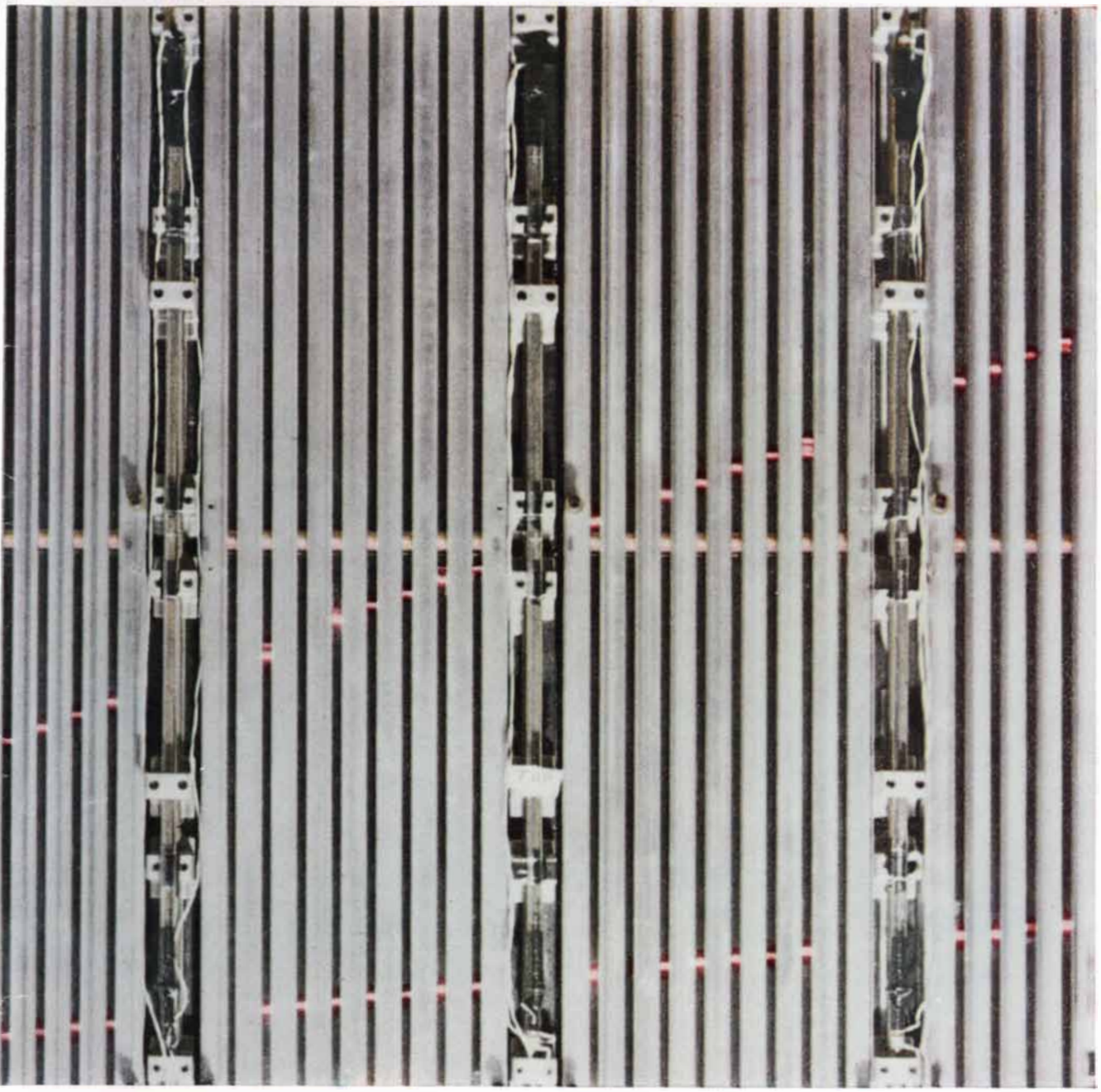
SCIENTIFIC AMERICAN



SPARK CHAMBER

FIFTY CENTS

August 1962

HOW TO KILL TEREDOS' APPETITE FOR WOOD: Now there is a highly effective answer to this destruction in salt water: bioMeT* TBTO*, one of the many M&T organotins. Applied easily to boats by brush or dip, its colorless appearance will not affect paintability. Long-term tests of protection of marine piling are under way. Other uses: water treatment, anti-fouling paints, textile purification, terrestrial wood protection.

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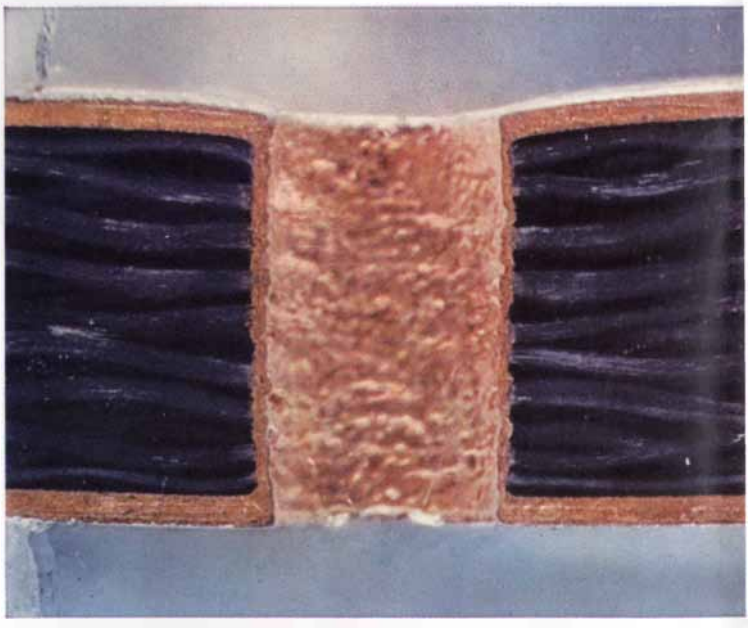
MILD STEEL TURNS TO STAINLESS IN THE ARC: A welder becomes a veritable alchemist with M&T's "Ferro-core" electrodes. A new addition to the wide M&T welding line, this type has a mild steel core wire, with alloying elements in the coating. The deposit turns to stainless steel in the arc. Advantages: substantially lower electrode cost; more metal deposited per electrode.



HOW TO PLATE THE SIDES OF A 1/32-INCH HOLE: Minuteman, Hound Dog, F-104, Polaris—all have high reliability systems using printed circuit boards plated by the M&T Pyrophosphate Copper Process. The deposit is smooth, has fine grain. It's just as uniform in every hole as on each side of board—assuring good, soldered connections. Electroplating chemicals are an M&T specialty.

Uniting imagination in chemicals with know-how in metals, M&T contributes scientific advances to many fields: marine protection, welding versatility, electronic reliability. With this background, M&T offers you new methods, unique materials, proven capabilities—for creative approaches to old and new problems. METAL & THERMIT CORPORATION

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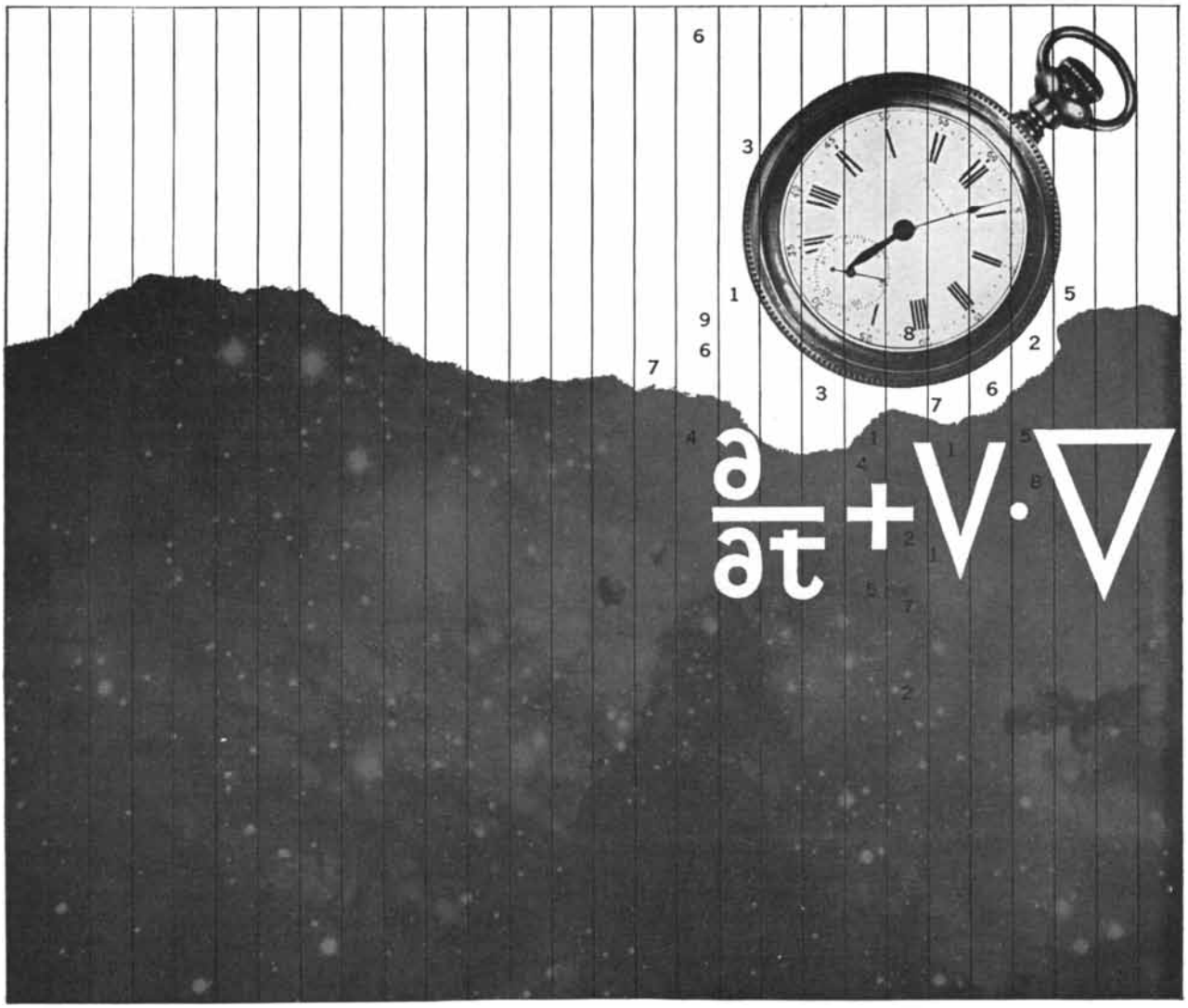

purposeful imagination....in time

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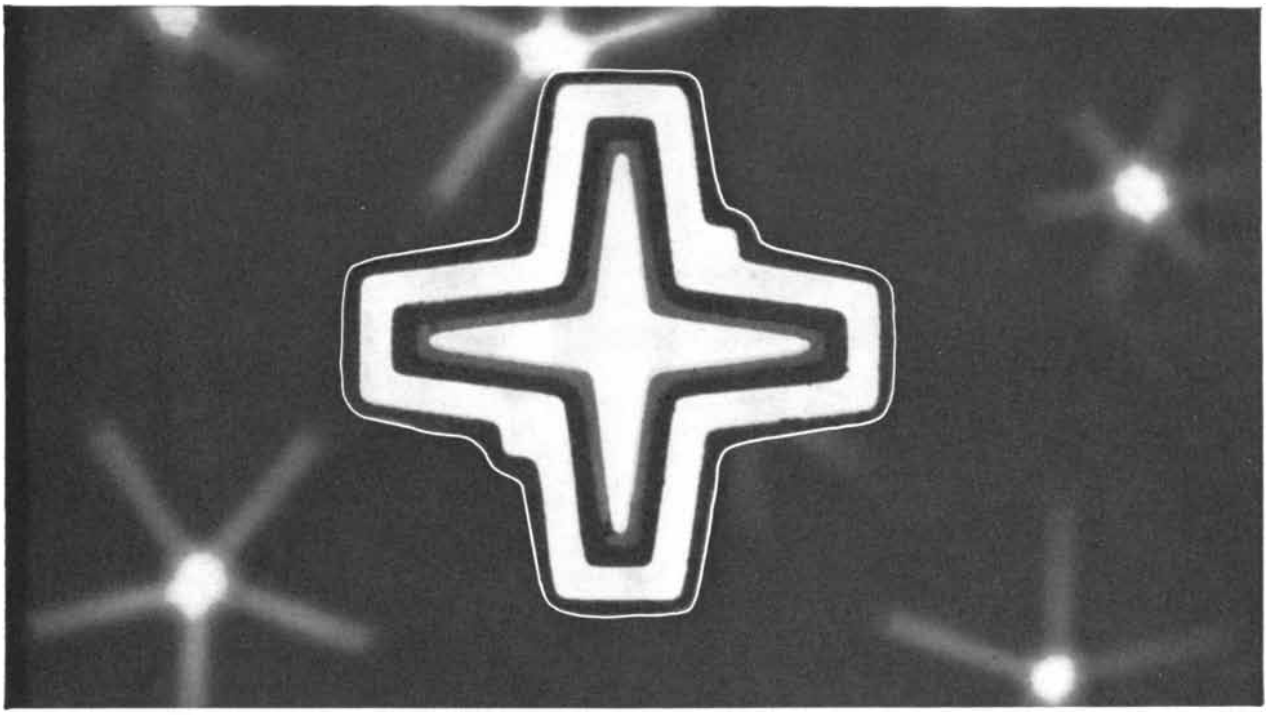


The basic shape of things to come ...in silicon planar transistors

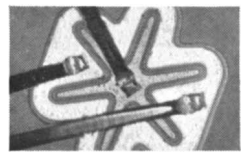
Hidden inside the can of every silicon transistor is the tiny silicon wafer, only a few hundredths of an inch square, which forms the active heart of the device. Even smaller is the configuration or geometry of the emitter and base regions (only .015" wide) which is laid down on the wafer.

When Motorola invented the Star* silicon planar transistor, which has a four-pointed base-emitter pattern as shown above, a high-speed transistor was available for the first time with excellent gain characteristics at all current levels... a transistor vitally needed in modern computer circuits. Recognizing the advantages of this new transistor design, other manufacturers are introducing similar devices which utilize the unique geometric concept of the Star transistor.

Why should the pointed geometry of the Star transistor make possible a device so universally applicable? First, the four-pointed pattern provides a high emitter perimeter-to-area ratio necessary for combined high current capability and high frequency performance. Second, the combination of this ratio, the circular symmetry, the tapered "fingers," and one central bonding area all contribute to giving the Star transistor advantages over all other geometries proposed for a high frequency, low or high current transistor.

From a practical viewpoint, the pointed pattern has called for abilities in precise micromanipulation, photo-resist masking, and alignment techniques never before achieved on a production scale. Only by keeping the emitter area in the center of the pattern as small as possible (barely larger than the area required for the emitter lead) has it been possible to achieve such frequency response. And the spacing between emitter and base is only .0005".

What about other variations?



Although for most applications, the four-pointed pattern is the ideal geometry, there are special requirements for higher current and higher power devices. These requirements are being met by the new Motorola-developed industry standard Snowflake* transistor (six points) and five pointed structures which provide substantially higher current capability than even the Star transistor. As is usually the case in transistor design, one is often forced to compromise, and in spite of our enthusiasm over the new Motorola "Snowflake" transistor, it appears that in its field of application the Motorola Star transistor is unequalled by any device that is likely to be developed for some time to come.

The Basic Shape Of Things To Come is here already... the Motorola Silicon Epitaxial "Star" Planar Transistor. If you haven't tried these devices in your most demanding circuits, we'd welcome the opportunity of proving their superiority. Simply call your nearest Motorola semiconductor field representative and request samples of the Star transistor.

*STAR and SNOWFLAKE are trademarks of Motorola, Inc.
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1987

Established 1845 **SCIENTIFIC AMERICAN** August 1962 Volume 207 Number 2

ARTICLES

DEPARTMENTS

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THE COVER

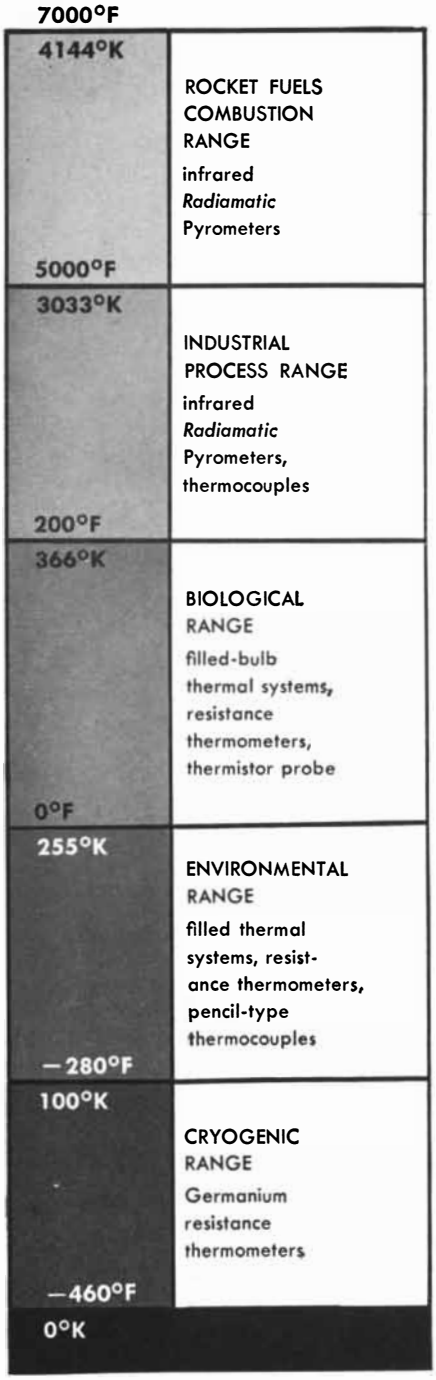
The photograph on the cover shows a spark chamber, an important new device of experimental physics (see "The Spark Chamber," page 36). Like the cloud chamber and the bubble chamber, the spark chamber makes visible the tracks of subatomic particles; the two diagonal rows of pinkish sparks in the cover photograph trace the paths of two-cosmic-ray particles. Basically the spark chamber consists of a series of metal plates, each of which bears an electric charge opposite that of the two adjacent plates. Between the plates is a gas; when a particle passes through the chamber, the atoms or molecules of gas in its wake are ionized and a spark jumps between the plates in the ionized region. The spark chamber in the cover photograph is located at the Brookhaven National Laboratory. It consists of 90 aluminum plates, each an inch thick and about four feet square; the entire chamber is about seven by seven by four feet. The gas between the plates is neon, which accounts for the color of the sparks. This particular chamber was recently employed in a significant experiment in which the 30-billion-electron-volt proton synchrotron at Brookhaven was used to demonstrate that there is not one kind of neutrino but two (see "Science and the Citizen," page 52). The experiment was a joint project of Columbia University and Brookhaven and was supported by the Atomic Energy Commission. It was performed by Leon M. Lederman, Melvin Schwartz, Jack Steinberger, Jean-Marc Gaillard, Konstantin Goulianos and Nariman Mistry of Columbia and Gordon Danby of Brookhaven.

THE ILLUSTRATIONS

Cover photograph by Paul Weller

Page	Source
31	Rudolf Freund
32–33	Widukind Lenz, University Pediatric Clinic, Hamburg
34–35	Rudolf Freund
36	Paul Weller
38	James Egleson
39	James Egleson (*left*), Lawrence Radiation Laboratory, University of California (*right*)
40–41	James Egleson
42–43	James L. Cronin, Princeton University (*top left*); Gerard K. O'Neill, Princeton University (*top right*); James Egleson (*bottom*)
44–47	Scripps Institution of Oceanography
48	U.S. Navy Hydrographic Office (*top*), Patra McElwee (*bottom*)
49–50	Bunji Tagawa
66–67	Tomi Ungerer
68–69	Fairchild Aerial Surveys, Inc.
70	James Egleson
71	Joan Starwood
72	Patra McElwee
78	Max Renner
80–86	Thomas Prentiss
90	William Vandivert
91–98	James Egleson
101–103	John Langley Howard
104–105	William Vandivert
106	Bradford D. Pearson, Harvard Medical School (*top*); John Langley Howard (*bottom*)
108	Morris J. Karnovsky, Harvard Medical School
112–114	Hatti Sauer
115–116	Dan Todd
117	Joan Starwood
118	Dan Todd
122–126	Bunji Tagawa
129–138	Roger Hayward

FIRST, CATCH YOUR TEMPERATURE



There's an old recipe for rabbit stew that begins: "First, catch your rabbit." The same could be said of extremely low, high and very precise temperature inputs for data reduction and data handling systems. Here, too, acquiring the proper raw materials for processing is of fundamental importance. And in this latter instance, wouldn't it save a lot of work, worry and wherewithal if the same people who helped you bag your game in the first place also helped you cook it to a turn? Here's what we mean . . .

ALL THE WAY FROM 1°K. Honeywell has developed standard sensors in hundreds of types, sizes and calibration ranges for measuring from the very bottom of the thermal scale to 7000°F, which is well beyond the combustion range of most rocket propellants. Even as you read this, Honeywell researchers are working to extend the measurement of temperature with standard sensors nearer and nearer to absolute zero at one end of the scale, and into the plasma range at the other.

AND IF YOU CAN'T FIND IT IN STOCK, we'll probably be able to make a super-sensor for you. If your project involves taking temperature under the most demanding conditions, extremely close measurement over a very short span, or meeting highly exotic research requirements, we'll custom-tailor a sensing element to order, and give you our word it will work. Some of these super-sensors are taking profile temperatures of aircraft engine exhausts; some, capable of withstanding the shock of ninety times gravity, are reporting rocket engine temperatures; others are measuring atomic reactor temperatures up to 4000°F with a sensing element 30″ long and 0.035″ in diameter.

ONLY THE BEGINNING. You might think that Honeywell would be content with the creation of standard and special temperature sensors for every conceivable area of scientific investigation. Far from it. For Honeywell supplies **everything** in the data processing chain. This includes every kind of sensing device or transducer for accurately measuring variable inputs, and this material is then passed on to Honeywell graphic recorders, oscillographs, data loggers, magnetic tape equipment, computers, and other data handling systems. This makes it highly practical to think in terms of an all-Honeywell system, complete from sensing to readout. Among other things, this offers the unarguable advantage of **compatibility:** every element along the way communicates in the same language, with the requisite speed and accuracy.

SOUND REASONS. There are many sound reasons for having an all-Honeywell data system. One of the most cogent: Honeywell guarantees that the whole assemblage will work satisfactorily, by taking full responsibility for the performance of each and every component making up a system. Still another: Honeywell's experienced manpower resources, which assure on-time installation and readily available follow-up maintenance service from any of 125 Honeywell service centers throughout the U.S. and Canada.

So whether your data handling system involves an environmental test chamber, or leisurely logging the temperature of sea water four times a day, you'll get usable results, faster and easier, if you'll put the whole assignment in the hands of your local Honeywell field engineer. He can tell you many ways that Honeywell can save you time, money and headaches throughout the entire area of data gathering and handling. Or write Industrial Products Group, Minneapolis-Honeywell, 4412 Wayne Avenue, Philadelphia 44, Pennsylvania.

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He needs time on the new IBM 7040 Data Processing System—so does his company's management.

The new 7040 is a medium- to large-scale computing system, operates in binary mode, has internal checking, utilizes advanced programming techniques, can be used with a variety of IBM TELE-PROCESSING® units, and can be expanded into the faster 7044.

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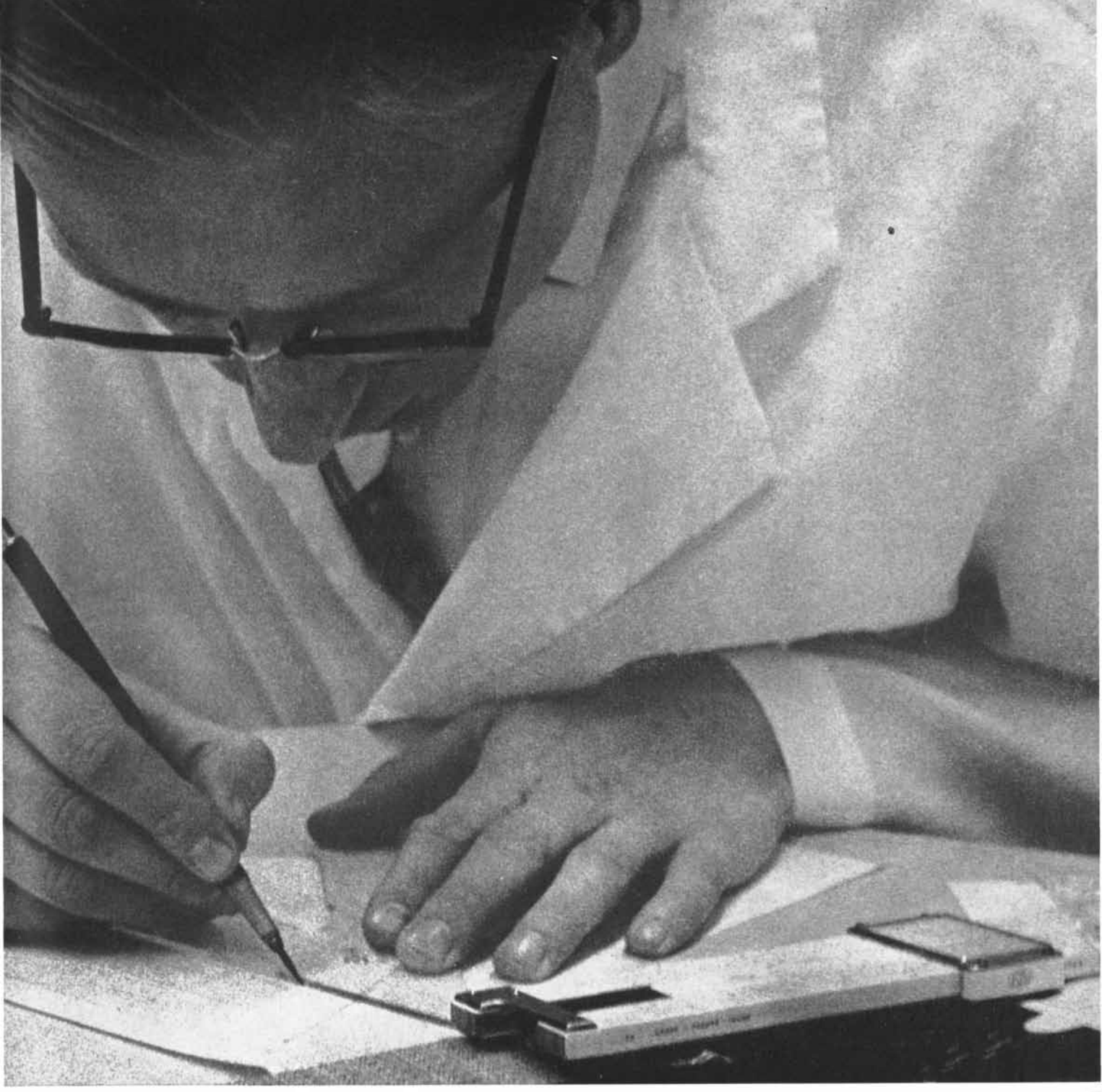
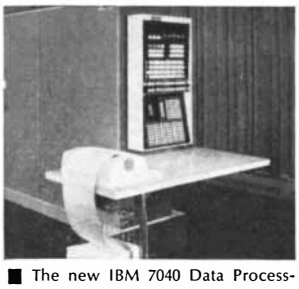
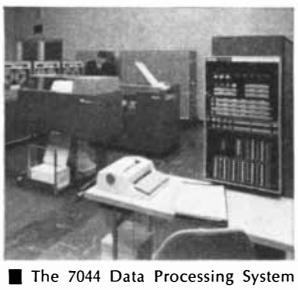
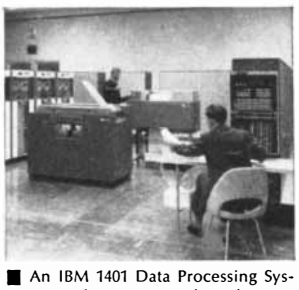




■ The new IBM 7040 Data Processing System for scientific computing, management science, and other data processing applications. Has a basic memory cycle of 8 microseconds.



■ The 7044 Data Processing System has a 2.5 microsecond cycle. Both systems have memory capacities of 8,192, 16,384, and 32,768 words. The 7040 is available with a 4,096 word memory.



■ An IBM 1401 Data Processing System can be connected on-line to either of the two systems. Other data processing units can be added in building block fashion.

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DATA PROCESSING

LETTERS

Sirs:

I found the article on malaria by Carlos A. Alvarado and L. J. Bruce-Chwatt [SCIENTIFIC AMERICAN, May] extremely interesting and well informed from a technical point of view. Knowing your reputation and that of the authors for careful objectivity and factual reporting, I know you will welcome further information regarding U.S. participation in this program, which, in your article, was mentioned only in passing. The U.S. has played a significant role in the development of this world-wide program through its technical and industrial leadership and its financial support. The Agency for International Development is responsible for carrying out this program for the U.S. Government.

While I appreciate the points of view of the authors because of their affiliation with the World Health Organization, as director of A.I.D. I feel that the picture of the world-wide campaign in which the U.S. is collaborating would not be complete without considering the following facts of U.S. participation in the program:

1. The U.S. has bilateral agreements with 24 countries to provide technical advisory service, insecticides and other commodities for their national malaria eradication campaigns. More than 600 million people are at risk of contracting malaria in these countries.

2. The U.S. has contributed approximately $150 million to the world-wide eradication program through bilateral and multilateral channels since the initiation of the Malaria Eradication Program in 1957. The Eighth World Health Assembly in Mexico City two years earlier had requested all member nations to undertake this effort. Of the $150 million total U.S. expenditure through A.I.D. and its predecessors, $123 million has been through bilateral contributions to the following countries: Cambodia, Republic of China, Indonesia, Philippines, Thailand, South Vietnam, Ceylon, India, Iran, Jordan, Nepal, Ethiopia, Liberia, Libya, Brazil, Colombia, Bolivia, Ecuador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua and Paraguay. The remainder, about $28 million, has gone to WHO, PAHO and UNICEF.

3. The U.S. has provided over 90 per cent of all the funds used by WHO and PAHO for malaria eradication activities. It should be noted that the U.S. supports about 33 per cent of the UNICEF budget, which includes $10 million annually in commodities for malaria eradication. A.I.D. carefully co-ordinates its activities with UNICEF so that there is no overlapping of commodity support or gaps that would weaken the program.

4. The Agency for International Development has a total of 75 technicians, including specialists in epidemiology, entomology, engineering and administration, who are assisting local governments in the execution of the national campaigns.

5. American industry has provided large quantities of high-quality insecticides and equipment essential for the campaign.

On the occasion of the issuance of the U.S. Malaria Eradication stamp on March 30, 1962, President Kennedy stated: "I am proud of the part which the United States is playing in the world-wide malaria eradication campaign. We have conquered malaria in our own country. Now, through the Agency for International Development, we are devoting our technical skills and financial resources to this greater effort. . . ."

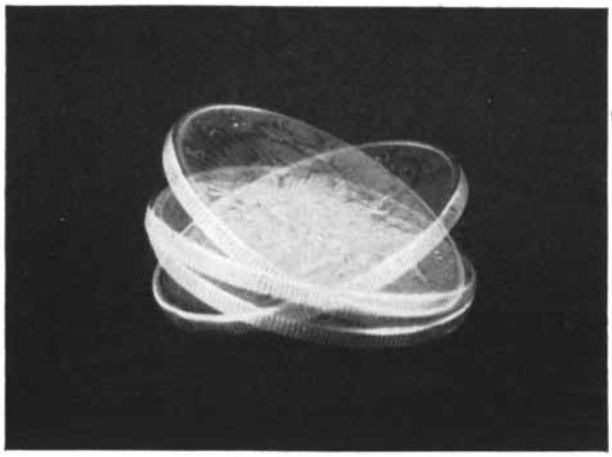
I bring these facts to your attention, as I know you are interested in the full story of the world-wide malaria eradication effort, which is so vital to the economic and social development of many areas and which benefits so many millions of people in the world today.

FOWLER HAMILTON

Agency for International Development
Department of State
Washington, D.C.

Sirs:

We wish to congratulate Fowler Hamilton on having made so authoritatively clear the decisive role played by the U.S. in the development and support of the global malaria eradication campaign. You will appreciate that in a relatively short article devoted to the historical outline, technical aspect and general appraisal of malaria eradication we were unable to expand on the subject mentioned by Mr. Hamilton. We did recognize it, however, when referring in our article to the Malaria Eradication Special Account of WHO and we said: "By the end of 1960 the total amount received or pledged amounted



Complex displacements—both periodic and random—can be thoroughly analyzed by the Bendix Microwave Interferometer to resolution limits of the order of microinches.

Microwave Interferometry: New Technique For Noncontacting Measuring

This was the question: how do you measure amplitude and period, including each harmonic, of high speed dynamic displacements when a sensor's touch might change the vibration pattern in question?

From our considerable experience in microwaves, it appeared that a high resolution microwave interferometer might be developed to solve this and other problems requiring a noncontacting measuring technique.

The interferometer input is a pulse containing a selected frequency spectrum generated by the klystron transmitter. When microwave energy from the system's antenna reflects from a surface to be measured, and then reenters the antenna, a standing wave is generated. Null positions in the wave are sensed, converted into dimensional information, and read out on a meter or strip chart recorder.

The starting point for this electronic measuring system was a klystron operating in the high frequency region (35 kmc). To maintain the degree of system stability which will permit resolution in the microinch range, the klystron is frequency-swept at a high rate, then the resulting spectrum sampled with a high-Q cavity. This solved the difficult problem of stabilizing klystron frequency in a *simple, direct manner.*

Resolution of the instrument for both static and dynamic measurement is in the order of microinches. Under any condition, however, the device offers the advantage of being useable both close to the target surface and as distant as 24 inches.

Because microwave interferometry is a new approach to noncontacting measurement, its full range of application can only be theorized. The device will be particularly valuable for applications such as: measuring dielectric thickness of radomes, measuring runout, out-of-roundness or roughness of high speed rotating surfaces; gauging thickness, smoothness or waviness of strip stock as it leaves mill rolls; and analyzing complex mechanical vibrations.

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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WHERE IDEAS UNLOCK THE FUTURE

to $12,772,000, of which $11 million came from the U.S." Mr. Hamilton's letter gives us an opportunity to endorse his factual statements. It seems, however, that we should not limit our answer to confirming the number of countries benefitting from the U.S. bilateral agreements or other aid; it is not enough perhaps to acknowledge the millions of people protected and the dollar value of such gigantic assistance to malaria eradication. Even more important for the success of this campaign is the unlimited faith shown by the U.S. with regard to the humanitarian and economic benefits of global malaria eradication and its confidence in international collaboration.

It should be remembered that, following the recommendations of the Eighth World Health Assembly in 1955, this world-wide campaign received its initial momentum thanks to the early decision of the U.S. to give it full support. It is not too much to hope that the continued faith and assistance of the U.S. in this greatest international human endeavor will help it to reach its end. We feel that, together with their President, all American citizens can be proud of the part played by their country in this difficult but hopeful task, which aims at lifting the burden of disease first of all from those countries that are striving for rapid social and economic advance.

CARLOS A. ALVARADO, M.D.

