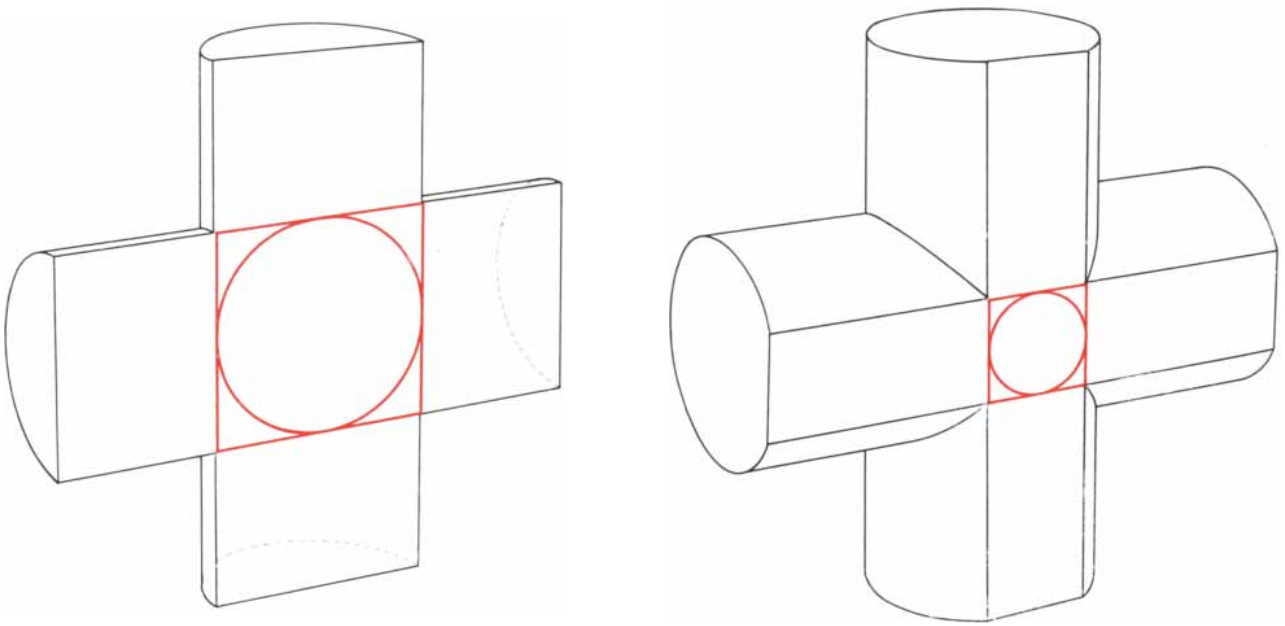
Imagine a sphere of unit radius inside the volume common to the two cylinders and having as its center the point where the axes of the cylinders intersect. Suppose that the cylinders and sphere are sliced in half by a plane through the sphere's center and both axes of the cylinders [*at left below*]. The cross section of the volume common to the cylinders will be a square. The cross section of the sphere will be a circle that fills the square.

Now suppose that the cylinders and sphere are sliced by a plane that is parallel to the previous one but that shaves off only a small portion of each cylinder [*at right below*]. This will produce parallel tracks on each cylinder, which intersect as before to form a square cross section of the volume common to both cylinders. Also as before, the cross section of the sphere will be a circle inside the square. It is not hard to see (with a little imagination and pencil doodling) that any plane section through the cylinders, parallel to the cylinders' axes, will always have the same result: a square cross section of the volume common to the cylinders, enclosing a circular cross section of the sphere.

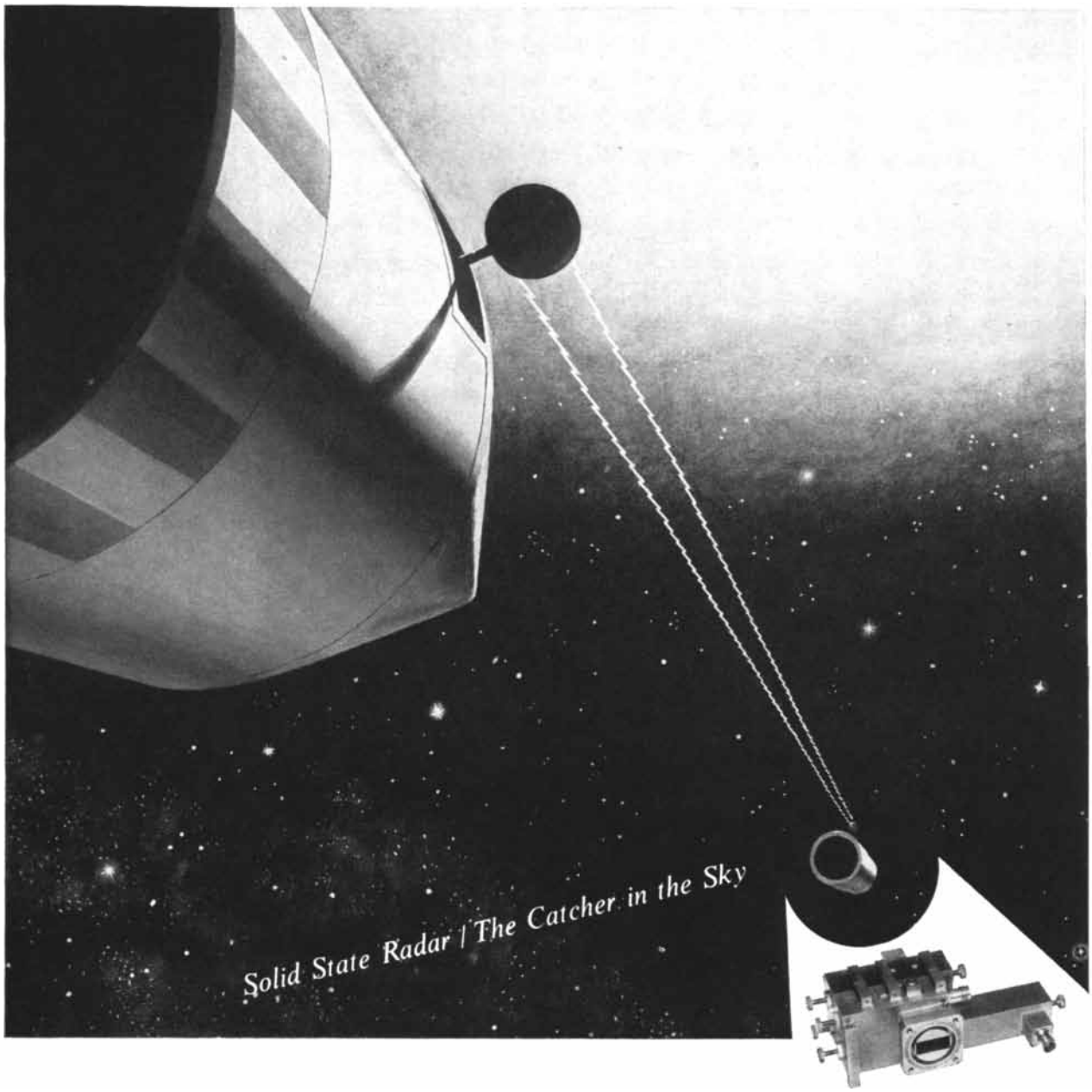
Think of all these plane sections as being packed together like the leaves of a book. Clearly, the volume of the sphere will be the sum of all the circular cross sections, and the volume of the solid common to both cylinders will be the sum of all the square cross sections. We conclude, therefore, that the ratio of the volume of the sphere to the volume of the solid common to the cylinders is the same as the ratio of the area of a circle to the area of a circumscribed square. A brief calculation shows that the latter ratio is $\pi/4$. This allows the following equation, in which x is the volume we seek:

$$\frac{4\pi r^3/3}{x} = \frac{\pi}{4}$$

The π's drop out, giving x a value of $16r^3/3$. The radius in this case is 1, so the volume common to both cylinders is 16/3. As Archimedes pointed out, it is exactly 2/3 the volume of a cube that encloses the sphere; that is, a cube with an edge equal to the diameter of each cylinder.



Two cross sections of Archimedes' cylinders and the interior sphere



A new solid state radar system built by STL engineers and scientists can send out and receive signals at X-band frequencies to help man rendezvous and dock vehicles in space. STELATRAC is its name. It is the first solid state system of its kind. The X-band transmitter is shown above. It has successfully passed temperature and vibration tests. STELATRAC can also be used as a command link between vehicles in flight. By altering its module design, the flexible radar system operates as an altimeter and doppler velocity sensor to guide spacecraft safely to the surface of the moon and planets. Today STL is busy on many such projects as STELATRAC. STL is also prime contractor for NASA's OGO and a new series of classified spacecraft for Air Force-ARPA. And STL continues Systems Management for the Air Force's Atlas, Titan and Minuteman programs. These activities create immediate openings in Theoretical Physics • Systems Engineering • Radar Systems • Experimental Physics • Applied Mathematics • Space Communications • Antennas and Microwaves • Inertial Guidance • Analog Computers • Solid State Physics • Computer Design • Telecommunications • Space Physics • Digital Computers • Guidance & Navigation • Electromechanical Devices • Engineering Mechanics • Aerodynamics • Propulsion Systems. For Southern California or Cape Canaveral positions, write Dr. R. C. Potter, Department J11, One Space Park, Redondo Beach, California, or Box 4277, Patrick AFB, Florida. Your inquiry will receive a prompt reply. STL is an equal opportunity employer.

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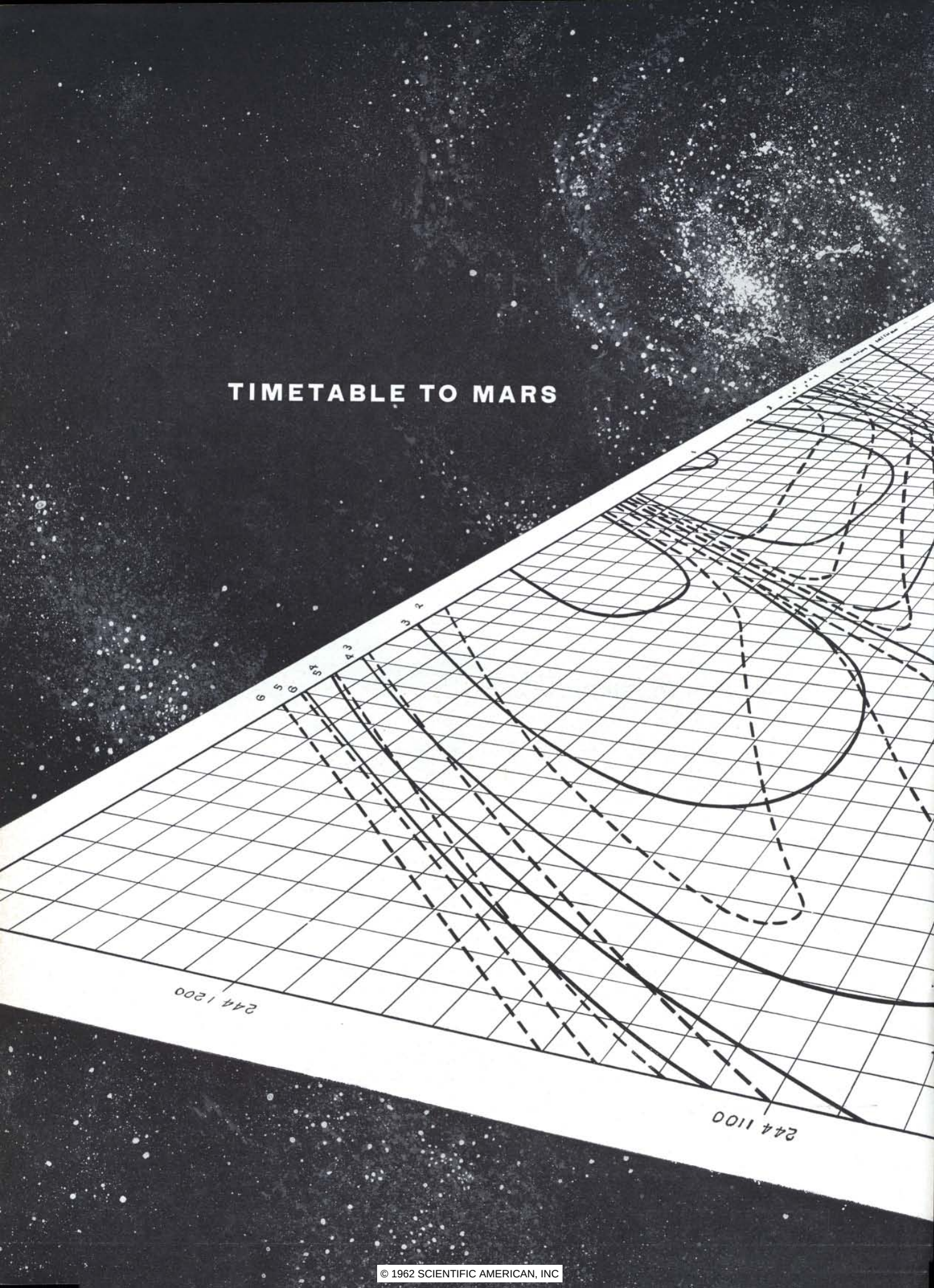

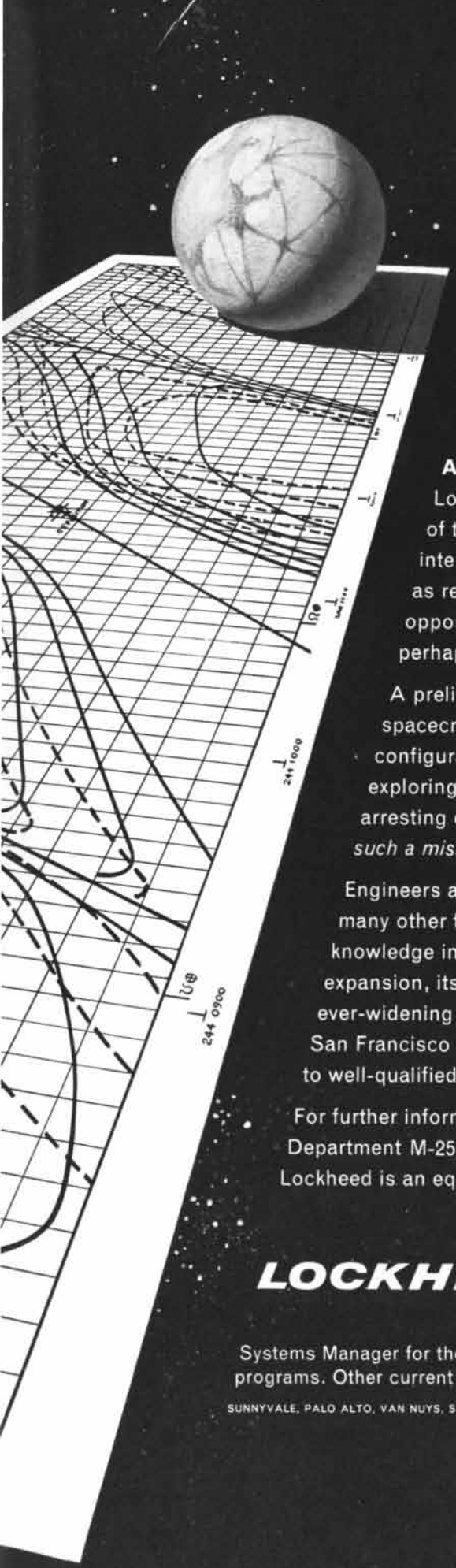

Arrive Mars: 10.3 August, 1971 Giant steps were taken recently at Lockheed Missiles & Space Company toward manned exploration of the planets Mars and Venus. For the first time, accurate interplanetary transfer orbits have been plotted to show velocities as related to departure and arrival dates for an entire cycle of planet oppositions. A "fast" round-trip would take a year, allowing perhaps ten days exploration time on Mars.