L. J. BRUCE-CHWATT, M.D.

World Health Organization
Geneva

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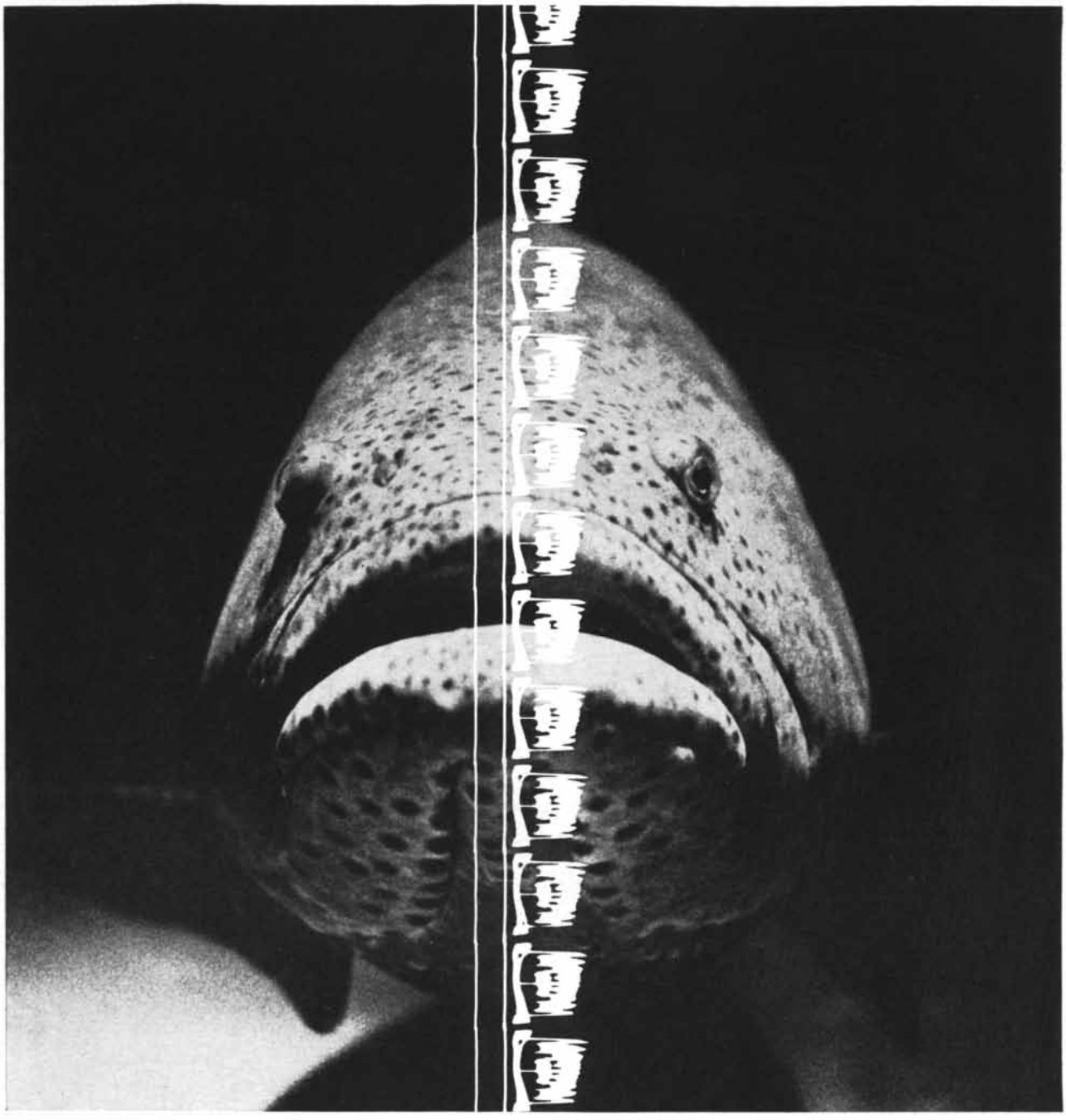

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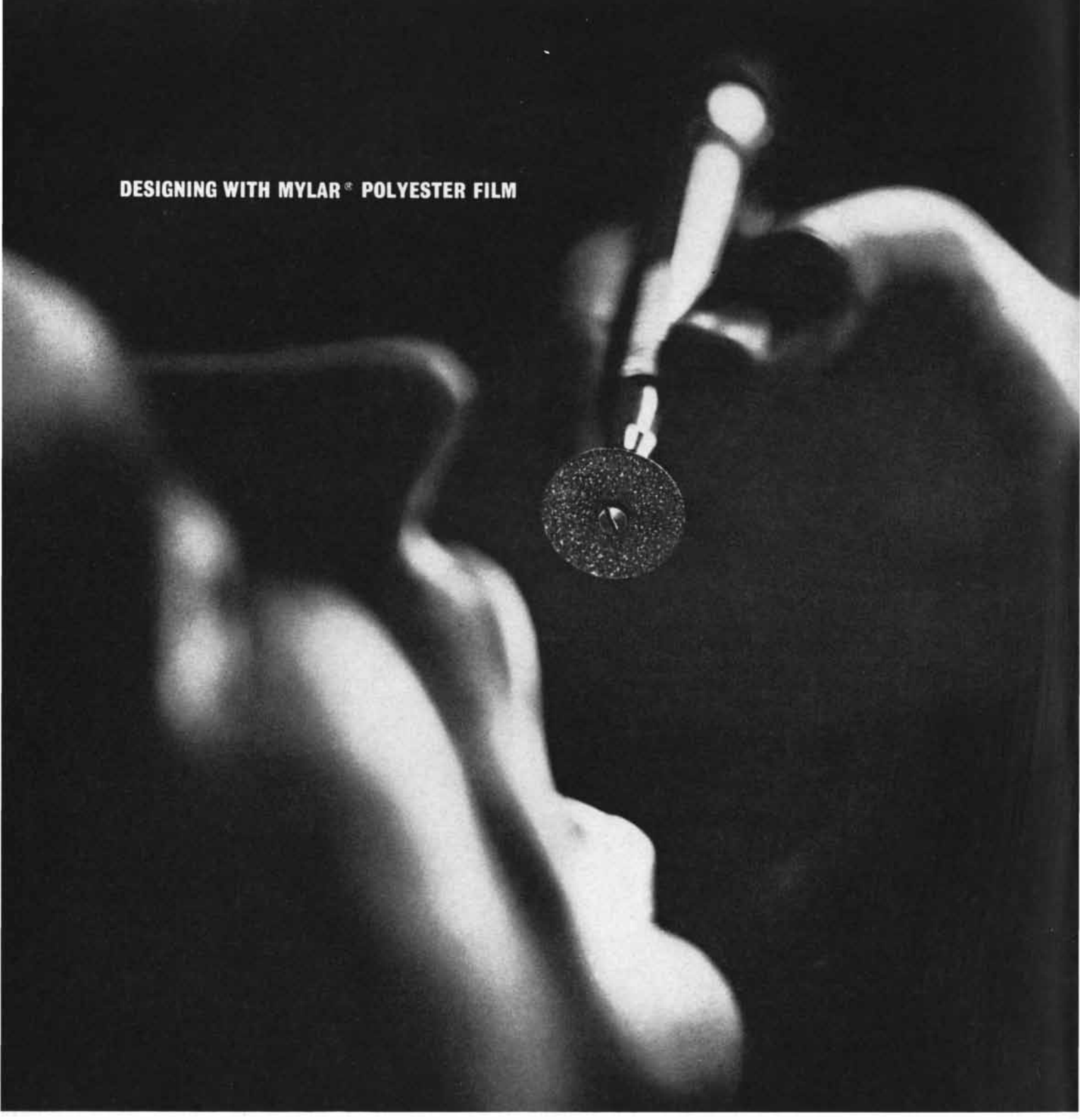

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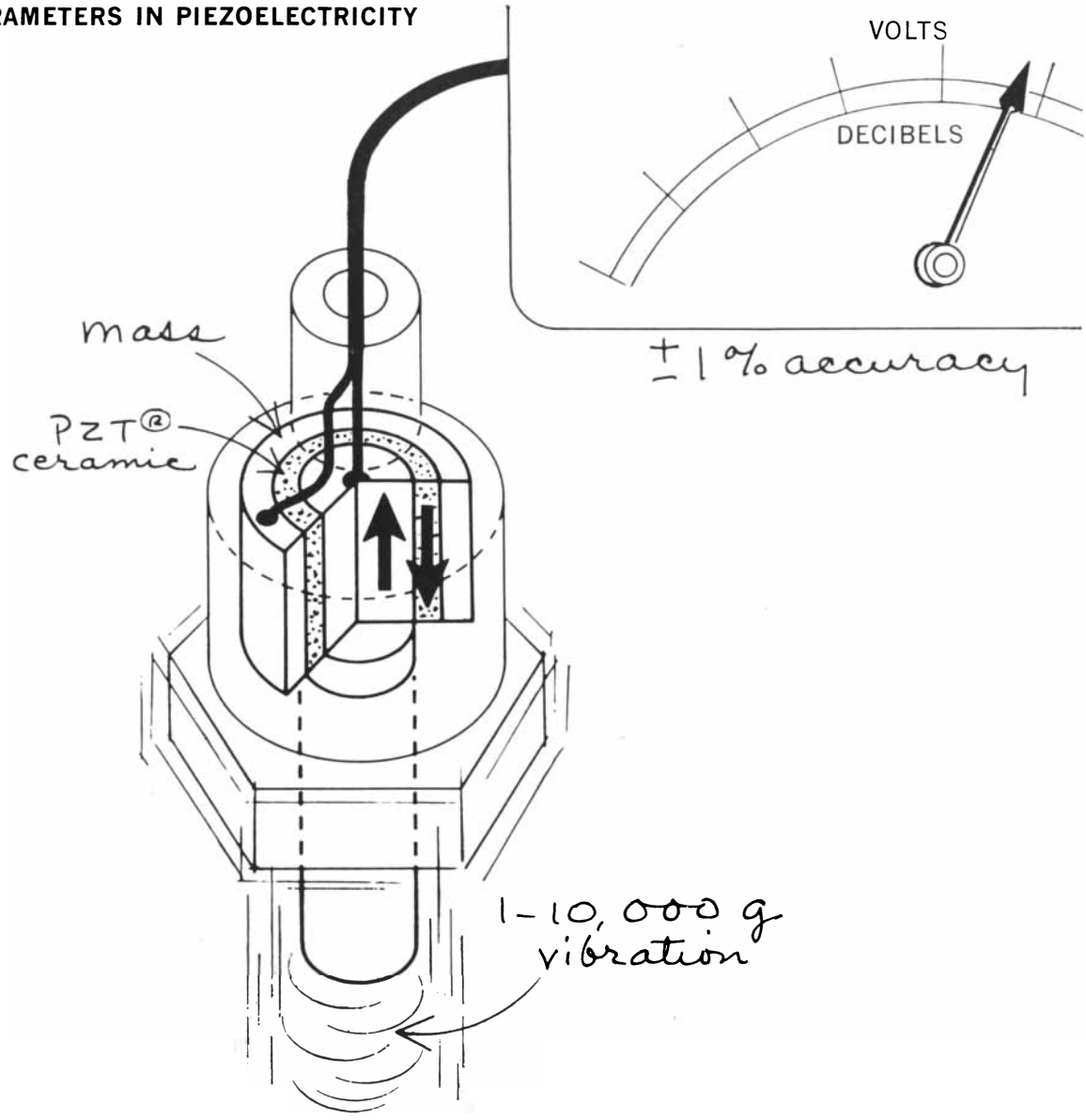

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

AUGUST, 1912: "In a brief and revolutionary monograph presented to the French Academy of Sciences, Prof. Jean Becquerel announces a discovery that will prove to be of untold importance in the practical workings as well as in the study of electricity. It is well known that if a thin strip of metal is fastened to a glass plate placed between the poles of an electro-magnet in such a way that the plane of the strip is at right angles to the lines of force of the magnetic field, a current passing through the strip from end to end is deflected to one side or the other, depending on the metal of which the strip is composed. Thus the current in a strip of zinc, iron or cobalt is deflected toward the right, but to the left if nickel, gold or bismuth is used. From its discoverer, Dr. Hall of Johns Hopkins University, this has been named the 'Hall effect.' It has been held as strong evidence that there are such bodies as positive electrons. M. Becquerel now proves that if the Baltimore experiment is carried out with a piece of bismuth in liquid air, the effect is made more conspicuous. Then, too, if the magnetic field is increased to above 3,500 gauss, the deflection abruptly becomes positive instead of negative. This upsets all known mathematical and physical theories that would make the negative electrons the only carriers of electrons in metals."

"One of the most noteworthy steps taken during the International Radio-Telegraphic Conference, which opened in London June 4 and closed July 5, is the laying down of a practical rule for attendance on the wireless apparatus on shipboard. It will be recalled that the distress signals of the *Titanic* went unheard by vessels in the immediate vicinity because the single operators employed on those ships were off duty at the time. Under the conference rule a permanent watch is required on ships of the first class, which means that two operators must be employed, and on ships of the second class, employing only one operator, the receiving apparatus must be attended during the first 10 minutes of each hour."

"The trials for the $5,000 Michelin prize for bomb-dropping from an aeroplane at a height of 2,400 feet ended at Châlons on August 11 in an American victory, subject to confirmation by the French Aero Club. The winner was Lieut. Scott of the United States Army. Scott dropped the bombs three at a time. The first three fell outside the target, which was a rectangular area 170 by 40 feet. Subsequently Scott succeeded in dropping eight projectiles within the target."

Scientific American.

AUGUST, 1862: "The siege of Vicksburg has been abandoned. The Mississippi is rapidly falling, and Commodore Farragut has withdrawn his vessels down stream to avoid being caught in too shallow water, and Commodore Davis is blockading the mouth of the Yazoo to prevent any more of the iron-plated vessels, which it is said the rebels have up that river, from coming out."

"We extract the following from Charles Dickens in the magazine that he edits, *All the Year Round*:—'We do not all come out of the photographic studio alike unhappy. There are those to whom the process does justice, as well as those to whom it does injustice. I have myself sat on two occasions for one of these portraits. On the first I was simply occupied in keeping still and presenting a tolerable favorable view; but the result was so tame and unimposing a picture that I determined on the next occasion to throw more intellect into the thing, and finding a certain richly gilded curtain tassel convenient to my gaze, I gave it a look of such piercing scrutiny, and so withered and blasted it with the energy of my regard, that I almost wonder it did not sink beneath the trial. That look has, I am happy to say, been reproduced faithfully, and no one could see the portrait without giving its original credit for immense penetration, energy and strength of character, and a keen and piercing wit. It is difficult to lay down rules of general application, but it may be safely said that the people who come out of the photographic struggle the best, and who are least injured in the engagement, are people of ordinary appearance, from whom we do not expect much. It is common to hear some

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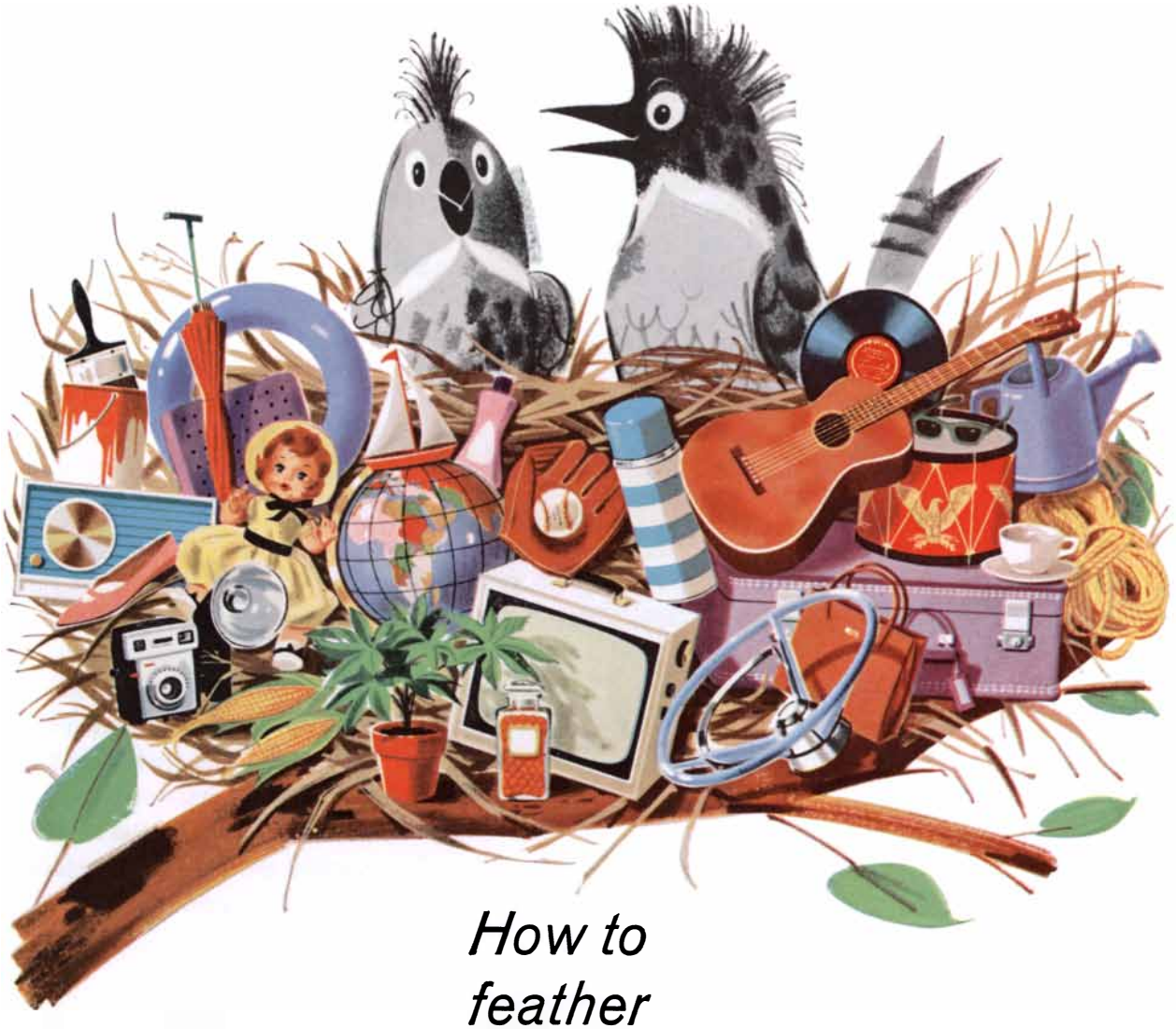
lady who is generally acknowledged to be pretty urged by her friends to sit for a *carte de visite*. "You would make such a charming portrait," they say. The portrait is taken and is, after all, not charming. On the contrary it is sufficiently the reverse to make the victim's female friends happy.' "

"Dr. Marcet, in a recent lecture on the chemistry of digestion before the London Chemical Society, said:—'It appeared that after a long fast the contents of the stomach were alkaline and very small in quantity; and an acid reaction was perceptible. The object of the action of the gastric juice was no doubt to render the food capable of absorption; and accordingly it was found that albuminous, gelatinous and other similar matters introduced into the stomach became converted into a substance called "peptone," which according to Lehmann might be viewed as the same body, whatever nitrogenous food was employed; it had been shown, however, that the peptones resulting from the digestion of cartilage and the mucous membranes rotated the plane of polarization of light, whereas peptones from albumen did not have this power.' "

"The rapid rise of the sewing machine business constitutes one of the wonders of this enterprising age. No industrial revolution can equal that which has been produced by it within the short space of 16 years. The first general notice given to the public that a sewing machine had been invented appeared in SCIENTIFIC AMERICAN in 1847. In 1852—10 years ago—a few companies had erected machinery and commenced to manufacture such machines for sale. In 1853 there were 2,529 made, and up to the present time more than 200,000. The three largest sewing machine establishments are the Wheeler & Wilson Manufacturing Company, I. M. Singer & Co. and Grover & Baker. The first has made about 85,000 machines, the second 55,000, the third about 55,000. Willcox & Gibbs since 1859 have manufactured 10,714. There are about a dozen companies now engaged in the manufacture of sewing machines, and the business has given rise to several immense manufactories in which a capital of several millions of dollars is invested in buildings and machinery."

"Martin Van Buren, the eighth President of the United States, died at his residence in Kinderhook, N.Y., on Thursday the twenty-fourth day of July, in the 80th year of his age."



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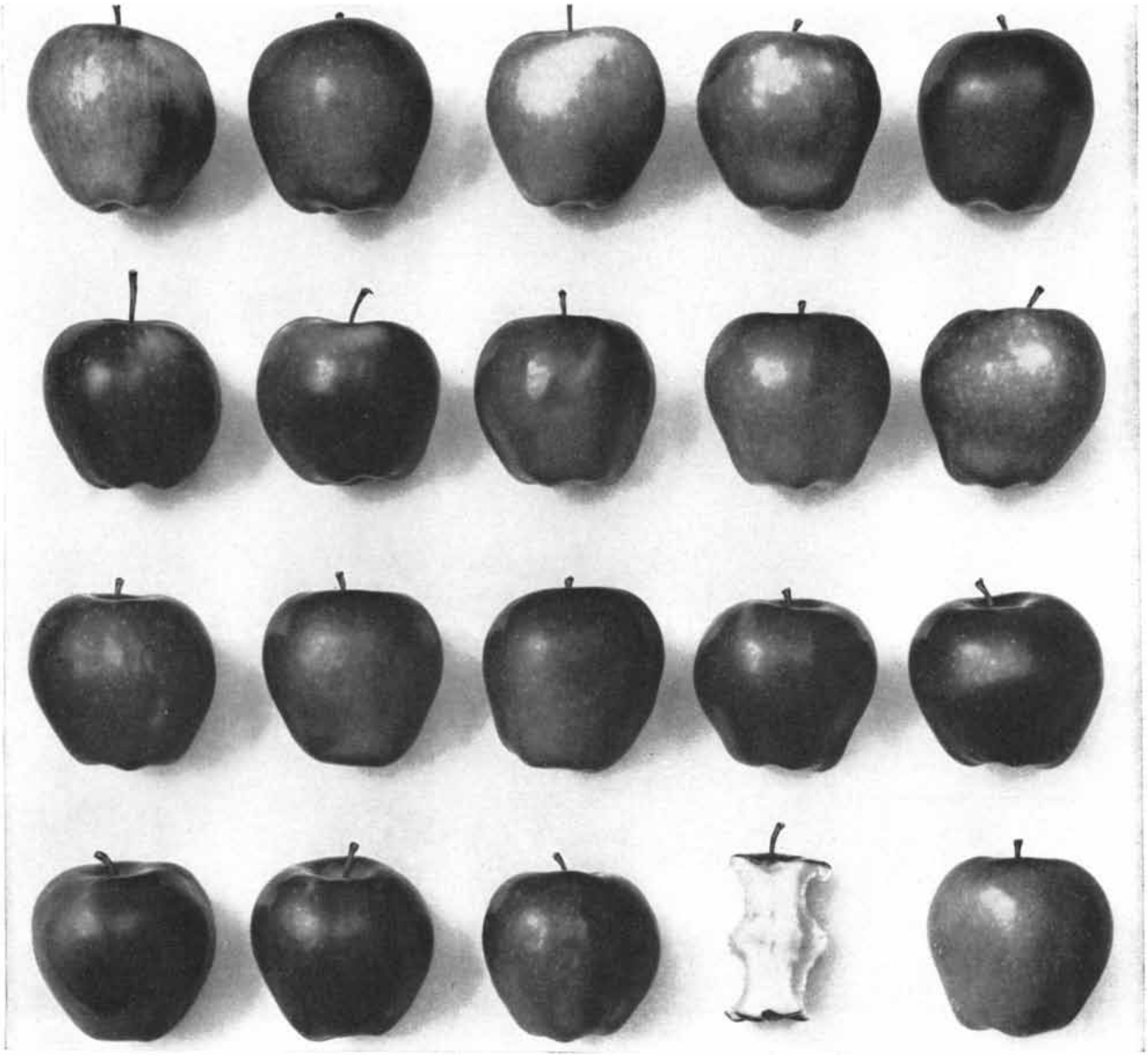

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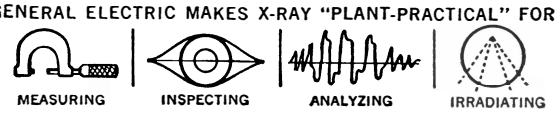

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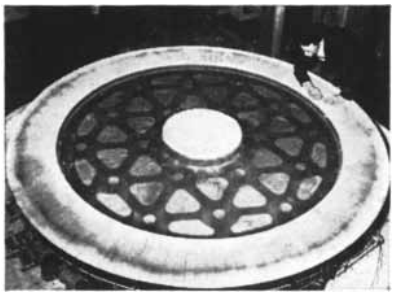
Precision by the ton—coming up



For astronomers, for instance.

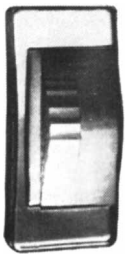
This 84-inch telescope mirror blank for the University of La Plata began with a chunk of glass which weighed 4,000 pounds.

We hoisted it on top of a mold and melted it to shape.

The geometric honeycomb ribbing you see on the back of the blank keeps its weight down without sacrificing strength or rigidity. There's considerable precision there, too.

We don't get many calls for mirror blanks 84 inches across and 13 inches thick, but we're ready to provide precision in bulk in whatever you might need.

Precision by the ounce—automatically

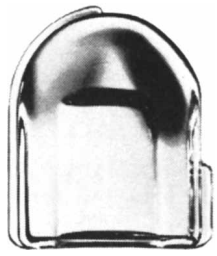


For designers, for instance.

These happen to be lighting lenses. One goes into a sewing machine, the other goes into a unit that's recessed into the centerline of airport runways.

Both of them come out of our molds ready to go right into the product. No finishing operations are required.

This is particularly significant in the case of the bulbous little runway lens. It's the first time we know of that anybody has pressed precise contours *automatically*. There were those, but not among us, who said it couldn't be done.



We can give you this kind of precision at high volume and low cost in small, pressed components of many kinds.

Precision by the nothing—cheaply

For people who design *holes* into metal castings, for instance.

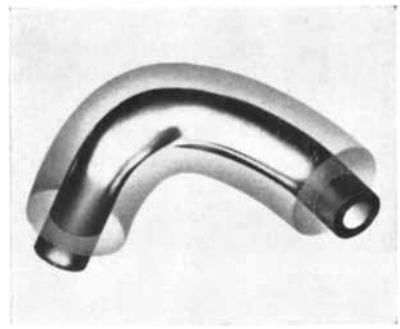
Now they can be more persnickety than ever about diameters, lengths, even curves and angles, and yet *eliminate* costly dies and drills.

They simply use precision VYCOR® core tubes. We make the tubes to the tightest dimensional tolerances. The tubes are inserted in the proper pattern into a refractory mold, and in goes the molten metal.

Hydrofluoric acid or molten caustic leaches the glass out of the hardened metal easily, leaving holes that are technically and economically impossible to make by conventional methods.

The converse of this interests other designers: they *cast* plastic or soft-metal parts or products *inside* precision VYCOR molds.

If the cost of precision coring and casting troubles you, VYCOR tubes may well be the answer. Or this high-temperature material may suggest itself for another application entirely.



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THE AUTHORS

HELEN B. TAUSSIG ("The Thalidomide Syndrome") is professor of pediatrics at the Johns Hopkins School of Medicine, where she received her M.D. in 1927. With Alfred Blalock, a surgeon at Johns Hopkins, she conceived the famous "blue baby" operation, first performed on a human patient in 1945. The operation alleviates an interrelated group of congenital heart defects that lead to inadequate oxygenation of the blood, producing a characteristic blueness of the skin. Miss Taussig has received honorary degrees from more than a dozen institutions, including Columbia University, Harvard University and the University of Athens. Her other honors include the Lasker Award and the Feltrinelli prize. She has also been decorated by the French as Chevalier of the Legion of Honor.

GERARD K. O'NEILL ("The Spark Chamber") is associate professor of physics at Princeton University. After spending two years in the Navy (1944–1946) he entered Swarthmore College and received a B.A. in 1950. After obtaining a Ph.D. in physics in 1954 from Cornell University he began teaching at Princeton. He spent most of the next five years helping in the design and construction of the three-billion-electron-volt proton synchrotron being built jointly by Princeton and the University of Pennsylvania. O'Neill became interested in building spark chambers in 1960. He is now preparing spark chamber experiments for the three-Bev synchrotron, which is due to start operation this year.

ROBERT S. DIETZ ("The Sea's Deep Scattering Layers") is an oceanographer at the Navy Electronics Laboratory in San Diego. As a member of Admiral Richard E. Byrd's last expedition in 1947, he traced the scattering layer from San Diego to the Antarctic. Dietz was an early collaborator of Jacques Piccard's and was instrumental in bringing the bathyscaph *Trieste* to the U.S. In their recent book *Seven Miles Down* Dietz and Piccard recount the history of the *Trieste* and describe its record-making dive into the Challenger Deep off Guam. Dietz received his Ph.D. in geology from the University of Illinois in 1941. After serving as an Air Force pilot in World War II he joined the Office of Naval Research, and later he received a Fulbright Fellowship to study in Japan. In addition to his contributions to marine geology, his primary interest, Dietz has made a study of ancient meteoritic impact scars, or "astroblemes." He is the author or coauthor of three earlier articles in SCIENTIFIC AMERICAN: "The Pacific Floor" (April, 1952), "The Bathyscaph" (April, 1958) and "Astroblemes" (August, 1961).

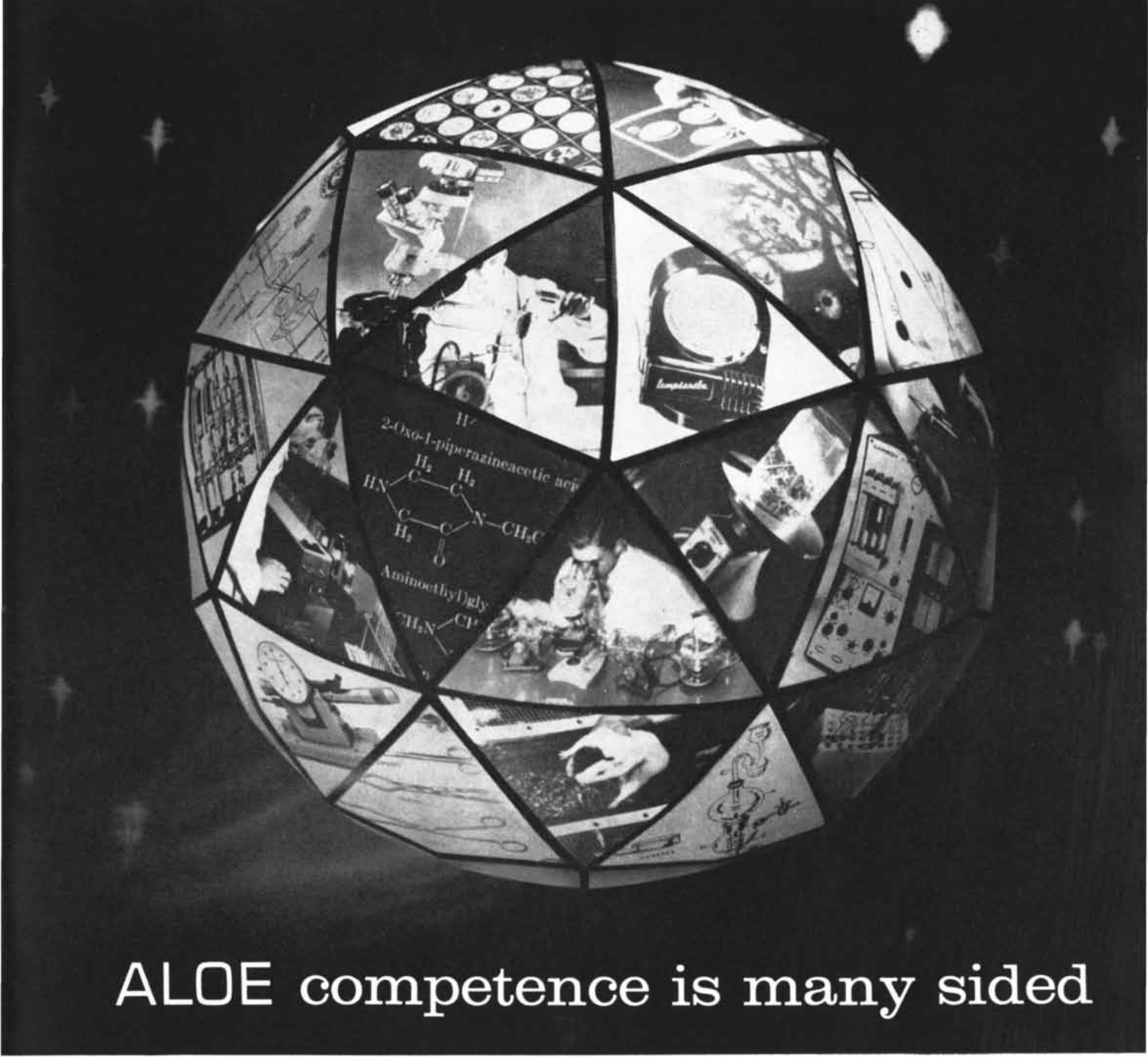
DON D. JACKSON ("Schizophrenia") is director of the Mental Research Institute of the Palo Alto Medical Research Foundation in Palo Alto, Calif. He is also associate clinical professor of psychiatry at the Stanford University School of Medicine. Jackson received his medical degree from Stanford University in 1944 and then served in the U.S. Army. Following World War II he worked at the Chestnut Lodge Sanitarium with Harry Stack Sullivan and Frieda Fromm-Reichmann. He is a recipient (for 1961–1962) of the Frieda Fromm-Reichmann Award of the Academy of Psychoanalysis. He is editor of *The Etiology of Schizophrenia,* published in 1960, and is the author of *Myths of Madness,* scheduled for December publication. Jackson has written two other articles for SCIENTIFIC AMERICAN: "Psychotherapy for Schizophrenia" (January, 1953) and "Suicide" (November, 1954).

KARL VON FRISCH ("Dialects in the Language of the Bees") until his retirement in 1958 was director of the Zoological Institute of the University of Munich, with which he had been associated for various periods since 1910. He became director of the institute in 1925 and supervised the building of new facilities in 1931–1932 with grants from the Rockefeller Foundation. The institute was destroyed in World War II and had to be rebuilt. Von Frisch's doctoral thesis in 1910 dealt with color changes in fish. He then studied color perception in fish and bees. His famous investigation of the "language" of bees began in 1921 and has been continuing ever since. An early account of von Frisch's study of communication among bees appeared in SCIENTIFIC AMERICAN in August, 1948. Von Frisch's honors include membership in the Royal Society of London, the Swedish Academy of Sciences and the U.S. National Academy of Sciences. In 1959 he received the Kalinga Prize given by UNESCO for popular writing on a scientific subject.

PHILIP MORRISON ("Neutrino Astronomy") is professor of physics and nuclear studies at Cornell University. He obtained his Ph.D. under J. Robert Oppenheimer at the University of California in 1940 and then worked on the Manhattan Project, first in Chicago and later at Los Alamos. His present research interests are on the borderline between astronomy and particle physics, including the subject matter of his article in this issue. "Neutrino Astronomy" is the eighth SCIENTIFIC AMERICAN article of which he has been the author or coauthor.

ARTHUR K. SOLOMON ("Pumps in the Living Cell") has headed the biophysical laboratory at the Harvard Medical School since 1946. He is also secretary-general of the newly formed International Organization for Pure and Applied Biophysics. This is his second article for SCIENTIFIC AMERICAN. The first, "Pores in the Cell Membrane," appeared in December, 1960. Solomon did graduate work under George B. Kistiakowsky at Harvard University, receiving his Ph.D. in 1937. He then took up residence at the University of Cambridge, where he studied the applications of nuclear physics to chemical problems, working under the direction of Sir John Cockcroft. Returning to the U.S. just before World War II, he collaborated with Kistiakowsy, James B. Conant (then president of Harvard) and A. Baird Hastings on biological applications of radioactivity. Solomon spent most of World War II working on the development of radar.

H. O. J. COLLIER ("Kinins") is director of pharmacological research at the London branch of Parke, Davis & Co. At Trinity Hall, Cambridge, his teachers included the Nobel Laureate Sir Edgar Adrian. From 1937 to 1941 Collier taught physiology at the University of Manchester and then went into the pharmaceutical industry, "partly to support a growing family and partly because I was interested in applying science to human welfare." He worked first for Imperial Chemical Industries and for Allen and Hanburys Ltd. before joining Parke, Davis. Collier has participated in the development of several drugs, some of which are widely used as anesthetics and disinfectants. Along the way he became interested in the cause and relief of pain, which introduced him to kinins, substances suspected of participating in pain and inflammation. For the British Broadcasting Company he has written dramatizations covering the history and uses of drugs such as curare and quinine. He also appears occasionally on a B.B.C. science-question program.



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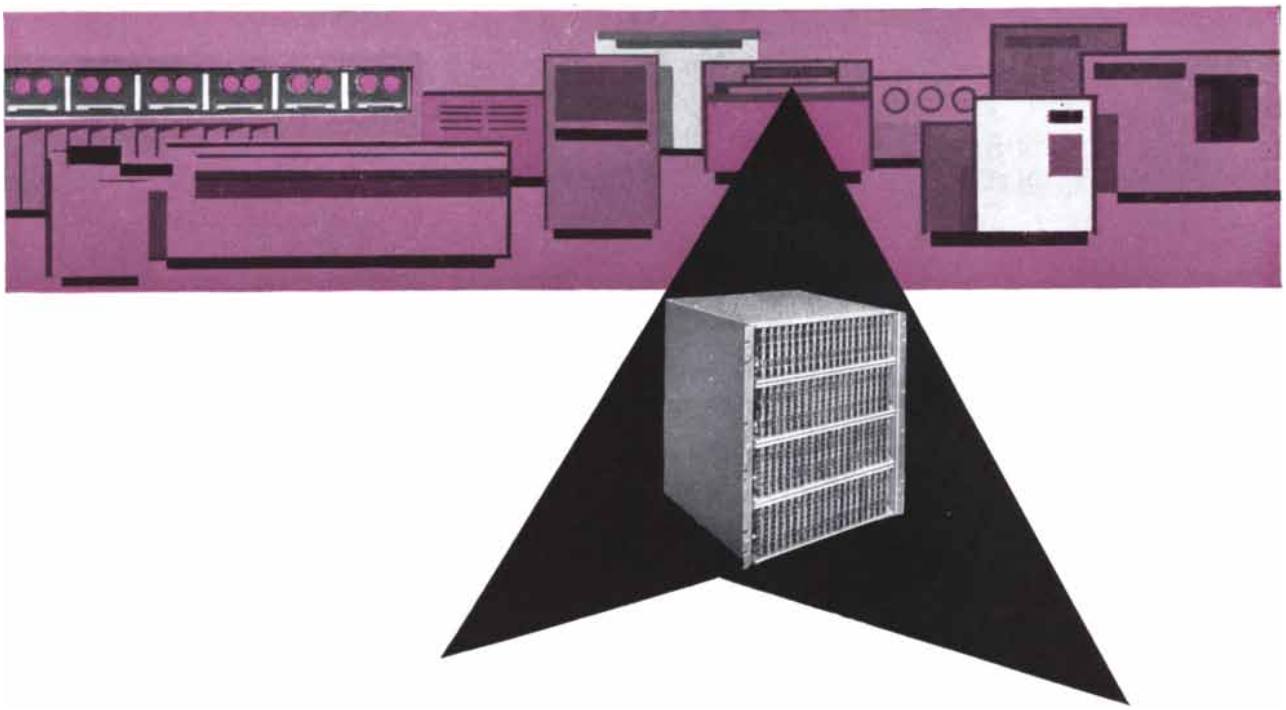

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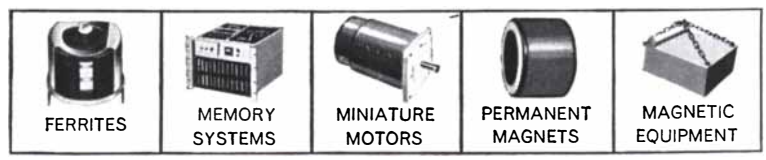

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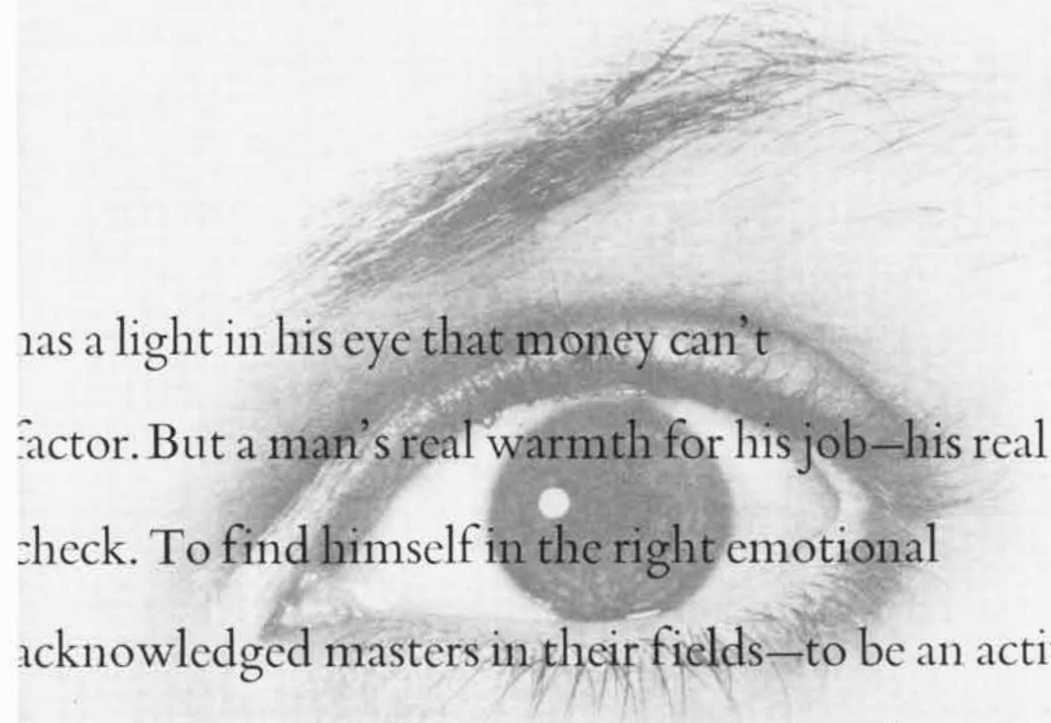

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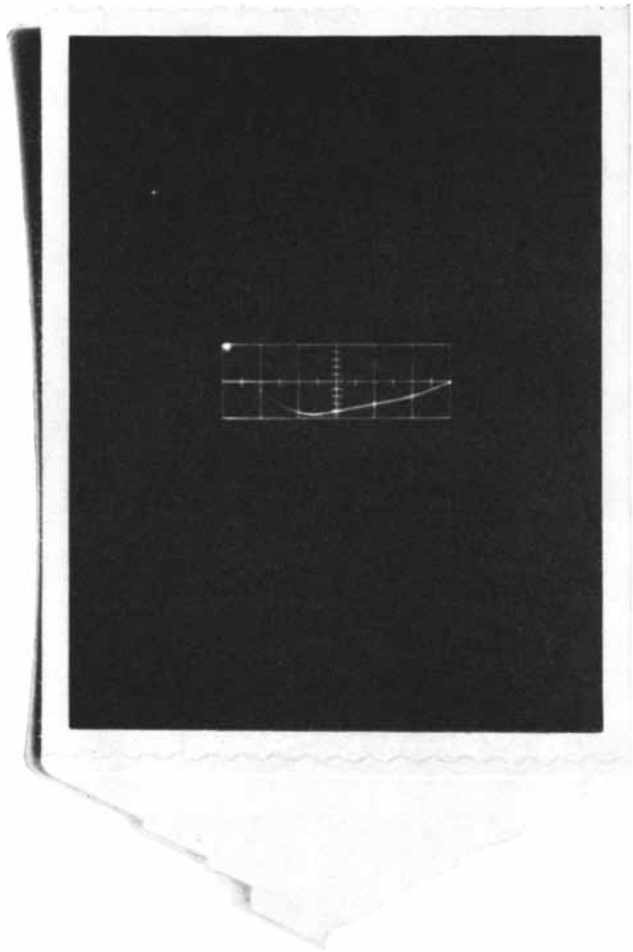


2 nanoseconds/cm: impossible to photograph until now

Polaroid has a new film that is so fast, it will reproduce scope traces that are almost invisible to the naked eye. The one above, a scintillation pulse, has never been photographed until now. Pulse duration was ten nanoseconds. Scope sweep speed was 2 nanoseconds/cm. *The new 10,000-speed Polaroid PolaScope Land film produced a finished usable print ten seconds after exposure.*

The maximum writing speed of the 10,000-speed film is about twice that of the Polaroid Land 3000-speed film, which is currently the standard for high speed photography. The new film not only gets "impossible" pictures, it also produces far better shots of slower pulses and steady state waveforms. Because of its high speed, less light is required; camera aperture and scope intensity can be reduced considerably, producing sharper pictures.

And besides oscillography, the PolaScope film opens up new possibilities in applications where light is at a premium, such as photomicrography and metallography. It is not suited, however, for pictorial work due to its high contrast and relatively coarse grain.

PolaScope film (designated Type 410) is packed twelve rolls to a carton. The price is actually lower than the 3000-speed film.

The film can be obtained through industrial photographic dealers. For the name of the dealer nearest you, write to Technical Sales Department, Polaroid Corporation, Cambridge 39, Massachusetts.

New Polaroid Land 10,000-speed film for oscillography.

Established 1845 SCIENTIFIC AMERICAN August 1962 Volume 207 Number 2

The Thalidomide Syndrome

A mild and supposedly safe sedative taken by pregnant women has deformed the limbs and other organs of several thousand infants in West Germany, England, Canada and other countries

by Helen B. Taussig

Two grossly deformed infants were the subject of an exhibit at the annual meeting of the pediatricians of the Federal Republic of Germany held in October, 1960, in the city of Kassel. Photographs and X-ray pictures showed that the long bones of the infants' arms had almost completely failed to grow; their arms were so short that their hands extended almost directly from their shoulders. Their legs were less affected but showed signs of a similar distortion of growth. Both infants were also marked by a large hemangioma (strawberry mark) extending from the forehead down the nose and across the upper lip; one of them was also found to have a duodenal stenosis, that is, a constriction of the beginning of the small intestine. The physicians who presented these cases, W. Kosenow and R. A. Pfeiffer, members of the staff of the Institute of Human Genetics in Münster, had never seen quite this combination of anomalies in a single infant. They regarded it as a new clinical entity.

The deformity of the limbs was characteristic of a malformation known as phocomelia, from the Greek words *phoke,* meaning seal, and *melos,* meaning limb. Phocomelia is so rare that most physicians never see it in a lifetime; moreover, it usually affects only one limb. Kosenow and Pfeiffer reported that they could find no hereditary indication for the condition in the history of either family, no incompatibility in the blood types of the parents and no abnormality in the chromosomes of the tissue cells of either child. Guido Fanconi, a Swiss pediatrician who has long been interested in congenital deformities, declared that he too had never seen infants afflicted this way. Otherwise little note was taken of the exhibit. I missed it myself, although I was at the meeting.

In retrospect it is surprising that the exhibit did not attract a great deal of attention. During 1960 almost every pediatric clinic in West Germany had seen infants suffering such defects. In Münster there had been 27, in Hamburg 30 and in Bonn 19. There had been perhaps a dozen cases of phocomelia in 1959, whereas in the preceding decade there had been perhaps 15 in all of West Germany. During 1961 the incidence of phocomelia increased rapidly; hundreds of afflicted infants were born.

When the West German pediatricians gathered for their 1961 meeting in November at Düsseldorf, almost all of them were aware of the mysterious outbreak of phocomelia. At the meeting Widukind Lenz of Hamburg made the disclosure that he had tentatively traced the disease to a new drug that had come into wide use in sedatives and sleeping tablets. The generic name of the drug was thalidomide. Under the trade name Contergan, it had been marketed as freely as aspirin in West Germany from 1959 into the spring of 1961. Lenz had found that many mothers of "seal limb" infants admitted to the Hamburg clinic had taken this drug early in pregnancy. Contergan and other preparations containing thalidomide have now been withdrawn from sale. But infants injured by the drug are still in gestation. When the last of them has been born by the end of this summer or early in the autumn, thalidomide will have produced deformities in 4,000 or even as many as 6,000 infants in West Germany alone, and probably more than 1,000 in other countries where it has been marketed. The one-third who are so deformed that they die may be the luckier ones.

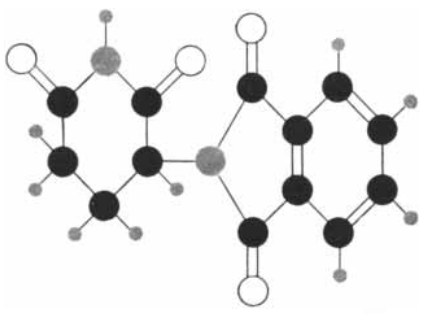
It happens that thalidomide-containing drugs did not reach the market in the U.S. This was because of a lucky combination of circumstances and the alertness of a staff physician at the Food and Drug Administration—not because of the existence of any legal requirement that the drug might have failed to meet. If thalidomide had been developed in this country, I am convinced that it would easily have found wide distribution before its terrible power to cause deformity had become apparent. The marketing techniques of the pharmaceutical industry, which can saturate the country with a new drug almost as soon as it leaves the laboratory, would have enabled thalidomide to produce thousands of deformed infants in the U.S. I believe that it is essential to improve both the techniques for testing and the legal controls over the release of new drugs.

The news that a large number of malformed infants had been born in West

Germany and that a sleeping tablet was suspected as the cause first came to me in late January of this year. I was particularly concerned because of my lifelong interest in malformations. That a drug was implicated was of especial interest, because little is known about the cause of the various congenital anomalies that arise in the course of gestation. I immediately went to West Germany to investigate the situation, and I have also conferred and corresponded with physicians in other countries where thalidomide, under various names, has been sold.

In West Germany I was told that a Swiss pharmaceutical house, interested in producing a new sedative, had first synthesized thalidomide in 1954. Because it showed no effects on laboratory animals the company discarded it. Then the West German firm Chemie Grünenthal undertook the development of the compound. Once again thalidomide showed no effect on laboratory animals. Since the structure of the molecule suggested that it should work as a sedative, Grünenthal tried it as an anticonvulsant for epileptics. It did not prevent convulsions, but it worked as a hypnotic, acting promptly to give a deep, "natural" all-night sleep without a hangover. Given the trade name Contergan, it became during 1960 the favorite sleeping tablet of West Germany, inexpensively available without a prescription and widely used in homes, hospitals and mental institutions. It turned out to be as safe for humans as for animals. Would-be suicides who tried it after it came on the market survived large doses of it without harm.

Grünenthal combined thalidomide with aspirin and other medicines. Germans consumed these compounds—Algosediv, Peracon Expectorans, Grippex and Polygrippan—for such conditions as colds, coughs, grippe, nervousness, neuralgia, migraine and other headaches and asthma. A liquid form made especially for children became West Germany's baby sitter. Hospitals employed it to quiet children for electroencephalographic studies. As an antiemetic, it helped to combat the nausea of pregnancy, and of course Contergan gave many a pregnant woman a good night's sleep. Grünenthal was manufacturing it almost by the ton.



THALIDOMIDE is a synthetic drug. In this diagram of its molecule, carbon atoms are represented by black balls, hydrogen by small gray balls, oxygen by white balls and the two nitrogen atoms by large gray balls.

Soon pharmaceutical companies in other countries began to make or market thalidomide under license from Grünenthal. Distillers (Biochemicals) Ltd. sold it as Distaval in the British Isles, Australia and New Zealand. Combinations received the trade names of Valgis, Tensival (a tranquilizer), Valgraine and Asmaval. An advertisement in Great Britain emphasized the safety of the drug with a picture of a small child taking a bottle from a medicine shelf. From Portugal it went into local and international channels of distribution as Softenon. In Canada Frank W. Horner Ltd. of Montreal marketed it as Talimol and the Canadian branch of the Wm. S. Merrell Company of Cincinnati as Kevadon. In September, 1960, the Merrell Company applied to the Food and Drug Administration for clearance to sell Kevadon in the U.S.

At that time no one had reported any untoward side effects from thalidomide. During the next few months, however, German medical journals carried reports of a new polyneuritis associated with long-term use of the drug. Patients complained of tingling hands, sensory disturbances and, later, motor disturbances and atrophy of the thumb. By April, 1961, there was a sufficient number of ill effects reported in West Germany following the use of the drug to place the thalidomide compounds on the list of drugs for which prescriptions were required. (It was under prescription from the beginning in most other countries.) Nevertheless, thalidomide remained popular and continued in widespread use in the home and in hospitals.

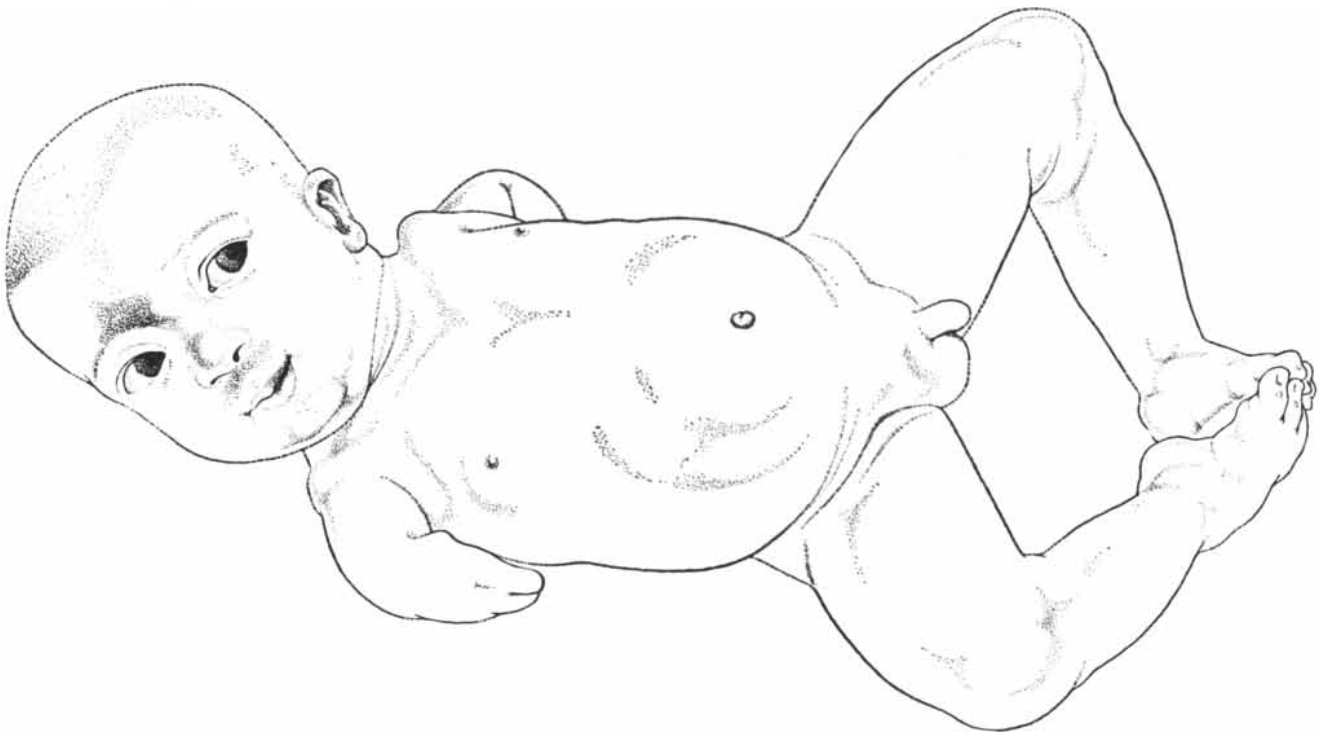
By the summer of 1961 physicians all over West Germany were realizing with alarm that an increasing number of babies were being born with disastrous deformities of their arms and legs. In Kiel, Münster, Bonn and Hamburg four different investigations were under way. From a study of 32 cases in Kiel and its environs H. R. Wiedemann found that the malformations followed a specific pattern, although they varied in severity.

Abnormality of the long bones of the arms characterizes the great majority of the cases, with the legs involved in half of these. The radius or ulna (the forearm bones) or both may be absent or defective. In extreme cases the humerus (upper-arm bone) also fails to appear. Typically both arms are affected, although not necessarily equally. When the legs are involved, the hip girdle is not fully developed. Dislocation of the hip and outward rotation of the stub of the femur turns the deformed feet outward. The worst cases have neither arms nor legs; since they cannot turn over in the crib or exercise they usually succumb to pneumonia.

The hemangioma of the face, as Pfeiffer and Kosenow pointed out, is possibly the most characteristic feature of the syndrome. It is, however, neither harmful nor permanent. A saddle-shaped or flattened nose is common. In some cases the external ear is missing and the internal auditory canal is situated abnormally low in the head. In spite of this deformity hearing tends to be fairly good if not normal. Many of the children display paralysis of one side of the face. Many suffered from a variety of malformations of their internal organs, involving the alimentary tract and also the heart and circulatory system. Most of the children seem to be normally intelligent.

Pfeiffer and Kosenow in Münster had found no evidence that the phocomelia in their first two cases was hereditary. Eventually they completed detailed studies of 34 cases, with the same result. This was surprising because many of the previous cases of phocomelia could be traced back in the family. These two investigators concluded that an unknown agent from the environment, affecting the embryo at some time between the third and sixth week of pregnancy, had caused the damage. During this period, when most women do not yet know they are pregnant, the embryo goes through the principal stages of development.

Was the unknown agent a virus? An infection by rubella, or German measles, during this critical period of gestation results in severe malformations but not in phocomelia. That it might be some other virus seemed to be ruled out by the fact that the increase in the incidence of phocomelia had been steady, not abrupt, and by the fact that the cases were confined within the boundaries of West Germany. By the time of last year's pediatric meeting at Düsseldorf in late



VICTIM OF THALIDOMIDE SYNDROME typically has short, deformed and useless arms and hands. The actual case shown in this drawing displays the hemangioma, or strawberry mark, on the forehead, nose and upper lip, which is the most characteristic (although harmless) feature of syndrome. Other abnormalities that may occur include deformed legs and feet and a wide variety of deformations of the ears, digestive tract, heart and large blood vessels. Most of the afflicted children have normal intelligence.

November the range of speculation included radioactive fallout.

Lenz meanwhile had formed a new suspicion. Like the other investigators, he had been sending out lengthy questionnaires to the parents of deformed infants and to the physicians who attended them, asking about X-ray exposure, drugs, hormones, detergents, foods and food preservatives, contraceptive measures and tests for pregnancy. In his initial returns he noted that approximately 20 per cent of the mothers reported taking Contergan during pregnancy. On November 8, he recalls, it occurred to him that Contergan might be the cause. He now asked all the parents specifically about Contergan, and 50 per cent reported use of the drug. Many of the mothers said that they had considered the drug too innocuous to mention on the questionnaire.

On November 15 Lenz warned Grünenthal that he suspected Contergan of causing the catastrophic outbreak of phocomelia and he urged the firm to withdraw it from sale. On November 20, at the pediatric meeting, he announced that he suspected a specific but unnamed drug as the cause of the "Wiedemann syndrome" and said that he had warned the manufacturer. That night a physician came up to Lenz and said: "Will you tell me confidentially, is the drug Contergan? I ask because we have such a child and my wife took Contergan." Before the meeting was over the doctors generally knew that Lenz suspected Contergan.

On November 26 Grünenthal withdrew the drug and all compounds containing it from the market. Two days later the West German Ministry of Health issued a firm but cautious statement that Contergan was suspected as the major factor in causing phocomelia. Radio and television stations and the front pages of newspapers promptly carried announcements warning women not to take the drug.

On the other side of the world W. G. McBride, a physician in New South Wales, Australia, saw three newborn babies with severe phocomelia during April, 1961. In October and November he saw three more. From the histories of the mothers he found that all six had taken Distaval in early pregnancy. McBride notified the Australian branch of Distillers Ltd. and it cabled his findings to the London headquarters on November 27. This and the news from Germany caused the firm to withdraw the drug on December 3. Because of the demand by physicians it has been returned to limited sale in England, but in Germany it is now illegal to possess thalidomide.

The news of the Australian experience prompted A. L. Speirs, a physician of Stirlingshire, Scotland, to review 10 cases of phocomelia that he had seen in his practice during the preceding months. By checking prescription records and medicine cabinets in the victims' homes, he obtained positive proof that eight of the mothers had taken Distaval in early pregnancy.

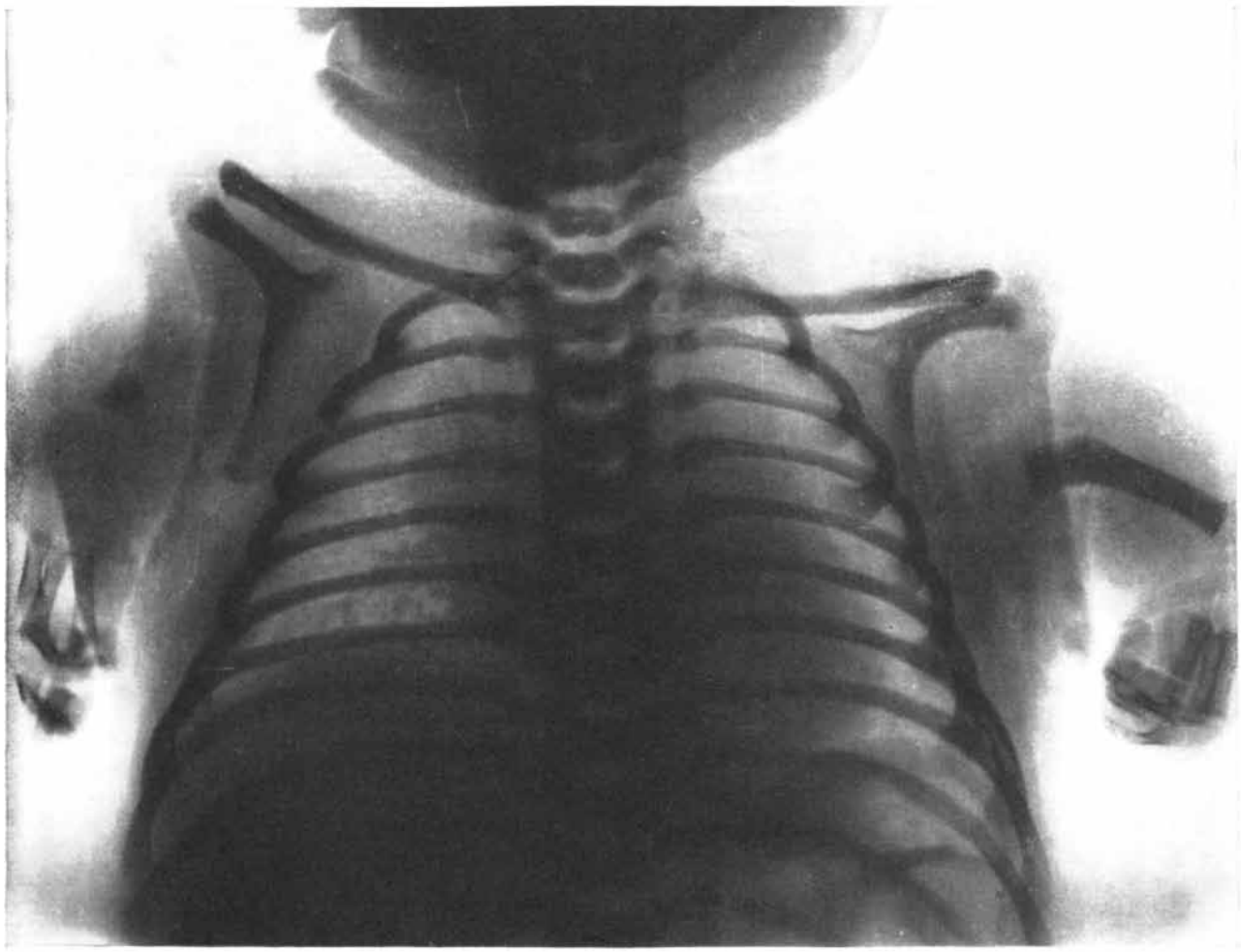
Thus in the last weeks of 1961 circumstantial evidence accumulating in various parts of the world indicated that thalidomide played an important role in the causation of phocomelia. Physicians now began asking women who were still pregnant about their experience with the drug. One obstetrician in Germany asked 65 pregnant women if they had taken Contergan in early pregnancy. Only one said that she had. The physician declared that if she had an abnormal baby, he would believe Lenz. She did!

Among 350 pregnant women in Lü-

beck, W. von Massenbach found that 13 had taken Contergan, six during the second half of pregnancy and seven in the first four and a half months. Of the seven, two had babies with phocomelia, one had a baby with a closed anus and four had normal infants. By March, 1961, clinical records in Düsseldorf showed that 300 women who had not taken Contergan had given birth to healthy infants, whereas half of those who reported taking Contergan bore deformed infants. At Hamburg, meanwhile, Lenz had set out to investigate the exact connection between phocomelia and the drug and to fix reliably the date or dates of exposure to the drug in each case. He considered the use of Contergan to be proved only by a photostatic copy of a prescription or by a hospital record. This was difficult because the drug had been sold without prescription before April, 1961, and because nurses in German hospitals dispense sleeping tablets as freely as nurses in the U.S. give laxatives. In one case, Lenz told me, the attending physician swore that the mother had not received Contergan, although her baby had been born with phocomelia. The physician insisted that he had prescribed a different sedative. At the pharmacy Lenz found the prescription marked by the druggist: "Drug not in stock. Contergan given instead."

By the middle of March of this year Lenz had assembled histories on 50 cases in which he had established documentary evidence for use of the drug and had determined the date of the last menstrual period before pregnancy. He had proof in each case of the date or dates on which Contergan had been taken. All but five of the women had taken the drug between the 30th and 50th day after the last menstrual period and the five had taken it between the 50th and 60th day. In the 21 instances in which Lenz managed to ascertain the date of conception, the mother had taken Contergan between the 28th and 42nd day after conception. Thus the exact time when thalidomide can damage the embryo varies somewhat, but the period in which the embryo is especially vulnerable to the drug appears to be relatively brief.

In the human embryo the first signs of future limbs can be discerned with a microscope when the embryo is only 10 days old. By 42 days the tiny limbs are visible to the naked eye, although the embryo is only a little more than an inch long. The fact that the arm buds develop slightly earlier than those of the legs may be of significance in accounting for the greater frequency of arm damage. As the malformations indicate, the drug arrests and deranges those processes of development that are in progress when the embryo is exposed to it. Just how thalidomide interferes with growth remains to be determined. Some German doctors still doubt that Contergan is the sole



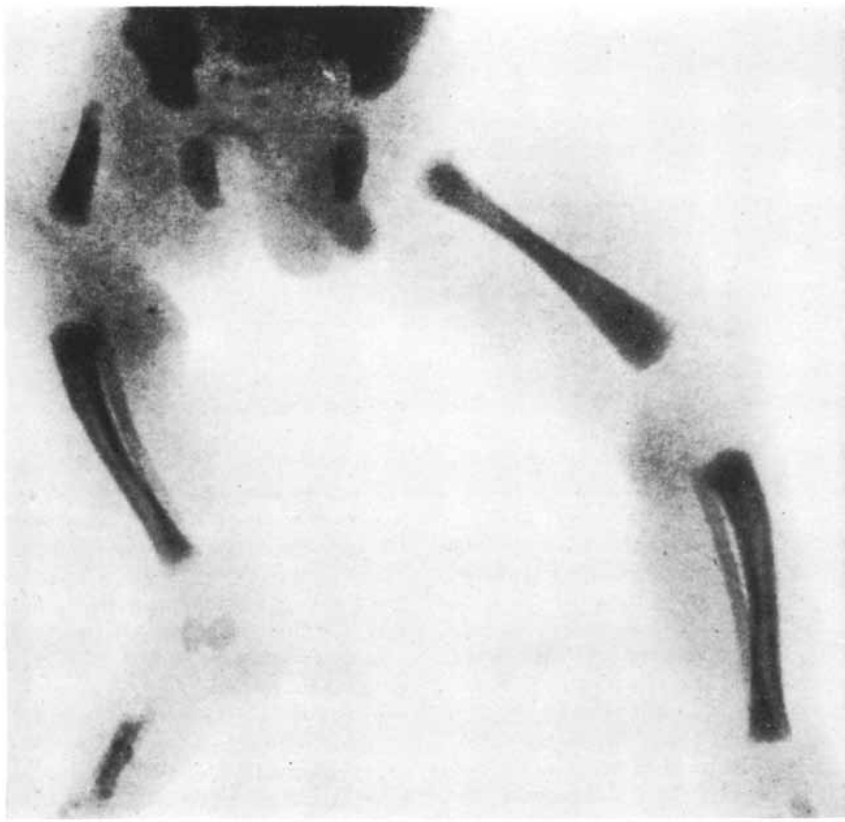
TYPICAL PHOCOMELIA, or "seal limb," is readily apparent in this X ray of chest, shoulders and arms of West German infant. In "classic" phocomelia usually only one arm was affected. Phocomelia caused by thalidomide almost always deforms both arms.

cause of the phocomelia syndrome, and a number of English physicians hold that some other substance or factor also causes phocomelia because they cannot get a history of Distaval or compounds containing it in every case. Furthermore, there is apparently no relation between the amount of the drug ingested and the severity of the malformation. A single dose of 100 milligrams appears to be enough to cause severe phocomelia, yet in other instances the same doses may produce only a mild abnormality. This must be due to a lack of susceptibility or to the fact that the drug was not taken in the sensitive period.

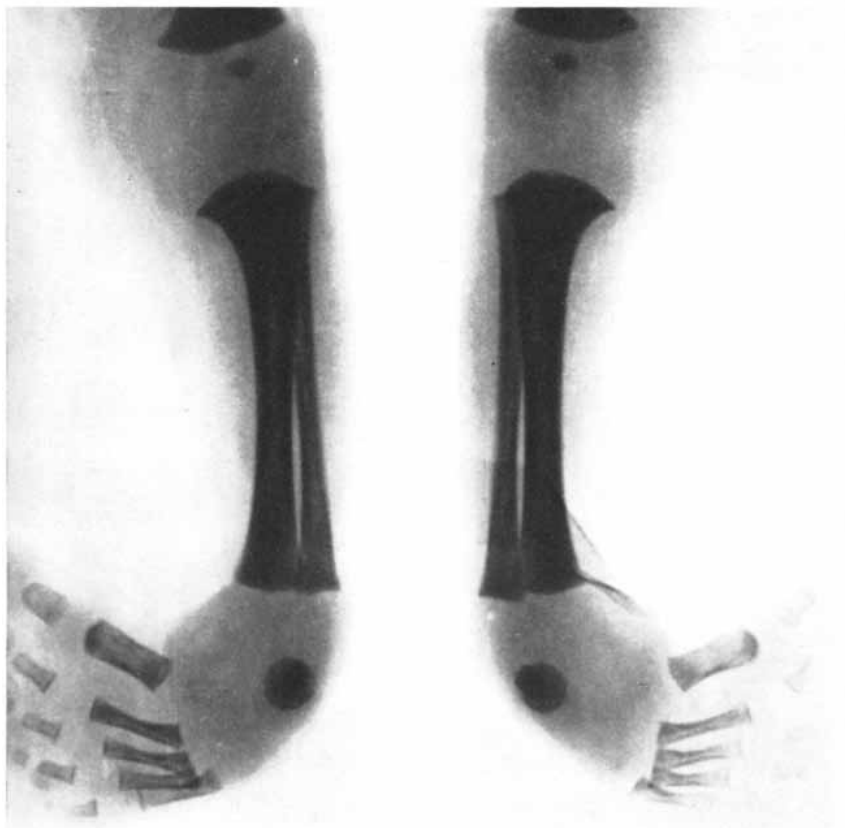
A drug with a molecular structure similar to that of thalidomide is Doriden, also used as a sedative. Although in a few cases of phocomelia the mother says she took Doriden, not Contergan, Doriden has been widely used in Switzerland since 1955, and phocomelia did not appear there until 1961. Almost all the few Swiss cases have been traced to Contergan from Germany.

Little is known about the metabolism of thalidomide, how the body excretes it or how long the deformity-producing factor persists in the body. About all that is certain is that it is insoluble in water and in fat. Obviously the usual laboratory animals metabolize it differently from human beings; it does not induce sleep in the animals. Investigators at the Grünenthal laboratories have tried unsuccessfully to produce phocomelia in rats, mice and rabbits. They have shown that the drug passes through the placenta of rabbits, but the offspring were normal in these experiments. G. F. Somers of the Distillers Ltd. laboratories has fed massive doses to pregnant rabbits. The rabbits did not sleep; they did, however, produce offspring with abnormalities remarkably similar to those in human infants. Since thalidomide makes a horse sleep, it may be that the horse will react in other ways as man does. Experiments with monkeys and apes will also be of interest. When the proper experimental animal is found, thalidomide does offer the possibility of studying the origin of malformations.

It is not yet possible to determine the exact number of infants born with phocomelia in West Germany, but the outbreak was devastating. The records of the Institute of Human Genetics in Münster show three cases of bilateral phocomelia in 1959, 26 cases in 1960 and 96 in 1961. Up to this spring 13 pairs of twins afflicted with phocomelia had been



DEFORMITY OF LEG, here a very short femur, or thighbone (*left*), characterizes quite a few cases of the thalidomide syndrome. The bones of the hip girdle are also abnormal.



FEET ROTATE OUTWARD in this case. Even though badly deformed, this child may be able to learn to walk. Widukind Lenz, Hamburg pediatrician, supplied these three X rays.

registered. Since twins occur once in every 100 births, the institute estimates that there will be 1,300 cases in the state of North Rhine–Westphalia, where it is located. It is an indication of the prevalence of phocomelia that the state's Ministry of Health has set up a registry for all children with defective hands and arms who will need orthopedic help. As of January, 800 had been registered, 80 per cent suffering from phocomelia, and reports were in from only half the state. By now the total may have reached 2,000. Applying this experience to the population of West Germany as a whole, the country anticipates a minimum of 4,000 cases. I should not be surprised by a total of 6,000. There is every reason to believe that two-thirds of the infants will live for many years; indeed, the children appear to have a normal life expectancy.

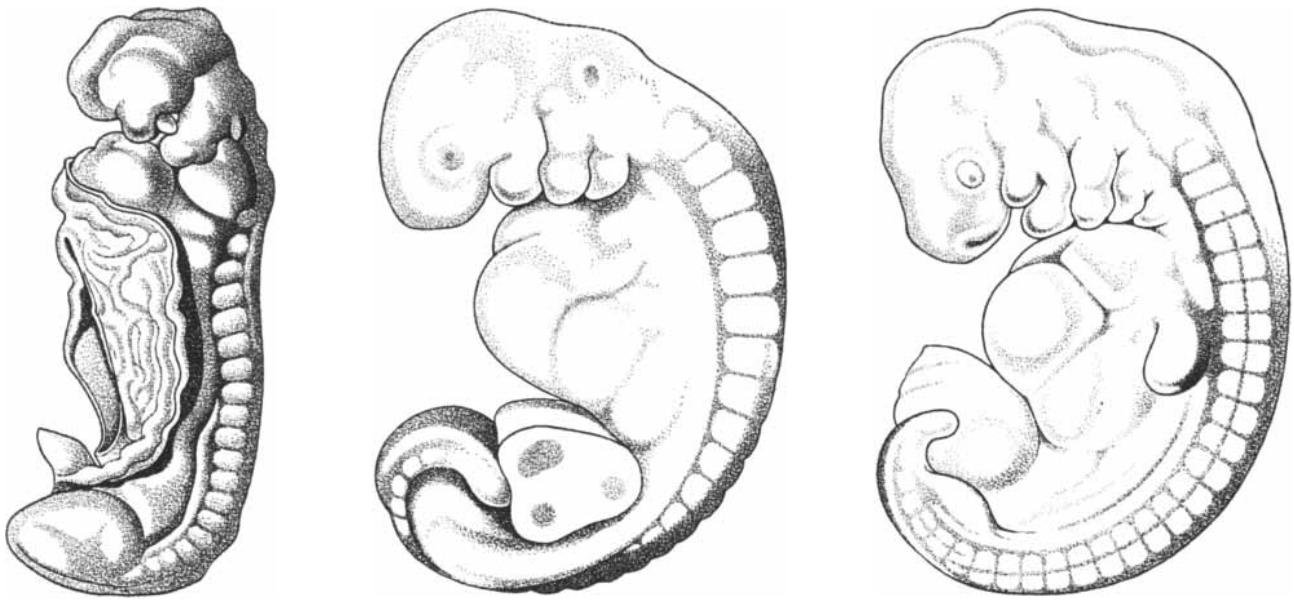
In England, alas, the incidence is also high. Reports of phocomelia associated with Distaval appear regularly in *The Lancet,* the British weekly medical journal. Clifford G. Parsons of Birmingham has advised me that almost every physician at a medical meeting in England last spring had seen at least one case. The total for the country will probably be in the hundreds, however, not in the thousands.

Reports are still coming in from all over the world showing that phocomelia has occurred wherever thalidomide has been used. Sweden has had 25 cases, from Contergan purchased in Germany. Switzerland has had four cases. The Portuguese preparation, Softenon, has caused seven cases in Lebanon. Distaval has produced a case in Israel. In Peru, Contergan obtained by the father in Germany caused a case. Lenz has written me of an outbreak of phocomelia in Brazil. As yet I have received no figures for Portugal.

In September, 1960, when the Merrell Company applied to the Food and Drug Administration for permission to distribute the thalidomide compound, none of these untoward developments could have been anticipated. Clearance was delayed because the initial submission of papers was found to be "incomplete." Over the next few months, while the manufacturer gathered and filed additional material in support of the application, the first indications of the drug's neuropathic side effects were reported in the German medical press. Frances Oldham Kelsey, a physician and pharmacologist at the agency, took note of these reports. She also noted that the proposed label for the drug recommended its use against the nausea of pregnancy. From her work with quinine in connection with the malaria project during World War II, Mrs. Kelsey had become "particularly conscious of the fact that the fetus or newborn may be, pharmacologically, an entirely different organism from the adult." She therefore requested more data from the manufacturer to show that the drug was safe in pregnancy. Before her questions were answered the outbreak of phocomelia in Germany had brought withdrawal of the drug from the market in that country.

If thalidomide had been developed in this country, the story would have been quite different. Almost everyone agrees that with no knowledge of the delayed neuropathic effects of the drug and no appreciation of its dangers in pregnancy, the thought would not have occurred to anyone that it might injure the unborn child. Therefore permission for sale of the drug as a sedative would have been granted; it was an excellent sedative and appeared to be safe.

In the U.S. there have been only a few cases of the syndrome—two of them the twin offspring of a German woman who had married an American and brought Contergan with her to the U.S. Even the families of U.S. personnel stationed abroad have escaped—with one exception. At the U.S. Army headquarters in Heidelberg, in March, Thomas W. Immon was able to assure me that not one of the 16,000 babies born in U.S. hospitals in Germany during 1961 had phocomelia. More recently, however, he has had to report the birth in a U.S.



DEVELOPMENT OF HUMAN EMBRYO from third week after conception (*far left*) through eighth week (*far right*) is crucial. The embryo grows from about a quarter of an inch in length at end of third week to one and a quarter inches at end of eighth. Thalid-

Army hospital of one infant with phocomelia. The mother, a German, reported that she had taken Contergan in the early weeks of her pregnancy.

Unfortunately the people of Canada have had a different experience, even though the Dominion Government has a drug-regulating agency like that of the U.S. With two thalidomide preparations on the market in 1961, many pregnant women were exposed to the drug. At least 12 have delivered offspring afflicted with deformed arms and legs. The manufacturers issued a warning to physicians in December, advising them not to prescribe thalidomide for pregnant women. It was not until March, however, that governmental authorities asked the manufacturers to withdraw the drug entirely. Between now and the fall there will undoubtedly be additional casualties.