A preliminary but comprehensive study also was made on the spacecraft's design considerations. Many facets were explored—configuration, single versus multi-stages, weight, thrust, payload, exploring, landing, and return equipment; and many more. The arresting conclusion of Lockheed scientists: *A vehicle can perform such a mission within the present state-of-the-art.*

Engineers and scientists at Lockheed Missiles & Space Company conduct many other feasibility and research studies, probing for advanced knowledge in a wide diversity of disciplines. Lockheed's constant expansion, its growing leadership in missiles and space, its ever-widening scope of projects, its ideal location on the beautiful San Francisco Peninsula—all open new and unusual challenges to well-qualified people.

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ANACONDA COMMENTS...

new facts about copper—man's oldest metal

SPECIAL STRENGTH ISSUE *NUMBER 8 OF A SERIES*

ANACONDA RESEARCH CENTER DEVELOPS IMPROVED HIGH-STRENGTH COPPER-BASE ALLOY

Through Anaconda American Brass Company's intensified program to improve the strength capabilities of copper-base materials, a new heat treatable copper-nickel-manganese-aluminum alloy with exceptional mechanical strength has been developed. This experimental alloy offers strength properties comparable to those possessed by the more costly copper-base and iron-base materials.

Properties characterized by exceptional yield strength

Through cold work and thermal treatment, yield strengths (0.2 percent offset) over 200,000 psi can be realized with small-diameter wire—and yield strengths over 150,000 psi can be developed with rod and strip. The elastic modulus for this high-strength alloy is about 19,000,000 psi: high for copper-base materials but sufficiently below that of steel to suggest spring-type applications where increased deflection and damping action are desired.

The electrical conductivity of this experimental alloy is about 3 percent IACS: low for copper-brass materials but of some interest where high resistivity or low thermal conductivity is sought.

Other properties of this high-strength alloy are typical of those offered by copper metals: excellent corrosion resistance to a wide range of media; good welding properties; moderate formability; and, of course, nonmagnetic characteristics.

Applications now under test

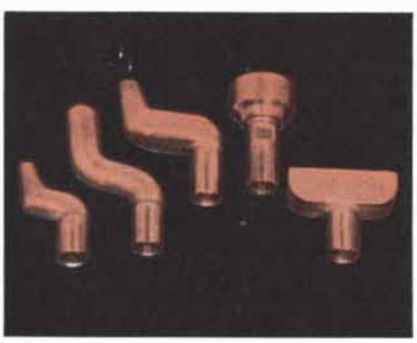
As part of the application development program for this alloy, many potential uses are under actual field evaluation. These applications include relay components in automatic telephone circuits, wire springs for high damping characteristics, garment fasteners, mechanical components in chemical process equipment, and self-tapping fasteners.

If your present work seems to require a lower cost high-strength copper alloy, tell us about it. We'd be glad to hear from you.

THREE HIGH-STRENGTH COPPER METALS FOR ELEVATED TEMPERATURE APPLICATIONS

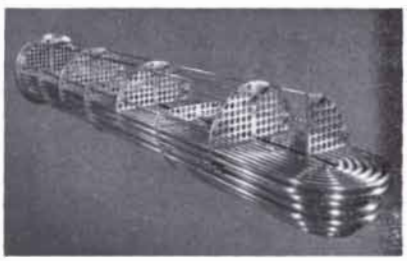
Chromium Copper-999. Cupro Nickel, 30%-707. And Amzirc* (Zirconium Copper)-134. These three copper alloys provide balanced combinations of properties—including high strength and elevated temperature stability—for many new applications. A quick rundown of each follows . . .

Chromium Copper-999, supplied in all standard mill forms, is a metal with a split personality: Untreated, it is soft, ductile, and easily cold worked or formed. After heat treatment, it is hard and strong—with a tensile strength of 65,000 psi and electrical conductivity of about 80% IACS. Mechanical properties are retained to a remarkable degree at temperatures as high as 750°F.



Chromium Copper is used for commutator bars, resistance welding tips (shown) and wheels, wire in vacuum tube assemblies, and high-temperature mechanical and electrical parts.

Cupro Nickel, 30%-707 is a high-strength, corrosion resistant alloy—finished with special stabilizing anneal to permit tight U-bends and a high degree of strength retention to 600°F and beyond. Highly adaptable, it can be cold worked or welded, used in tube sheets or for bolts and screws. Mechanical properties are competitive with "premium" high-strength materials; cost is substantially lower. (Value analysis, anyone?)



Cupro Nickel, 30% 707, originally designed for heat exchanger tubes in power station feedwater heaters, is adaptable to many applications where corrosion resistance and high strength are required.

Amzirc (Zirconium Copper)-134, available in strip, wire, and rod, offers high electrical conductivity (up to 95% IACS), high strength (up to 70,000 psi), hardness, and ductility: properties which are well retained at high temperatures. Its tensile strength, for example, falls only to 52,000 psi at 750°F.

Amzirc (Zirconium Copper)-134 is at home in resistance welding wheels and tips, high-temperature magnet wire, commutators and similar application calling for strength, hardness and conductivity.

Whatever your next application may involve—if you need a material that blends high strength and elevated temperature stability with conductivity or machinability . . . Think Copper. And think of Anaconda. As the world's largest supplier of copper metals in all mill forms, we can provide the alloy you need.

For more information about high-strength, high-temperature, high-performance copper metals, write: Anaconda American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Ltd., New Toronto, Ontario. 61-1968

*Trade mark of American Metal Climax, Inc.

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THE AMATEUR SCIENTIST

How to build and maintain aquariums for organisms that live in the ocean

Conducted by C. L. Stong

Sea water, like fertile soil, is a remarkably complex mixture—a broth of reactive chemicals in dynamic equilibrium with the life it supports. Maintaining that balance in a small marine aquarium can present a challenge to any one who enjoys the exotic organisms of the sea, particularly if he has a flair for chemistry. The essential supplies are not inexpensive if the experimenter lives some distance from the coast: no adequate substitute for sea water has been compounded, and the transportation of live specimens runs into money. With the development of relatively inert materials such as plastics and glass fiber, however, methods of conserving sea water have been perfected. In recent years even beginners have succeeded in minimizing the cost of specimens by breeding at home some species of marine fishes and a number of fascinating invertebrates. A small salt-water system that is well adapted for amateur operation has been constructed by Lars H. Carpelan, assistant professor of biology at the Riverside campus of the University of California. In this system the water is pumped through a battery of aquariums from a relatively large reservoir that serves as a settling basin and oxidation pond. The reservoir minimizes the accumulation of organic wastes in the aquariums and tends to concentrate bacterial action at a point remote from the specimens.

"According to theory," writes Carpelan, "it should be possible to achieve chemical stability in a stagnant, isolated aquarium. In practice, however, it is extremely difficult to establish a precise balance between the nutritional requirements and the metabolic products of plants, bacteria and herbivorous, carnivorous and scavenging animals. An arrangement that allows water to flow through the aquarium from a comparatively large reservoir simplifies the problem greatly by removing wastes, aerating automatically and diluting local contamination. In addition, it is fairly easy to maintain a large tank of water at the uniform temperature required by many marine animals, whereas small aquariums tend to follow fluctuations in the temperature of the surrounding air.

"The system I constructed occupies a space two feet wide and eight feet long in a vivarium at the university. It was built of wood, glass fiber, plastic pipes and a pump at a total cost, exclusive of labor and the aquariums, of about $250. Aquariums can be constructed at a cost of about $12 each for materials. A considerable saving could be made by using a second-hand bathtub for the reservoir. Care would have to be taken to coat all exposed metal parts of the tub with an inert material such as paraffin. Don't worry too much about ferrous metals, but keep brass or bronze away from the water; they will react to form copper ion, which is highly toxic to most marine organisms. Be sure that the stoppers used for closing the drain and overflow holes of the tub are leakproof and coated with paraffin.

"An arbitrary rule of thumb calls for a reservoir with twice the total capacity for storing the water when the aquariums are empty and a minimal ratio of aquariums-to-reservoir volume for the dilution of contaminants when the system is in operation. A reservoir of adequate proportions provides a favorable surface-to-volume ratio for the diffusion of atmospheric oxygen into the water. When the surface is small in relation to the volume, animals consume dissolved oxygen faster than it can be replaced by diffusion.

"My system serves 12 10-gallon aquariums. The reservoir has a capacity of 240 gallons. In practice the containers are kept three-quarters full, so that there are 90 gallons in the aquariums and 90 gallons in the reservoir when all the aquariums are in use. The reservoir is then filled to a depth of only nine inches, a surface-to-volume ratio adequate for maintaining equilibrium between dissolved oxygen, dissolved carbon dioxide and the atmosphere.

"To maintain the water at a constant level in the aquariums one must balance the inflow and the outflow. This could be accomplished by installing a drain tube at the desired height in one wall of each aquarium, but such an arrangement has the disadvantage of permanency: the hole can't be shifted when one wants to change the water level. Moreover, in the case of glass aquariums holes are difficult to drill and they weaken the glass. An alternative but equally permanent solution is a vertical overflow pipe penetrating the bottom of the tank, in which case the height of the open end of the pipe determines the water level.

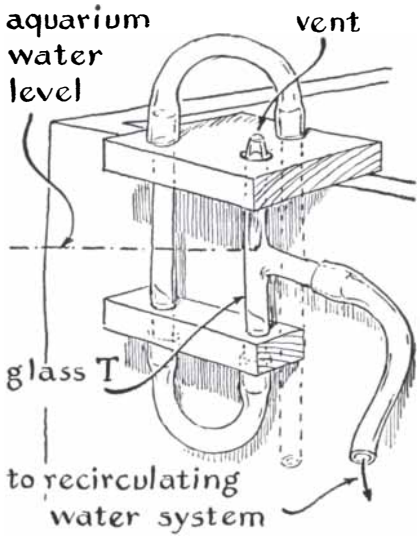
"The usual aquarium outflow is a siphon. I use automatic siphons assembled from simple glass T's and straight glass tubes coupled by short lengths of flexible plastic tubing [*see illustration on next page*]. Conventional siphons are not satisfactory because they must be restarted when the level of the water drops low enough to admit air. The vented branch of the automatic siphon prevents water in the aquarium from falling below the level of water trapped in the external U of the siphon. Once installed, the device requires no attention other than periodic cleaning. To prime it one stoppers the discharge tube and applies suction to the vent. If the vent is closed, the device functions as a conventional siphon. A flexible tube leads from each siphon to an open trough or to a 3/4-inch plastic pipe fitted with open T joints, either of which returns the outflow water to the filter.

"A filter must be placed somewhere in the circuit to serve as a 'kidney' for ridding the circulating water of wastes. The required amount of filtration will vary according to use. If only animals that take food in large particles are to be kept, the water should be sparkling clear, and this calls for maximum filtering. Thorough filtering is ill-advised, however, for invertebrates. The food cycle in a closed system can be made almost

self-regulating when the system includes adequate populations of filter-feeding animals, such as bivalve mollusks, and grazers, such as gastropod mollusks. Once a properly filtered recirculating system for invertebrates is in operation, the accumulation of organic matter supports a natural cycle of bacterial action that liberates nutrients for the growth of algae. The algae, in turn, support the growth of encrusting algae and other phytoplankton—if enough light reaches the aquarium to maintain photosynthesis. The consumption of phytoplankton and encrusting algae by filter-feeding and grazing animals then completes the food cycle. A deposit of organic matter on the bottom of an aquarium will simultaneously provide a substrate of nutrients for protozoa and other organisms to support bottom-feeders. Excessive filtering breaks the cycle. When a variety of invertebrates are kept in the aquarium, the filter-feeders can do the filtering and the bottom-feeders can do the cleaning.

"Minimal filtering can be accomplished by returning the overflow from an aquarium to the reservoir through an inch or so of replaceable glass wool on top of a few inches of calcareous gravel (beach gravel that contains a substantial amount of broken mollusk shell). The loose materials can be packed in an inert container equipped with the necessary tubing [*see illustration on page 172*]. The filtering action can be increased substantially by adding a layer of fine sand above the calcareous gravel and still more by placing a layer of activated charcoal on top of the sand. Both the charcoal and the glass wool must be replaced when they become loaded with waste. The calcareous gravel plays only an incidental role in the removal of wastes but maintains the hydrogen-ion concentration within the slightly alkaline range of the sea.