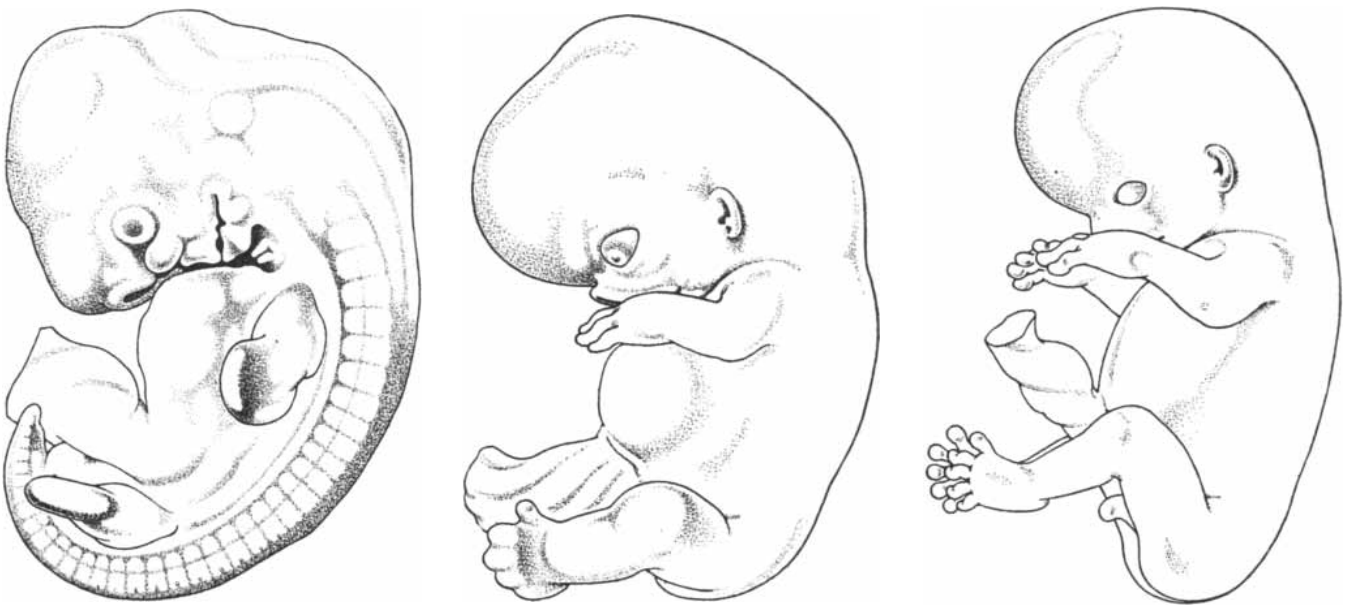
A generation ago new drugs, particularly those for relatively minor complaints such as insomnia, only gradually achieved widespread popularity. The rather small number of people using them in the first few years provided, albeit unwittingly, test cases not only for the efficacy but also for the long-term safety of the drug. Today "educational" representatives of drug houses visit each physician regularly. Pounds of lavish and expensive drug brochures assault the physician by mail. Most medical journals are crowded with handsome advertisements, many printed in full color on heavy cardboard or metallic paper, extolling the virtues of this year's model or modification of some recently invented tranquilizer, diuretic or antihypertensive compound. New drugs thus find huge markets within a few months.

In most countries, with the exception of Canada, governmental regulation of the pharmaceutical trade is less stringent than it is in the U.S. The Food and Drug Administration, however, is limited to considering only the safety and not the efficacy of a drug, and it exercises no control until the drug is ready for sale. During testing, conducted by and for the drug houses, a new compound may be distributed for clinical trial to many physicians. They are supposed to warn patients that the drug is experimental and to obtain a release signed by the patient. Not all physicians keep careful records of the cases in which they have distributed such test drugs. Clearance by the Food and Drug Administration, which rests on evidence of safety submitted by drug companies, must often be based in part on reports from observations made under clinical conditions that are, to say the least, not ideal. Certainly the procedure needs strengthening here.

Until recently no thought had been given to the need for the testing of drugs for potential harmfulness to the human embryo. In my laboratory at the Johns Hopkins School of Medicine I have not been able to obtain abnormalities in baby rabbits with thalidomide primarily because the massive doses I have used bring on so many abortions. This illustrates one of the problems of testing new drugs: what size dose in animals makes for a fair test? As thalidomide shows, animals may not react at all like humans.

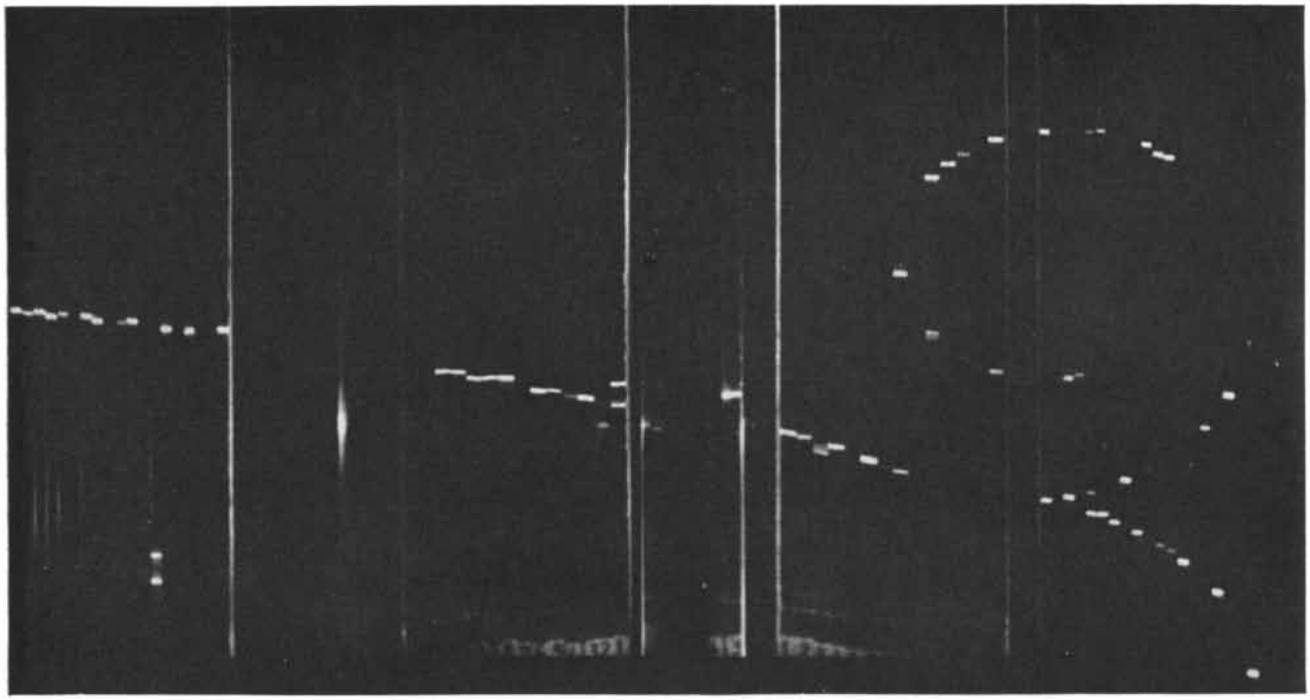
Of course, no drug can ever be certified as completely safe. But all the hazards of a given drug should be established before it is marketed. In dealing with cancer and other serious diseases there is some justification for taking chances with new drugs. The less serious the illness is, the more certain it should be that the drug is harmless as well as effective. In the case of thalidomide, I wonder how long it would have taken to determine the cause of the malformations if the drug had produced some more common but less spectacular congenital defect. Any drug labeled safe should be relatively harmless for all people of all ages, including the unborn. Married women of childbearing age should avoid drugs as much as possible, particularly new ones.

For most people the story of thalidomide has ended. The tragedy will go on, however, for the infant victims of the "harmless" sedative and their families for the rest of their lives.

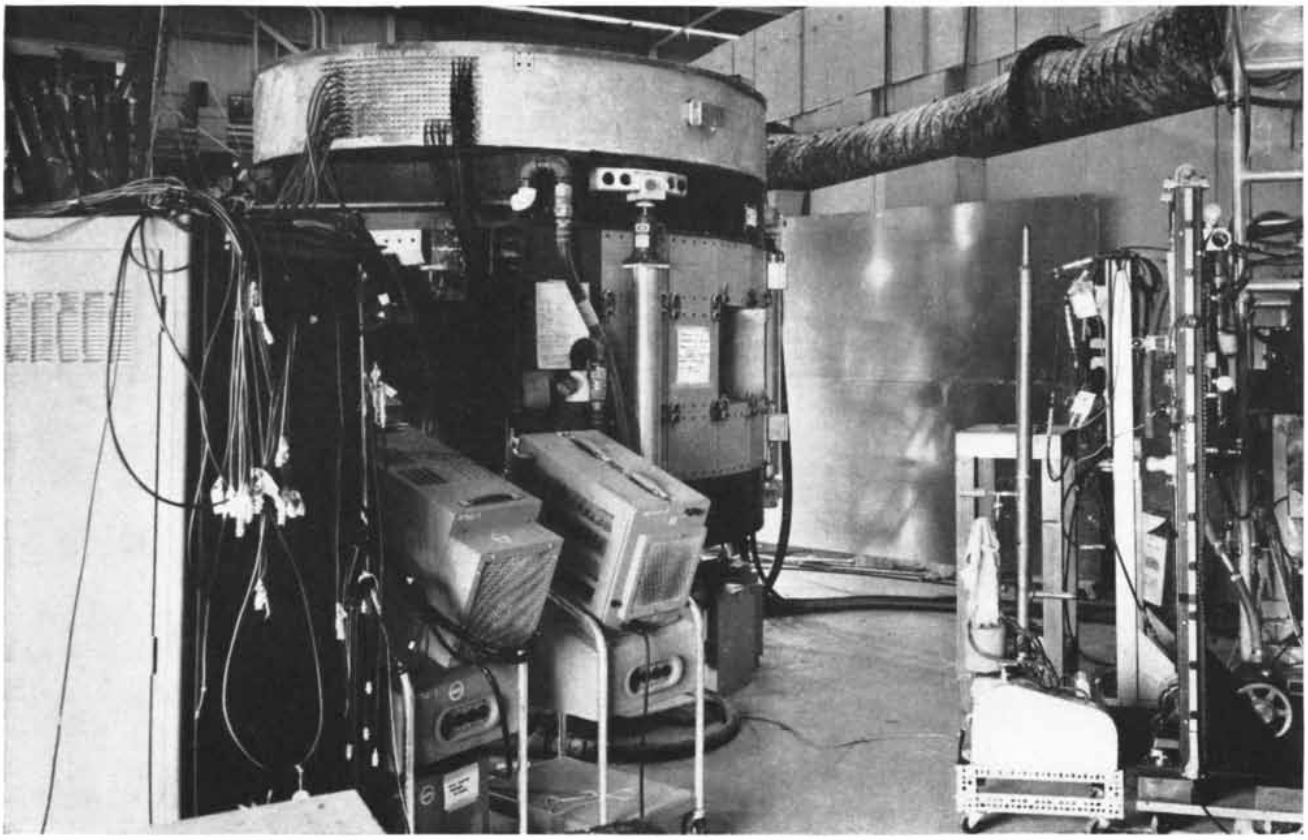


SIXTH WEEK SEVENTH WEEK EIGHTH WEEK

omide seems to cause almost all its deformities when the mother takes the drug during the fourth, fifth or sixth week of pregnancy, as limb buds, ears, intestinal tract, heart and blood vessels are forming and going through first growth. These embryos are normal.



TRACKS OF CHARGED PARTICLES are made visible by spark chamber operated at the European Organization for Nuclear Research (CERN) in Geneva. The chamber contains a series of metal plates surrounded by neon, in which a charged particle leaves an ionization trail. If a high-voltage pulse is applied quickly to alternate plates, sparks follow the trail. Here a negative pi meson enters at left and reacts to give an invisible neutral pion, which decays into two invisible gamma rays. One gamma ray yields the tracks of an electron and positron, which are curved in opposite directions by a magnetic field. The chamber was built by Arthur Roberts, G. R. Burleson, T. F. Moang, P. Kalmus, L. Niemala and T. A. Romanowski of the Argonne National Laboratory and B. Leontic of CERN.



SPARK CHAMBER INSIDE MAGNET at Brookhaven National Laboratory was built by the author, F. V. Murphy, Richard B. Watson and Kenneth E. Wright of Princeton University. The diameter of the magnet is eight feet. The spark chamber has a volume of two cubic feet and contains 128 metal plates spaced three millimeters apart. The magnet makes charged particles curve as they pass through the chamber. The particles originate in the 30-billion-electron-volt proton accelerator, beyond the wall at right, and enter through the port at the right side of the instrument. A photograph made by this device appears at upper right on pages 42 and 43.

THE SPARK CHAMBER

It is a new device to make visible the tracks of subatomic particles. Basically it consists of a series of charged plates. When a particle passes through the plates, its path is traced by sparks between them

by Gerard K. O'Neill

The present understanding, imperfect but growing, of the fundamental nature of matter has come largely from observation of the elementary particles. The protons, neutrons, electrons, mesons and other particles reveal the most when they can be studied one at a time or when only two or three of them interact. When larger numbers are present, the sheer mathematical complexity of their interaction hides the fundamental simplicities. For this reason the efforts of many experimental physicists over several decades have gone into the development of sensitive methods for detecting single particles.

There is no single best design for a particle detector. To obtain certain characteristics it is usually necessary to sacrifice others, and the choice depends on the nature of the experimental "events" one wishes to observe. Physicists working with the large particle-accelerating machines have increasingly been concerned with extremely rare events, epitomized by the recent discovery at the Brookhaven National Laboratory that there are two kinds of neutrino rather than one [see "Science and the Citizen," page 52]. To obtain the evidence for this discovery the 30-billion-electron-volt proton accelerator at Brookhaven was operated for six months. Over this period the number of recorded events caused by neutrinos averaged fewer than one every three days. The particle detector used in the experiment is of an entirely new type: it is called a spark chamber. Before explaining its operation I shall describe the general nature of the particle-detection problem.

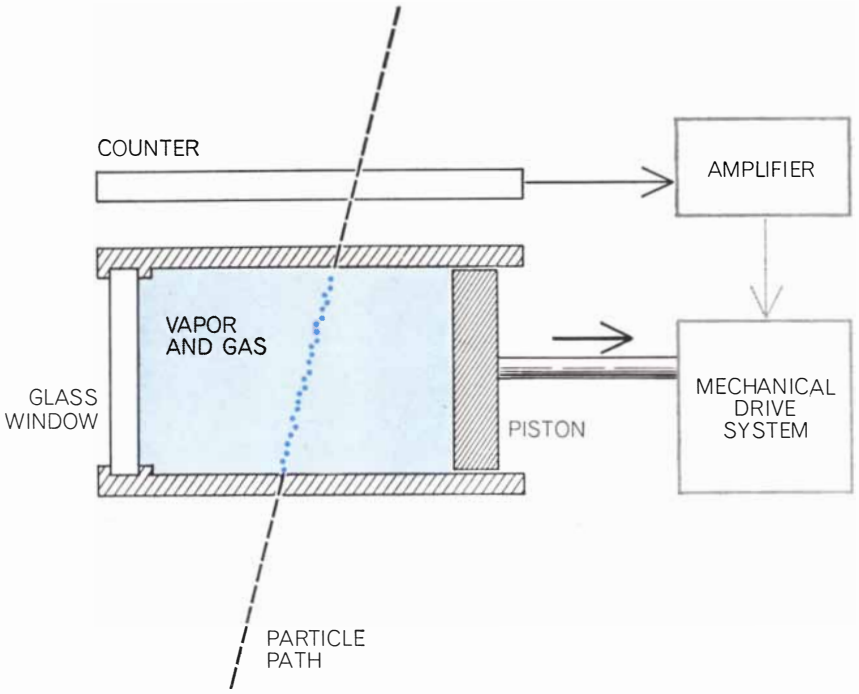
The problem is far from easy, because an elementary particle can pass freely through many atoms of any substance without leaving a trace. Even at present there is no practical device that can detect electrically neutral particles without destroying or deflecting them. Charged particles, however, exert a strong electrostatic force on the electrons of the atoms through which they pass. Usually the electrostatic force between the negative electron and the positive nucleus is enough to keep the electrons from breaking free, but occasionally—roughly once in every 1,000 atoms through which a charged particle passes—an electron is jolted loose. In air, for example, about 100 electrons are freed along each centimeter of the path of a charged particle, and for each free electron a corresponding positive ion is formed. If the small amount of energy contained in this "ionization trail" can be made to produce some visible effect, the physicist can find out where the particle went. He can also measure the momentum of a particle by observing the radius of curvature of its track in a magnetic field, and he can obtain information about the way it interacts with other particles by observing sudden changes in direction of its track.

In one of the first of all elementary-particle experiments Hans Geiger and Ernest Marsden, working in the Cavendish Laboratory at the University of Cambridge, detected the small energy of an ionization trail without amplification by using the extreme sensitivity of the dark-adapted human eye. They observed the small flashes of light made when alpha particles went through certain crystalline materials called scintillators. From Geiger and Marsden's observations of the angles at which alpha particles scattered from a target into the scintillator, Ernest Rutherford concluded by 1913 that the positive charge of the atom was concentrated in a nucleus.

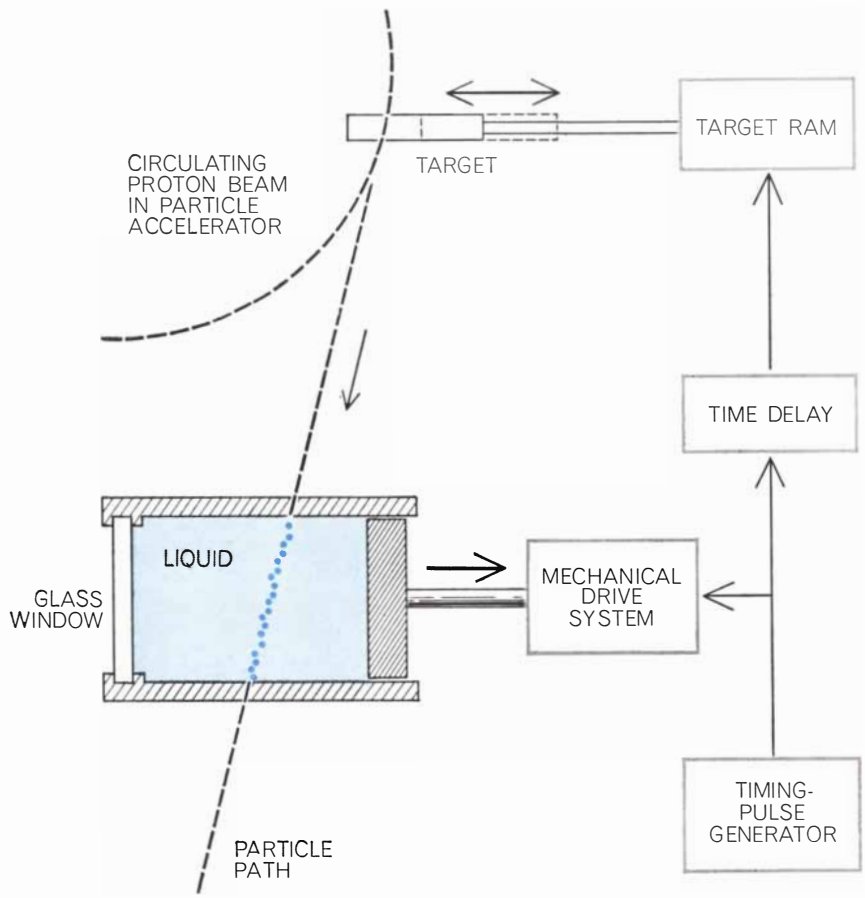
A fast, singly charged particle—a cosmic ray meson, for example—produces only about a thousandth as many free electrons per millimeter of track as a slow, doubly charged alpha particle does. The detection of fast particles therefore requires some kind of amplification of the energy of the ionization trail. Since Rutherford's time the devices used to detect elementary particles have divided into two broad classes, both of which amplify. One class consists of "counters." Every counter includes a sensitive volume of gas, liquid or solid with well-defined dimensions in space. When a charged particle passes through the sensitive volume, the counter produces a brief electric pulse, or signal. The pulses can be tallied electronically; hence the name "counter."

The other class does not have a well-recognized generic name, but it can be called the class of "track detectors." A track detector shows where a charged particle went by indicating many points in space along the particle's ionization trail. Usually the information provided by a track detector is recorded by photography. In fact, for certain purposes stacks of photographic film or a single block of photographic emulsion can be used directly as a track detector. A charged particle sensitizes emulsion grains along its track and amplification is achieved by means of a chemical developer. In the next few years some advanced track detectors may be built that will put out information in the form of electrical signals.

If one compares the two classes, it is apparent that the counter gives only a limited amount of information, but it gives it immediately in a simple form suitable for direct use in electronic circuits. In modern counters the information is often available in less than 10 nanoseconds (10 billionths of a second). The track detector gives much more information, but the information goes into photographic emulsion, where it is unavailable until the emulsion is developed



CLOUD CHAMBER, invented in 1911 by C. T. R. Wilson, was the first of the particle-track detectors. A counter, which simply senses the arrival of a particle, triggers the movement of a piston that expands the gas and vapor inside the chamber. This makes the vapor supersaturated, and fog droplets rapidly grow along the ionization trail left by passage of the particle. The droplets form clear tracks, which are photographed stereoscopically for analysis.



BUBBLE CHAMBER, a track detector invented by Donald A. Glaser, contains a liquid near its boiling point. When the chamber pressure is lowered, the liquid becomes superheated and bubbles of vapor grow along the ionization trail left by a charged particle. A timing mechanism moves a target into the beam of circulating protons in an accelerator, thereby directing particles into the chamber at the instant it is most sensitive to bubble growth.

and analyzed. A counter with a sensitive volume of a cubic foot can only signal that a charged particle has passed somewhere within that cubic foot. Some track detectors with the same sensitive volume can indicate each point of the particle's path within a thousandth of a centimeter. The space resolution of the track detector balances against the reporting speed of the counter.

In modern elementary-particle experiments the experimenter often wants to trace all or part of the life histories of particles entering his detectors. He wants to identify the mass, charge and frequently the energy of each particle that enters. In addition he wants to observe if and in what way the entering particles react with the atoms in his detector. If new particles are produced by reactions, he wants to measure the properties of these product particles and to see if they decay spontaneously into combinations of other particles. In most cases, the rarer the reaction, the greater its significance. Typically only one in many thousands of particles entering a detector will produce an interesting event. If the experimenter's apparatus includes track detectors, it is much to his advantage to use counters to select those events that are worth recording in the track detector. Otherwise he may have to search through hundreds of thousands of pictures to find the rare events of interest.

The first successful track detector was the cloud chamber, invented by C. T. R. Wilson in 1911. Wilson recognized that a supersaturated vapor is unstable and that the vapor will condense into droplets around any available free ions. In cloud chambers (which are still used) a saturated vapor is maintained in a closed volume under well-controlled conditions of temperature and pressure. When a charged particle passes through the chamber, the ionization trail it leaves persists for a fraction of a second. Either before or directly after passing through the cloud chamber the particle traverses counters, which produce an electric pulse. The pulse, signaling the passage of a particle, is made to initiate the outward motion of a piston; this allows the gas inside the chamber to expand and renders the vapor in the gas supersaturated [*see top illustration at left*]. The vapor then begins to form droplets of fog, which condense around the ions of the charged-particle track. Droplets also tend to form around dust particles or droplets left over from a previous expansion. But under the right conditions (achieving

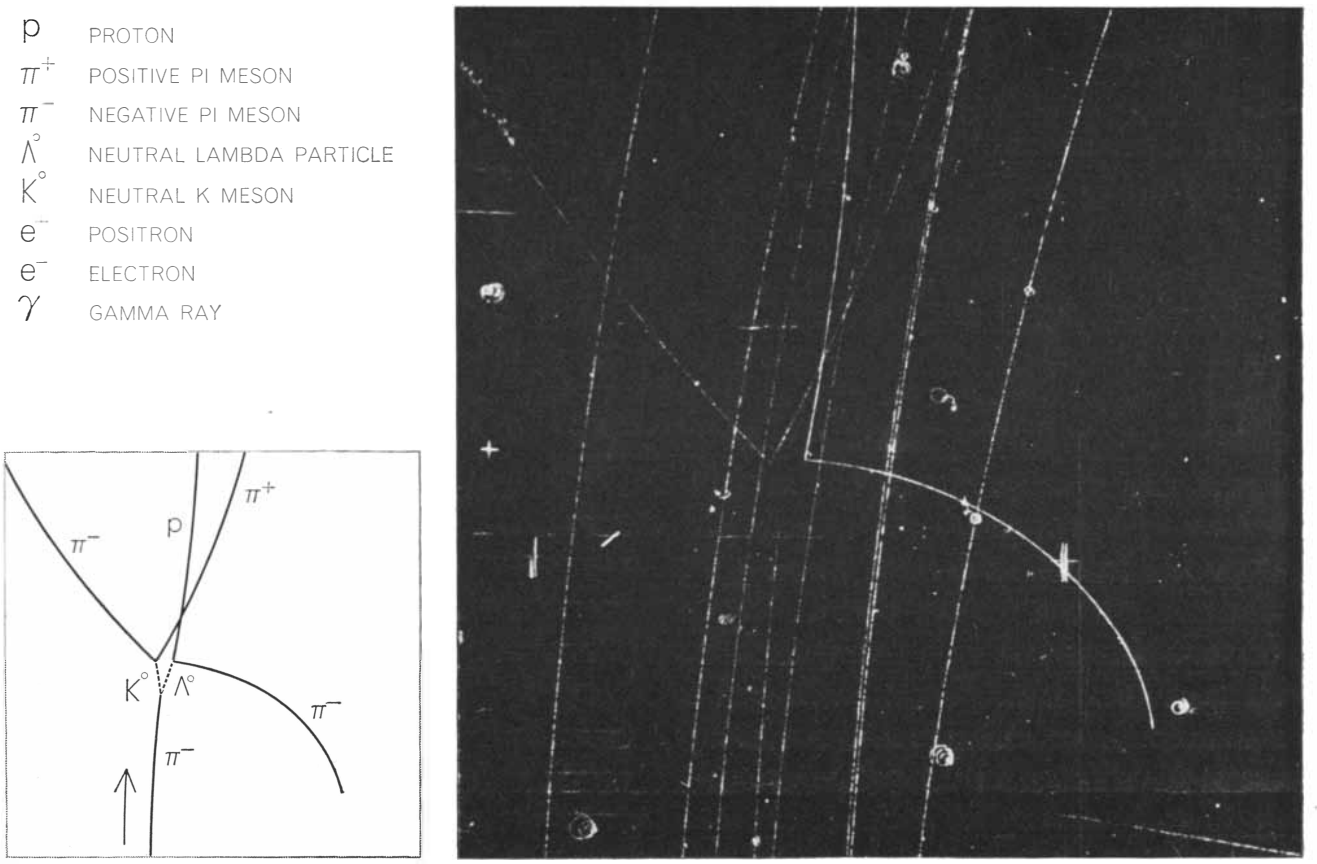
them is rather tricky) there forms in the chamber, in a fraction of a second, a clear trail of vapor droplets, which shows with good fidelity the path of the particle that triggered the counters. The advantage of the cloud chamber is that it can be triggered. A chamber may remain idle for hours waiting for a rare cosmic ray event, but when the event occurs and is recognized by the counters, the chamber operates on demand to record it.

Unfortunately cloud chambers have two rather serious drawbacks. First, the device is slow to set in operation, and the ionization trails persist for a large fraction of a second. As a result the number of incoming particles must be limited to prevent chamber pictures from being cluttered with more tracks than one can "read." The second drawback is the difficulty of putting into the chamber materials with which one might like to see particles interact. If material is introduced in the form of plates, the plates must be relatively few and widely spaced; otherwise the chamber will not work. If much material is needed, it must therefore be in the form of thick plates, with the result that interactions tend to occur deep in the plates, where the tracks cannot be seen. It is rather like Greek tragedy, in which all the mayhem occurs offstage and the audience is treated only to a secondhand account of it.

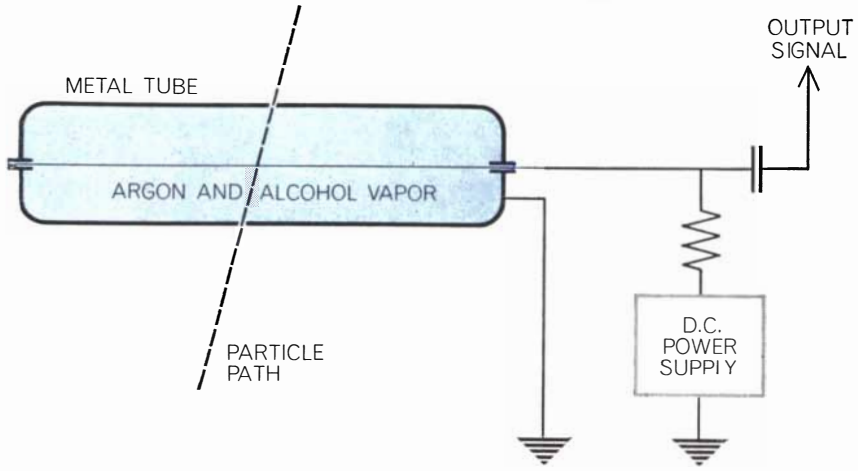
In the early 1950's Donald A. Glaser, then at the University of Michigan, developed a new type of track detector, the bubble chamber, for which he received a Nobel prize in 1960. This detector is also based on an amplification principle—the growth of bubbles in a superheated liquid. Some of the energy from an ionization trail goes into a few fast electrons, which can give up 1,000 or 2,000 volts of energy in a small volume to produce rapid local heating. If the trail is in a liquid that has suddenly been superheated by expansion, the bubbles will tend to grow fastest along the "heat track" and only slowly in other parts of the liquid. Glaser's invention was soon in use in many laboratories throughout the world, and it is safe to say that by 1959 more than half of all experimental research in elementary particle physics employed the bubble chamber.

An important virtue of Glaser's device is that one can fill the chamber with a wide variety of liquids, choosing the one that provides interactions of particular interest. For many purposes liquid hydrogen is ideal because it presents as a target for incoming particles only electrons and protons. In all other substances neutrons are also present. Other useful liquids are propane—in which the target atoms are carbon and hydrogen—and xenon, whose massive nucleus (54 protons and 77 neutrons) provides high stopping power. In addition the bubble chamber produces particle tracks of higher definition than those made by any other track detector, except for tracks made directly in photographic emulsion.

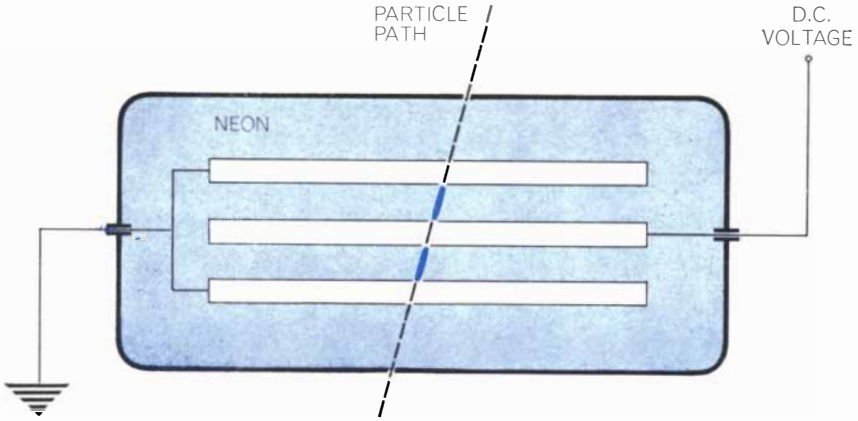
The bubble chamber shares with the emulsion method one serious disadvantage: it cannot be triggered. Since there is no way to select rare events one has no choice but to photograph the chamber at every expansion cycle, develop the films and examine hundreds or thousands of exposures looking for events of interest. Triggering is impossible because the heat track produced by a charged particle cools down in much less than a millionth of a second. This is far too short a time for the mechanical expansion system to set the chamber in operation. As a result bubble chambers are used almost exclusively with large accelerators, where a timing se-



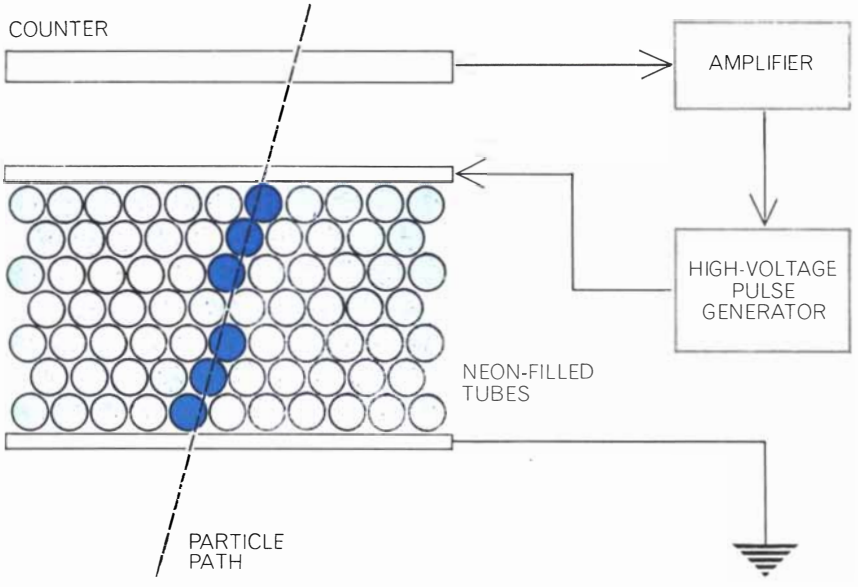
BUBBLE CHAMBER TRACKS (*right*) **were photographed in the 72-inch liquid-hydrogen bubble chamber at the Lawrence Radiation Laboratory of the University of California. The map and key at left identify the particles taking part in the event recorded.**



GEIGER-MÜLLER COUNTER, invented in 1928, was the first device to use the amplification process available in an electric spark to detect the passage of a charged particle. A central wire inside a tube is placed at high voltage. Electrons set free from gas atoms by the passage of a particle are accelerated by the strong electric field and free other electrons in a chain reaction. The result is a large output pulse that needs no amplification to be detectable.



SPARK COUNTER was a nontriggered forerunner of the spark chamber. A high constant voltage is maintained on a metal plate placed between two grounded plates. Passage of a charged particle provides free electrons that initiate sparks in the gas between the plates.



HODOSCOPE CHAMBER, another forerunner of the spark chamber, utilizes the triggering scheme usually employed with cloud chambers. The chamber consists of neon-filled glass tubes stacked between two metal plates. When a charged particle trips the counter, a high-voltage pulse is sent to the plates, placing the tubes in a strong electric field. Tubes through which the particle passed contain ions and free electrons and therefore glow.

quence first expands the chamber, then sends in a burst of particles to be analyzed [*see bottom illustration on page 38*]. The chamber must then be given about a second in which to recover.

Unlike the cloud chamber and the bubble chamber, the spark chamber was the work of many hands. Its development was based on one of the most spectacular methods known for making ionization trails visible—the electric spark. The generation of an electric spark is an extremely complicated process, but it is clear that under some conditions a spark can develop from a type of chain reaction. The reaction starts when an electron from an ionized atom, accelerated by a strong electric field, bumps into and ionizes other atoms. The electrons from these atoms cause further ionizations, leading in a very brief time to a brilliant electric spark. In 1928 the amplification process available in the electric spark was used in the first of all electrical detectors for single charged particles, the Geiger-Müller counter. In this simple device, named for Hans Geiger and Walther Müller, a central wire inside a tube is charged to high voltage. When a particle goes through the counter, the electrons of its ionization track are swept toward the wire. Accelerating as they approach the wire's strong field, they ionize more atoms. The ionized atoms emit photons (light quanta), which release additional electrons from the gas, spreading the discharge. Within millionths of a second the gas all along the center wire serves as the path for an electric spark. Geiger counters make tremendous pulses, which was a great virtue when sensitive electronic amplifiers were still difficult to build.

In the 1930's the standard equipment of the elementary-particle physicist consisted of a cloud chamber triggered by Geiger counters. In the late 1940's, when Geiger counters had been generally superseded by the development of scintillation counters (faster and capable of giving more information), a few physicists began trying to use the mechanism of the electric spark in a detector that would make visible the track—not just the presence—of a charged particle. J. W. Keuffel, working at the California Institute of Technology and later at Princeton University, built several spark counters, consisting of well-polished condenser plates kept at high voltage. If the plates were carefully aligned, clean and dust-free, and maintained just below the potential needed for a spark to jump between them, they would sometimes spark preferentially along the trail

of an incoming cosmic ray particle. Keuffel suggested the use of arrays of his parallel-plate spark counters to obtain tracks of the passage of a charged particle, but these counters were so difficult to build and to operate that it was not easy to follow up the suggestion.

In 1955 M. Conversi and A. Gozzini described in the Italian physics journal *Nuovo Cimento* an intermediate type of track chamber somewhat similar to the Keuffel spark counter. Their device, called a hodoscope chamber, consisted of many neon-filled glass tubes stacked between two parallel metal plates [*see bottom illustration on opposite page*]. Within a few millionths of a second after the passage of a charged particle through the stack of tubes, a set of counters outside the stack triggered an electronic circuit that placed a strong electric field on the tubes. Those through which the particle had passed then glowed, much as a neon sign glows. Other tubes remained dark if the applied pulse was on for only a short time. The hodoscope chamber was fairly easy to build, and its inventors had introduced a technique that was essential for the development of spark chambers: the use of counters to pulse the electric field. In their chamber the high voltage was on only when they were sure a particle track was there to be photographed. If the high voltage had been left on continuously, as it was in the earlier spark counters, some neon tubes would eventually have fired even in the absence of an entering track. The chief defect of the hodoscope was that it revealed only two dimensions of a particle's three-dimensional path.

In 1957 two British physicists, T. E. Cranshaw and J. F. de Beer, reported in *Nuovo Cimento* the next step toward a practical spark chamber. They combined the parallel-plate geometry of the spark counter with the pulse-triggering technique of the hodoscope chamber to make an efficient spark chamber with six one-millimeter gaps. They also introduced the use of a continuous electric clearing field to remove from the chamber ionization trails older than a few microseconds. This electric field, well below the threshold needed to make a spark, caused a slow continuous drift to the plates of all free electrons and ions released in the chamber gas. In this way it "erased" ionization trails in a few microseconds. A similar clearing field had long been used in cloud chambers to sweep out the slow-moving positive ions.

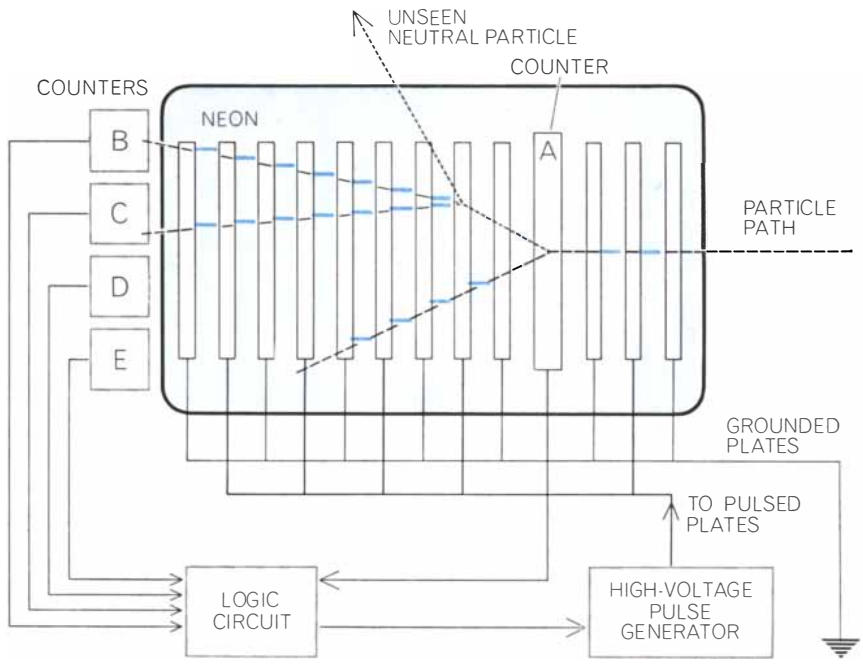
It happened that Cranshaw and de Beer chose to use air rather than neon in their chamber, and this small difference made it impossible for their chamber to detect two or more simultaneous tracks. Still, their work was so successful that several other groups—in Germany, Japan, the U.S.S.R. and the U.S.—continued to work along similar lines.

The final step—substitution of neon for air—was taken by S. Fukui and S. Miyamoto of Osaka University and reported in 1959. The two Japanese physicists were interested in developing a track detector that could be used for cosmic rays. Bubble chambers are not useful for such work, since they cannot be triggered. Fukui and Miyamoto found that in a chamber containing neon rather than air several simultaneous particle tracks could be seen.

One big difference between the behavior of air and of neon in spark chambers is that oxygen molecules (O_2) in air can combine with the free electrons of the ionization trail, whereas neon atoms cannot. The inertness of neon—and of other "noble" gases—is explained by the fact that it has a full complement of eight electrons in its outer electron shell. In contrast an oxygen molecule can acquire one electron and thereby become a negative ion (O_2^-). The electrons are well anchored to the oxygen molecules, some 60,000 times more massive than themselves, and cannot be freed except by application of a strong electric field. Consequently an air-filled spark chamber requires an operating pulse of 7,000 to 10,000 volts for each millimeter of space between its plates. This is about three times the voltage needed for a neon spark chamber.

The formation of oxygen ions also explains other characteristics of an air spark chamber. If the electron in an ionization trail can migrate freely to the plates of the chamber, its travel time is brief. But if it is attached to an oxygen molecule along the way, the velocity of the resulting ion is much slower than that of the electron. In fact, if the mass of a particle is suddenly increased by 60,000 times, its velocity must decrease by the square root of 60,000, or by a factor of about 250. Because most of the electrons liberated in an air spark chamber are slowed down in this fashion, they require many microseconds to migrate to the plates of the chamber. Such a chamber therefore remains sensitive for a long time, and in it old tracks cannot be quickly erased.

It is not so clear why air chambers show only one spark per gap even though several ionization trails may be present. It may be that at the high electric fields needed to operate such chambers the spark produced by the first electron freed from an oxygen ion occurs so rapidly that the plates are quickly dis-

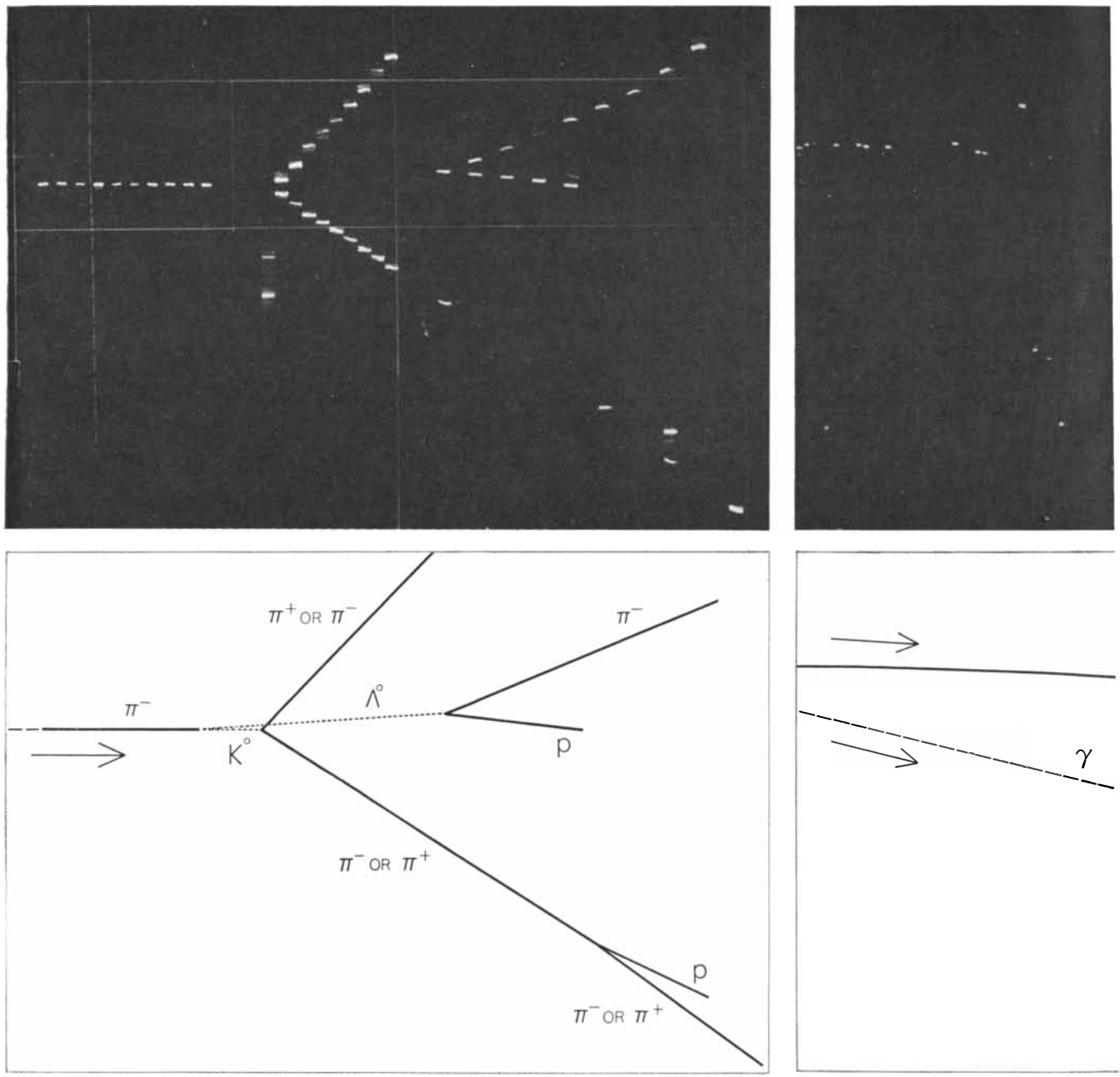


SPARK CHAMBER, which became practical with the work of S. Fukui and S. Miyamoto in 1959, consists of an array of thin metal plates surrounded by neon. It is also provided with counters and a "logic" circuit for determining when a particle meeting certain criteria has appeared. When it appears, a high-voltage pulse is sent to alternate plates and sparks occur along the ionization trails left by each charged particle. In the example shown, a charged particle interacts in counter *A*, yielding one neutral and one charged secondary. The secondary decays in the chamber, producing two charged particles and a neutral one.

charged below the threshold field, preventing any other attached electrons from getting free to start other sparks. This is consistent with an observation by Cranshaw and de Beer that only one electron is needed to start the spark.

Following the announcement of a practical spark chamber by Fukui and Miyamoto in 1959, the idea was immediately taken up by physicists in the U.S. and elsewhere. Within a matter of months Bruce Cork of the University of California had built a six-gap spark chamber and had operated it in a beam of particles from the six-billion-electron-volt accelerator of the Lawrence Radiation Laboratory. Almost simultaneously James L. Cronin of Princeton University built and operated a large 18-gap spark chamber, which yielded high-quality pictures of the tracks made by cosmic rays and by accelerator-produced particles. Both of these chambers used noble gases (neon or argon) and employed clearing fields to erase the ionization trails. Cork and Cronin were also the first to conduct actual experiments using a spark chamber as a particle detector.

In their work, as in most subsequent experiments using spark chambers, the occurrence of an interesting event was recognized by a system of conventional counters, which then triggered the operation of the chamber. Typically particles arrived at the spark chamber at intervals of a few microseconds and their tracks were swept to the plates by the continuous clearing field after only one microsecond. Consequently the pulsing of the spark chamber had to be carried out in much less than one microsecond so that

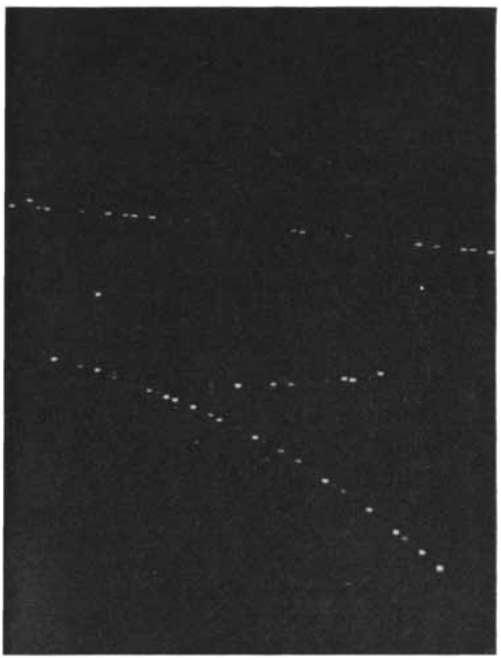


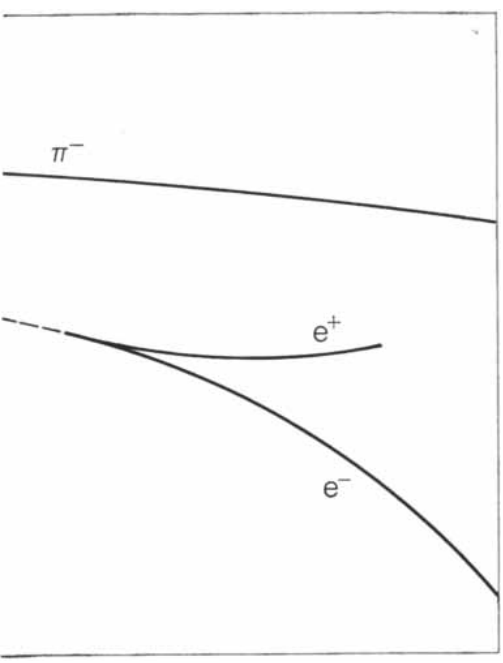
SPARK CHAMBER PICTURES show the appearance of particle tracks when the particles are curved by a magnetic field (*top right*) and when they are not (*top left*). The maps below each picture identify the charged particles, which leave tracks, and the neutral ones, whose presence is inferred. The reaction at the left was seen in a spark chamber operated at Brookhaven by James L. Cronin

the interesting track would still be there to be detected by spark amplification.

Within the past three years a wide variety of spark chambers have been built, each designed to exploit certain desirable features. Some have been made with thick carbon plates to allow interactions of the incoming particles with carbon. Others have been built in the form of a cylinder, to study the scattering of particles by a target located on the axis of the cylinder.

Along with several other physicists, I have been particularly interested in the design and use of thin-plate spark chambers that can be operated in a magnetic field. In a uniform magnetic field the path of a charged particle of constant energy is a circle whose radius is proportional to the momentum of the particle. The idea of using a magnetic field to obtain momentum information goes back to the early days of the cloud chamber, and bubble chambers are nearly always operated in such a field. The measurement of the momentum of each charged particle in a reaction is always useful, and frequently essential, for identifying the particles and learning the details of their interactions.





of Princeton. The picture at right was made in author's two-cubic-foot spark chamber at Brookhaven, shown at bottom of page 36.

When a magnetic field is used in a spark chamber, the sparks trace the ionization trails more closely if the spacing between the chamber plates is small. As the spacing is reduced, however, it becomes increasingly important for the plates to be flat and uniformly spaced, and the triggering pulse has to rise from zero to the peak voltage at higher speed. Fukui and Miyamoto had used spacings of 10 millimeters. Cork's chamber had a six-millimeter spacing. Within a few months we found in our laboratory at Princeton University that the spacing between spark-chamber plates operated in neon could be as small as two millimeters.

Unless very close plate-spacing is wanted, the construction of a spark chamber is not too difficult and might make a feasible project for an amateur scientist. A chamber with an adjustable plate spacing of two to 10 millimeters, the first model built by our group, was largely the work of college sophomores majoring in physics. Our second instrument was small but operated in a magnetic field. It contained 50 gaps of three millimeters each, separated by aluminum foil a thousandth of an inch thick. A third chamber, with 128 gaps of three-millimeter spacing and a volume of two cubic feet, can measure the momentum of particles with good accuracy. When the tracks cross 100 or more gaps, the accuracy of momentum measurement approaches that obtainable in a good bubble chamber.

At present the advantages the bubble chamber retains over the spark chamber are two. First, pure liquid hydrogen can be used as the only material in the bubble chamber, thereby limiting nuclear reactions to those between elementary particles and hydrogen nuclei (protons). In 1960 we studied the possibility of imitating a hydrogen bubble chamber by using liquid-hydrogen-filled hollow plates in an atmosphere of gaseous helium. We established that such a chamber would work but so far no one has needed its properties badly enough to build one. The second advantage of the bubble chamber is that it yields very fine ionization trails, and it produces them no matter which way the particle is moving. The bubbles trace a particle's path with an uncertainty of less than a thousandth of an inch. Even in narrow-gap spark chambers the sparks scatter in a region 15 or 20 thousandths of an inch wide. Moreover, in a spark chamber the path uncertainty increases as the particle approaches a course parallel to the plates.

In spite of these drawbacks the spark chamber has two big advantages over the bubble chamber. First, the decision to photograph a given event can be made after the event has occurred. Second, because old ionization trails are swept to the walls after only one or two microseconds the spark chamber picture shows only the tracks produced during the last microsecond before the chamber was pulsed. Because of these two features one can select and photograph an interesting event caused by a single entering particle out of many thousands, all arriving over a few thousandths of a second. Each ionization trail of the uninteresting majority of tracks is swept away and does not remain to confuse the picture.

The decision as to which events to photograph is made by "logic" circuits that analyze the output of counters, which may be located outside or inside the spark chamber itself. Frequently the logic requirements are severe and the pulses from many counters must be digested and analyzed before a decision is made whether to pulse the chamber or not. Ordinarily a time of about 100 nanoseconds (100 billionths of a second) is available for the decision. This is not uncomfortably short with present-day circuitry. For the past 10 years it has been practical to use circuits that operate in 20 nanoseconds or less.

Those of us who have jumped on the spark chamber bandwagon are naturally enthusiastic about future prospects for the instrument. We have found that physicists who formerly used bubble chambers are delighted to have a device that eliminates great masses of uninteresting pictures. And former counter physicists are happy to see the tracks they knew were going through their counters. We all know that neither bubble chambers nor counters are going to be put out of business by the new track detectors, but to a remarkable degree spark chambers allow us some of the best of both worlds.

The Sea's Deep Scattering Layers

The sound pulses of devices used to measure the depth of the ocean are often scattered by several "phantom bottoms" that rise by night and sink by day. The animals that make up these layers are now being identified

by Robert S. Dietz

Nautical charts display hundreds of shoals rising from the deep sea and marked "ED"—existence doubtful. Each of them represents an echo sounding made by some ship passing through the area. Lacking the time to make a careful survey and fearful of running aground, the captain simply reports the reading to a hydrographic office, where it is duly recorded. More likely than not the sounding is spurious—a reflection not from the true bottom but from a "phantom bottom" now known to exist throughout most of the seas. A ship later passing one of the supposed shoals may find blue water to depths of two or three miles. But hydrographers are naturally reluctant to erase any possible hazard to navigation, so the charts remain cluttered with fictitious banks.

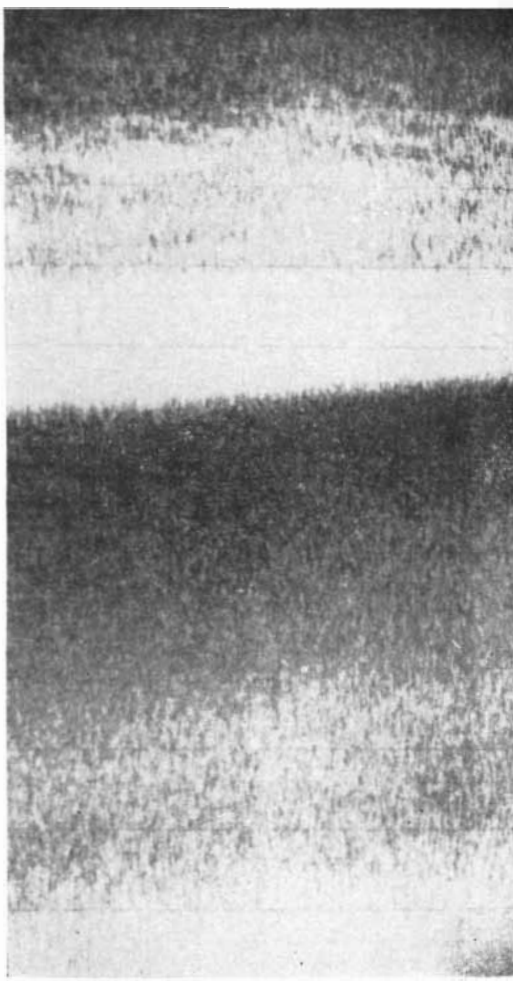
The existence of a phantom sound-reflecting layer was not recognized until 1942. At that time physicists were experimenting off San Diego with underwater sound for detecting submarines. Beyond the continental shelf, over water several thousand feet deep, their transmitted sound pulses, or pings, regularly and annoyingly returned an echo from about 900 feet. Unlike the sharp echo from a submarine, it was a diffuse, soft reverberation. On pen tracings of echoes from various depths it appeared as a layer of heavy shadowing. The zone confounded experiments only during the day; at sundown it would rise nearly to the surface and diffuse. With the first light it would re-form and descend to its normal depth. It never reflected all the sound energy striking it; the echo from the ocean bottom could always be detected through it, although sometimes only faintly. The source of the unexplained reverberation was named the deep scattering layer, or DSL (soon amended to DSL's because three and sometimes as many as five layers are often found).

At first it was supposed that the DSL's, like the D layer of the ionosphere, which fades away at night, had a physical cause, such as a temperature discontinuity. No one, however, could suggest a physical effect that would account for the diurnal migration. Martin W. Johnson, a zoologist at the Scripps Institution of Oceanography, surmised almost at once that the echo must come from marine animals that rise to the surface at night and return to the depths in the morning.

This interpretation is now universally accepted. What animals they might be, how they survived the enormous changes of pressure and temperature during their migrations, what physiological mechanisms were involved in the process—all these were mysteries. Even now the answers are far from complete. Nevertheless, this nuisance to the physicist has presented the biologist with a powerful new ecological tool for understanding the mass distribution of life in the sea.

Among the first animals suggested as a deep sound-scatterer was the squid, which lives throughout the oceans. Some investigators have wishfully supposed that the DSL's consist of vast schools of large, commercially valuable fish. It has been found, however, that such large fishes, which are sometimes present in the scattering bands, return hard echoes that stand out against the soft reverberations of the DSL's. Those of us who study echograms call the animals "tent fish" or "blob fish," depending on whether their echo is traced as an inverted V or an irregular bulge [*see illustration on pages 46 and 47*]. Almost always these larger fishes rise to the surface at night. Sometimes they can be "seen" on the echogram working their way toward the surface in the evening along with the DSL's. Curiously they rarely show up in the descending scattering layers of early morning. Instead they suddenly appear at full depth.

Today it is clear that the scattering layers consist of small, nocturnal marine organisms. They cannot be too small; at the frequencies used by echo



DEEP SCATTERING LAYERS are well developed in this echogram, made in the deep

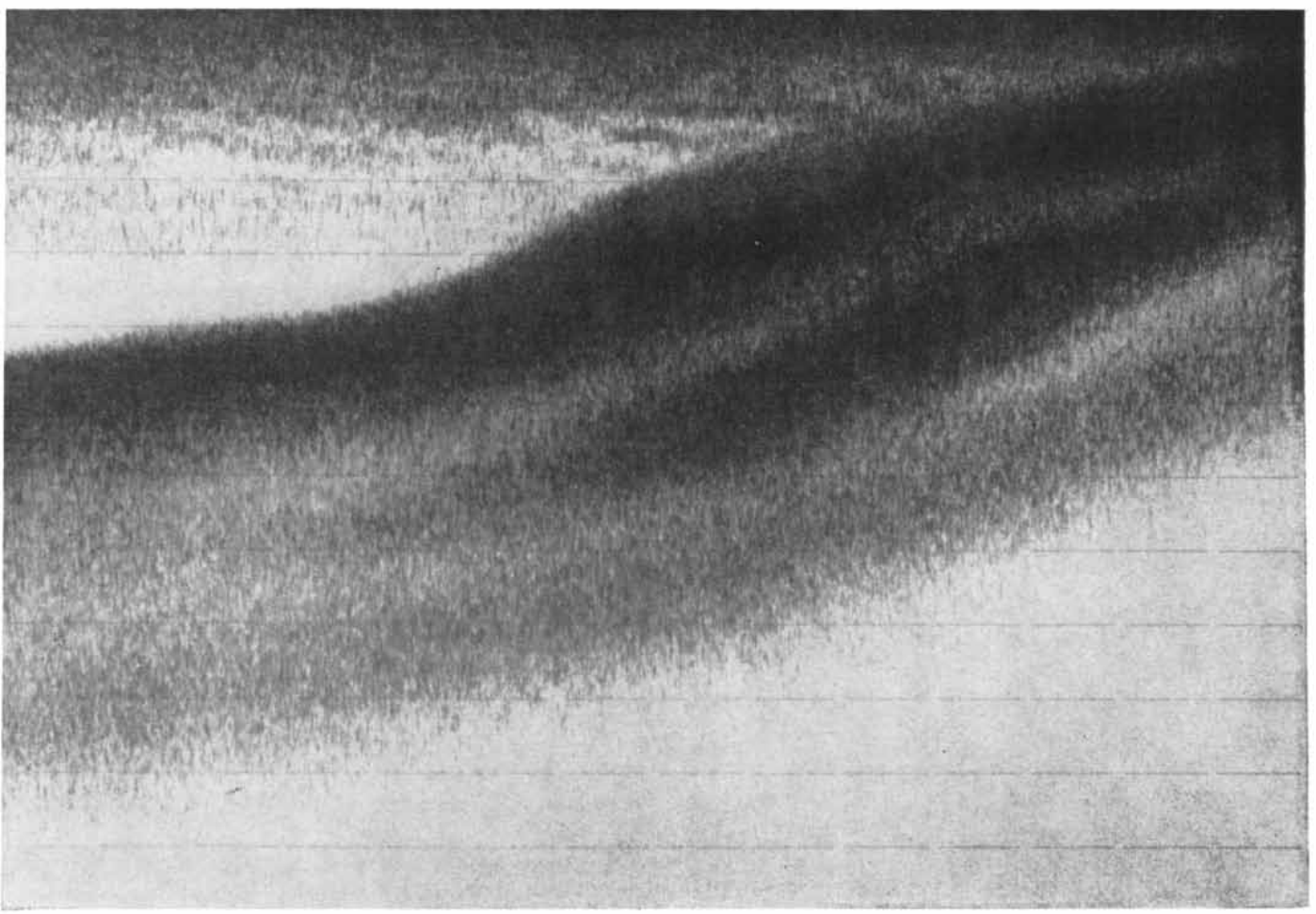
sounders nothing shorter than about an inch will scatter sound effectively. Among habitats only the sky offers as little refuge as the sunlit upper regions of the sea. An animal sighted by a predator in either place is almost as helpless as grass in a meadow. In the open sea many small organisms conceal themselves by assuming the same transparency and refractive properties as the water itself. Others contain poisons or have hard shells or sharp spines. The animals of the deep scattering layers hide in the dark. In the daytime they seek the deep water, where sunlight hardly penetrates; they rise only at night to browse in the plankton-rich surface waters.

During the day DSL's lie at depths roughly between 700 and 2,400 feet. At night they rise almost to the surface and diffuse, or they may merge into a broad band extending down to 500 feet. The nature and the complexity of the bands vary with time and place. Off California they generally lie at about 950 feet, 1,400 feet and 1,700 feet. Most places in the ocean usually have three layers, the deepest at an average of 1,900 feet. In studying echograms covering about 200,000 miles of ship tracks, the deepest one I found was at 2,350 feet south of the Aleutian Islands. This must mark the approximate boundary of the twilight zone even in the clearest waters. From bathyscaph dives we know that the last glimmer of light fades into blackness at about 2,000 feet. The twilight organisms have more sensitive eyes than ours and their threshold of vision extends somewhat deeper. Even if their eyes can respond to single photons of light, as has been suggested, the greatest depth at which they can possibly see anything is no more than 3,000 feet.

Occasionally discrete echoes have been observed from depths below 3,000 feet. They may be caused by animals that sometimes descend this deep, but no one really knows. Scattering bands also appear in the waters above the continental shelves, which are no more than 600 feet deep. None of these compare in importance or stability with the "true" DSL's, which may be defined as the layers between 700 and 2,400 feet, most of which rise to the surface at night. Sometimes the echograms show very diffuse layers that stay at the same depth day and night. They may in part represent stay-at-homes among normally migrating species—immature forms or individuals that are resting or breeding. Some of the layers must consist of nonmigrating organisms that always stay in the twilight zone, probably salps, ctenophores, medusae, pteropods, pelagic worms and others. In any case they too are less important than the migrating DSL's.

Although we are far from knowing all the animals that make up DSL's in all parts of the world, it is clear that two groups predominate: (1) myctophids, or lantern fish, so named because of the luminous spots on their bodies, and similar small bathypelagic fishes; (2) shrimplike crustaceans called euphausiids and sergestids. Nets towed at night near the surface commonly pick up from one to five of these individuals per cubic yard; exceptionally rich bands bring in as many as 20 per cubic yard.

Whether the fish or the crustaceans



Pacific off the coast of Peru. The three layers can be seen descending to depth (*starting at right*) with the coming of dawn. Echogram covers about one hour. This echogram and the ones that follow were made by vessels of the Scripps Institution of Oceanography.

play the most important role in sound-scattering is an open question. Edward Brinton of the Scripps Institution of Oceanography has found the euphausiids to be 10 times more abundant than fish off San Diego. In their effect on sound pulses the lantern fish may offset the abundance of the euphausiids by their larger size—several inches compared with one inch for the crustaceans. Furthermore, many lantern fish have swim bladders, each of which contains a minute bubble of air that can resonate with the sound waves to make a highly effective scatterer.

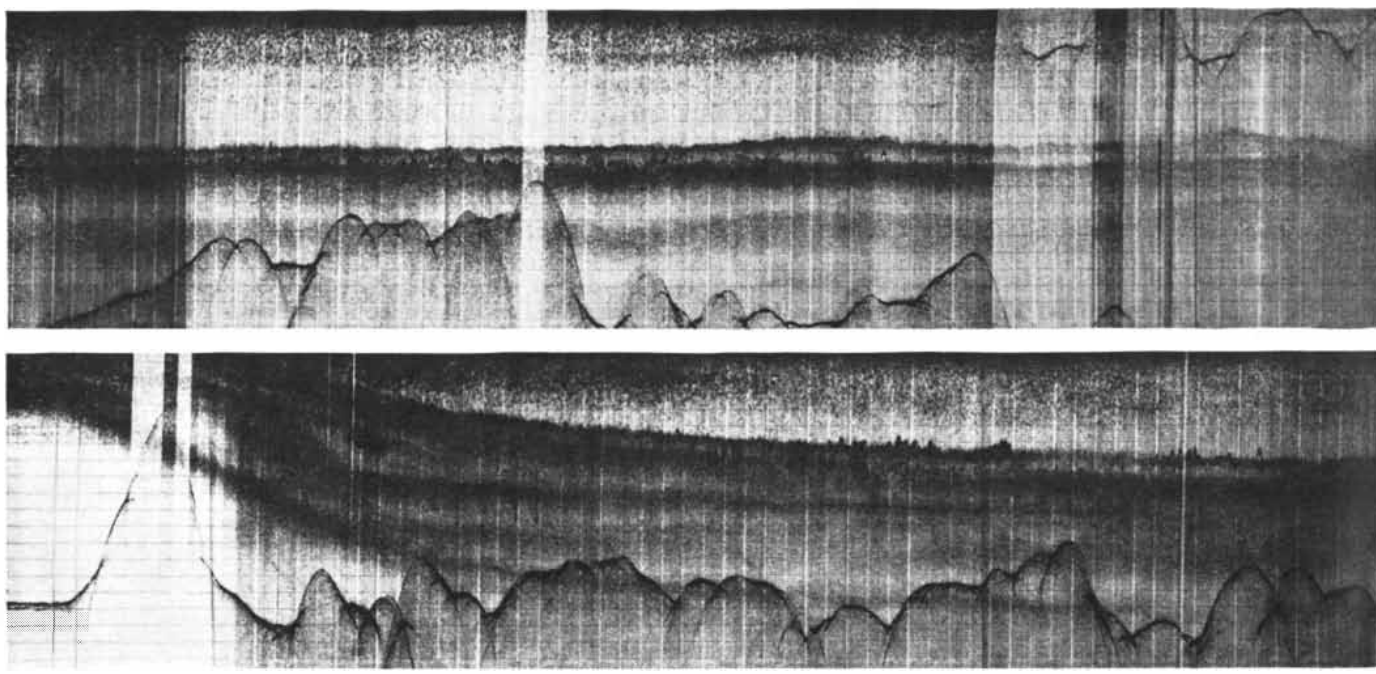
The striking changes in animal population with depth in the sea were known long before the discovery of the scattering layers. Most biologists have tried to explain the phenomenon in terms of temperature. The late Danish oceanographer Anton F. Bruun divided the oceans into two temperature levels separated by the 10-degree-centigrade isotherm. The upper, warmer zone he termed the thermosphere; the lower, colder region, the psychrosphere. But the DSL's suggest that light exerts a considerably more important control than temperature does. From the evidence of scattering layers the sea can be divided into three light zones: the sunlit zone, inhabited by both plants and animals, extending down to about 500 feet; the twilight zone, populated only by animals, from 500 feet down to 2,400 feet; and the black abyssal region with its few and highly specialized animals. The lower boundary of Bruun's thermosphere rises with distance from the Equator, eventually reaching the surface in the higher latitudes. The scattering layers show no such warping. Of course toward higher latitudes tropical species fade out and boreal species become predominant, but all the animals move in response to light, not to water temperature.

Both the crustaceans and the lantern fish of the DSL's display acute sensitivity to light. On the darkest nights dip nets pick them up at the very surface, but even moonlight sends them down many feet. Echograms occasionally show scattering layers descending to moderate depth as the full moon rises. With the first glimmer of daylight, often an hour before actual sunrise, the various organisms begin their descent. Off San Diego the myctophids, the most sensitive to light, generally start down first, because they must dive to the greatest and darkest depth. A short time later the second layer, probably consisting of euphausiids, takes form and settles, and it is soon followed by the third layer, probably composed of sergestid shrimps. (The order cannot be exactly specified because it depends on the species present in a given population at a given time.) The layers never cross one another; each appears to be precisely adjusted to some particular level of twilight. Diving at speeds of as much as 25 feet a minute, the scatterers are at least halfway to their ultimate levels at sunrise. Within one hour after sunrise they attain their preferred depth. As the sun approaches the zenith, however, they sink a bit lower to their maximum depth to avoid the penetrating light rays. When passing clouds darken the sky, the scatterers react by rising to somewhat higher levels than normal for the daytime.

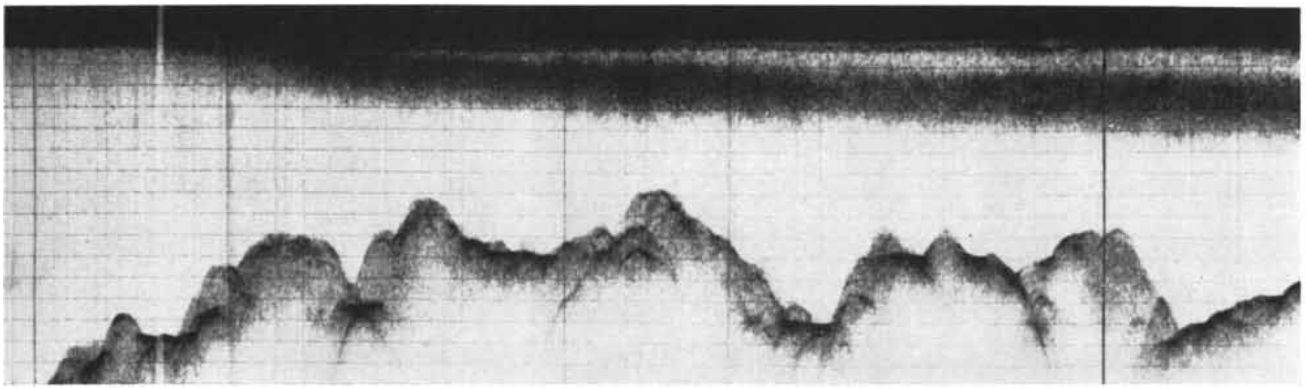
While aboard the U.S.S. *Cacapon* in 1947 I traced the DSL's all the way from California to the Antarctic. By day the ever present layers, sometimes dense and at other times thin, hung like decks of stratus clouds between 900 and 2,100 feet. Each night the scatterers rose toward the surface and diffused. As the days grew longer the diurnal migrations remained precisely synchronized to sunrise and sunset. But near Antarctica, where the nights were reduced to a mere four hours, the migrations seemed to break up in confusion. The organisms of the shadows apparently could not cope with a 20-hour day.

The DSL's are almost, but not quite, universal in the deep ocean. In the nearly lifeless central South Pacific the bands become extremely faint and may even disappear completely. They do not exist in the Arctic Ocean, where the permanent cover of pack ice cuts off so much sunlight that diatoms cannot flourish. The Arctic Ocean is the most sterile of all the seas.

Most attempts to photograph the scattering layers on film or by television have failed. Deep trawling with nets has also met with indifferent success in catch-



FULL DAY'S CYCLE of the deep scattering layers begins at far upper right with descent from surface at daylight. The organisms remain at depth throughout the day, in separate layers. At night they rise again to feed (*far lower left*). "Tent fish" and "blob fish"

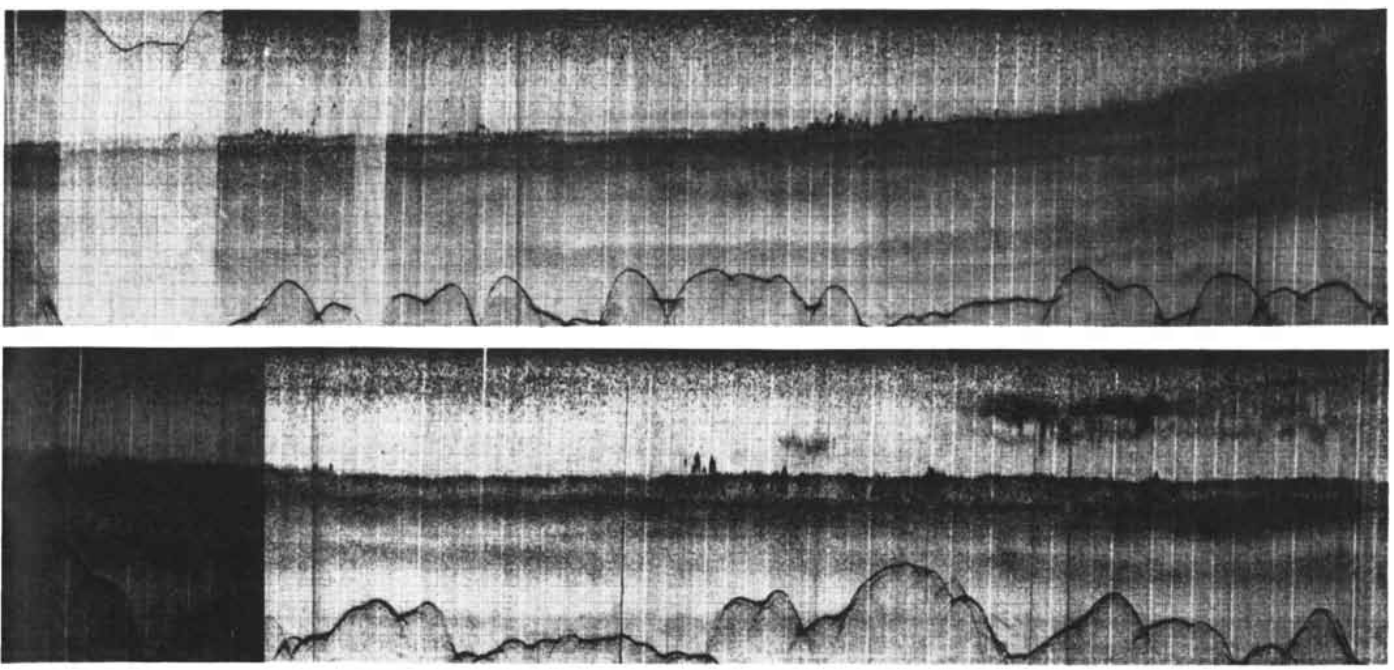


EFFECT OF BRIGHT MOON on deep scattering organisms is to hold them at shallow depth. Deep scattering layer can be seen rising to surface (*toward left*) after moon sets. This echogram was recorded between 11:45 p.m. and 1:15 a.m. in the eastern Pacific.