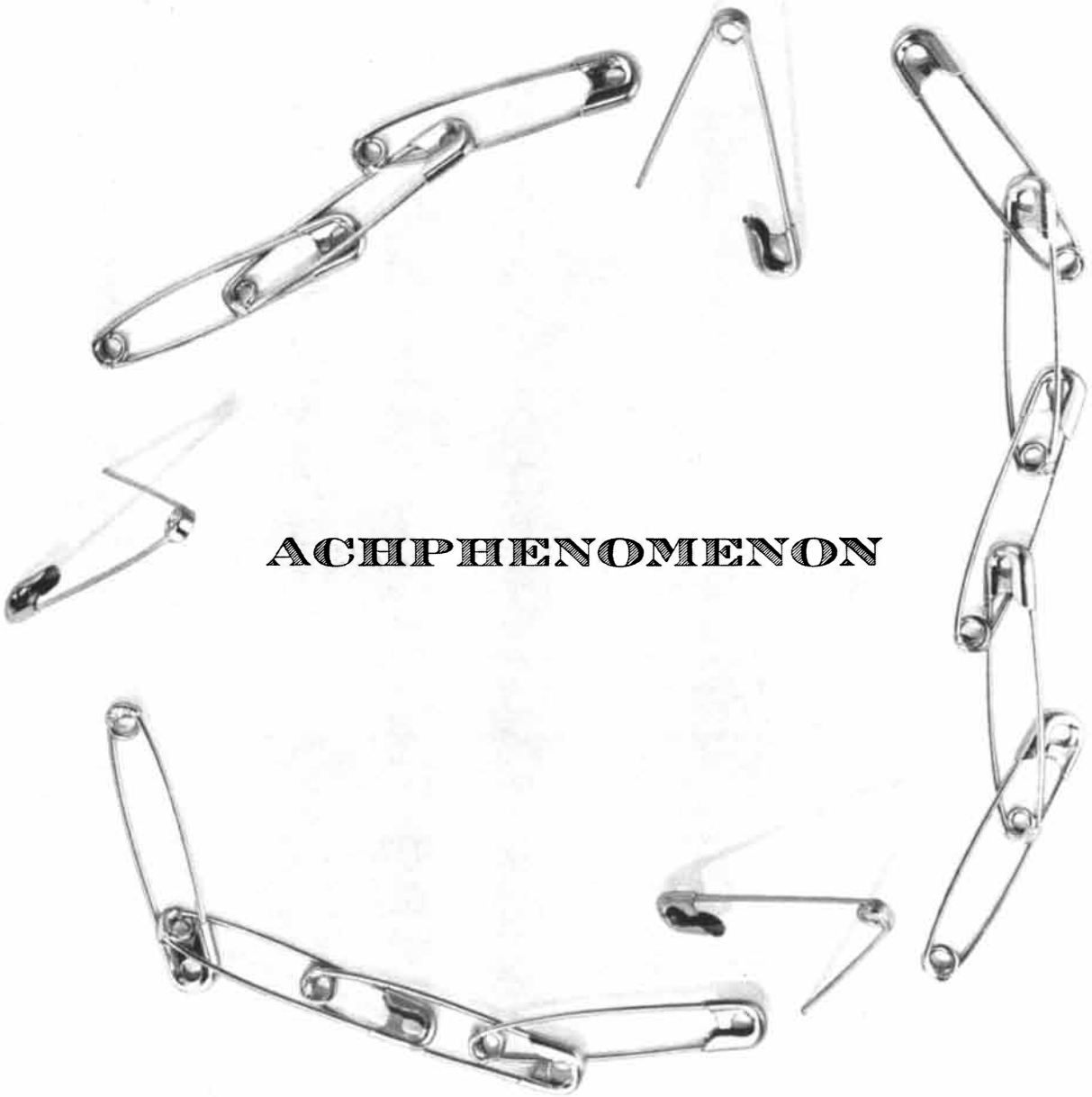
"Maintaining the temperature of the water within a range favorable to specimens may or may not be a problem, depending on the tolerance of the organisms and the room temperature. The temperature of the vivarium at the university is held at 75 degrees Fahrenheit, which is high for many marine organisms but which can be tolerated by tidepool forms, particularly those native to tropical waters. A temperature of 64 degrees F., which is about right for many species, could be maintained either by lowering the temperature of the room or by circulating the water through a coil of plastic garden hose kept in a small refrigerator of the type used for cooling bottled drinks. The amount of cooling would depend on the length of the coil, the speed of flow and the temperature of the refrigerator and would have to be determined by trial and error.



Automatic siphon

"The salinity of deep-sea water ranges between 33 and 38 parts per thousand by weight, but water near the shore is frequently more dilute. Many tide-pool organisms can survive fluctuations in salinity ranging from 25 to 45 parts per thousand. Even so, a conscientious effort to maintain salinity in the range of 33 to 38 parts per thousand will be repaid in terms of more vigorous specimens. This range corresponds to a specific gravity of 1.025 to 1.029 at the temperature of 64 degrees. The specific gravity at 25 parts per thousand is approximately 1.02 and at 45 parts per thousand about 1.035. Hydrometers of adequate sensitivity for determining density are available from dealers in scientific supplies for about $2. Under normal conditions density can be expected to increase gradually as the system loses water by evaporation. Salinity should be checked weekly and lowered by adding distilled water when the specific gravity increases to 1.03. If the available sea water for stocking the system is too dilute, either allow water to evaporate at room temperature or add one of the preparations compounded to simulate sea water. A number of these are on the market and can be ordered from manufacturers through dealers in tropical fish.

"In the normal course of cleaning aquariums, inserting or removing specimens from the water and otherwise maintaining the system, and in the event of a clogged outflow pipe, some water is inevitably spilled over the sides. For



ACHPHENOMENON

A cursory analysis leads some to say that five breaks and rejoins are required to make a fifteen-link chain out of five chains of 1, 2, 3, 4, and 5 links. If you say four, you show imagination and perception. The optimal solution, three, requires the ingenuity, acumen—Achphenomenon, if you will—that is welcome at Litton Systems.

We are looking for engineers who can disregard the brick-and-mortar approach and see the unobserved. Engineers who avoid the tendency to think in traditional channels. If you're relatively unhampered by stereotypes, send a resume to Mr. Don F. Krause, Manager Professional and Scientific Staffing. Anticipate a prompt reply.

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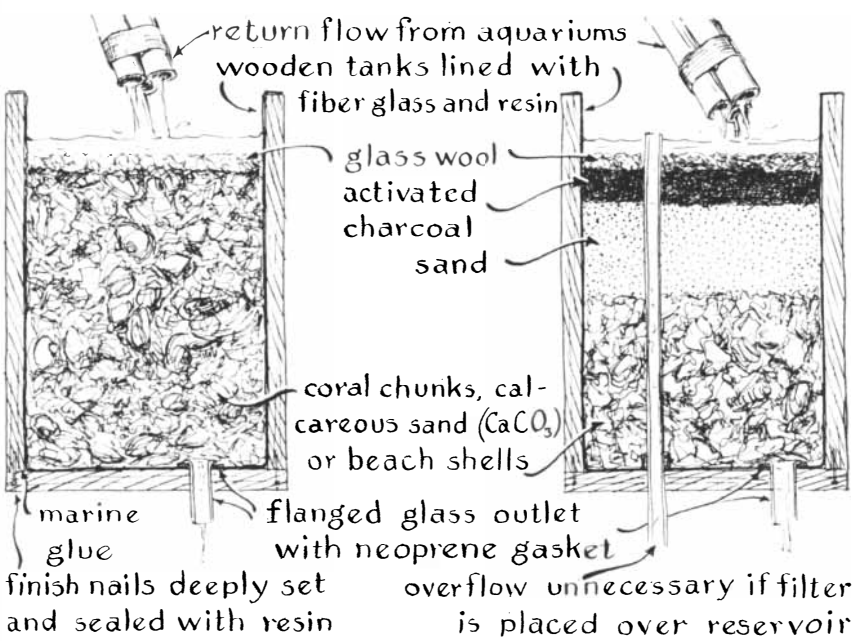
this reason I place my aquariums on shelves made in the form of shallow trays equipped with drains that lead to a plastic catch bucket. The trays are made of marine plywood 3/4 inch thick, which can be bought from lumberyards that cater to boatbuilders. (Ordinary plywood comes apart when it is soaked.) In my arrangement the lowest shelf, or tray, is a foot above the reservoir, with succeeding shelves spaced at 18-inch intervals above the first [*see illustration on page 174*].

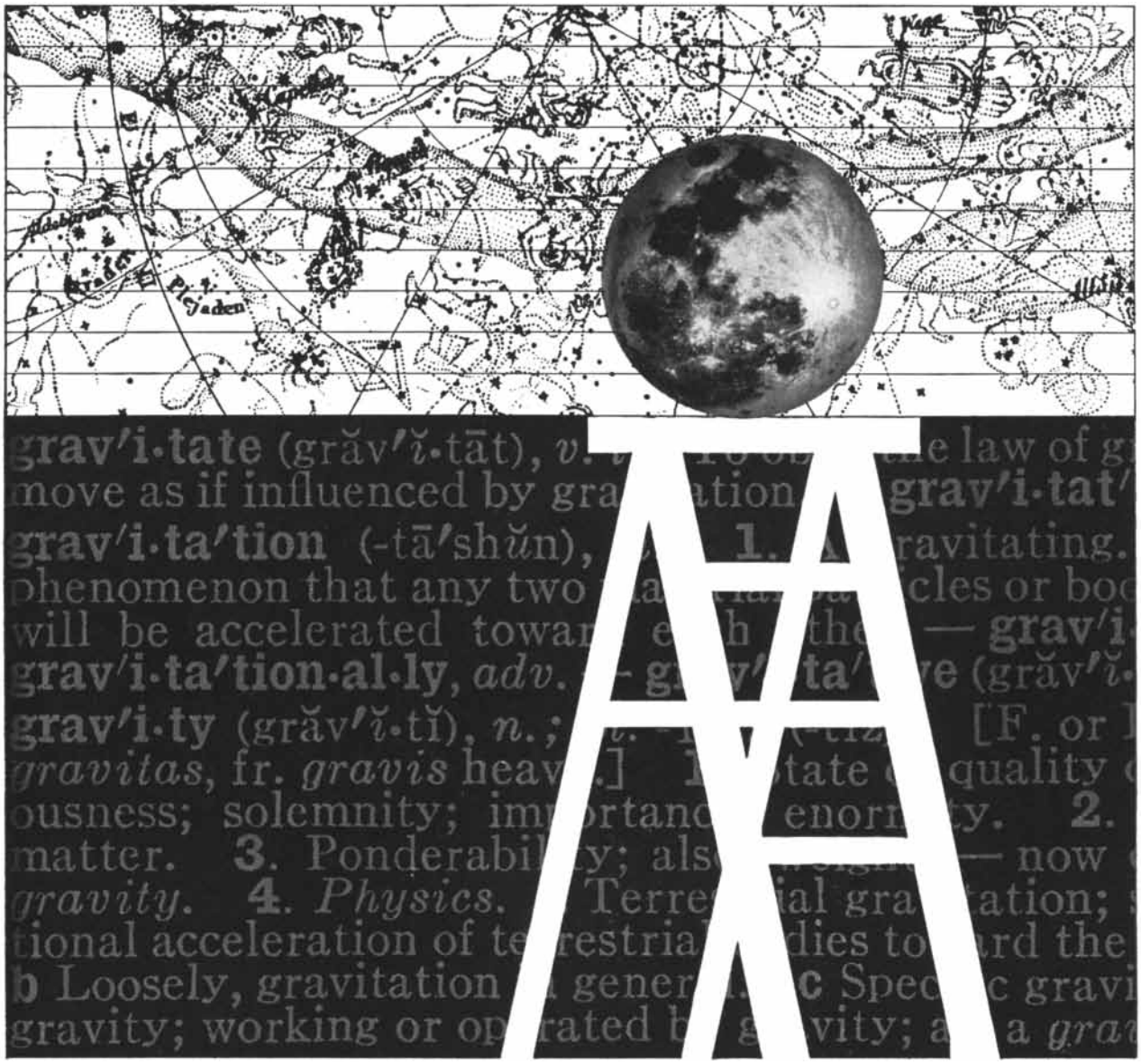
"The construction of the trays and reservoir is not difficult if care is taken to make straight cuts and to keep the ends square. The job is easy if one has access to a power saw. Marine plywood of the necessary thickness comes in sheets four feet wide and eight feet long priced at about $5 a sheet. My construction required four sheets and about 100 feet of two-by-four stock for the base and supporting structure. The shelves and reservoir were assembled with nails and waterproof glue. The nails were countersunk and the holes were calked to prevent corrosion. The interior surfaces of all shelves and the reservoir were coated with glass fiber, a material that provides a smooth, inert, waterproof finish. It can be obtained from boat-supply dealers, along with excellent advice on the technique of applying it to wood. The material, which consists of glass filaments woven into a clothlike fabric, comes in various widths. I used the 50-inch width at $1.60 a yard. When split down the middle, it fitted the two-foot width of my shelves and reservoir with a 1/2-inch overlap at the sides. Glass fiber is applied to wood with a fluid resin priced at about $7 a gallon, enough for three coats over an area of 45 square feet. One simply paints the wood with resin and applies the fabric like wallpaper. For a watertight seal the material must overlap at the corners and edges. When the first coat of resin has hardened, two more coats are applied directly over the fabric to seal the spaces between filaments. Drainpipes can be installed after the layers have hardened by drilling slightly oversized holes through the walls and cementing the pipes in place with a filler made of scraps of fabric mixed with resin.

"All the plumbing is of glass, Tygon, polyethylene or rubber, with no metal parts coming in contact with the water. Various flexible and rigid tubes together with a wide selection of fittings for lawn-sprinkler systems are available from most hardware stores and mail-order houses. Flexible transparent tubing smaller than 1/2 inch in diameter, together with plastic and glass stopcocks, are stocked by dealers in scientific supplies. The stopcocks range in price from $3 to $5 each. A substantial saving can be made by substituting flexible tubing and pinchcocks for stopcocks, although at some cost in terms of convenience.