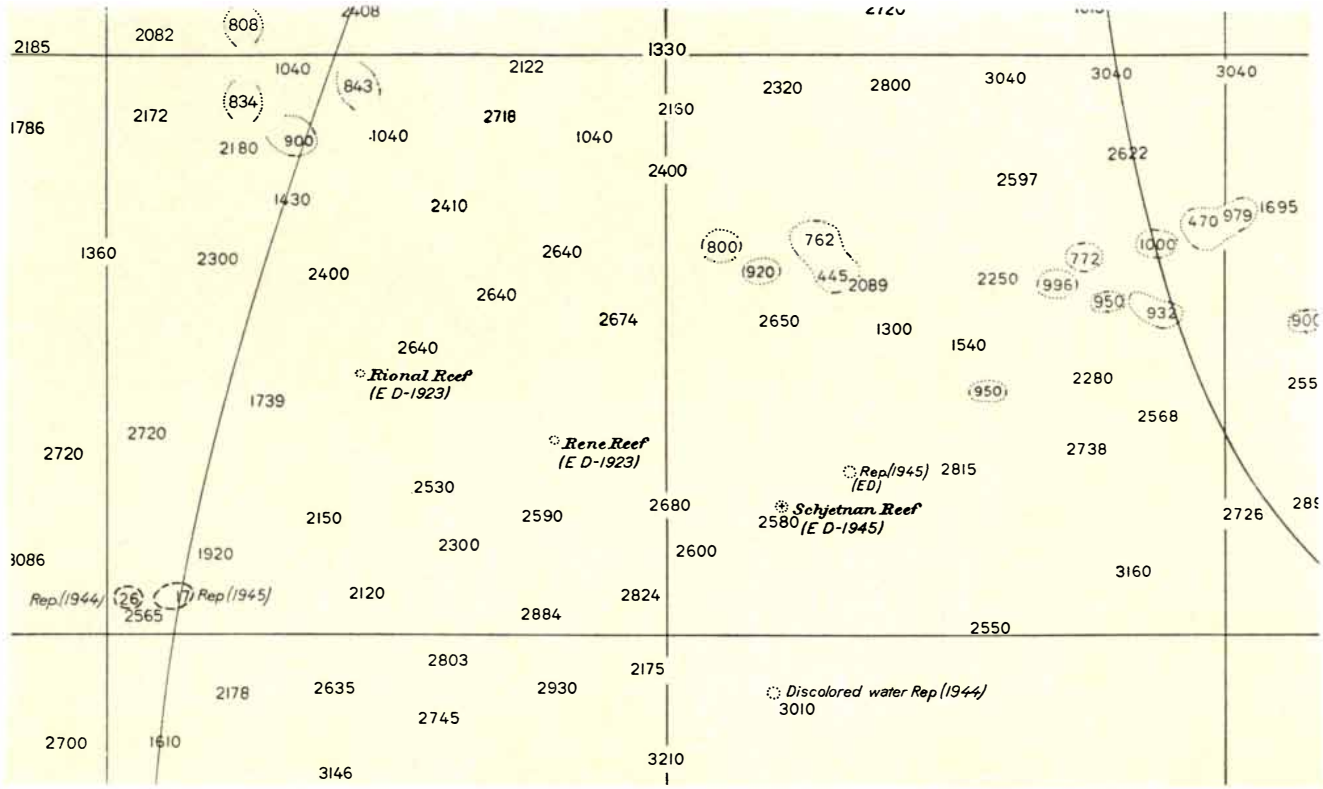
ing and identifying the DSL organisms. They are too small and too widely dispersed. Bathyscaph divers looking through portholes have fared somewhat better, at least when they did not expect to see great schools of fish. Crustaceans and lantern fish have appeared occasionally at the depth of the scattering layers but seldom in real abundance. On a bathyscaph dive to 3,600 feet in the Mediterranean I saw no organisms big enough to be effective sound-scatterers. Down to 2,100 feet there was an increasing abundance of minute suspended detritus from living plants and animals called sea snow; it scattered our underwater light beam as dust motes scatter a shaft of sunlight. Just below 2,100 feet the water abruptly became crystal clear; apparently this is the boundary between the ocean's twilight zone —the realm of the scattering layers and their light-sensitive organisms—and the almost lifeless, eternally dark waters of the abyss.

In bathyscaph dives off San Diego, Eric G. Barham of the U.S. Navy Electronics Laboratory has had better luck than I have had. He has repeatedly seen concentrations of four-to-six-inch fish between 650 and 1,000 feet; they were probably young hake. Hard echoes (tent fish) often come from these depths. Euphausiids have been found in the stomachs of these fish, so it seems likely that the hake feed on the scattering layer organisms.

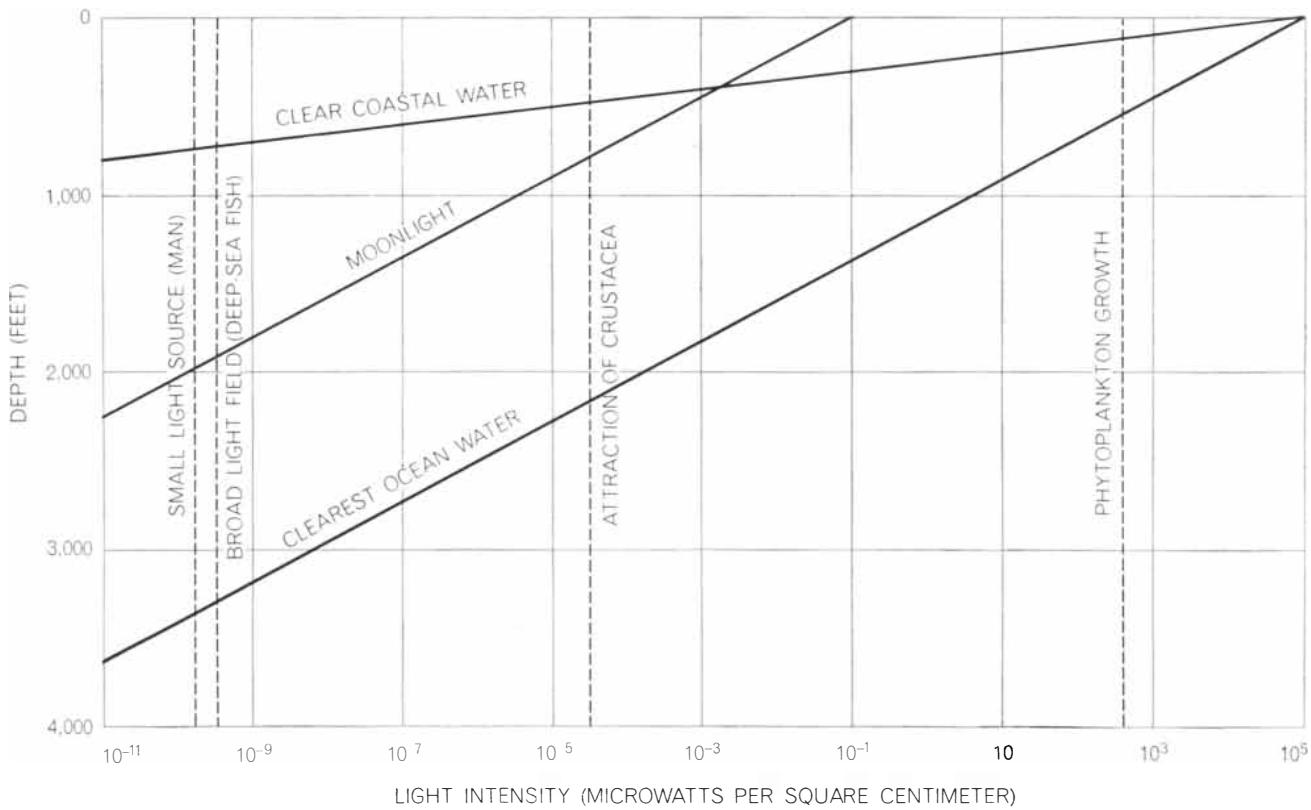
In a recent bathyscaph dive into the San Diego Trough, Barham reported that he saw much sea snow but no large organisms between 850 and 1,200 feet. Then he entered a zone inhabited by deep-sea prawns. From 1,200 to 1,500 feet he saw so many of these sergestids that he could not count them. In the next 200 feet he encountered a large number of lantern fish. Below 1,700 feet the bathyscaph entered a region relatively free of large organisms. Then from 2,150 to 2,300 feet it sank through a zone containing the greatest concentration of fish he had seen on any dive. Again these appeared to be lantern fish, as many as eight in view at a time until he could not keep count of the sightings. Most tended to avoid the lighted area, and Barham saw them only at the edge of the cone of light. Within the abyssal zone, from 2,300 feet to the bottom at 3,900 feet, he saw only an occasional red



appear among the layers. The "mountains" represent echoes from the sea bottom, exaggerated 20 times in the vertical dimension. The echo-recording apparatus repeats its cycle for every 2,400 feet of depth; the bottom echo is actually on the fifth cycle.



DEEP-OCEAN CHART of a portion of the Pacific between the Hawaiian Islands and the Marshall Islands displays four "reefs" marked "ED" (existence doubtful). Those reported in 1945 were found by echo sounders and could represent scattering phenomena.



INTENSITY OF LIGHT decreases with depth. The lines "Clear coastal water" and "Clearest ocean water" refer to sunlight. Coastal water may appear clear to the eye but is always turbid. Black vertical lines denote amount of light necessary for each function. "Small light source (man)" is the faintest light source a man can detect. The broad light field for deep-sea fishes indicates minimum quantity of general daylight these fishes can see. More light is needed to attract crustaceans, and phytoplankton require light many orders of magnitude more intense in order to grow. The diagram is adapted from a paper by G. L. Clarke of Harvard University and the Woods Hole Oceanographic Institution and by Eric J. Denton of the Marine Biological Association laboratory in Plymouth, England.

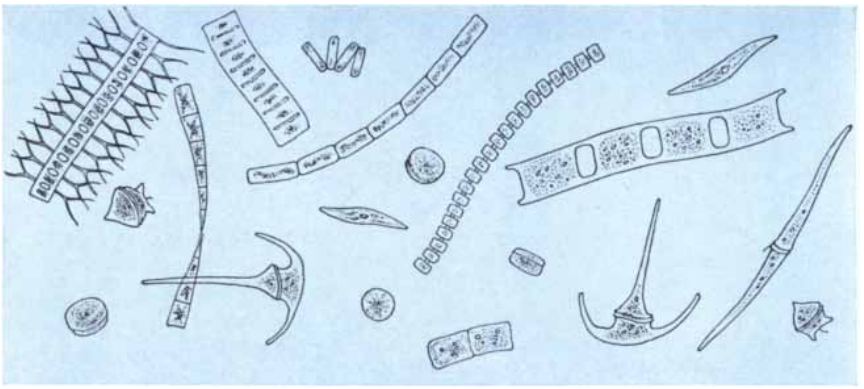
prawn, some shrimplike mysids, medusae and two types of worm.

In spite of their distribution, the DSL's can never be a sea-food cornucopia for man. The echo effects indicate a concentration no greater than a few animals per cubic yard. Nevertheless, the animals of the scattering layer must constitute an important source of food for commercially important fish; surely they are an important link in the food chain of the oceans.

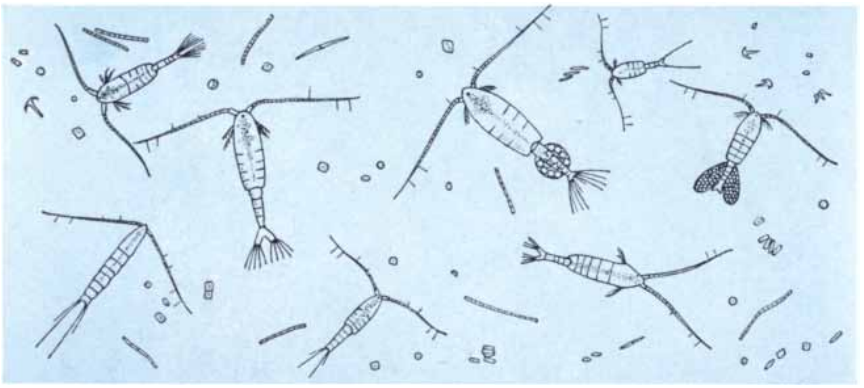
The DSL forms themselves feed on tiny surface organisms: euphausiids and sergestids are herbivores, grazing on diatoms; lantern fish eat other crustaceans that are nourished by diatoms. The DSL population in its turn falls prey not only to larger deep-sea fishes but also to surface swimmers. One reason oceanic banks and shelf margins make good fishing grounds may be that they are often richly populated by animals from the DSL's. During the night, when they are near the surface, many of the little creatures must drift over the banks and shores. In the morning they are trapped in the shallow lighted waters and are quickly devoured by predatory fishes. Above the submerged tops of sea mounts the DSL's sometimes practically disappear, presumably as a result of such devastating grazing.

As human beings we sometimes tend to forget that we are not the only end of nature's branching food chain. Until quite recently the source of food of the fur seal was a mystery. Every year during the breeding season some three and a half million of these voracious mammals migrate from their deep-water habitat far out in the northern Pacific and come ashore on the Pribilof Islands. Experience with fur seals in zoos indicates that it must take three and a half billion pounds of fish a year to feed the enormous wild population. Yet the fur seals never seem to compete with commercial fishing. Clearly they are tapping some vast reservoir of noncommercial sea food. Recently we have learned that in the deep ocean they feed largely on lantern fish, probably catching them at night when they rise to the surface.

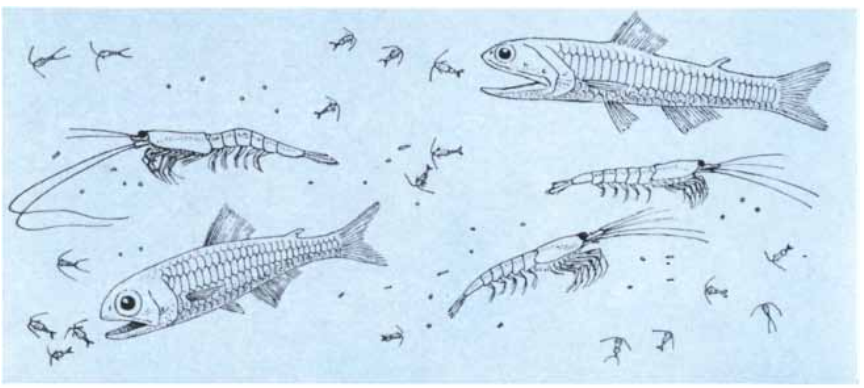
Another eventual consumer of the twilight animals is the cachalot, or sperm whale. Unlike the seal, it goes down to hunt for its food. Although it is a mammal, forever tied to the surface, it sometimes takes a single gulp of air and dives as much as two-thirds of a mile to forage. The cachalot does not feed on the scattering-layer organisms but eats the squids and larger fishes—the echogram



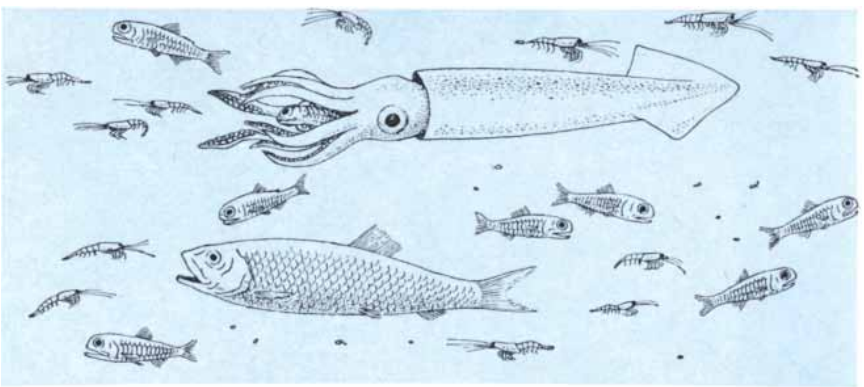
PHYTOPLANKTON, tiny drifting plants, are the "grass" of the sea: they form the basis of the food chain. These are diatoms and dinoflagellates, enlarged approximately 200 diameters.



ZOOPLANKTON are tiny animals that feed on phytoplankton and in turn furnish food for larger animals. These copepods, enlarged about 10 diameters, drift near the sea's surface.



"DEEP SCATTERERS" rise from depths at night to feed in photic zone. The myctophids (lantern fish) eat copepods; the euphausiids (crustaceans) consume the phytoplankton.

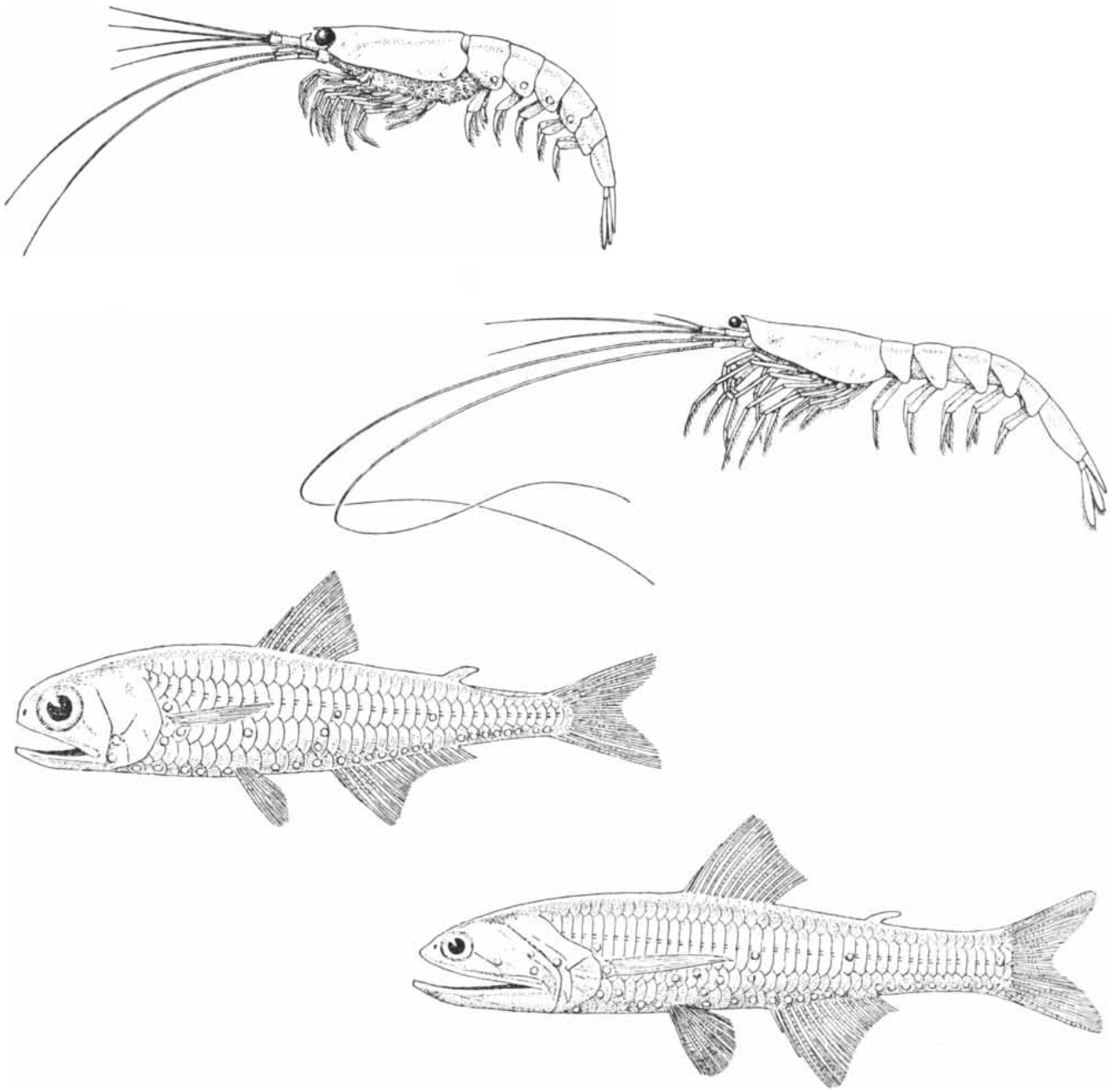


LARGER ANIMALS, such as this squid and herring, may well eat the organisms of the deep scattering layers at night near the surface. Fur seals also feed extensively on myctophids.

blob fish and tent fish—that do feed on the scatterers. These constitute its whole diet. Many rare species of deep-sea fishes are known only from the stomach contents of the sperm whales that abound around the Azores and are still harpooned from open boats as they were by the New Bedford whalers of old. Apparently the animals of the deep scattering layers are safe during the day from foraging by the plankton-sieving baleen whales. According to the whale expert Raymond M. Gilmore of the Museum of Natural History in San Diego, Calif., these whales limit their dives to the upper 200 to 300 feet of the sea, or considerably above the DSL's.

A basic tenet of oceanography is that parcels of water throughout the ocean, although they look exactly the same, in reality differ from one another. We do not need precise chemical analyses to prove the point: the organisms of the sea are remarkably sensitive indicators. Nothing illustrates variation in the sea more dramatically than echograms and their DSL's. For example, off Peru the echograms are heavily blackened by the teeming life of the Humboldt Current, but a little farther out the life dwindles to nothingness. The scattering is an index of organic productivity and in turn of those chemical factors that control the distribution of living things.

It is unfortunate that the world's expanding population cannot look to the deep scattering layers as a direct source of food. Nevertheless, the organisms of the DSL's are well up in the pyramid that requires 1,000 pounds of diatom fodder to support the growth of a pound of commercial fish. The deep scattering layers play a major role in the biological economy of the seas.



SCATTERING-LAYER ORGANISMS include crustaceans and fishes. Among them are (*top to bottom*) a euphausiid, a sergestid and two forms of myctophid, or lantern fish. The animals range in size from about an inch for the euphausiid up to three inches for the lantern fish. The four spots on the euphausiid and the similar spots on the myctophids are photophores, or light-producing organs.

Kodak reports on:

a decision for infrared optical designers . . . KODAR—a name with a ring to it . . . how to cope with many, many, many oscillographs

Achromat for roasting

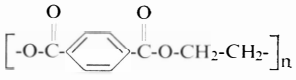
We have designed and constructed for Lockheed-California Company a 21½-inch *f*/3.6 lens which is not even transparent by visible light but is a jim dandy by infrared. The minimum circle of confusion as "seen" by the 2μ-5μ band and measured at a diameter 85% down from peak intensity is only .003″ larger than the .002″ diameter of an impossible perfect image of our testing source. Furthermore, since both elements of this achromat are made of KODAK IRTRAN optical materials, the lens can get as hot as 500C without blinding itself by its own radiation.

Anybody else who needs an achromat for any two infrared wavelengths should decide whether to buy the IRTRAN blanks and proceed on his own or whether to have us design and deliver it ready to go. Eastman Kodak Company, Special Products Division, Rochester 4, N. Y., can assist in the decision.

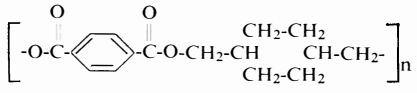
The improvement of capacitors

This is being written by a man wearing a suit and necktie of blended KODEL Polyester Fiber. Until we came out with "KODEL," the way to be chemically specific about polyester fiber, sheeting, and film without mentioning somebody's trademark was to say poly(ethylene terephthalate).

Whereas p(e t) is



KODEL polyester is



That large added ring preserves the

bond between -C and O- against moisture attack and raises the melting point substantially to as high as 290C. Thence stem complex consequences that have encouraged us to market the polymer in addition in granular form as TENITE Polyester and to bring into production a new plant at Orangeburg, N. Y. that puts it out as biaxially oriented KODAR plastic film.

You cannot take pictures on KODAR, but of the many other things you can do with it, one of the most impressive is to roll it up with metal foil into capacitors.

When the president of Kodak visited the laboratory where the many electrical advantages of KODAR were discovered, we set up ten .05-μfd 200-v capacitors for him, identical except that five of them had that cyclohexane ring in the polyester and five did not. We put them all in an oven at 185C and applied 700 volts of dc across them. Within three minutes all five of the p(e t)'s had shorted out. This was the logical moment for the president to leave, but realism is company policy. The president wanted to watch the first of ours fail. It took 10 minutes. With the relief of tension as soon as he left the room, we absently turned off the test. Statistically we calculate that the last of our five would have detained him 30 minutes. That was four years ago. KODAR dielectric film has continued to improve.

On March 26, 1959, having replaced 15 of the regular capacitors in a TV set with our kind, we set it to running 9 hours a day, 7 days a week. All other components that failed (naturally, there were many) we replaced. For the Electrical Insulation Show in February this year we removed the set from the room where the lab manager hides it and took it to Washington. It was the hit of the show. The coincidence that it happened to be the only TV set in the

hall on the day when the first American was orbiting the earth might have helped focus attention on it. It would not have been a good place to have one of our capacitors go. (Life is full of tensions. Everybody knows that next to the tubes, the most likely components to fail are capacitors.)

On the table alongside the TV set in the picture above is a tone generator for an electronic organ. It uses 53 capacitors made of KODAR dielectric film. It has been operating 24 hours a day since 10 a.m., April 20, 1959 except for travel time to the show and outage to replace other major and minor components that have failed.

Back home in Tennessee we have a controller that we built to represent by capacitor charge the temperatures at 100 points in a chemical plant process. It senses rates and corrects accordingly. We couldn't find any other capacitors with sufficiently low leak rate, low dissipation factor, and constancy of capacitance with temperature, so we equipped the instrument with 200 KODAR film capacitors.

The remarkable fact is that these capacitors can be cheaper than p(e t) ones because the inertness of KODAR to high temperature and humidity lets it act as its own monolithic case and survive conditions that crumble even the cased p(e t) variety into dust. Furthermore, without the variation introduced by measures necessary to protect the p(e t), capacitance can be held to ±2% at little added cost to pay for the rejects. The prominent capacitor manufacturers know all about this. If you want to be one yourself, you can find out a great deal more from Eastman Kodak Company, Plastic Sheeting Division, Rochester 4, N. Y.

Feet, not inches

America's oscillographs are spewing out paper so fast that processing facilities are swamped.

To smash the bottleneck, we marketed last autumn what we called KODAK EKTALINE Paper and Chemicals. Instant success.

We were a little crafty. We advertised 180 inches/min processing speed and hoped that would sound fast. (You can't hang us, since available oscillogram processors couldn't operate much faster.)

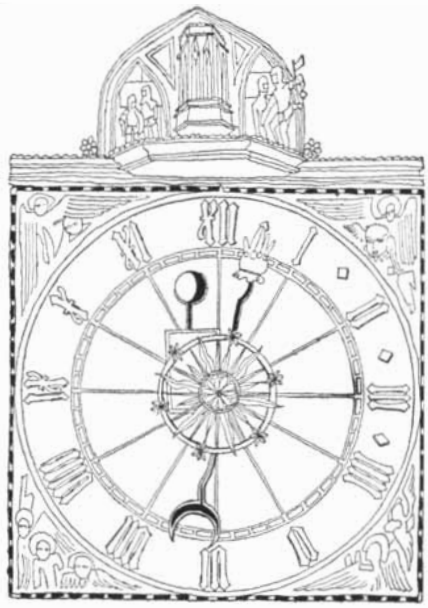
How primitive that figure looks, now that the last link of the EKTALINE chain is in place!

We hereby offer the new KODAK EKTALINE 200 Processor that processes KODAK EKTALINE 12, 16, or 18 Paper at 200 ft/min. (Feet, not inches!) With this machine in your darkroom, evaluation of a 475-foot roll of data can commence less than 3 minutes after the paper has been brought in from the oscillograph and placed on the supply spindle. You can operate the machine slower if you want to.

It stands 66 inches high by 31 inches wide by 52 inches long. Threading, cutoff, and winding are all automatic. The machine presents you with tight, evenly aligned rolls. Quality of the result meets our ridiculously high standards. We'll sell you the machine for $19,500. If people are standing around waiting for their data, you can't afford to go much longer without addressing an inquiry to Eastman Kodak Company, Professional Apparatus Division, Rochester 4, N. Y.

Price subject to change without notice.

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

Two Neutrinos

A massive experimental effort, almost two years in the planning and execution, has demonstrated that two distinct kinds of neutrino exist. One of them is connected in some way with the electron; the other, in apparently the same way, with the mu meson, or muon. The experiment was performed with the 30-billion-electron-volt accelerator at the Brookhaven National Laboratory by a group of physicists from Columbia University and Brookhaven. In 700 hours of actual running time over the past six months 50 mu-type neutrinos were caught, out of an estimated total of 100 trillion that passed through a 10-ton detector.

The neutrino is a massless neutral particle that was first proposed about 30 years ago to explain an apparent discrepancy in the process known as beta decay—the emission of an electron (or positron) by a radioactive nucleus. The energy of the emitted electron is almost always less than the nuclear energy lost. It was suggested that the missing energy is carried away by an undetected particle emitted together with the electron. Theory indicated that the particle, named the neutrino, would be almost undetectable because of its fantastically small probability of interacting with other forms of matter (see "Neutrino Astronomy," page 90). The beta-decay neutrino was directly detected only seven years ago.

Meanwhile, in studying the decay of the pi meson, or pion, physicists noted another energy discrepancy. The pion turns into a muon, but again with missing energy. By analogy the physicists who first saw the decay assigned the energy to a "neutretto." Subsequent experiments showed no differences between the properties of neutrettos and neutrinos, and so it was generally assumed that they were all neutrinos or, strictly speaking, neutrinos and antineutrinos, since every particle has an accompanying antiparticle. (Neutrinos are created with positrons in beta decay; antineutrinos, with electrons.)

There was no theoretical reason, however, why the particle created with a muon should be the same as the one created with an electron. A few years ago suspicions began to arise that they were not the same. Certain reactions that would be expected to occur if the two neutrinos were identical could not be found. In particular the muon should have decayed occasionally into an electron and a photon (quantum of light). Its failure to do so was termed the muon-decay crisis; several physicists noted that the crisis would be averted if the muon-connected neutrino were different from the electron-connected one.

At the same time the possibility emerged of putting the question to a test. Ordinary neutrinos—of either sort—are so hard to detect at all that the task of distinguishing between them is virtually hopeless. But neutrinos with high energies should, according to theory, interact more strongly and so be easier to detect. The huge 30-billion-electron-volt accelerators at Brookhaven and at the European Organization for Nuclear Research (CERN) in Geneva were just being finished, and they were expected to furnish neutrinos with enough energy to make an experiment possible.

The experimental phase of the Columbia group was to allow a pure beam of muon-connected neutrinos to interact with nuclei in a target material and to examine the products of all the reactions. If all neutrinos are the same, then their interactions should produce electrons and muons impartially. If they are not the same, muon-connected neutrinos should make only muons.

The target consisted of 10 tons of aluminum in the form of inch-thick, four-foot-square plates in a "spark chamber" (*see cover of this issue*). A high voltage between successive plates caused a spark trail whenever a muon or electron passed

through the chamber. Muon trails look different from electron trails.

To obtain the beam of test neutrinos, the proton beam of the accelerator was directed against a beryllium target, producing a beam of pions. These were allowed to decay into muons and neutrinos over a 60-foot path. Then the muons and undecayed pions were filtered out through 42 feet of solid iron. The neutrinos, which passed through the iron almost as if it were not there, continued into the spark chamber. Counters placed around the chamber were arranged so that sparking voltage was applied only when the charged particles of an "event" originated within the chamber and did not come in from outside. By thus reducing the background of unwanted tracks the experimenters were able to photograph and count the tracks of the extremely infrequent reactions they were looking for.

They observed 50 such reactions in about six months. In 29 reactions a single energetic muon was produced; in the other 21 reactions, muons were produced together with other particles. There were no energetic electrons. Therefore the muon-connected neutrino is intrinsically different from the electron-connected neutrino, although no one as yet has the faintest idea wherein the difference lies.

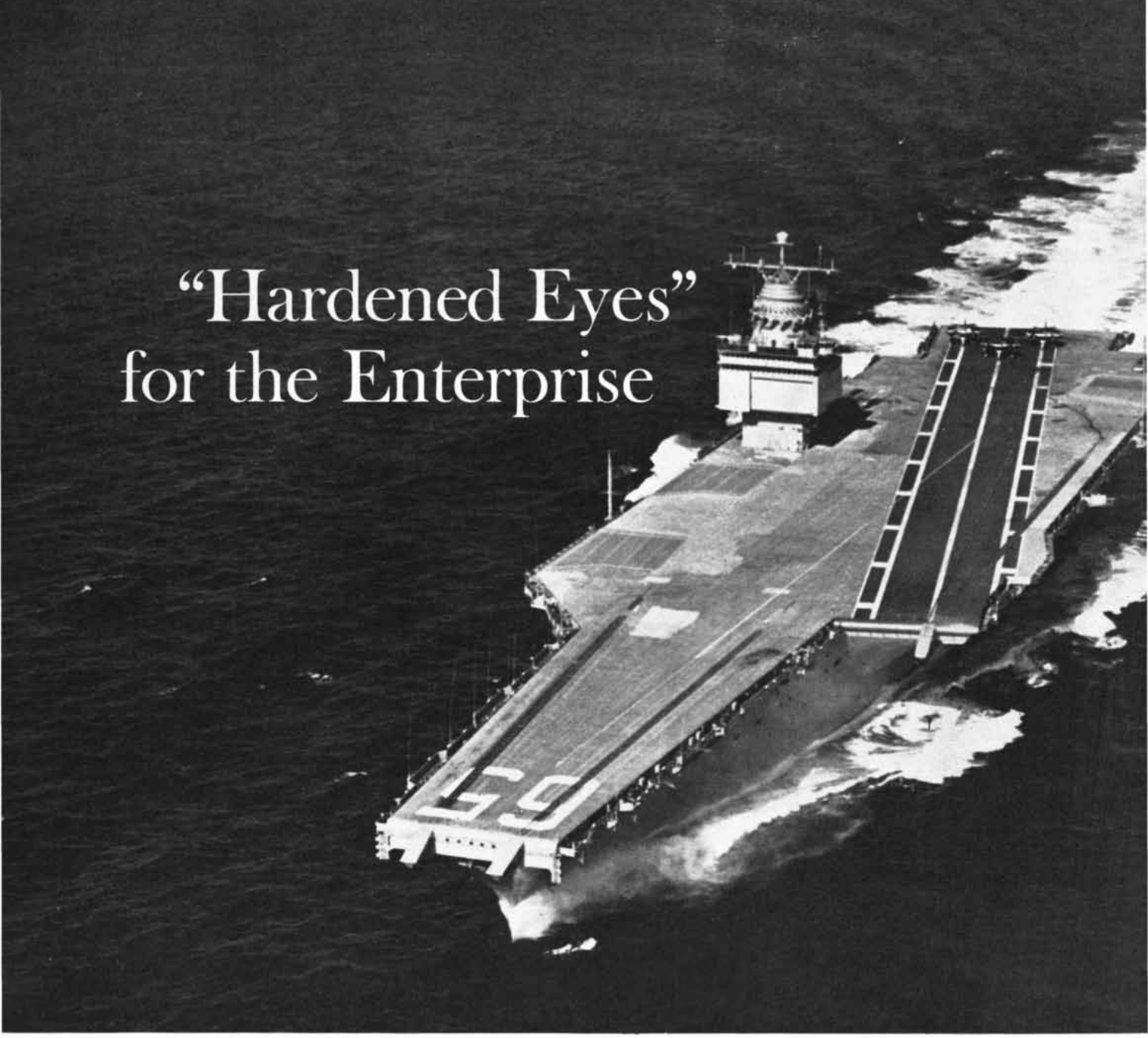
The experiment was conducted by Leon M. Lederman, Melvin Schwartz, Jack Steinberger, Jean-Marc Gaillard, Konstantin Goulianos and Nariman Mistry of Columbia and Gordon Danby of Brookhaven.

Another Twisted Molecule

The structure of ribonucleic acid (RNA), after puzzling investigators for more than a decade, turns out to resemble closely the double-stranded configuration of deoxyribonucleic acid (DNA) proposed in 1953 by James D. Watson and F. H. C. Crick. The determination of the RNA structure is reported in *Nature* by M. Spencer, W. Fuller, M. H. F. Wilkins and G. L. Brown of King's College London.

Although DNA and RNA both consist of the subunits called nucleotides, their roles in the living cell are quite different. DNA is the hereditary material—the genes. RNA has two well-established functions. "Messenger" RNA carries in-

"Hardened Eyes" for the Enterprise



The new U.S.S. Enterprise is a ship full of superlatives. "Queen of the Seas," she is the world's largest ship, the world's first nuclear-power carrier. She displaces 8,000 tons more than the Queen Mary, and stood on end she would be as tall as the Empire State Building. On her sea trials, Enterprise did over 35 knots, leaving her destroyer escort in her wake. Six squadrons of supersonic interceptors and bombers give her an offensive punch unmatched in history. Her "eyes" are new Hughes long range detection and 3-dimensional target tracking radar antennas—hardened to withstand even atomic blasts. Modern as the Enterprise herself, these new antennas are a radical flat-faced type. In operation they make no mechanical movement, instead, they position radar beams electronically. Unlike the conventional "rock and roll" antennas, these new antennas have no parts to wear out, no fragile assemblies to break down. With 8 of these new Hughes antennas mounted to the 4 sides of her control tower (see photo below) the Enterprise can scan infinitely greater ranges. Her commanders can keep continuous track of a great many aircraft flying at supersonic speeds, at all altitudes and in all directions. Hughes engineers at the Fullerton facility,

Revolutionary Hughes 3-D, flat-faced radar antennas are mounted on all four sides of the Enterprise tower. Each antenna can track many targets simultaneously—providing range, bearing and altitude information without physical motion of any kind.

Creating a new world with electronics

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working with the Navy, pioneered the concept of 3-D radar—the most important advancement in the art since radar itself was invented. The first prototype Frescan was delivered in 1957. Today this advanced radar is aboard many of the Navy's latest missile cruisers and destroyers. **Systems management at Hughes** includes projects in all areas of advanced electronics, space and missile work. Current activities include the SURVEYOR lunar landing spacecraft, Falcon air-to-air missiles, ion engines for long space journeys, "Missile Monitor" truck-mounted air defense systems, airborne controls systems for the F-106, and VATE computer-controlled missile checkout systems.

formation from DNA to the cellular particles called ribosomes, instructing them how to synthesize proteins. "Transfer" RNA comes in 20-odd varieties specifically coded to recognize each of the 20-odd amino acids that are assembled into proteins. Transfer RNA delivers amino acids as needed to the ribosomes.

The British workers focused their efforts on transfer RNA because its molecular chain contains only about 80 nucleotide subunits. It is therefore considerably smaller than messenger RNA and easier to purify. They found that when transfer RNA from baker's yeast was obtained in crystalline form, it produced clear X-ray-diffraction pictures in which previous ambiguities could be resolved. They concluded that the polynucleotide chain of RNA is folded double and twisted into a helix. The helix is about 100 angstrom units (a millionth of a centimeter) long and is twisted around its long axis about three and a half times. As in DNA the two chains of the helix are cross-linked by pairs of subunits called bases. In RNA these pairs are adenine linked to uracil and guanine to cytosine. Because of this base pairing, transfer RNA should contain equal numbers of adenine and uracil units and of guanine and cytosine units, if one ignores the bases at the folded end of the helix and a small unpaired remnant at the opposite end. The equivalence has been confirmed by base analysis.