"The pump, mounted on a wooden support, is suspended from a wooden slat across the top of the reservoir by nylon cords, as shown in the illustration. The suspension reduces noise and makes vertical adjustment easy. Incidentally, be sure to set aquariums with exposed



Minimal filter (left) *and a more thorough one* (right)



purposeful imagination....in space

The men of Aerospace probe all disciplines of the space sciences. Chartered exclusively to serve the United States Government, Aerospace Corporation applies the full resources of modern science and technology to advanced space and ballistic missile systems. □ As part of the Air Force-science-industry team, the men of Aerospace evaluate and stimulate the free flow of information that results in the imaginative concepts required for national leadership in space. From concept to countdown and beyond, Aerospace provides advanced systems analysis and planning; theoretical and experimental research; general systems engineering and corresponding technical direction of programs. □ Aerospace Corporation, an equal opportunity employer, now needs more men to meet these responsibilities. Highly skilled engineers and scientists with advanced degrees, knowledgeable in interdisciplinary problem solving, are urged to contact Mr. Charles Lodwick, Room 120, Aerospace Corporation, P. O. Box 95081, Los Angeles 45, California. □ Organized in the public interest and dedicated to providing objective leadership in the advancement and application of science and technology for the United States Government.

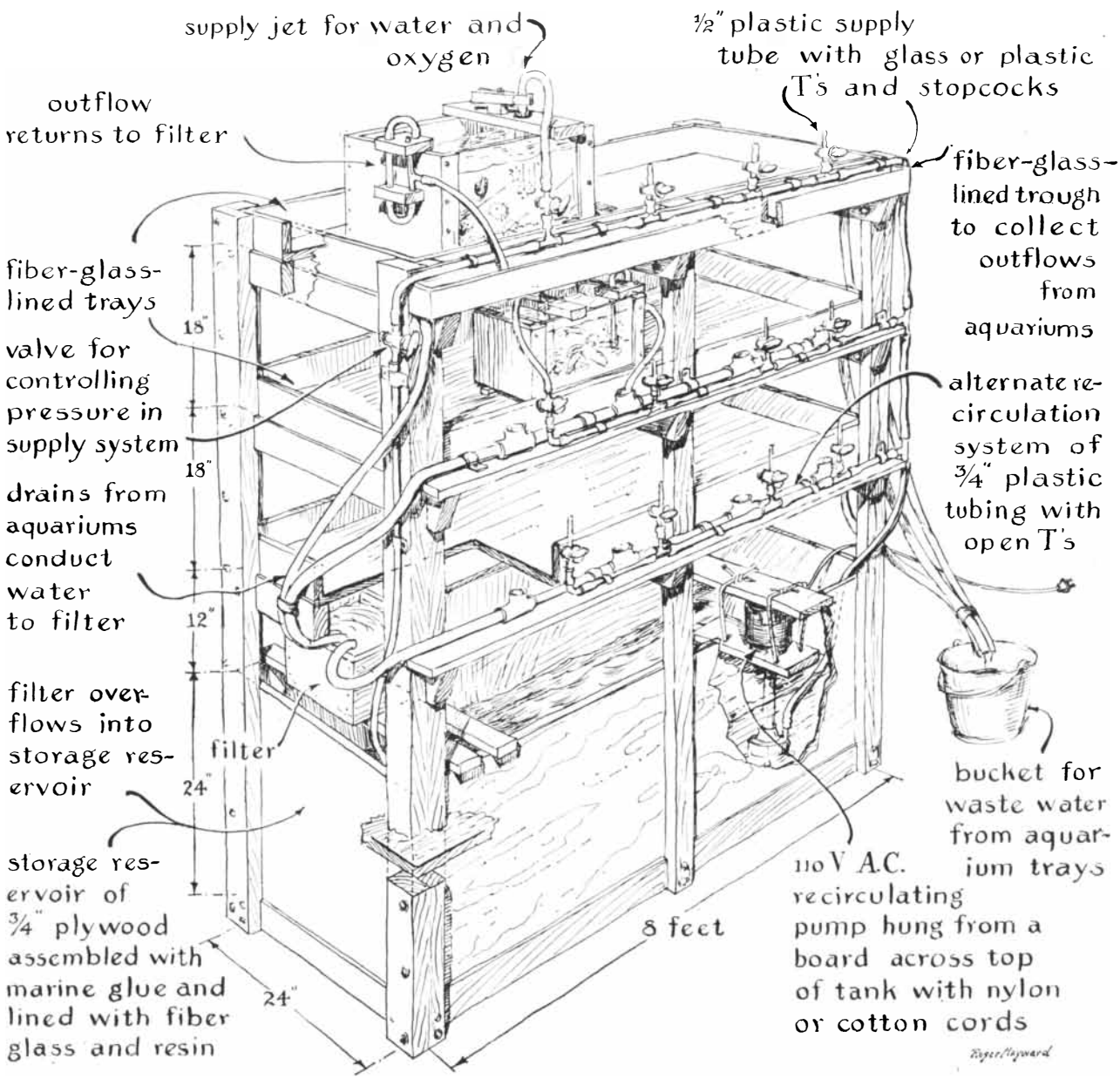
AEROSPACE CORPORATION

wooden bottoms on small 1/2-inch sticks to provide air circulation. Wood should be kept either all wet or all dry. It goes to pieces if it is allowed to become alternately wet and dry. The plumbing system must also include a device at some point for regulating the water pressure. A standpipe can be used or, as in my system, a valve in the return line. The system should be operated at the lowest pressure consistent with adequate recirculation, which will vary with the number of aquariums in use.

"Supplementary aeration can be supplied as required by discharging water into aquariums through bubbler jets. These can be improvised from the glass part of a medicine dropper and either glass tubing of somewhat larger diameter or close-fitting plastic tubing [*see illustration on page 176*]. In each version air is drawn into the stream by the force of the jet. The dimensions of the bubbler jets are not critical.

"The plumbing should be cleaned periodically to prevent debris or growths of organisms from clogging the siphons or other parts of the system and causing the aquariums to overflow. Float valves that shut off the inflow when water in an aquarium rises above a predetermined level are effective. Equipping the siphon inlet with glass or plastic strainers keeps the siphons from clogging and causing an overflow. In my opinion trays fitted with drains that empty into a plastic catch bucket are adequate to cope with the few emergencies that may arise.

"Aquariums can be of wood and glass fiber construction, but most amateurs will surely prefer to make at least one side of glass so that the specimens can be observed. A sheet of 1/4-inch plate glass can be sealed into a wooden tank successfully by the use of either vinyl tubing or vacuum tape [*see illustration on page 178*]. The seams could also be calked with a remarkable new compound called Silastic RTV 731, a product of the Dow Corning Corporation. Although I have had no experience with this preparation, I understand that it comes in collapsible tubes and has the



Marine aquariums with recirculating sea-water system

Firm, Long-Range Program in Nuclear Power Plant Development Expands Need at Allison for More Top Level Scientists and Engineers

● Atomic Energy Commission selection of Allison as prime contractor for development of a Military Compact Reactor (MCR) creates challenging, new opportunities for Engineers and Scientists in a substantial, long-time program in the nuclear field.

The MCR is a lightweight, completely self-contained nuclear fission power system—easily transportable by truck, aircraft or rail—designed to provide electric power in remote areas. It will have a high temperature, liquid metal cooled reactor coupled to a power conversion system. Incorporating long plant life characteristics compatible with military field equipment, the power plant is expected to reduce the burden which shipment and storage of petroleum imposes on combat forces.

Allison will design and develop the overall power system —(capable of generating 3000 kw)—with other GM divisions taking part in specific phases of the program.

Our need is urgent for additional, high calibre engineering and scientific personnel. Advanced degrees and minimum of 3 years experience in following areas desirable:

NUCLEAR POWER SYSTEMS ANALYSTS—(Powerplant Dynamics)—Nuclear or Electrical Engineers with broad background in areas of steady state powerplant performance and transient or dynamic analysis.

(Thermal Hydraulic)—Mechanical Engineers with background in liquid metal heat transfer, fluid dynamics and gas turbine thermodynamics.

(Hazards)—Nuclear Engineers with background in definition, analysis and evaluation of nuclear powerplant safety and hazards.

(Mechanical)—Mechanical or Chemical Engineers with background in nuclear powerplant layout, nuclear powerplant mechanical integrity and high temperature component design.

(Electric Power)—Electrical Engineers (Power Systems) with background in steady state system performance and power system stability.

REACTOR PHYSICISTS—(Analytical)—Physicists with substantial experience in reactor physics field to analyze nuclear behavior of projected reactors; generate new concepts in design or control of nuclear reactors.

(Experimental)—Physicists, preferably nuclear, with experience in experimental nuclear physics, to analyze and evaluate experiments on compact reactor core configurations.

(Shielding)—Physicists with capabilities in nuclear reactor shielding, including experience in experimental shielding investigations and associated minimum weight shield configurations.

NUCLEAR REACTOR DESIGNERS—Mechanical Engineers with nuclear experience or training. Extensive experience in layout and detail design of structures and mechanisms operating under conditions of high temperature, thermal stress, irradiation and corrosion, and with close dimensional tolerances.

HEAT TRANSFER SPECIALISTS—Experience with liquid metal heat transfer preferred. To plan, analyze and conduct research programs involving liquid metal boiling and condensing heat transfer, convective heat transfer, and radiant heat transfer.

ELECTRICAL ENGINEERS—(Power Systems)—Power system engineers for study of MCR applications. Experience in design of central station or standby powerplants, with knowledge of load analysis, synchronous machines, switchgear control and specifications.

(Instrumentation Systems)—Nuclear or Electrical Engineers with instrumentation or control experience for design of MCR console, instrumentation, and data transmission link.

(Design)—Electrical Engineers to design controls and switch gear. Also, EE's to conduct studies on electrical power systems, including load analysis and stability requirements.

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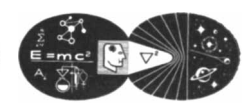
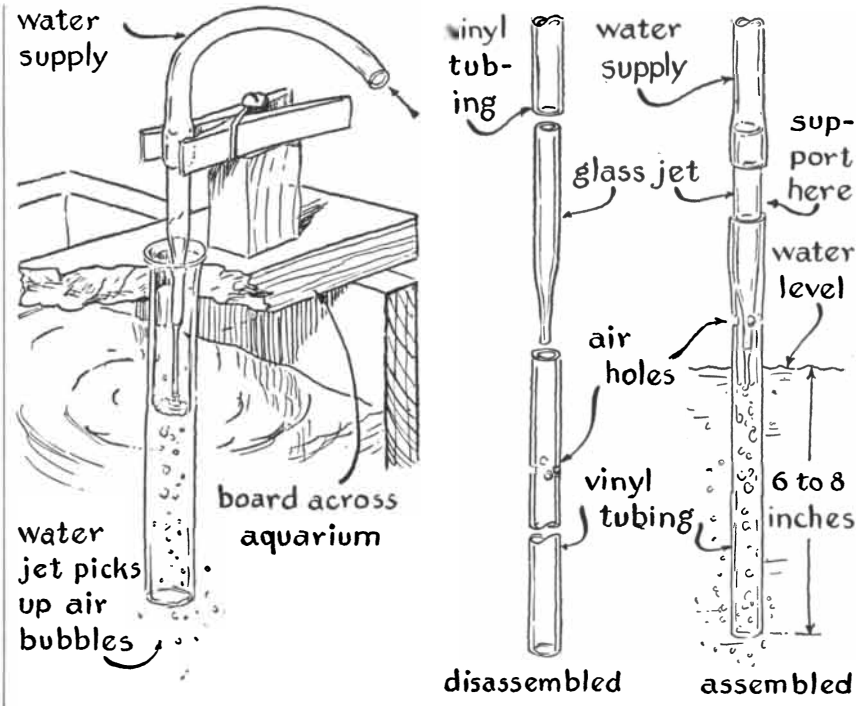
Energy Conversion  *Is Our Business*

ALLISON DIVISION, GENERAL MOTORS CORPORATION



Bubble-jets for aerating marine aquariums

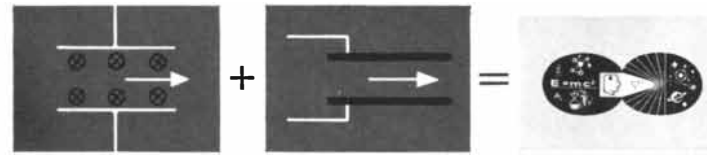
consistency of tooth paste. When it is exposed to humid air, the material sets in the form of a tough, inert rubber that adheres to clean glass so firmly that it will tear before separating from the glass. It should be possible to assemble an effective all-glass aquarium with this preparation, particularly if the glass structure is supported in part by an external framework. Within recent years seamless aquariums made of acrylic plastics have been marketed, some perforated for inlet and outlet tubing. Prices appear to average about $2 a gallon in the 10-gallon to 40-gallon sizes.

"In operating the system under suboptimal conditions—at about 75 degrees F. without supplementary aeration or special nutritional supplements for individual species—we found that about two-thirds of the specimens readily available in the coastal waters of California could be kept from two weeks to two months. About a third lived indefinitely. Tide-pool fishes such as the blenny, kelp greenling and the opaleye are particularly easy to maintain. Other interesting specimens from these waters include the topsmelt, sargo, mudskipper and killifish. Large sea horses of the kind that abound in the Gulf of Mexico and along the coast of Florida have also done well in small aquariums and will mate occasionally if they are kept apart from other specimens. Incidentally, young sea horses develop in a pouch on the tail of the male and occasionally, with luck, a shipment may include a 'pregnant' male. The 'herd' that ultimately emerges from the pouch may number as many as 400 baby sea horses! Other Florida vertebrates that do well in small marine aquariums include the clownfish, cowfish, batfish, boxfish and the fearsome toadfish. Still other species, including some of nature's most beautifully colored animals, will survive for long periods with proper care, including the queen angelfish, the rock beauty, the neon goby and the spectacular (but poisonous) lionfish.

"The great diversity of invertebrate animals that thrive in small aquariums opens the hobby to amateur biologists whose interests go beyond fishes. Without an aquarium it is not easy to observe the mussel *Mytilus* in the act of spinning byssus threads for anchoring, to catch a starfish dining on a mussel, to watch the hermit crab's erratic search for a larger shell in which to take up residence or to feed an anemone by dropping bits of shrimp on its tentacles. West Coast invertebrates that do well in small aquariums include the mussel, starfish, sea anemone and crab. Of these the easiest to keep are the California and horse mussels; the hermit and hairy hermit crabs; the Southern California starfish, sand star, sea bat and common purple starfish.