The distinctive feature of the RNA molecule is the fold, or junction, at one end, which consists of at least three unpaired nucleotides. These three units may specify a particular amino acid, matching the code for amino acid sequence dictated by messenger RNA. The function of the remaining nucleotides may be to react with a specific amino-acid-activating enzyme so that the correct amino acid is picked up by the transfer RNA. The British group has evidence that extensive helical regions exist in all other forms of RNA.

Best Clock

An atomic clock has been built with the simplest of all possible "pendulums," or resonant systems—free hydrogen atoms in the ground (lowest energy) state. As a result it runs more steadily than any other timepiece in existence. In its present version it gains or loses at the rate of a few seconds in 100,000 years, which represents about 100 times the precision of the best previous atomic clocks.

All such clocks are based on a transition from one quantum energy state to another in a group of atoms or molecules. Each transition produces (or absorbs) electromagnetic radiation of a characteristic frequency. In principle the frequency is unique, but in practice it is spread over a range of values by interactions among various electrons of the atoms or molecules. Hydrogen has only one electron, and free hydrogen atoms are therefore subject to a minimum of frequency spread.

In the ground state of hydrogen the electron can have its magnetic axis parallel to that of the proton of the nucleus or antiparallel. (Both proton and electron have magnetism because of their intrinsic spin.) The parallel alignment has slightly more energy, and when the atom shifts to the antiparallel configuration it emits radiation of 1,426 megacycles per second. The difficulty in using hydrogen for an atomic clock has been that, in the usual arrangement of the device, the radiating atoms spend less than a thousandth of a second in the resonating cavity where their energy must be released. This is too short a time for a significant proportion of atoms to flip to change alignment and emit a photon of radiation.

Now Norman F. Ramsey, Daniel Kleppner and H. Mark Goldenberg of Harvard University have resolved the difficulty by trapping hydrogen atoms in a storage chamber for a long enough time to obtain useful quantities of energy. The chamber is a quartz bulb coated on the inside with a silicone compound with which hydrogen atoms do not interact. As a result they can collide with the wall tens of thousands of times and still retain their energy for an eventual spontaneous transition. Hydrogen atoms are introduced into the bulb after passing between the poles of a magnet that diverts atoms in the lower-energy, antiparallel configuration and admits only those in the parallel configuration.

When the first storage-bulb maser was built, it proved so much more accurate than existing atomic clocks that it could be tested only by building another. Comparison of the two has shown that the device can maintain a 1,426-megacycle radiation with an error of only a few parts in a million million. The ultimate hope is a precision of one part in 10^{15}—a gain or loss of one femtosecond per second (see below).

It's a Femto- World

The scientific imagination is proving richly equal to the task of thinking up new prefixes to accommodate the

By SAM PUCKETTE
District Manager
Non-Linear Systems, Inc.
Del Mar, California
and
HENRY W. LAUB
Project Engineer, Cell Development
Diamond Alkali Company
Deer Park, Texas

Digital Measuring Technique Yields up to $8,000 Annual Saving

A simple, digital measuring technique that can result in significant savings in AC or DC power helped solve a production problem for Diamond Alkali Company.

The problem centered around the question:

"How do you measure very small changes in voltage quickly and accurately?"

The method used by Diamond Alkali to detect small voltage drops can provide power savings in such applications as electrolytic processing, electrical power generation, and in the nuclear sciences. More broadly, it can serve as a general design tool by accurately and automatically measuring a wide range of voltages.

In the specific case of Diamond Alkali, personnel at the diaphragm plant in Deer Park, Texas, had believed that optimum placement of internal cell components would provide more efficient use of power in producing chlorine from sodium chloride brines by electrolysis. Also, voltage drops in bus bar connections had to be minimized to reduce power loss. In fact, a voltage drop of 0.01 volt at 30,000 amps would result in a loss of $8,000 a year. But because the voltage changes involved were only several hundredths of a per cent, it was difficult to recognize them with existing equipment.

The answer was a bit of ingenuity and an automatic digital voltmeter made by Non-Linear Systems, Inc., originator and world's leading manufacturer of DVM's. By allowing one or two men to make the measurements and observe instantly and accurately changes as small as one millivolt in 5 volts, the NLS 4-digit voltmeter (now $1,460) aided in producing power savings of up to $8,000 annually in this one area. Of significance was the fact that personnel making measurements could observe the digital readings from as far as 30 feet away. A long cable permits the operator to place the input probes anywhere along the long line of chlorine cells.

For information on how digital voltmeters and other digital measuring instruments might be of assistance to you, please contact one of the 19 NLS factory offices or write Non-Linear Systems, Inc., Del Mar, Calif.

PHOTO COURTESY-DIAMOND ALKALI COMPANY

Digital voltmeter is used to detect small voltage drops.

decimal system to the worlds of the very small and the very large. A list of prefixes recently approved by the International Union of Pure and Applied Physics contains some rococo additions to the vocabulary.

Deci-, centi- and milli- still mean tenth (10^{-1}), hundredth (10^{-2}) and thousandth (10^{-3}). Micro- for millionth (10^{-6}) is passing into general usage, but nano- (10^{-9}) and pico- (10^{-12}) are still somewhat special. Ready and waiting for things to get small enough are femto- (10^{-15}) and atto- (10^{-18}). In the other direction the list is sparser, proceeding from kilo- (10^{3}) and mega- (10^{6}) to giga- (10^{9}) and tera- (10^{12}). Compound prefixes are discouraged. Don't say micromicrofarad, say picofarad; it is not kilomegawatt but gigawatt.

Perfect Crime

"My death is premature. I have been assassinated by the English oligarchy and their hired murderer...." Napoleon Bonaparte entered this solemn charge in his last will and testament, signed on April 15, 1821, in the sixth year of his captivity on the lonely island of St. Helena in the South Atlantic. He died there three weeks later, not yet 52 years old.

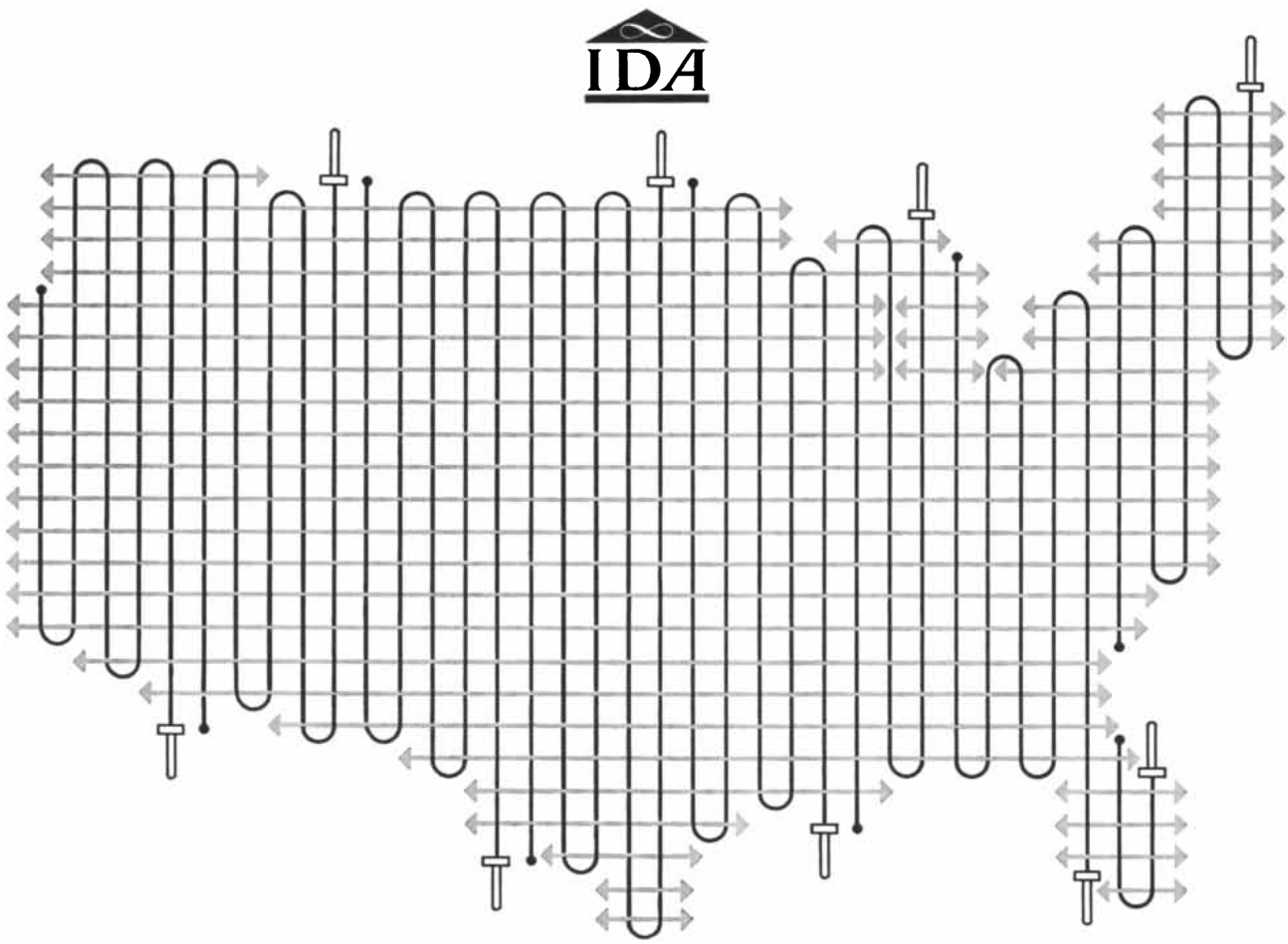
The finding of the autopsy conducted by his warders was cancer of the stomach. Although Napoleon was endowed with a robust constitution and enormous vitality, he had fallen into chronic illness almost from the time he set foot on St. Helena. Eyewitness accounts of his wretchedness have caused many medical writers to question the official diagnosis. From such secondary evidence it has been deduced that the fallen conqueror suffered from a great variety of diseases, from epilepsy to syphilis. Last October in *Nature* three physicians published primary evidence indicating that Napoleon's own diagnosis was the right one.

Sten Forshufvud and Anders Wassén of Göteborg, Sweden, working on the theory that Napoleon had been murdered by arsenic poisoning, enlisted Hamilton Smith of the Department of Forensic Medicine at the University of Glasgow to test a few short strands of Napoleon's hair for the presence of arsenic. Smith applied the technique of neutron-activation analysis. He exposed the sample of hair along with a control sample of arsenic for 24 hours in the neutron flux of a nuclear reactor at the British Atomic Energy Research Establishment at Harwell. He then gauged and compared the radioactivity of the two samples for the presence of radio-

Woof

Warp is the threads that run the long way in woven fabric, and woof is the threads that run the short way. When they are interwoven, a strong and useful product results. * Let's say the warp is the Department of Defense and that the fabric desired is an effective national defense. The Institute for Defense Analyses helps to weave in the technical inputs that make the fabric strong. * IDA is an association of nine universities, formed at the behest of the government to serve as a medium by which the academic and scientific community can provide the technical advice needed in the Department of Defense to develop the fabric of national defense. Many universities that are not Members also participate in the substantive work. * The IDA roster is filled from all sources of scientific and engineering talent from industry, from research laboratories, and from academic faculty and graduates. The IDA staff grapples with problems of great moment, and often of great urgency, in which science is a principal ingredient. * Thus IDA weaves separate but interdependent strands into the protective clothing of the national body. Its work involves the highest level of sophistication in technology, and affects the highest level of responsibility in the national defense. * IDA seeks highly qualified scientific and engineering talent. A permanent career with IDA is a most satisfying possibility for capable people. IDA also welcomes, and due to its unique nature can put to good use, learned and skillful people for comparatively short periods of time. If you feel you are qualified to make a contribution to this vital work, & wish to do so, let's discuss the matter. It's possible that you could be a great help to us.

INSTITUTE FOR DEFENSE ANALYSES *Department A, 1710 H Street, NW, Washington 6, DC An equal opportunity employer*



active arsenic 16. The hair showed an arsenic content 13 times higher than that normally found in human hair. It was impossible to tell, however, "whether the arsenic was evenly distributed (as expected in continuous exposure) or located in one point (as would be the case in a single large exposure)."

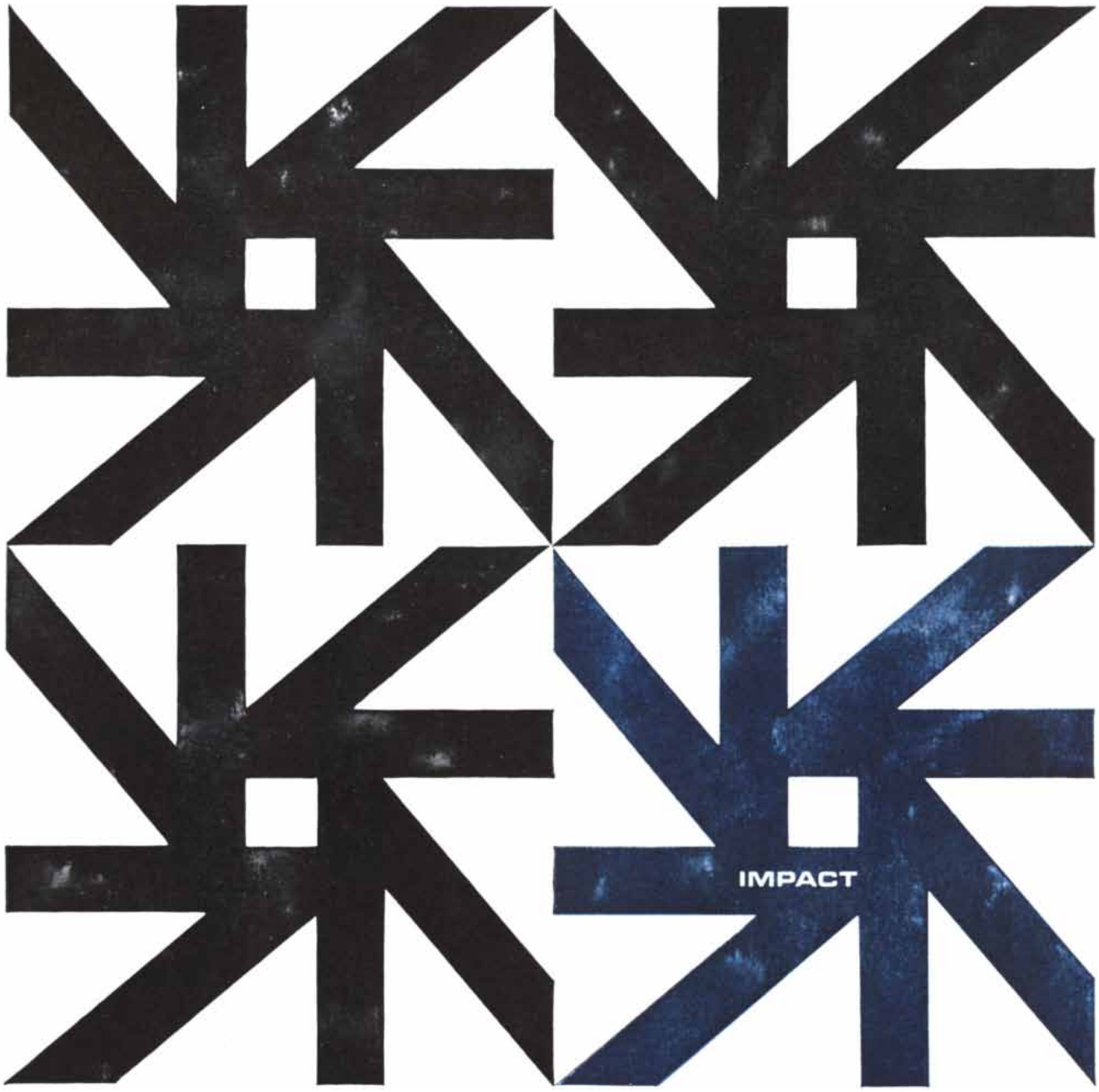
Their report and its concluding qualification brought the gift of a much more substantial sample of Napoleon's hair, a lock shaved from his head on the day after his death and long enough to be tied in an overhand knot. Smith was allowed to select a number of hairs about five inches long, a length that represents a year's average growth. After exposure in the Harwell reactor these were cut in short lengths, each representing about two weeks of growth. The measurement of arsenic content in each short length, plotted against time, now yielded a curve showing that Napoleon must have been fed arsenic intermittently throughout the last year of his life.

Reporting their new findings in *Nature*, the authors observe that the "periodicity of the exposures agrees remarkably well with what can be deduced about the course of Napoleon's disease from the accounts of eyewitnesses." They declare, however, that "no estimate of the size of the arsenic dosage given to Napoleon can be made on the basis of our results; such very desirable information could probably be obtained after exhumation of the corpse."

Smooth Venus

Radar signals beamed through Venus' dense cloud cover have revealed that the surface of the planet can have practically no great hills or valleys and very few irregularities of more than a few feet in height. These conclusions have emerged from two sets of radar experiments, one carried out at the Jet Propulsion Laboratory of the California Institute of Technology and the other at the Massachusetts Institute of Technology's Lincoln Laboratory.

In the Jet Propulsion Laboratory study, reported in *The Astronomical Journal* by Gerald S. Levy and Danver Schuster, Venus was scanned with a double beam of 12.5-centimeter radio waves. One part of the beam consisted of a horizontally polarized wave, the other of a vertically polarized wave a quarter of a wavelength behind the horizontal component. When such a combined beam strikes a rough reflecting surface, the relations of its component waves are distorted, and the amount of distortion is a measure of the roughness



Modern simulators are evidence of the impact electronics has had on many relationships between man and machines. Science has created systems influenced by more factors than the average person can readily visualize and simulators provide the analogs that pre-determine the effect of variables on the performance of a system or its human operators.

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of the surface. The amount of distortion found in three different sets of scanning experiments was nearly the same as that obtained in similar studies of the smooth areas of the moon.

The Lincoln Laboratory group, which was headed by G. H. Pettengill and which also described its results in *The Astronomical Journal*, employed a different procedure. The surface of the planet was scanned with a 68-centimeter beam and the strength of the echo was recorded. The latter was then used to calculate the reflectivity and other properties of the Venusian surface. The results obtained suggest that Venus has an arid and rocky but smooth surface.

Lifesaving Locks

A minor change in the design of automobile door locks is saving at least 800 lives a year in U.S. road accidents. Contrary to the implication of the phrase "thrown clear," the fatality rate among people thrown from cars has been found to be about five times higher than among passengers not ejected from the vehicles. In 1954, according to a study by the Cornell University Automotive Crash Injury Research project, ejections in collisions were causing about 5,500 deaths a year.

These findings led to a change in the door locks on all U.S. cars manufactured since 1956. A lip was added to hold the striker lever more securely and lessen the chance of the door springing open on impact. By 1961 more than 40 per cent of the cars on U.S. roads were equipped with the improved locks, and the Cornell group undertook a new study to assess their effectiveness. The results have been summarized in *Public Health Reports* by John W. Garrett. An analysis of several thousand injury-producing accidents showed that one or more doors of pre-1956 cars opened in 44 per cent of the cases, compared with 29 per cent for the newer models. The frequency with which passengers were thrown from the cars dropped from 13 to 8 per cent, a decline of nearly two-fifths. If all cars had had the new locks, Garrett estimates, about 1,800 lives would have been saved. As it was, the saving amounted to almost half that number and can be expected to rise as the proportion of post-1956 cars increases. Moreover, although no lock can prevent car doors from springing open under all circumstances (in many accidents a hinge or the door frame itself gives way), some manufacturers have developed still more secure locks, which should further increase the saving of lives.

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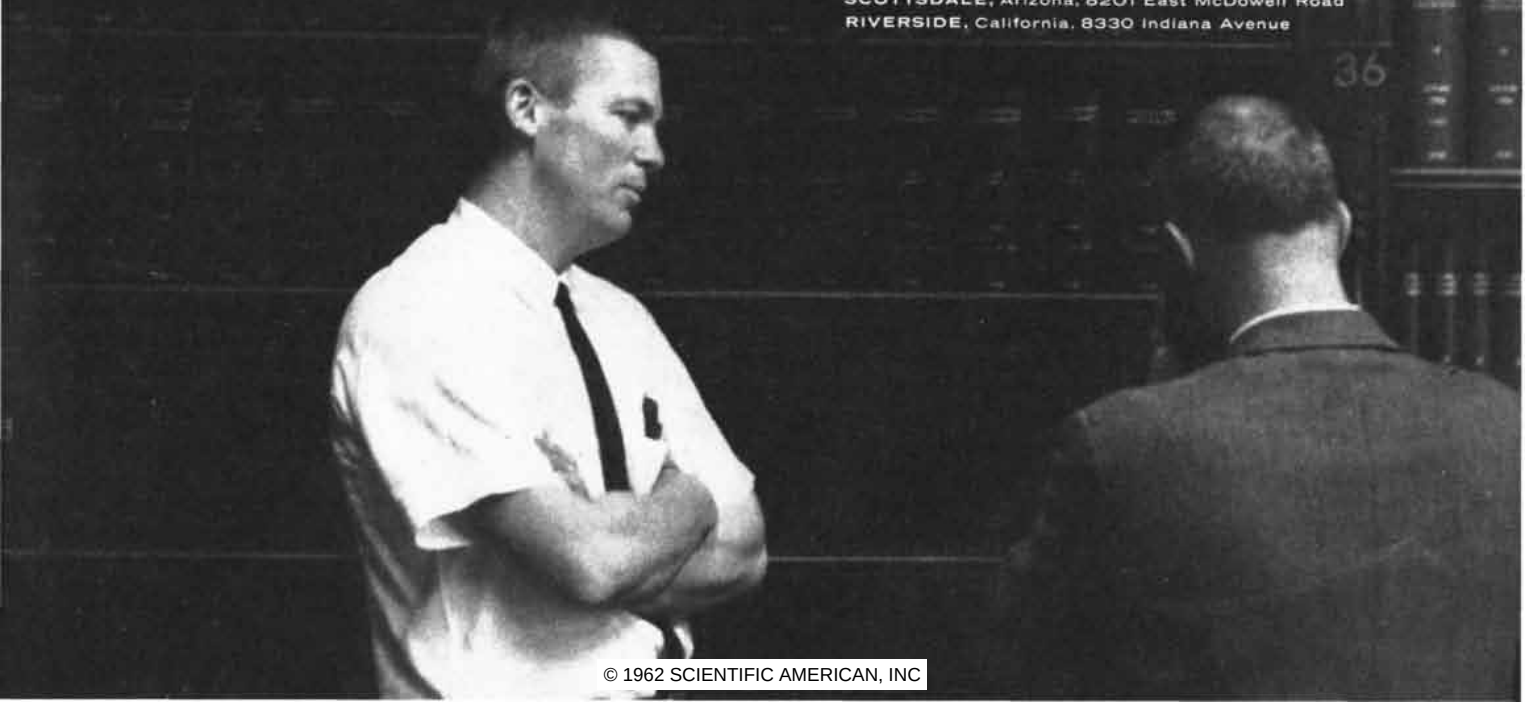

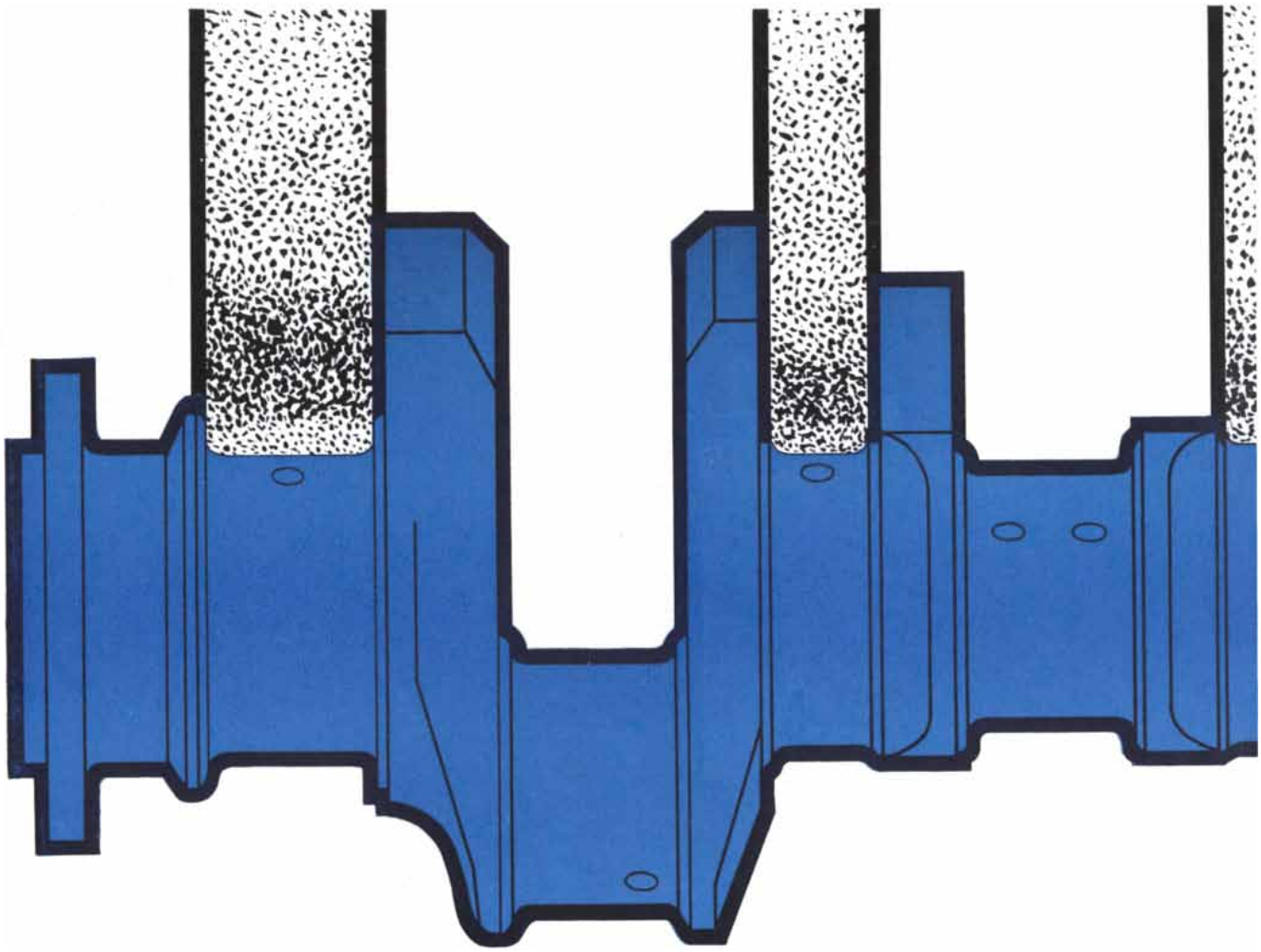

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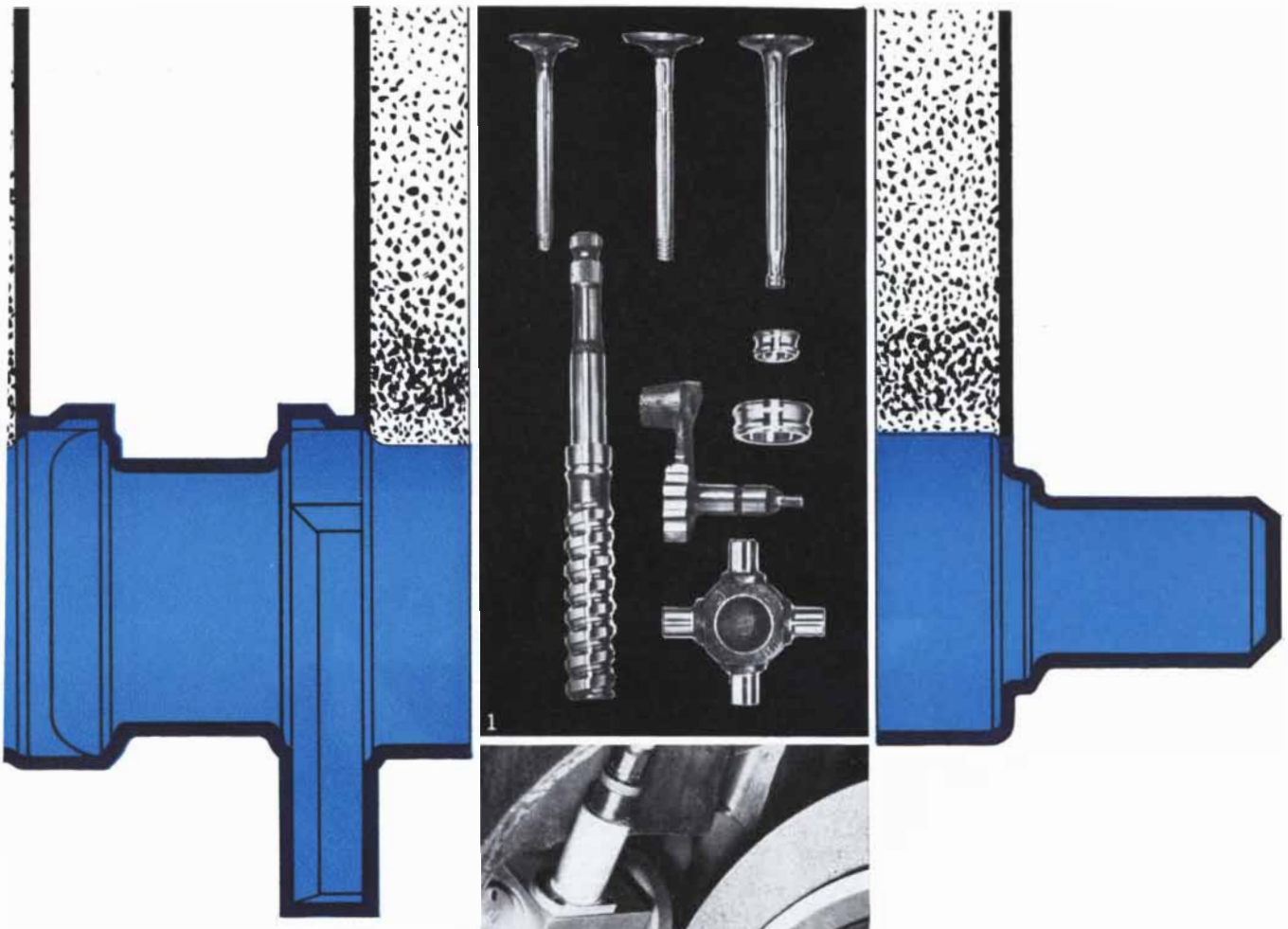

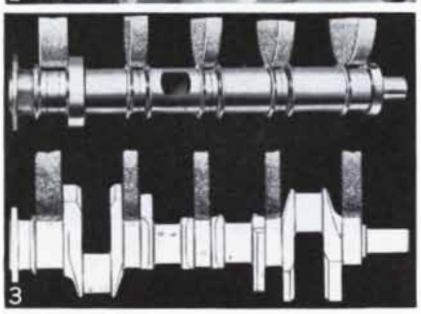

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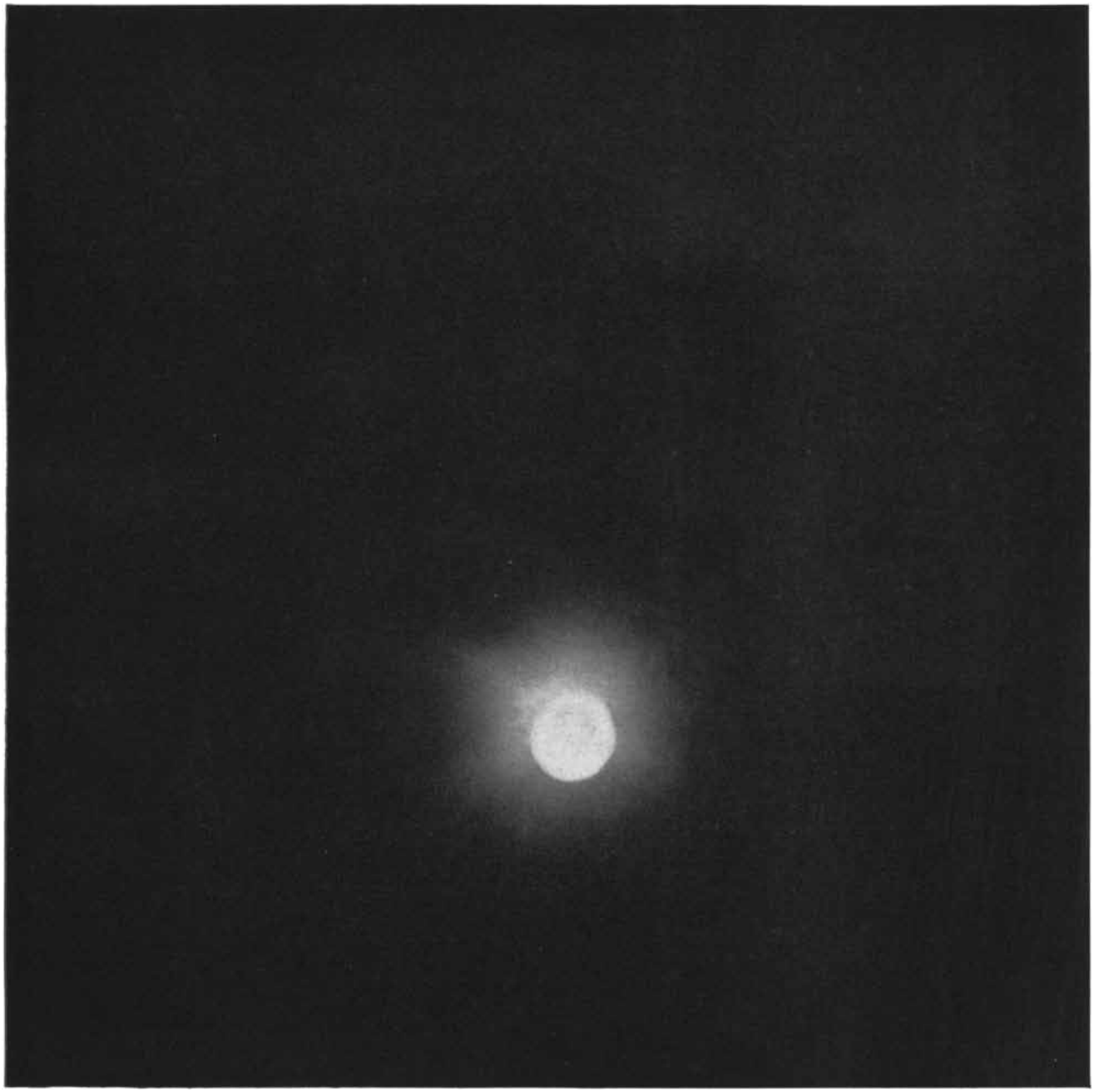

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SCHIZOPHRENIA

This grave mental illness now hospitalizes at least 250,000 Americans. Its investigators have sought to explain it on either a physiological or a psychological basis. The latter explanation is currently favored

by Don D. Jackson

Schizophrenia is a major public health problem compounded of the private and individually unique catastrophes of its victims. The diagnosis of schizophrenia accounts for more than half of the mentally ill patients who fill more than half of the hospital beds in this country. Typically the disorder overtakes younger people—"between the ages of 18 and 28." Often it maims them for life: the schizophrenic entering a state hospital has little better than an even chance of ever returning to society as a functioning member. The symptoms of the disease are behavioral, and they are as diverse as the personalities of the patients themselves. Of schizophrenics in general it can be said only that they show little or no response or inappropriate response to other people and to their environment. Frequently they exhibit secondary symptoms, including hallucinations and delusions, confusion, fluctuation of mood from manic to depressed, stupor and catatonic rigidity. In a sense the symptoms are the disease. There is no agreement among therapists and investigators as to the underlying nature of schizophrenia and its cause.

It is not for lack of study that schizophrenia remains a mysterious and intractable disease. Since the turn of the century it has occupied the forefront of psychiatry in the U.S. and Europe. From a survey of the huge literature that I have recently completed I can testify that the difficulties arise not only from the nature of the disease and the unsatisfactory character of its victims as research subjects but also from the human frailty of its investigators. The symptoms of schizophrenia are ambiguous and so various from culture to culture that the consistency of diagnosis and recorded data must be correspondingly low. The chronic patients in state hospitals, who are readily available and therefore the subjects most often studied, are members of a subculture: the mental hospital. The social effect of being imprisoned and of feeling abandoned and the physical effect of poor diet and lack of exercise bring on behavioral problems and even physiological and constitutional changes that are peculiar to this culture.

But the study of schizophrenia must include also study of its investigators. They have tended to gravitate toward one of two extremes: to investigation of some easily isolated and controllable aspect of the patient—his urine, for example—or to generalized sociological observations that may be interesting but that are difficult to prove or to replicate. On the whole the largest effort has gone into the search for some neat biological explanation for schizophrenia, and hence a cure, at the expense of broader research. Certainly it would be agreeable if some abnormal biochemical process or some pathological change in the brain could be made to explain the malfunctioning of the schizophrenic, because a drug or an operation could then undoubtedly be devised to cure him. If the accumulating literature proves anything, however, it shows with increasing clarity that there will be no such simple answer to schizophrenia.

Fortunately this bleak conclusion does not constitute the sole finding of my survey of the literature. I also note encouraging signs in recent years of willingness to encompass broader questions. Instead of chopping the patient into bits in order to study the variables in isolation, the trend is now toward study of the many variables involved—physiological, psychological and social—in their interaction.

The Taxonomy of Mental Illness

Schizophrenia is one of the many categories of mental illness worked out by 19th-century German psychiatrists in the confident expectation that the laboratory would soon match diagnosis with specific cure. In the psychiatric classification of Emil Kraepelin it was first called dementia praecox, meaning early, as contrasted with senile, deterioration of the brain. In 1911 Eugen Bleuler renamed the disorder "schizophrenia," from the Greek for "split" (*schizein*) and "mind" (*phren*). The term was intended to express the common observation that patients exhibit a splitting of psychic function in which one set of ideas, or "complexes," dominates the personality for a time while others are suppressed. Bleuler also pointed out that there is no anatomical deterioration of the brain and that the affliction does not occur exclusively or primarily in the young, as Kraepelin's label implied. Bleuler urged that the disorder be called "the group of schizophrenias," because he felt that psychiatrists were dealing with a variety of disorders linked by certain common symptoms.