"I have not tried any of the Gulf and Florida organisms, but collectors report that the spider crab, the 'daddy longlegs of the sea,' survives well on ordinary care. Other semitropical invertebrates recommended by Florida collectors in-

Physics Research at ALLISON



● These familiar symbols, representing broad areas of investigation at Allison, add up to our guiding theme, "Energy Conversion Is Our Business."

Long-range objective of Allison scientific investigation is the creation and development of practical energy conversion devices for such applications as direct nuclear conversion systems . . . plasma acceleration for space flight propulsion . . . energy depots and other forms of energy conversion systems.

An immediate objective centers on the Military Compact Reactor (MCR). Allison has been selected by the Atomic Energy Commission to design and develop MCR—a highly mobile, completely self-contained nuclear fission power system—to provide electric power in remote areas.

To implement these expanding and long-range programs, we need additional scientists and engineers—both theoretical and experimental:

NUCLEAR PHYSICISTS—(Shielding)—Ph.D. or M.S. or equivalent, with capabilities in nuclear reactor shielding field, including experience in experimental shielding investigations and associated minimum weight shield configurations.

(Reactor)—Ph.D. or M.S. or equivalent with substantial experience in reactor physics field to analyze nuclear behavior of projected reactors; generate new concepts in design or control of nuclear reactors.

(Experimental)—Ph.D. preferably in nuclear physics, or equivalent with experience in experimental nuclear physics, to plan, conduct and analyze critical experiments on compact reactor core configurations.

SOLID STATE PHYSICISTS—(Section Chief)—Ph.D., 5-10 yrs. experience in experimental solid state physics to direct group of scientists in experimental research on materials of interest in direct energy conversion.

(Senior Research)—Ph.D. in theoretical physics. Energy conversion experience desirable. Will carry out theoretical work on the thermodynamics and physics of energy conversion devices. Considerable use will be made of computing systems (analog and digital). Radiant energy conversion, thermionic, liquid metal systems will be analyzed initially.

(Research)—Ph.D. Must be capable of carrying out independent research in property evaluation of semiconductors and metals. Some attention also to liquid state physics. Radiant energy conversion devices emphasized in early work.

MATHEMATICAL PHYSICISTS—Ph.D. or M.S. in mathematics, or equivalent. Prefer experience in reactor analysis and programming for digital and analog computer. Must be capable of carrying out all computer operations (digital or analog) required by nuclear engineering.

M.S. in mathematics with courses in nuclear physics. Requires strong analytical training in field of mathematics with experience in nuclear reactor field.

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clude banded coral shrimp, colorful but predatory sea anemones, corals, flame scallops and the amusing mantis crab.

"The cost of specimens and sea water depends on the distance to the aquarium from the coast. Sea water is normally transported in sealed polyethylene bags. Glass containers are better but less convenient. Water near the beach usually contains too much suspended matter for satisfactory use; the water shipped by most collectors is taken from the open sea, which requires the use of a boat and increases the cost.

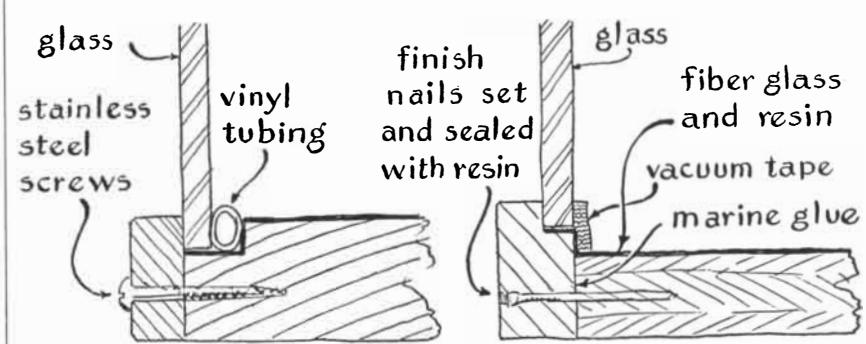
"The collection of specimens is an art in itself. Professional collectors make use of all the techniques and gear familiar to skin divers as well as the services of commercial fishermen. Small organisms are usually shipped in polyethylene bags that contain about two gallons of sea water along with an equal volume of pure oxygen injected just before the bags are sealed and crated. Minimum transportation charges for air express shipments average about $20.

"The price of sea water varies with individual collectors and is determined by the cost of collecting and packaging. Specimens are priced from $2, with rare species commanding as much as $100 each. Prices, which tend to vary with the season, are quoted on request by commercial suppliers such as Aron Enterprises, Haywood, Calif.; The Gulf Specimen Company, Carrabelle, Florida; The Aquarium Stock Company, Inc., 31 Warren Street, New York 7, N.Y.; and the General Biological Supply House, 8200 South Hoyne Avenue, Chicago, Ill.

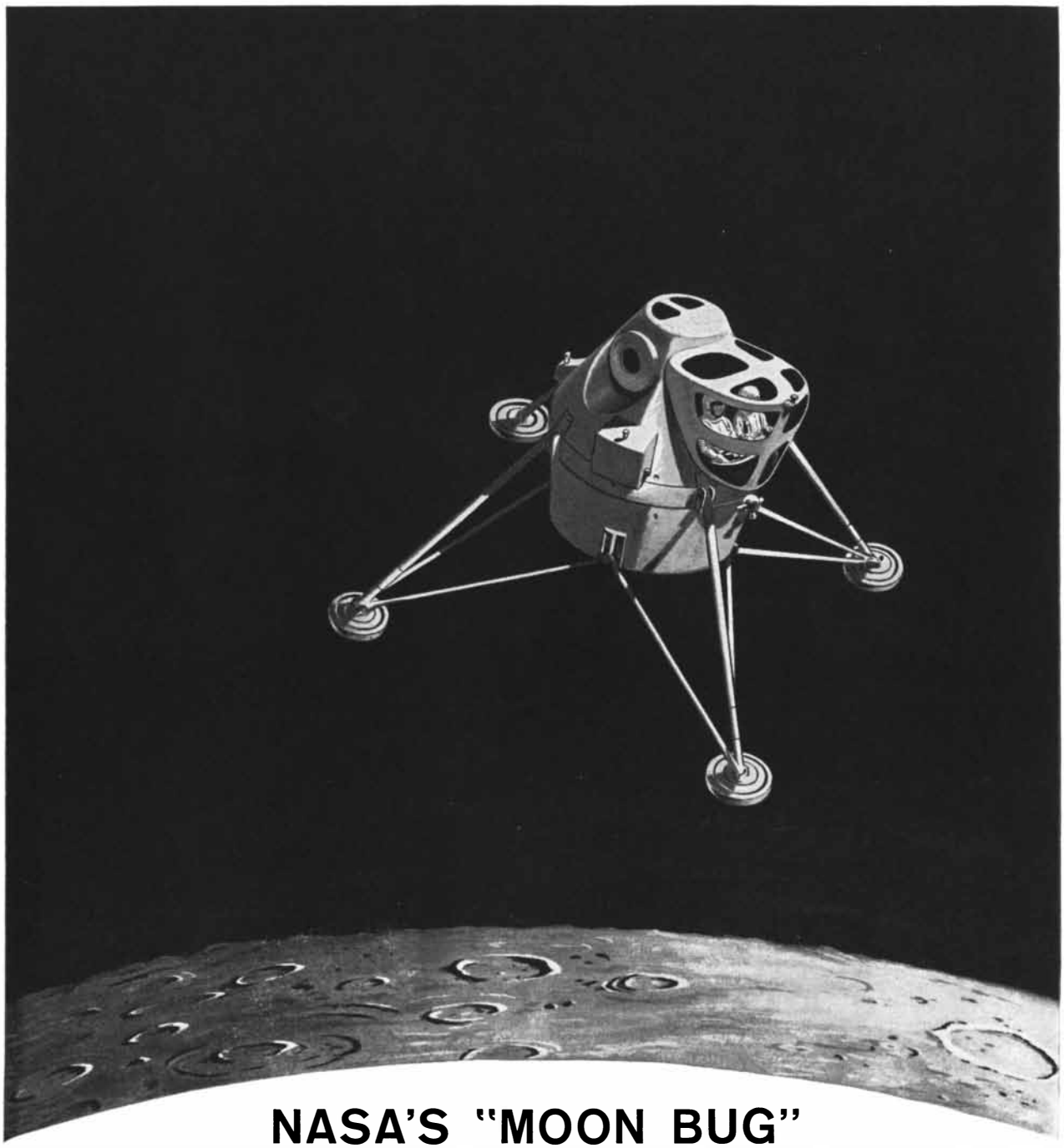
"Extreme care must be taken to equalize the temperature and salinity of the water when one is transferring specimens from shipping containers to the aquariums. If the differences are great, the specimens may not survive the shock of transfer. The temperature can be adjusted by immersing the shipping bag in the aquarium for several hours. The specific gravity of the water inside and outside the shipping bag is then measured. If a difference in specific gravity of more than two parts per thousand is observed, transfer about two ounces of shipping water to the aquarium and two ounces of aquarium water to the shipping container once every 15 minutes until the difference in specific gravity is reduced to two parts per thousand. Use a glass or plastic dipper.

"Nutritional requirements vary with the nature of the specimen and its age. In general it can be said that the venerable cliché still holds: 'The best food for fish is fish.' Hardy species such as clownfish do well on dry food, chopped shrimp, brine shrimp and bits of worm. The more exotic types, such as lionfish, require small live minnows, fed one or two at a time and supplemented with bits of earthworm and fresh shrimp. Starfish need live clams. Sea urchins and other invertebrates prefer finely chopped shrimp, green algae, fish roe and decayed plant matter.

"In theory the cultivation of the sea in miniature should pose no more technical difficulty than the operation of a farm. But the agricultural revolution that generated solutions for so many of the farmer's problems stopped at the beach; the marine aquariist finds himself some 8,000 years behind the tiller of the soil, his problems not only unsolved but in substantial measure awaiting identification. It should be possible to condition sea water for the optimum growth of specific organisms, much as the farmer encourages good crops by proper fertilization or as the specialist in hydroponics compounds ideal mediums for cultivating lettuce and tomatoes. Sea water, however, evidently contains one or more elusive substances essential for the long-term support of its population that have so far escaped detection. Numerous attempts have been made to duplicate sea water by dissolving various combinations of salts in distilled water, but no effective long-term substitute has been developed. The task of finding one poses a real challenge."



Details of watertight seals between glass and wood



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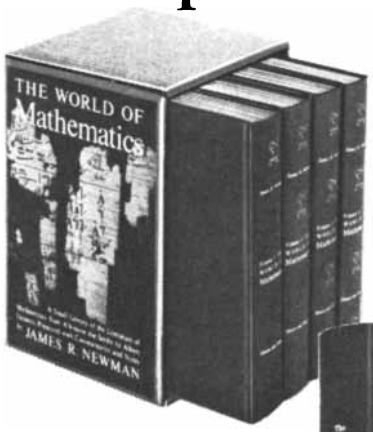

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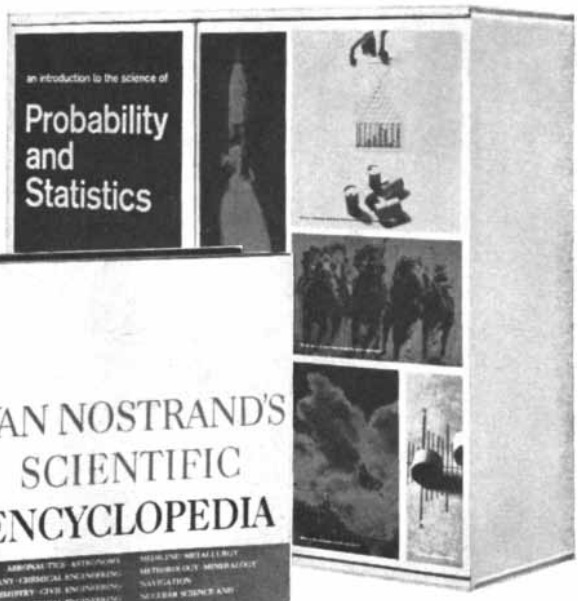

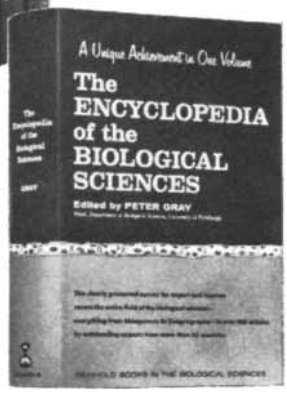

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BOOKS

The fruitful career of Enrico Fermi, as revealed by his collected papers

by Enrico Persico

ENRICO FERMI: COLLECTED PAPERS (NOTE E MEMORIE). VOLUME I: ITALY, 1921–1938. Edited by Edoardo Amaldi, Enrico Persico, Franco Rasetti and Emilio Segrè. Accademia Nazionale dei Lincei and the University of Chicago Press ($15).

The neutron has had a peculiar history. Almost half of the weight of our bodies, and of anything else, is represented by the neutrons in the nuclei of the atoms that constitute matter. Yet no one even suspected the existence of neutrons (apart from a few virtually fantastic speculations) until 1931 and 1932, when Walther Bothe extracted them from matter and James Chadwick identified them. This discovery at first appeared to have only academic interest, and it was scarcely remarked outside the scientific world. Only 13 years later its consequences put a dramatic end to World War II, upset the rules of military strategy and the course of world politics and confronted mankind with unprecedented problems. At the same time it was apparent that neutrons had opened to man an abundant new source of energy for peaceful purposes.

The man who put neutrons to work, for good and ill, was Enrico Fermi. When neutrons appeared on the horizon of science, Fermi was a young professor of theoretical physics at the University of Rome. He had already published several first-class papers, and he was particularly known among the physicists of the world for having developed what were called the Fermi statistics. This is a statistical method for dealing with any multitude of electrons, for instance the free electrons in a metal, or even the bound electrons in an atom with a reasonable number of them. Later not only electrons but also the other particles that obey the laws of the Fermi statistics came to be called fermions.

Fermi's first use of neutrons was theoretical. In 1933 he undertook to explain the radioactivity of all beta-ray-emitting substances as being due to the radioactivity of the neutrons in their nuclei; he assumed that a neutron can spontaneously emit an electron and a neutrino and become a proton. Although this theory was presented by Fermi as a tentative one, it is still considered substantially correct.

Next came the discovery that when almost any element is bombarded with neutrons, it becomes artificially radioactive. This was practically the first experimental work done by Fermi, who until then had been mainly a theoretician. When he learned in 1934 that Irène Curie and Frédéric Joliot had made light elements artificially radioactive by exposing them to alpha rays, he immediately saw, on theoretical grounds, that a much more efficient method would be to expose the elements to neutrons. He also perceived that this method would work with the heavy elements, on which alpha rays have no effect. He tried the experiment, and his theoretical previsions were confirmed. Thus began a historic series of experiments in which Fermi and a small group of younger collaborators explored, in a few months of feverish work, almost all the vast realm of artificial radioactivity produced in the various elements by neutrons.

During this period an odd new phenomenon came to light: the effect of neutrons on some of the elements was greatly enhanced if a piece of paraffin happened to be in the vicinity. Here Fermi's theoretical insight showed up in a most spectacular way. In a few hours, to the astonishment of his collaborators, he interpreted the strange effect of paraffin as being due to the combination of two quite unexpected phenomena: first, that the hydrogen atoms in the paraffin had the property of slowing down neutrons, and second, that slow neutrons were more effective than fast ones in producing radioactivity in certain elements. As is well known, this discovery led to the practical utilization of neutrons in nuclear reactors.

Uranium has the highest atomic number (92) of all the natural elements, and for this reason Fermi and his collaborators deemed it particularly interesting to investigate its behavior under bombardment by neutrons. The behavior of the element was very peculiar indeed—much more peculiar than it was possible for any physicist to predict at the time! Some of the nuclei of the uranium atoms split in an unprecedented fashion, giving rise to elements with atomic numbers much lower than 92 and liberating far more energy than any other nuclear reaction. Moreover, the splitting nuclei liberated more neutrons than were needed to produce the reaction. The correct interpretation of these phenomena escaped Fermi's group, as it did other groups that attacked the problem in other countries. Nuclear fission was discovered only four years later by Otto Hahn and Fritz Strassman, who used Fermi's technique for slowing neutrons.

In 1938 Fermi was awarded the Nobel prize for his work on neutrons, and at the end of the same year he emigrated to the U.S. He was pressed to take this step by Mussolini's sudden decision to start an anti-Semitic persecution, which would have affected Fermi's wife and probably his two children.

Almost coincidentally with Fermi's arrival in the U.S. the discovery of fission became known. Fermi quickly understood that this phenomenon would make it possible to enlarge the scale of nuclear reactions by a tremendous factor. The subsequent story of the construction of the first nuclear reactor (at that time called a pile) and of the realization of the atomic bomb is too well known to bear repetition. In this enterprise Fermi showed, in addition to his gifts as a theoretical and experimental physicist, impressive practical talents. In fact, he can rightly be considered the first nuclear engineer.

In the last four years of his life Fermi quit the subject of neutrons and their applications, to which he had dedicated 18 years of tremendously fruitful work, and tackled researches on the newly discovered elementary particles, for which the high-energy particle accelerators

opened promising perspectives. He had already obtained remarkable results in this field when in 1954, at the age of 53, a malignant disease prematurely ended this memorable life.

All of this fascinating story can be traced, through original documents, in Fermi's *Collected Papers* (*Note e Memorie*), the first volume of which has now been jointly published by the Accademia Nazionale dei Lincei and the University of Chicago Press. The first volume contains all the papers published by Fermi before his emigration to the U.S. The second volume, which collects the remainder of the papers, is in press.

All the papers are presented in the language in which they were written; a few exceptionally important ones that were not written in English are accompanied by an English translation. Of the 134 papers in the first volume 93 are in Italian, 30 in English and 11 in German. (Fermi had had a fair command of German since he had been a schoolboy; he had also learned English early.)

The first volume was edited by a committee consisting of Edoardo Amaldi, Franco Rasetti, Emilio Segrè and the author of this review. Segrè was the chief editor. All the editors are physicists and were close friends and collaborators of Fermi's from the beginning of his scientific activity, one of them (the reviewer) from the time Fermi was 14 and they attended the same *ginnasio* in Rome. The long acquaintance of the editors and the author has given the book some unusual features, which may be of interest to the history of science. Almost every paper is preceded by an introduction written by someone (usually one of the editors) in a position to recollect or reconstruct the circumstances in which the paper had been written. In addition, many of the introductions give a short account of the relation of the paper to other papers and of the influence the paper had on the subsequent development of physics. Most of the introductions are in English.

The volume opens with a biographical introduction by Segrè; this introduction is in English in the copies of the book sold in the U.S. and England and in Italian in those sold in continental Europe. Twenty-six pages long, it relates the most important events of Fermi's life, but it is much more than a biography. It emphasizes, rather than the exterior events of Fermi's life, his intellectual development from early youth, his method of teaching and the slow evolution of his habits and techniques of work.

It is not known how old Fermi was when his interest in physics was awakened. When the writer met him at the age of 14, this interest was already strong, even if the boy had not yet decided what his future profession would be. It must be borne in mind that at that time physics as a career was almost unknown in Italy. Physics was taught on an elementary level only in the last two years of *liceo,* at the ages of 16 and 17. A normal boy of 14 might well have been unaware that a science called physics existed, all the more because at that time boys were not exposed, as they are now, to a steady bombardment of science fiction and popularized science. Even a gifted boy with strong scientific tendencies was likely to be handicapped by not knowing in what kind of book to look for the explanation of the phenomena that had attracted his attention and raised questions in his mind.

Fermi was helped to start on the path of science by a friend and colleague of his father's, Adolfo Amidei, an engineer with scientific interests. At the age of 13 Enrico often discussed with Mr. Amidei the doubts and problems that concerned him; for example, how could one explain the strange behavior of a top? Mr. Amidei was wise enough not to reply, as many people do to children's questions: "These are difficult things; you will learn them in due course." Instead Mr. Amidei, recognizing Enrico's exceptional talent, showed him how to solve his problems. He told him that the behavior of a top, as well as of many other things, is explained by a science called rational mechanics, but that this science cannot be studied without one's having first studied trigonometry, algebra, analytic geometry and infinitesimal calculus. The boy accepted the advice to take this long route, and from his 13th to 17th years Mr. Amidei lent him the necessary books in order. They were not popular or elementary books but university texts of high standard. Nevertheless, Fermi mastered them without any difficulty, not in a scholastic way but deeply and efficiently. For him, even at that age, to know a theorem or a law meant being able to use it.

This Mr. Amidei was a very orderly and meticulous gentleman. He kept a record of all the conversations he had with the young Fermi and of all the books he lent him. Thus when, some 40 years later, he was asked by Segrè to contribute to the biographical sketch of Fermi, he was in a position to provide detailed and precious information.

In advanced studies as well as elementary Fermi was essentially self-taught. This was partly because he was far ahead of the curriculum of the ordi-

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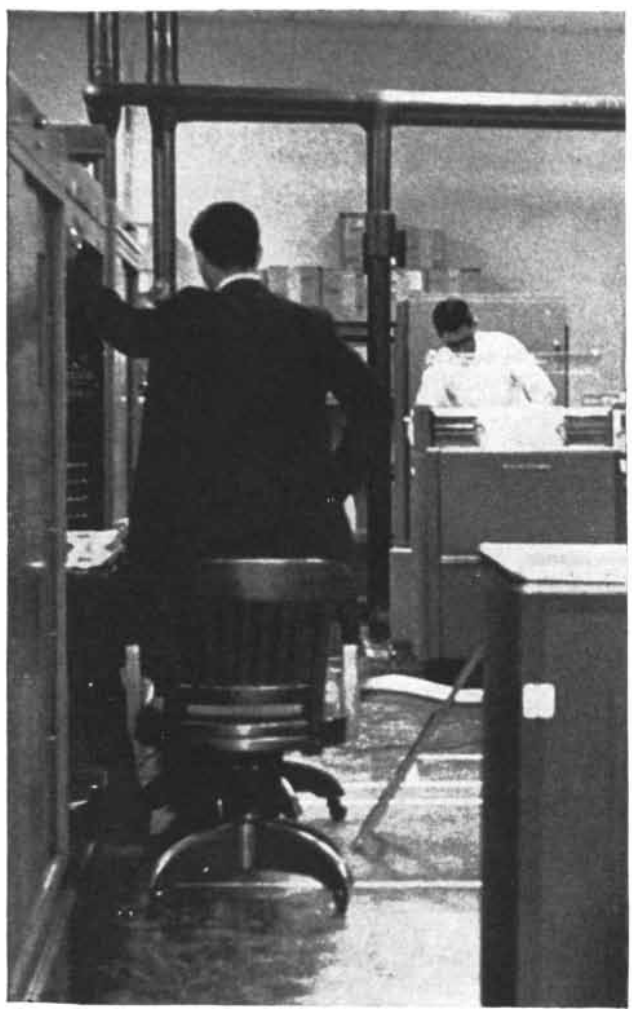

nary student and partly because the subjects in which he was most interested (basically the theory of the structure of matter) were at that time virtually ignored by Italian physicists and scarcely mentioned in university courses.

Although Fermi received little from his teachers, he was throughout his life a generous and wonderful teacher. In addition to teaching regular courses, he liked to give to the young physicists of his group informal talks on any subject that happened to be of interest at the moment. He could improvise a perfectly clear and orderly lecture on any classical topic in physics suggested by his friends. Sometimes he mixed his research work with his teaching in a very personal way. Here is how Segrè describes this method:

"At that time we repeatedly had occasion to witness the execution of a new and original piece of work. Naturally it is impossible to say how much preliminary work Fermi had done consciously or unconsciously. Certainly there were no written notes. What one saw was the development of a calculation at a moderate speed but with exceedingly few errors, false starts or changes of direction. The work proceeded almost as in a lecture, although more slowly, and at the end the manuscript, or at least the equations, were ready to be copied for publication with little need of improvements. A curious characteristic of Fermi's working habit was the steady pace at which he proceeded. If there were easy passages, he still proceeded quite slowly, and a simple-minded observer might have asked why he wasted so much time on such simple algebra; however, when difficulties arose that would have stopped a man of lesser ability for who knows how long, Fermi solved them without a change of speed. One had the impression that Fermi was a steam roller that moved slowly but knew no obstacles. The final result was always clear and often one was tempted to ask why it had not been found long ago since everything was so simple and natural."

This admirable didactic ability is evident in all Fermi's papers. The reader is often deluded by the apparent simplicity of Fermi's reasoning, and only when he quits his guide and tries to proceed by himself does he realize that he has been cleverly led by the hand through a dense, dark forest.

Fermi was black-haired, gray-eyed and not very tall; his small, regular facial features contrasted with the strong, solid appearance of his body. He liked physical exercise—tennis, skiing, hikes in the mountains—but none of these diversions ever bulked very large in his life. He was a calm, methodical man; he was never in a hurry, yet everything he had to do was done with the utmost efficiency. He spoke in a peculiar way of his own: slowly and in a deep voice. His manner of speech appears to have been contagious: many of the young physicists in his group, after a few months of contact with him, consciously or unconsciously spoke in the same way.

From his adolescence onward Fermi had a quite definite positivistic view of the world, although it is doubtful that he would have accepted this or any other conventional label for his philosophy. He had not been raised in a religious environment, and so did not have to pass through a religious crisis, as many Italians do when they reach the age of autonomous thinking. As a matter of fact, philosophical discussions did not interest him very much, and even the development of scientific philosophy that occurred during the years of his maturity, through the activity of the Vienna Circle and other groups, seems to have left him rather indifferent. This was perhaps because many of the fundamental ideas of logical positivism were already deeply rooted in his mind as self-evident truths, and because philosophical subtleties and polemics did not appeal to his taste.

Fermi had definite predilections and aversions in the style of scientific work. From his college days onward he strongly disliked the kind of physics in which elegant and elaborate mathematical methods are employed for the solution of problems of little scientific or practical interest, or in which long and accurate calculations are conducted on a problem that does not warrant such a high degree of accuracy. He considered mathematics to be a tool for describing and understanding natural phenomena, and he was exceptionally clever in applying it, but he was irritated by those who use trivial physical problems as a pretext for displaying mathematical ability. He had a flair for devising mathematical methods with the degree of approximation that exactly fitted the problem at hand, but he usually refused to justify these methods by a rigorous mathematical procedure. If someone else succeeded in solving the same problem with all the rigor and exactness of an impeccable mathematical calculation, Fermi's results almost always turned out to be correct to their degree of approximation. An instance of this is afforded by Fermi's paper No. 23, in which the excitation or ionization of an atom caused by collision with a charged particle is reduced, by means of an ingenious application of

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Fourier's integral, to a process of absorption of radiation. The calculation is carried out with a daring and largely approximate method, which was later rigorously justified by other workers and widely employed in other problems.

Another dislike of Fermi's, not so strongly expressed but apparent throughout his scientific work, was for theories that were too abstract or too formalistic. For example, he wrote to the reviewer on September 23, 1925: "My feeling is that the progress in the past few months has not been very great, notwithstanding the formal results in zoology of spectral terms obtained by Heisenberg. To my taste, I think they are really beginning to exaggerate in the trend of renouncing to understand things." The "zoology of spectral terms" must refer to a paper by Werner Heisenberg in *Zeitschrift für Physik* (Volume 32, page 841; 1925), which was admittedly formalistic and unsatisfactory but which a few months later evolved into matrix quantum mechanics. Matrix quantum mechanics, however, seems to have been uncongenial to Fermi's mind. Fermi's early contributions to quantum mechanics were stimulated not by Heisenberg's approach but by Erwin Schrödinger's first papers on wave mechanics, and these contributions clarified the relations between wave mechanics and the older corpuscular mechanics. Typical of Fermi's style is the elementary but elegant paper on the principle of causality (No. 59). Heisenberg's assertion in 1927 of the principle of indeterminacy gave rise in Italy to many discussions among mathematicians and philosophers, some of whom, on the basis of a rather foggy knowledge of the question, refused to renounce a strictly deterministic interpretation of nature. Many of these discussions were based on misunderstandings of words such as "determinism," "causality" and "uncertainty." Fermi's paper, which stemmed from one of these discussions, puts the question in a clear and definite form, discussing the following problem: Is it possible to make a measurement on a system at time $t = 0$, such as to predict exactly the result of another measurement to be made at a future time t_0? The answer is yes, in quantum mechanics as in classical mechanics. The difference is that in quantum mechanics the experiment to be made at time $t = 0$ must be chosen in a way that depends on the type of measurement that will be made at time $t = t_0$, and on the value of t_0 (and is generally incompatible with other measurements). In classical mechanics, on the other hand, one and the same experiment per-

mits predictions for any future measurement. This gives a concrete answer to many questions on the amount of determinism that survives in quantum mechanics.

This preference of Fermi's for concrete methods was not without exceptions (an example is the celebrated paper No. 80, on the theory of beta-particle emission), and it became somewhat attenuated later in his life. The reviewer nonetheless remembers that Fermi, during a visit to Italy a few months before his death, expressed in private conversation his advice to young theoretical physicists not to indulge in theories too abstract and too formalistic. On the same occasion he manifested his enthusiastic interest for the electronic computers recently developed and not yet widely employed. He exhorted physicists to learn to use the computers by themselves, without the intercession of mathematicians, and he took pleasure in teaching Amaldi and the reviewer the principles of programing calculations for the MANIAC computer that he had used at Los Alamos.

In experimental work Fermi also had a very personal style. His experimental ability did not consist in being able to build complicated devices or to perform measurements of high precision. It lay rather in the capacity to find out at the right moment which was the most important experiment to do, to project it in the simplest and most efficient way and to carry it out with energy and patience without wasting time and labor on nonessentials. His experimental work was always intimately connected with his theoretical work, and he carried both of them through methodically and calmly, with great perseverance and an exceptional resistance to mental and physical fatigue.

Fermi's scientific and human personality comes through vividly in this collection of his papers. Notwithstanding the rapid evolution of physics in the past few decades, advanced students will still find it useful and stimulating to resort to Fermi's original papers in order to read in brilliant yet simple exposition some of the greatest achievements of modern physics.

Short Reviews

ORIGINAL CHILD BOMB, by Thomas Merton. New Directions ($1.95). "Original Child" is one of the names the Japanese gave the bomb dropped on Hiroshima. Born in 1945, the offspring of great minds, it was the first of its kind. In this satiric threnody, subtitled "points

for meditation to be scratched on the walls of a cave" (for any survivors of a nuclear war), Father Merton recites in 41 short paragraphs the events that led to the decision to drop the bomb on a live target, describes the profound thinking, informed throughout by exquisite considerations of morality and humanity, of the men at the top (with the exception of Admiral Leahy, who was sure the bomb would never work) who advised President Truman that one or two good knocks of this kind would not only force Japan out of the war but also assure eternal peace. Living as we do in a time that has accustomed us to lunacy piled on lunacy, it is of more than clinical interest to look back on the beginnings, to be reminded of the day we got sick. Somehow the attendant circumstances, mindless and coy, are even more revealing than the main plot. When a target was to be selected and Kyoto was suggested, Secretary Stimson, who "had recently read up on the history and beauties" of that city, insisted it should be left untouched. Hiroshima was picked because it had never been bombed and therefore deserved at least a quick taste of the war. The code name of the Alamogordo test was "Trinity"; when the news that it had succeeded reached Potsdam, Stimson hurried to lay before Winston Churchill a sheet of paper bearing the code message "Babies satisfactorily born." The commander of the B-29 that was to drop the bomb baptized it *Enola Gay*, after his mother in Iowa. The plane's secret radio call was changed for the occasion from "Visitor" to "Dimples"; the code name for Tinian, from which the *Enola Gay* took off, was "Papacy." After the original child was born President Truman summed up the philosophy of the situation in a few words: "We found the bomb," he said, "and we used it." For those who can read and are capable of feeling, Father Merton's stark little masterpiece will be unforgettable.

THE JOURNALS OF CAPTAIN JAMES COOK. VOLUME I: THE VOYAGE OF THE "ENDEAVOUR," 1768–1771 ($15); VOLUME II: THE VOYAGE OF THE "RESOLUTION" AND "ADVENTURE," 1772–1775 ($19.50). Edited by J. C. Beaglehole. Cambridge University Press. James Cook, who at age 12 left the village haberdasher to whom he was apprenticed and boarded the coastal vessel *Freelove* as an apprentice seaman, became the greatest maritime explorer the world has known. It may be that this praise will be deemed so extravagant as to be meaningless, but there are few

who would not be tempted to confer it after reading these superlatively edited, beautifully produced jumbo volumes that present Cook's journals of two of his famous voyages of discovery: that of the *Endeavour* (1768–1771) and that of the *Resolution* and its consort ship, the *Adventure* (1772–1775). Cook led the *Endeavour* expedition, accompanied by Joseph Banks and other scientific men, to Tahiti for the purpose of making observations, at the behest of the Royal Society, of the transit of Venus across the face of the sun. This accomplished, he turned his bark south in search of what his secret Admiralty orders described as a "Continent or Land of great extent," long imagined to exist in the vast expanse of the southern Pacific. He circumnavigated and charted the islands of New Zealand (unexplored since its discovery by Abel Janszoon Tasman in 1642); he sailed to New Holland (Australia), pushed up along its eastern shore, was caught and almost destroyed by the Great Barrier Reef, charted the coast of New South Wales and then beat his way back to England, where he arrived a little over three years after he had left. It was a masterly voyage and, although Cook was not a man lavish of emotion, the geographical names he conferred in the struggle to escape the Great Barrier Reef—Cape Tribulation, Weary Bay, Providential Channel—reflect the struggle, the patience and the gratitude at the escape from doom. The voyage of the *Resolution* and *Adventure* was an even more impressive feat. From start to finish Cook sailed almost 75,000 miles. He crossed the Indian and Pacific oceans in high latitudes, thereby demonstrating that at least north of 60 degrees the supposed southern continent was a figment of imagination; he crossed the Antarctic Circle (never before crossed by a European ship) three times and navigated his miniature craft safely through ice, fog and the stormiest oceans of the world; he penetrated as far south as 71 degrees 10 minutes (no one else, says Beaglehole, has ever got that far by sea); he discovered the islands of New Caledonia, South Georgia and Norfolk; he rediscovered and explored the Marquesas, the New Hebrides and Easter Island. In this prodigious sweep, during which he was absent from England three years and 18 days, he lost but four men—only one by sickness, and that not scurvy. (Carrot marmalade and sauerkraut were among the solvents Cook adopted against this dread disease.) It was, Beaglehole observes, "safer to be with Cook in the Antarctic than it was to live in London."

The deeds proclaim themselves but the journals breathe life into them and show us the kind of man Cook was: a brilliant navigator and explorer; a practical scientist and a leader; of granite determination, yet not foolhardy; responsive to every circumstance and exigency; firm, yet kindly and understanding in his dealings with his own men; remarkably forbearing and humane—considering the times—in his attitude toward the natives of the many places he visited. (This underscores the irony of his losing his life in Hawaii, on the third voyage, during a scuffle with some natives who had stolen one of the boats of the *Discovery.*) One of Cook's few personal statements, made on the day when he reached his farthest south, is revealing of his general character as an explorer: "I will not say it was impossible anywhere to get in among this Ice, but I will assert that the bare attempting of it would be a very dangerous enterprise and what I believe no man in my situation would have thought of. I whose ambition leads me not only farther than any other man has been before me, but as far as I think it possible for man to go, was not sorry at meeting with this interruption, as it in some measure relieved us from the dangers and hardships, inseparable with the Navigation of the Southern Polar regions. Sence therefore we could not proceed one Inch farther South, no other reason need be assigned for our Tacking and stretching back to the North...." It is a rare good fortune for the ordinary reader as well as historians that so scrupulous and literate a scholar as Beaglehole has edited these volumes (two others are yet to appear). He has had an immensely difficult task working with several different holograph manuscripts and various copies of them, which contain later additions by Cook and others; he has also drawn on a large variety of supplementary material. From Beaglehole's introductions, appendices and innumerable (but never superfluous) footnotes one learns almost as much about the voyages as one does from the journals themselves. A magnificent edition.

BETWEEN PACIFIC TIDES, by Edward F. Ricketts and Jack Calvin; revisions by Joel W. Hedgpeth. Stanford University Press ($8.75). Revised version of the third edition (published in 1952) of a delightful book on natural history. Ricketts, who was killed in 1948 when his car was struck by a train, was a more or less self-taught, nonconformist seashore biologist who ran a small biological supply business on the Pacific

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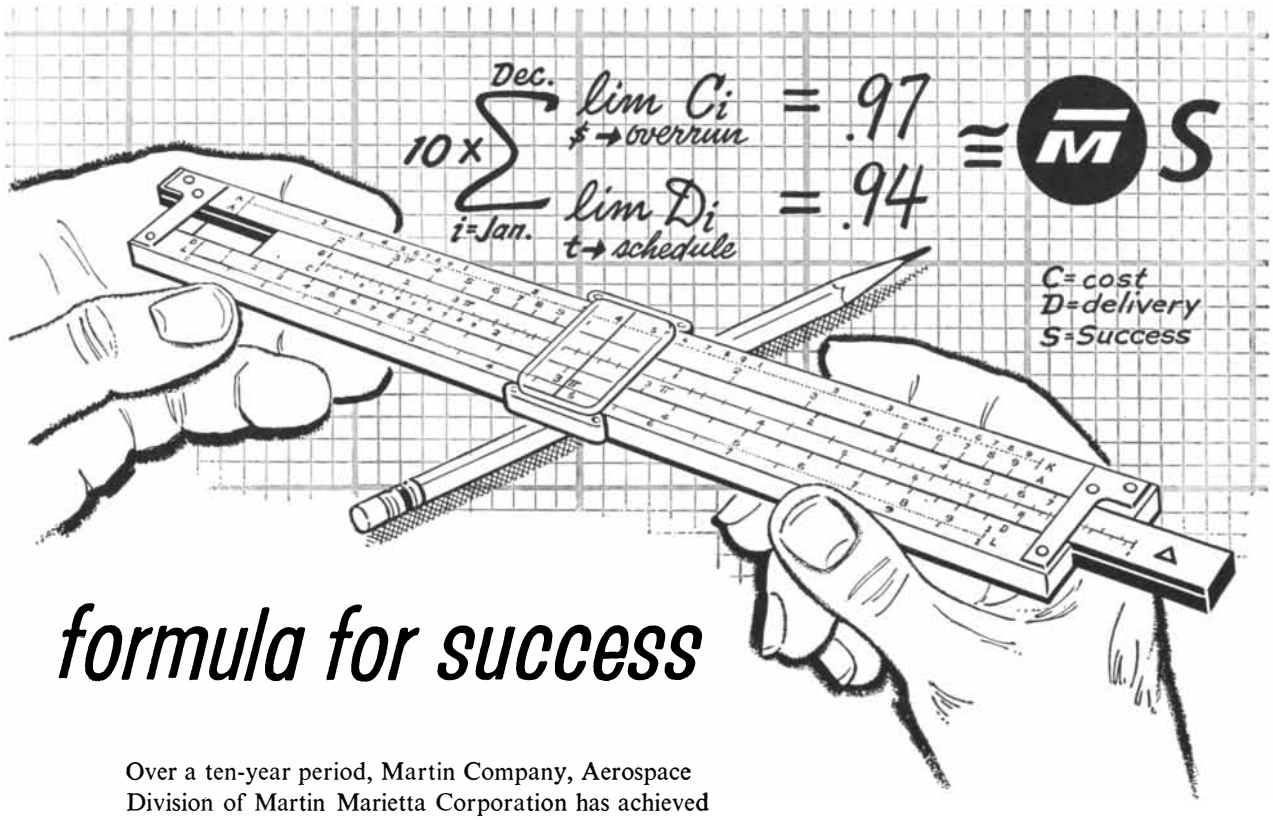
Coast and who was the inspiration for one of the main characters in John Steinbeck's *Cannery Row*. The supply business suited Ricketts perfectly because it left him plenty of time to slosh up and down the tide pools and beaches of the Pacific coast observing the plant and animal life he loved, collecting specimens and selling them to school laboratories. The junior author, Calvin, was the literary collaborator and photographer for the original edition of the book. Both men possessed the wonderful combination of the trained and the innocent eye. At low and high tide, on rocky shores and in caves, on sandy beaches and mud flats, in eelgrass, in tidal pools, on exposed pilings—everywhere along this shore-line marine world—they found and patiently studied the little animals that dwell there or are passing through. Their book is informal but sharp and accurate. It is warmly and unpretentiously written, packed with fascinating information and communicates the enthusiasm of the authors to the reader. In this new revision a chapter on marine ecology replaces the chapter on plankton, the bibliography has been brought up to date and some illustrations have been replaced with new photographs. No better book could be found for the beginning marine biology student or for anyone who enjoys exploring tide pools.

MOALA: CULTURE AND NATURE ON A FIJIAN ISLAND, by Marshall D. Sahlins. The University of Michigan Press ($12.50). Sahlins, one of the ablest of the young anthropologists who follow the evolutionary approach, describes the year he and his wife spent on the small island of Moala in the south central part of the Fiji Islands. Few such reports, of which there is now a flood, offer much to the general reader. They are usually infested with the jargon of anthropology and sociology and often attempt to fit the society being studied to a theory rather than the other way round. Sahlins' book rises above its dismal contemporaries. He writes well, has a sense of humor, sympathy and a becoming modesty and evidently does not regard the people he is studying as beetles to be classified. Not that his book is entirely free of the tiresome terms of the trade; nor is he without certain strong preconceptions. All the same he succeeds in arguing a persuasive brief to the effect that the kinship behavior of the Moalans, from the smallest groups and families to the larger organization of village and island, embodies the economic and political adaptations of the people—their way of adapting so as



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to survive—and therefore constitutes the very tissue of their society. It is obviously a long way—and this is one of the author's main points—from a society whose kinship relations determine every phase of its life to the impersonal societies in which we live. Good illustrations, but by no means enough of them.

PSYCHOLOGIST AT LARGE, by Edwin G. Boring. Basic Books, Inc. ($6.50). In the fall of 1959 the American Psychological Foundation conferred on Edwin G. Boring its Gold Medal as a "psychologist whose lifetime career has made a truly distinguished contribution to the content and status of the science of psychology." This well-conceived, ably written book is vivid proof of the merit of the award. In 80-odd pages Boring presents a thoughtful, engaging and most unassuming autobiographical memoir; this is followed by a sampling of his letters and papers that shows the diversity of his occupations and interests over a 50-year span of professional life. Among the papers are a sharp-witted critique of statistical methodology in psychology, an evaluation of his own psychoanalysis, a brief history of introspection, biographies of leading contemporaries–Edward B. Titchener and Lewis M. Terman—and a study of the psychological and social pressures against women in professions. Boring is an ornament to his science and is held in affection and esteem by his students and colleagues. As a writer, experimentalist, historian, teacher, critic and human being he has achieved, as few others have done, a harmonious union of the two cultures.

TEACHING CHEMISTRY WITH MODELS, by R. T. Sanderson. D. Van Nostrand Co., Inc. ($5.75). The author of this book, who is professor of chemistry at the State University of Iowa, is an ingenious artificer in the construction of atomic and molecular models for use in lecture, laboratory and other demonstrations. His atomic models show the relative sizes of atoms, the number and distribution of electrons in the outer shell, valence orbitals and the relative electronegativity of the element; his molecular models show the geometric structure and multiplicity of bonding, and the charge distribution. Data for the construction of the models are summarized in 22 tables listing about 400 individual compounds and the more familiar types of crystal structure, with additional instructions for building any others that may be wanted. Many illustrations, some of amazing complexity; a considerable

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LOGIC, METHODOLOGY AND PHILOSOPHY OF SCIENCE, edited by Ernest Nagel, Patrick Suppes and Alfred Tarski. Stanford University Press ($12.50). This volume, consisting of 63 papers, constitutes the proceedings of the 1960 International Congress for Logic, Methodology and Philosophy of Science held at Stanford University. The main categories are mathematical logic, the foundations of mathematical theories, the philosophy of logic and mathematics, general problems of the methodology and philosophy of science, foundations of probability and induction, and the methodology and philosophy of the physical, biological and social sciences. Many of the papers are of broad interest and highly readable; an example is John A. Wheeler's "Curved Empty Space-Time as the Building Material of the Physical World: An Assessment."

APPLIED GEOPHYSICS, U.S.S.R., edited by Nicholas Rast. Pergamon Books. The Macmillan Company ($15). A selection of papers, published in Volumes 18 and 20 of the Soviet journal *Applied Geophysics*, dealing with seismology, gravimetry, electrical sonde methods and oil geophysics. Geophysical research has been vigorously pursued in the U.S.S.R. not only in an effort to find useful minerals but also in order to accumulate information on the geological structure of the country. This compendium will find an audience among oil geophysicists and geologists.

THE DECLINE OF THE WEST, by Oswald Spengler. Alfred A. Knopf, Inc. ($6.95). This book refuses to die for the sufficient reason that it contains, mixed in with a vast amount of overblown Germanic philosophy and pretentious historical theorizing, some striking insights and original ideas. It was first published in German in 1918, then extensively revised and reissued in 1923. A few years later the English translation appeared. It is now offered in an abridged edition that consists of selections from the original, linked by explanatory passages. For those who might not have the patience to wade through the two-volume original this shorter edition should provide some solid intellectual enjoyment.

JOHN D. ROCKEFELLER'S SECRET WEAPON, by Albert Z. Carr. McGraw-Hill Book Co., Inc. ($6.95). An intelligent, well-written book about

A Message to the Engineer/Scientist Community At Large — and a Question: there's a dynamic technological race going on at the Atlantic Missile Range, a race between the fast-increasing capabilities of new missiles and space vehicles and the capacity of range instrumentation to test their performance. □ We wonder how much you have heard about this. . . . and about the challenge it offers engineers and scientists with PAN AM at Cape Canaveral? □ You may know a small segment of the work . . . many do. But only a handful are aware of its scope. In fact, we of PAN AM'S Guided Missiles Range Division sometimes think that only the ubiquitous seagulls know the full story of the new range instrumentation technology we've created in the 9 years we've been charged with development and management responsibilities for AMR by the U.S. Air Force. □ The measure of the distance we've come is the measure of the technological jump between MATADOR and MARINER. □ In the simplest terms, this has meant acquiring ever greater funds of data, of ever higher accuracy, at ever greater distances — and converting and transmitting it at ever increasing speeds. □ FIRST, the existing range instrumentation and communications techniques were pushed to the utmost bounds of their capacities — THEN they were replaced with new range systems built to new concepts, as specified by PAN AM engineers and scientists backed by research groups. □ *Today — a new phase of range technology development is under way — staff build-up is proceeding on schedule.* □ To meet the demanding requirements of both today and tomorrow, much of the work of the Range is divided into three time projections:

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THE COLLECTED DIALOGUES OF PLATO, INCLUDING THE LETTERS, edited by Edith Hamilton and Huntington Cairns. Pantheon Books ($7.50). A complete one-volume Plato with an index and helpful notes prefacing each dialogue. The translations represent the editors' judgment of the best British and U.S. examples of the last century ranging from Benjamin Jowett to scholars of the present day. Included, among others, are Lane Cooper, F. M. Cornford, W. K. C. Guthrie, R. Hackforth, Michael Joyce, W. H. D. Rouse, Paul Shorey, A. E. Taylor, Hugh Tredennick and W. D. Woodhead. For this compact, clearly printed, manageable edition, at an almost incredibly low price, all students of Plato will be profoundly grateful to the Bollingen Foundation, which, by its financial support, has made the volume possible.

MY FATHER, MARCONI, by Degna Marconi. McGraw-Hill Book Co., Inc. ($7.50). A not uninteresting, mainly personal and anecdotal biography of the developer of wireless by his daughter. Marconi was a skilled and ambitious mechanic, an astute businessman, a ferocious social climber and a moody, restless, unhappy man who had the misfortune to achieve success and fame at a very early age. After that, everything that happened to him was an anticlimax, including his Nobel prize, and he managed to make his family almost as miserable as himself.

AMERICAN SCIENTIFIC BOOKS 1960–1962, edited by Phyllis B. Steckler. R. R. Bowker Co. ($10). A cumulation of titles from the monthly issues of the American Book Publishing Record, including scientific, medical and technical books published in the U.S. from January, 1960, to March, 1962. Juveniles and texts below the college level are excluded. Coverage extends to the books of all publishers; omitted are Government and business publications not primarily intended for public distribution,

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and most serials. The subjects range from abdominal surgery and Abelian groups to zero-G simulators and zoology.

ENCYCLOPAEDIC DICTIONARY OF PHYSICS: VOLUME I, edited by J. Thewlis and others. The Macmillan Company (eight volumes and glossary, $298). The first volume of a comprehensive undertaking that aims to present in some 60 sections articles in English by scientists from both sides of the Atlantic dealing with every branch of pure and applied physics. The plan to be followed throughout is that, with few exceptions, no articles are to be longer than 3,000 words (many will be much shorter); each is to be self-contained, although it will allow the reader through cross references and bibliographies to pursue his studies further. This volume, which runs from the Abbé refractometer to compensated bars, is clearly printed and soundly produced; there are many well-drawn diagrams. Altogether the new dictionary promises to be a worthy successor to Glazebrook and a sturdy addition to the physics reference shelf.

Notes

THE PLANET SATURN, by A. F. O'D. Alexander. The Macmillan Company ($12). A nonmathematical survey of the progress of the observation of Saturn from 650 B.C. to the present. Based on many original sources, this comprehensive work will be of interest to amateur and professional astronomers and to historians of science. Plates and diagrams.

SCIENCE IN PROGRESS: TWELFTH SERIES, edited by Wallace R. Brode. Yale University Press ($7.50). The 12th series of the National Sigma Xi Lectures, dealing with a wide range of topics, among them geology, astronomy, genetics, psychology, botany and geophysics.

THE STORY OF MAN, by Carleton S. Coon. Alfred A. Knopf, Inc. ($7.50). The second edition of this book, first published in 1954, has been substantially rewritten to take account of advances in knowledge of human evolution and new discoveries in archaeology. A few maps and other illustrations have been changed.

THE PHILOSOPHY OF MATHEMATICS: AN INTRODUCTION, by Stephan Körner Harper Torchbooks ($1.35). A Britisl philosopher presents an illuminating ex position, in which technical language is as little used as possible, of classical and modern philosophies of mathemat-

ics, concentrating chiefly on the relation between philosophical theses and the construction or reconstruction of mathematical theories, and on the relation between pure and applied mathematics.

A HISTORY OF THE CALCULUS OF VARIATIONS DURING THE NINETEENTH CENTURY, by I. Todhunter. Chelsea Publishing Co. ($7.50). A reprint of a well-known survey of the development of the calculus of variations from Lagrange to Jacobi. In spite of the title the survey runs only to 1860, having been published in 1861.

MONASTIC LIFE IN MEDIEVAL ENGLAND, by J. C. Dickinson. Barnes & Noble, Inc. ($7.50). An account of the monasteries of medieval England, their architecture and the daily life of their inhabitants.

PENGUIN SCIENCE SURVEY, 1961: PART I, edited by Arthur Garratt; PART II, edited by S. A. Barnett and Anne McLaren. Penguin Books Inc. ($1.45 each). These two volumes consist of reviews of advances in the physical and biological sciences too recent to have found their way into texts or monographs. The articles are addressed to the professional scientist interested in subjects other than his own and to the intelligent layman. The quality of the articles is well above average. Contributors include J. D. Bernal, Freeman J. Dyson, Graham Sutton, J. B. S. Haldane and N. W. Pirie. An attractive pair of paperbacks.

INSECT CONTROL IN PUBLIC HEALTH, by C. B. Symes, R. C. Muirhead Thompson and J. R. Busvine. American Elsevier Publishing Company ($11). A summary in simple language of the biological facts in the life histories and behavior of organisms and insect vectors involved in the transmission of such diseases as malaria, filariasis, plague, dysentery, yellow fever, typhus and sleeping sickness. The emphasis is on the insecticides that can be effectively applied against these diseases. Illustrations.

PROCEEDINGS OF THE RUTHERFORD JUBILEE INTERNATIONAL CONFERENCE, MANCHESTER, 1961, edited by J. B. Birks. Academic Press Inc. ($32). In this 856-page volume are recorded the proceedings of a conference held at the University of Manchester in 1961 to commemorate the discoveries of Lord Rutherford at Manchester and in particular the 50th anniversary of his scattering law and the discovery of the atomic nucleus.

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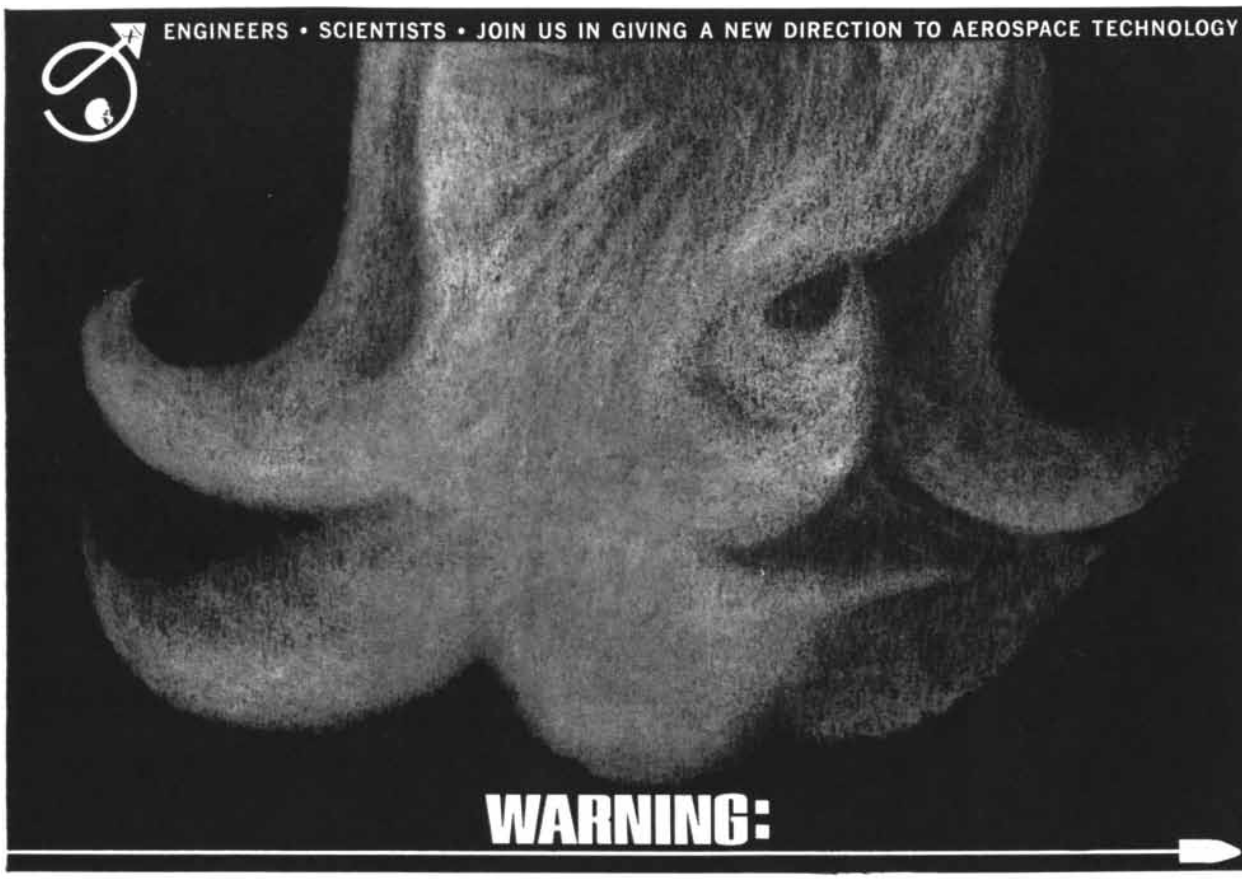

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