Unfortunately Bleuler's cautioning too often goes unheeded nowadays, and many research reports prove meaningless because the author tells nothing about his cases except that they are "schizophrenic." Kraepelin originally distinguished four subclasses of the disorder: hebephrenic, characterized by undue concern with the body image, hypochondriac symptoms and silliness; catatonic, characterized by mute, rigid withdrawal; paranoid, characterized by suspicious, embittered attitudes and feelings of persecution; and simple schizophrenia, characterized by an insidious onset leading to withdrawal, confusion and secret grandiosity. The usefulness of Kraepelin's classification is attested by the fact that it continues in use to this day in hospital psychiatry. In the standard nomenclature of U.S. psychiatry schizophrenia is broken down into nine forms,

to which most psychiatrists add two paranoid syndromes. Many authorities now feel that the picture of schizophrenia is too mixed to permit such fine-grained classification. They point out that it is much easier to classify chronic, hospitalized patients than to classify more acute cases at onset.

Next to schizophrenia the most common diagnoses on admission to state hospitals in the U.S. are senile psychosis and alcoholism, which respectively account for roughly 20 per cent and 10 per cent of all patients. In both cases the behavioral disorder is usually accompanied by some observable constitutional defect. Involutional melancholia, which principally afflicts women at the crisis of menopause, is the diagnosis in 10 to 15 per cent of the patients. In a dwindling number of cases the patients are initially diagnosed as suffering from manic-depressive psychosis. This condition is characterized by the cyclic emotionality implied by its name and is distinguished from schizophrenia because the patient does not show the flattening or disengagement of emotional response to others. In the medical records of the U.S. today the manic-depressive shows up increasingly in the depressive phase of his illness. Whatever the diagnosis on admission, as Lionel S. Penrose of University College London observed in 1941, the longer a patient remains in a mental hospital, the more the diagnosis tends to become that of schizophrenia.

Agreement as to diagnosis may conceal the most diametrically opposed opinions as to the nature of the disease. In the view of classical psychiatry schizophrenia was a "thinking disorder." The patient could say, for example, "Mother is dead," while smiling because he lacked all feeling or because his feelings were inappropriate. This lack of apparent feeling led Sigmund Freud to the conclusion, early in the century, that the schizophrenic was too narcissistic—that is, too self-preoccupied—to be reached by the psychotherapist. It was not until the 1920's that the U.S. psychiatrist Harry Stack Sullivan and his associates came forward with the view that the schizophrenic's apparent lack of emotion hid an extreme sensitivity; they found that their patients were able to form intense relationships in psychotherapy. On the other hand, the more organically minded investigators understand the lack of emotional response as a defect, and they postulate an anatomical or physiological cause. One can say in general that the closer an investigator is to the medical sciences and to European traditions in medicine, the more likely he is to ascribe organic causation to the symptoms of schizophrenia. Correspondingly, the closer he is to the behavioral sciences and to U.S. traditions, the more likely he is to view schizophrenia as a psychologically determined condition.

For their part schizophrenics seem to be obligingly responsive to the attitude of the investigator. A patient may seem hopelessly ill to the organically oriented psychiatrist, and with the same patient a psychologically oriented psychiatrist may strike immediate promise and future hope. Who is to say how much such factors may influence the eventual outcome, not only in particular cases but also in the ultimate understanding and management of this cruel disorder?

The Genetic Hypothesis

One of the most fruitful hypotheses, measured in terms of the volume of work it has inspired, holds that schizophrenia is a hereditary disease. Most human geneticists have long since set aside such primitive notions as "poor protoplasm," advanced by 19th-century German physicians in explanation of many afflictions, from leprosy to insomnia. They recognize also that the entity of personality embraces many variables to which the Mendelian laws of single-factor inheritance are inapplicable. The principal difficulty in the way of this line of research, however, remains the fact that the same individuals who provide the genetic inheritance of the schizophrenic also furnish the early environment in the overwhelming majority of cases. It has therefore been an impossible task to sort out the relative influences of nature and nurture.

The idea of studying identical twins in order to accomplish this sorting out was suggested as early as 1885 by the English mathematician and geneticist Francis Galton. Today the most widely quoted evidence for a hereditary cause of schizophrenia comes from the study of the disease in identical twins conducted by Franz J. Kallmann of the Columbia University College of Physicians and Surgeons. He showed that if one identical twin is located in a state hospital suffering from schizophrenia, there is an 85 per cent chance that the other twin will be found to suffer from the same disorder. This is an impressive figure, even discounting the fact that concordant pairs are much more likely to attract attention than discordant ones. Identical twins, however, have been the subject of intensive psychological study, and it is clear that the relation involves something more than just two individuals who have a similar genetic inheritance. In twins, as in other pairs of individuals who are emotionally close to each other, the condition known as *folie à deux* has been commonly observed. The two partners tend to develop shared delusions and symptoms and to become mentally ill at about the same time. A study of the case histories of sibling pairs reveals a strong homosexual element that shows up in the content of their delusions and seems related to difficulty in

FIVE PIONEERS in the study and treatment of schizophrenia are, reading from left to right, the psychiatrists Sigmund Freud of Austria, Frieda Fromm-Reichmann of the U.S.,

distinguishing "me" from "you." The condition is four times more common in women than in men and typically results in two spinster sisters living in semi-seclusion in their 30's or 40's. This is undoubtedly related to the fact that in our culture "closeness" between brothers is likely to receive opprobrious notice because of suspicion of homosexuality, whereas intimacy between women is acceptable. Published reports on fraternal as well as identical-twin pairs show a much higher concordance for schizophrenia among female pairs. One report, in fact, shows that female fraternal twins were nearly 50 per cent concordant, a figure that compares with Kallmann's finding for identical twins.

What about identical twins who are reared apart? There is a fiction rampant to the effect that schizophrenia tends to afflict both twins simultaneously. In a careful search of the literature I have been able to turn up only two instances that partially satisfy the terms of this story. In each case the twins were adopted by relatives on opposite sides of their natural families and were well aware of each other's existence; in fact, they were caught in the middle of family feuding. The effects of heredity and environment could not be said to have been separated in these cases. In an intensive effort to assess the incidence of schizophrenia, without regard to simultaneity, in pairs of identical twins reared apart, a group of investigators led by H. H. Newman and Frank N. Freeman collected 19 cases after scouring the entire U.S. This labor came to no conclusion because the investigating team disagreed on the relative weight to be accorded to nature and nurture in these cases.

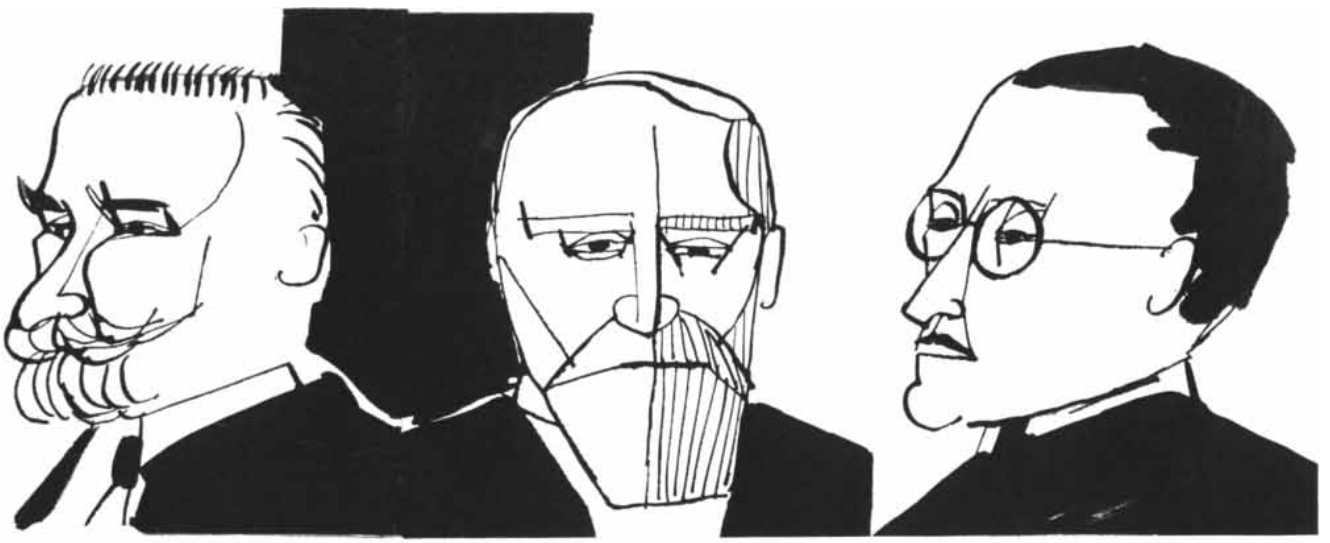
Apart from identical twins the statistics show that schizophrenia does tend to "run in families." To some investigators the figures suggest the classical Mendelian dominant mode of inheritance; to others the genetic factor appears recessive. But all of these statistical series betray evidence that cultural influences are at work. The shadow of *folie à deux* is apparent, for example, in a Swiss study that shows that sister pairs and mothers and daughters are more likely to be found in mental hospitals than brother pairs and fathers and sons. Two recent Scandinavian studies reveal an almost complete absence of the disease in the fathers of schizophrenics and a significantly higher incidence in mothers. But geneticists do not claim that schizophrenia is a sex-linked disorder!

Some geneticists have attempted to tie schizophrenia to other aspects of inheritance: to type of physique or to a predisposing "schizoid personality," characterized by tendencies to introversion. These studies have foundered on the observation that schizophrenics and their relatives come in all shapes and sizes and on the discovery that the schizophrenic patient has been found to be extroverted as often as introverted prior to his illness.

The more modern idea is that schizophrenia is a hereditarily determined disease that requires psychogenic stress for its precipitation. Such a proposition is difficult to prove one way or the other. Until the ill-defined abstraction of "personality" can be broken down into enduring traits that are shown to have a genetic basis it is surely fruitless to look for a genetic mechanism behind the symptomatic disorder of schizophrenia. If the apparently unitary and measurable "trait" of intelligence comes under suspicion, as it has in recent years, then personality must seem even less subject to hereditary determination. All are agreed that sick patients come from sick families, but the question of whether this commonplace observation rests on psychological or physiological grounds or both has scarcely been broached.

Biochemical Investigation

It would appear that a genetic cause of schizophrenia would have to manifest itself in some metabolic or other biochemical defect. No such defect has been uncovered in 60 years of persistent investigation. Biochemical investigation of schizophrenia usually pursues one of two major courses: (1) the body chemistry of "normals" is compared with that of schizophrenics or (2) the same drug is administered to the two classes of subjects and the difference in effect, if any, is compared. A review of published reports indicates that work along both lines has been largely inspired by chance discoveries or by purely empirical leads. In the early 1900's, for example, Sir David Bruce observed that the administration of thyroid-gland extract had an apparently beneficial effect on schizophrenics. There followed a large number of papers on the activity of the thy-



Emil Kraepelin of Germany, Eugen Bleuler of Germany and Harry Stack Sullivan of the U.S. Their researches in this field span a period of approximately 75 years, extending from the last quarter of the 19th century through the first half of the 20th century.

roid gland in schizophrenia. Manfred Sakel of Germany made a similar finding with respect to insulin; hundreds of papers have since explored the carbohydrate metabolism of schizophrenics.

The most recent notable surge of effort along these lines has surrounded the role of serotonin in the biochemistry of the human organism. This substance, originally discovered in the lining of the intestine, was found to play an important role in the function of smooth (involuntary) muscle. Eventually it was isolated from various sites in the central nervous system, in particularly high concentration from certain parts of the brain stem. Some investigators then measured serotonin in schizophrenics and reported it to be high, although a few others found it to be low.

What brought serotonin to the center of the stage in biochemical studies of schizophrenics was the finding that lysergic acid diethylamide (LSD) is antagonistic to serotonin in its action on smooth muscle. LSD had already attracted attention because it induced hallucinations and other symptoms in volunteer subjects; investigators were encouraged to believe that they had come on a means to induce "experimental psychoses" [see "Experimental Psychoses," by Six Staff Members of the

LARGEST MENTAL HOSPITAL in the U.S. is the Pilgrim State Hospital near New York City. Of the 13,991 patients there on March 31, 1958, 60 per cent were schizophrenic. Of the 535,000 patients in all public mental hospitals in the U.S. in 1959, approximately 50

Boston Psychopathic Hospital; SCIENTIFIC AMERICAN, June, 1955]. It was postulated that LSD might produce its peculiar behavioral effects by competition with serotonin in the central nervous system. This idea acquired even more stirring implications from the finding that reserpine, a tranquilizer already in wide use in mental hospitals, apparently produced its effects by a parallel sort of action. It was only one more step to the conclusion that schizophrenia was a disorder of serotonin metabolism and another step to the use of serotonin in the treatment of schizophrenics. Some investigators went so far as to inject the substance into the ventricles of patients' brains, a rather difficult neurosurgical procedure.

per cent were schizophrenic. Fifty-three per cent of these were women; 47 per cent, men.

The enthusiasm over serotonin was heightened by the discovery of a breakdown product of adrenalin called adrenochrome. This substance bears a structural resemblance to LSD and to mescaline, the active ingredient in the hallucinatory mushrooms and peyote cactus employed in religious rituals by the Indians of the U.S. Southwest and the Mexican highlands. The discoverers of adrenochrome found that it induced hallucinations when they administered it to themselves. They proposed, therefore, that an excess of adrenochrome in the biochemistry of schizophrenics brings on their psychotic symptoms.

Further research has failed to sustain these ideas and the hopes they excited. The function of serotonin in the central nervous system remains unknown. A serotonin antagonist called 2-bromolysergic acid produces none of the mental symptoms characteristic of LSD. Chlorpromazine, a tranquilizer more effective than reserpine in quieting schizophrenics, shows no sign of biochemical competition with serotonin. Adrenochrome has yet to be found in the body and has been labeled a laboratory artifact. A painstaking study of the turnover of adrenal substances in the bodies of normal and schizophrenic women by direct measurement from the adrenal arteries and veins has shown no detectable differences. Finally, the much heralded experimental psychoses have turned out to be nothing other than "toxic psychoses," familiar to clinicians for many years and clearly differentiated from schizophrenic states. In toxic psychosis, whether it is induced by drugs or by bodily poisons as in uremia, the patient suffers from depression of higher cerebral function and deficiency in interpersonal transactions. The schizophrenic does not necessarily show such depression and is often capable of complex interpersonal relations.

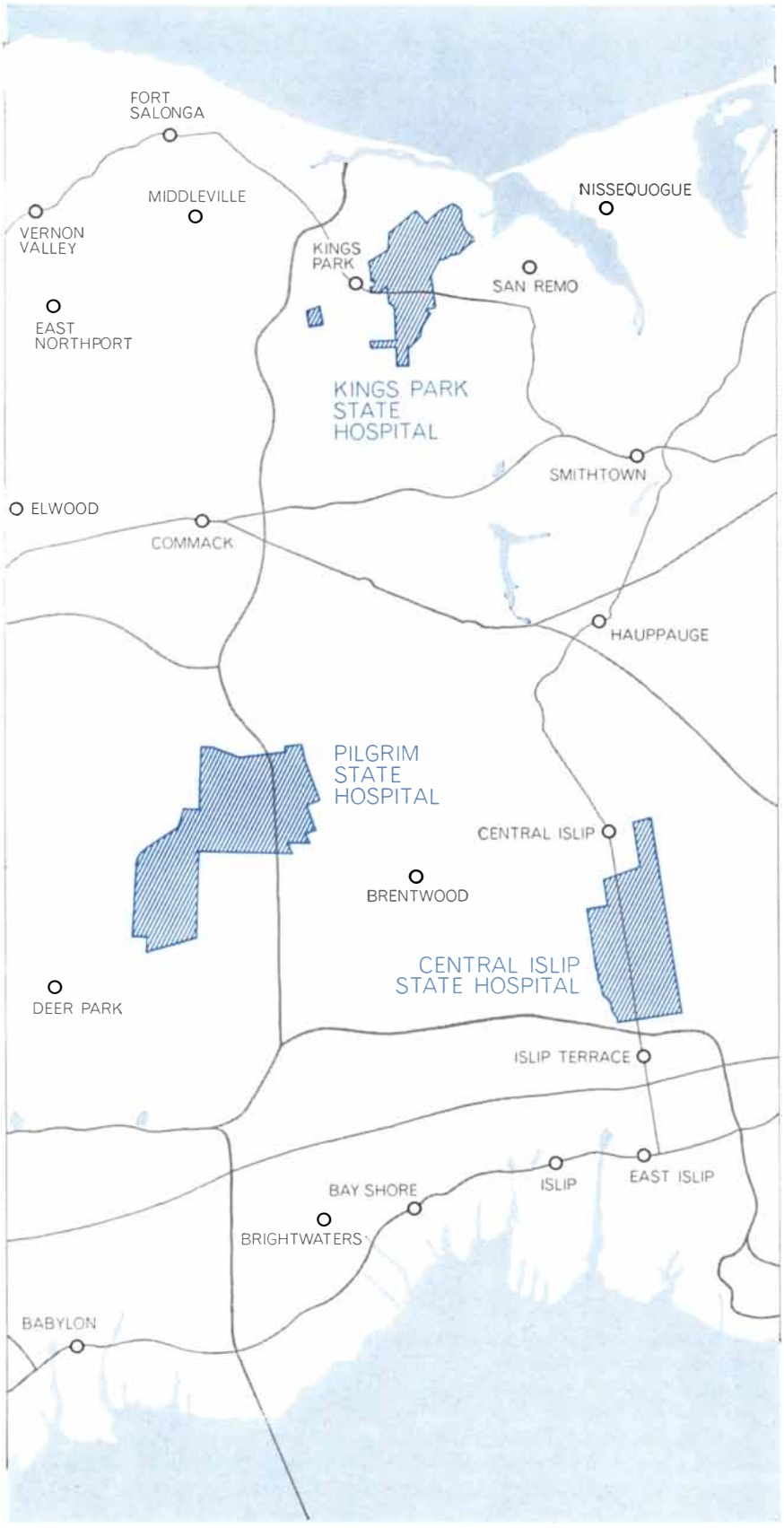
Toxic psychosis is familiar to anyone who has weathered a cocktail party. As is well known, alcohol affects different people differently and the same person differently at different times. By the same token mescaline might enhance the religious ecstasy of a member of the peyote cult and might have quite another effect on an Irishman on a Saturday night in a bawdyhouse. Studies that set out to compare the reactions of schizophrenics and volunteers to drugs must therefore be designed with adequate respect for psychological variables.

Customarily investigators rely on placebos (inert substances) as controls for the drugs being administered. Yet a recent study has shown that the placebo and the tranquilizer function with equal effect in improving the schizophrenic's ability to stop soiling himself. Withdrawal of either substance was accompanied by regression in behavior, and restoration was accompanied by improvement again. This study casts doubt on hundreds of previous investigations that have served to demonstrate the efficacy of tranquilizers as such in the management of schizophrenic patients. It should serve as a caution against hastily conceived programs for testing drugs without proper regard for the context in which they are given.

Failure to observe this practical rule explains most of the false enthusiasms and disappointments that the biochemical approach to schizophrenia has engendered in the past. Although much of importance is being learned about the mechanisms of the living cell and of the body, these advances have shed no light on schizophrenia. It has not been shown that any biochemical substance is involved in the cause of the disorder. It is not even known if schizophrenia is accompanied by an increase in the production of any chemical substance in the body. These questions are not unworthy of investigation, but they cannot be usefully pursued in isolation.

Psychological Causation

Some of the hopes vested in drug-induced psychoses have recently been transferred to purely psychological methods for producing the so-called experimental psychoses. One of the most effective of these techniques is to cut down environmental stimulation to a minimum. Apparently the human organism requires a certain rate of sensory input in order to maintain the functioning of its perceptual apparatus. When the input is naturally lowered, as it is in sleep, those projections of already registered percepts called dreams occur. That the dreaming process has physiological significance as well has been shown by Nathaniel Kleitman of the University of Chicago, who has established that dreaming is essential to physical well-being. Sensory deprivation is accomplished in a number of ways in the laboratory—by submerging the sub-



THREE LARGEST MENTAL HOSPITALS in New York are located in this one section of Long Island. On March 31, 1958, they contained 32,277 patients, of whom 18,993 were schizophrenic. Of the 51,453 schizophrenics in all New York state hospitals at that time, about 60 per cent had been hospitalized 10 years or more and only 13 per cent one year or less.

ject in water at body temperature, for example, or by confining him in a room with his hands isolated in special cuffs, a translucent mask over his eyes and no sound but the hum of an air conditioner. After relatively brief periods, in a majority of cases, the subject begins to have hallucinations and to experience the most unpleasant psychosis-like reactions [see "The Pathology of Boredom," by Woodburn Heron; SCIENTIFIC AMERICAN, January, 1957].

These studies have led some investigators to postulate a psychological mechanism for the induction of schizophrenia. It is thought that the victim is driven by severe anxiety to repress and reject the input of sensory experience from the environment that has become so disturbing to him. Such withdrawal, combined with attempts at restructuring his experience, leads to hallucination and the formation of a delusional system. The psychoses of old age suggest an interesting parallel; in these cases defects in the sensory system lead to disorientation and misperception of environmental cues and therefore to disturbed behavior. One of the most familiar examples of this process is the paranoid feeling on the part of a deaf elderly individual that "people are talking about me."

It is difficult to test hypotheses of this kind, for instance to determine objectively whether a schizophrenic's difficulty in assimilating perceptions is constitutional or learned. Schizophrenics are notoriously uncoöperative, and one cannot be sure how to motivate them properly to do their best on, say, an intelligence test. The evaluation of such a test presents further problems, because the patient may have been daydreaming in school and not taking in material that he "should" have learned and was otherwise capable of learning at a given chronological age in school. Psychological studies of schizophrenics show a ruling tendency toward scatter—that is, toward a chaotic mixture of good and bad performance.

Family Study and Therapy

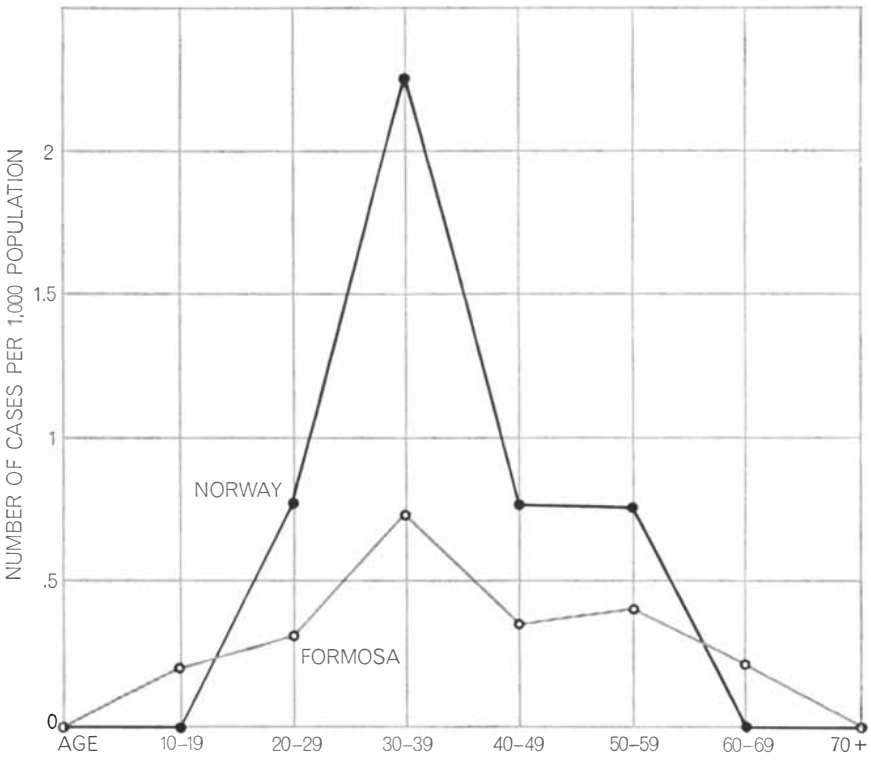
Some useful insights have come from recent studies of the families of schizophrenics. The so-called Benjamin proverbs have long been used in making the diagnosis of schizophrenia. To the question "What is the meaning of the old proverb 'A rolling stone gathers no moss'?" the sick person characteristically gives a literal rather than an interpretive answer. Now there are indications that the parents of schizophrenics also answer in a literal fashion. Such answers

on the patient's part may therefore be regarded as the result of a learning process rather than a thinking disorder.

Ordinarily a physician treats just one person: his patient. In psychiatry the intimacy of the therapist-patient relation has reinforced tradition. Psychiatrists have been slow to think of the disturbed family that may have produced the disturbed patient. This is not to say that the importance of family relations in the genesis of schizophrenia has gone without recognition. But the early psychoanalytic papers, in accordance with the plot of the Oedipus complex, focused on the patient's relation to his mother and neglected the family system. Many therapists today continue to rely on the "patient's-eye view" of the family and conduct only the most superficial interviews with parents, siblings and, in the case of mature patients, spouses.

It was not until the 1950's that therapists began to see the patient's family as a group and to undertake conjoint family therapy. At the National Institute of Mental Health, Murray Bowen arranged for families and patients to live together at the hospital; at other institutions the families visit the hospital once or twice a week for sessions of therapy. As might be expected, such experience has encouraged the formulation of new hypotheses. Among these is the "double bind" theory advanced by Gregory Bateson, Jay Haley, John H. Weakland and me, which sees the traumatic situation of the schizophrenic as arising fundamentally from aberration in communication. The "binder," who may be parent or spouse, demands two quite different and mutually contradictory responses from the patient at the same time but on two levels of communication, as by voice and by action. The patient is so dependent on the binder that he is strongly inhibited against acknowledging or pointing out the contradiction; yet he can neither ignore nor fail to respond to this paralyzing injunction. In a model situation, a mother says to her child: "Don't be so obedient!" She thereby places the child in an impossible paradox. If he obeys the injunction, he is disobedient; if he disobeys, he is obedient. In a real situation the contradiction is, of course, covert and arises perhaps from parental hostility that is camouflaged by the external cultural trappings of the parent-child relation. Such disturbed patterns of communication may obtain in other relations; the motion picture *Gaslight*, in which a husband willfully subjects his wife to such treatment, has added the verb "to gaslight" to the language. In a study of a mental-hospital ward Alfred H. Stanton and Morris S. Schwartz, then working at the Chestnut Lodge Sanitarium, found in every case where a patient became assaultive or had a psychotic episode there was a covert disagreement between the psychotherapist and the physician who ran the ward.

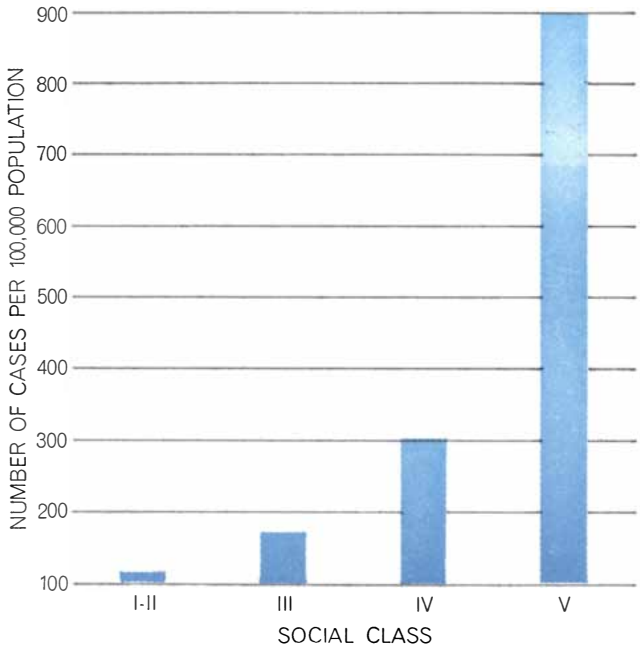
Another observation from family studies relates the patient's condition and progress to "family homeostasis." In some cases it has been found that the family system is able to function "normally" only at the expense of the patient's mental health. Ulcers, heart attacks, gall bladder disfunction and other



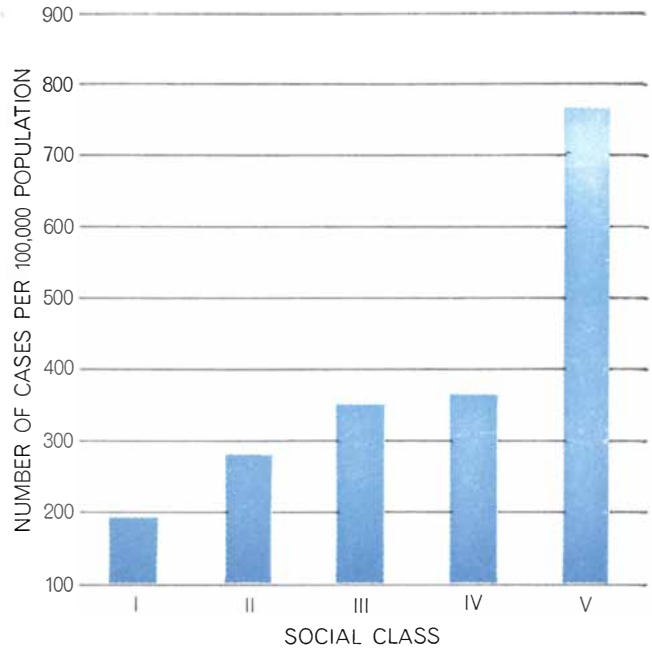
INCIDENCE OF SCHIZOPHRENIA in the total population of a community was studied both for the island of Formosa and for a small fishing village in Norway. The studies, by different investigators, were made in the 1940's. As the graph shows, the incidence of schizophrenia was highest in both communities among members of the 30-to-39-year-old age group.

INVESTIGATOR	YEAR	NUMBER OF PAIRS		INCIDENCE OF SCHIZOPHRENIA	
		FRATERNAL	IDENTICAL	FRATERNAL	IDENTICAL
LUXENBERGER	1930	60	21	3.3	66.6
ROSANOFF	1934	101	41	10.0	67.0
ESSEN-MOLLER	1941	24	7	16.7	71.0
SLATER	1951	115	41	14.0	76.0
KALLMANN	1946	517	174	14.5	85.6
KALLMANN	1952	685	268	14.5	85.6

IDENTICAL AND FRATERNAL TWINS have been studied by several investigators to discover if schizophrenia has a genetic basis. All agree in finding that both identical twins are more likely to have the disease than are both fraternal twins. But the figures vary widely from one study to another, suggesting that factors other than the genetic may be at work.



RELATION OF CLASS MEMBERSHIP to mental illness in a U.S. community was studied among patients undergoing psychiatric treatment, in and out of hospitals, in New Haven, Conn. Class membership was determined by residence, education and occupation. As the chart shows, the rate of schizophrenia was nearly nine times higher in the lowest class than in the two upper classes together.



FIRST ADMISSIONS of male schizophrenics to mental hospitals in Great Britain over a five-year period suggests the relation of class membership to mental illness in that country. Class status, as determined by the British census, is based solely on occupation. Unskilled workers make up the lowest class; professionals and administrators of various sorts constitute the two upper classes.

disorders appear to afflict other members of the family with suspicious frequency just at that time in conjoint family therapy when the patient makes a significant change for the better.

These insights from the first tentative steps in family therapy suggest the promise of deeper investigation of the family. There is need especially for longitudinal study of representative families over long periods of time. In cases where schizophrenia develops such study would show not only the character of the family at the time of crisis but also the earlier environment and the patterns of interpersonal relations and personality structure it promoted.

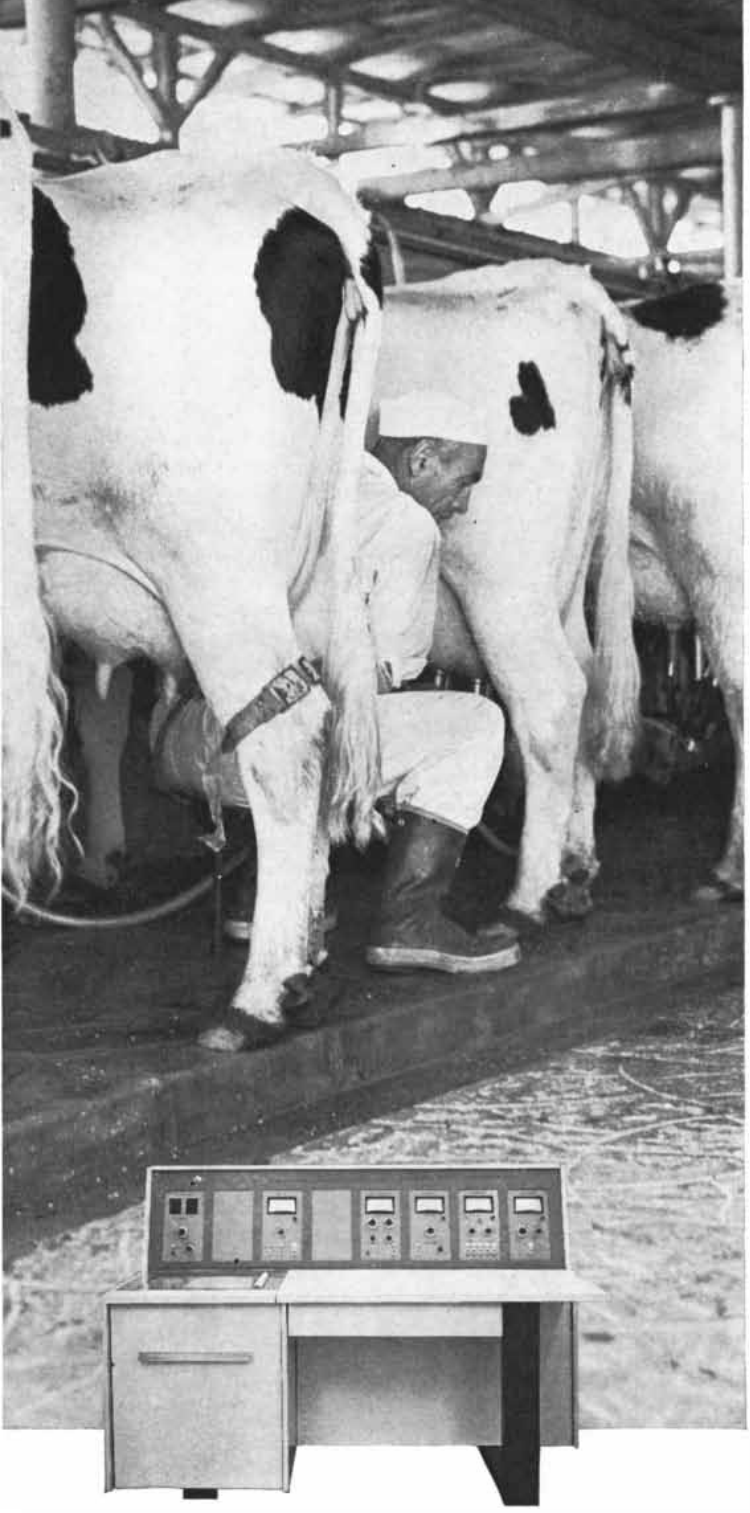
The Sociocultural Milieu

In undertakings of this kind psychiatry must enlist the collaboration of sociology and anthropology. Without the broader perspective of these other disciplines psychiatrists tend to generalize their observations of a few atypical patients into resounding pronouncements about mankind everywhere. A remarkable example of collaborative enterprise is the Nova Scotia study, led by Alexander H. Leighton of the Cornell University Medical College, which established the incidence and characteristic symptomatic patterns of mental illness in three sociocultural groups in that community. Another is the Midtown Manhattan study, initiated by the late Thomas A. C. Rennie of Cornell, which has shown that psychiatrists may have underestimated the incidence of schizophrenia by some 300 per cent.

Considering the dimensions of schizophrenia as a public health problem, there is a dearth of straightforward statistics about it. State hospital admissions apparently offer a poor indication of the true incidence of the disease in the population. A recent survey of a portion of Salt Lake City indicates an incidence of 3 per cent, far in excess of the .85 per cent that figures in so many genetic studies. The work of August B. Hollingshead and Fredrick C. Redlich of the Yale University School of Medicine has demonstrated that the lowest socioeconomic group has 12 times the incidence of hospitalized schizophrenia compared with the highest. People living singly and in an economically deprived condition in the heart of a large city develop the illness far more often than their rural counterparts do.

Such findings barely suggest the insights into the true nature of the disease that can come from a full picture of its epidemiology. Sociologists have shown, moreover, that something more than mere head-counting is involved in gathering statistics on mental illness. To evaluate the incidence of mental illness in a given social group, it is necessary to consider the character and degree of behavioral deviation from the group norms that will be tolerated by its members. It is obvious that a widely scattered rural population may accommodate many individuals who in a more closely knit community would interfere with their neighbors' lives to such an extent that they would be labeled insane. The culture of a group also has much to do with the nature of the disease as it occurs among the members. The patterns of schizophrenic psychosis that show up in Irish-American families contrast sharply, for example, with those of Italian-American families [see "Schizophrenia and Culture," by Marvin K. Opler; SCIENTIFIC AMERICAN, August, 1957].

Sociological studies have also illuminated the process of therapy in surprising ways. It has been shown that therapy is much more likely to be successful when therapist and patient come from similar social backgrounds and share similar value systems and goals. A review of the records of a New York hospital revealed that the social background, income and age of the patients were plainly correlated with the kind of treatment administered, ranging from



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electroshock to psychotherapy. This study also showed that while the foreign-born older patients tended to receive organic therapies, they also tended to get out of the hospital sooner than the middle-class, youthful schizophrenic. The longer stay in the hospital was evidently a function of the therapist-patient relation and not of the severity of the illness.

Theory and Therapy

Such observations lend support to the view, held by many, that there is in practice little or no relation between theory and therapy in schizophrenia. One can readily agree that this applies to the more radical approaches to therapy that have been advanced from time to time. Egas Moniz, the Portuguese psychiatrist and surgeon, designed and promoted the now discredited prefrontal lobotomy for schizophrenia on the strength of the purely empirical observation that lobotomized cats exhibited more placid and less excitable dispositions. The surgical interruption of the tract linking the thalamus and the frontal lobes in the human brain also produced more manageable patients but no cure for their affliction [see "Prefrontal Lobotomy: Analysis and Warning," by Kurt Goldstein; SCIENTIFIC AMERICAN, February, 1950]. An equally narrow and empirical observation suggested the first shock therapy. On the strength of the mistaken observation that epileptics do not develop schizophrenia it was thought that schizophrenics might be cured by subjecting them to convulsive seizures. The rationale for this kind of therapy now takes somewhat different forms, depending on the agent employed.

The few groups that relate theory to therapy on a one-to-one basis today stand at the extremes of the continuum from organic to psychological cause. For example, certain groups in Italy attribute schizophrenia to parasitic infestation, and so they purge the patients. On the other hand, there are American and a few European workers who attribute schizophrenia to family interaction and treat their patients by conjoint family psychotherapy. More frequently one finds investigators used the same techniques but espoused different theories of the disease. In two different centers, for example, large doses of reserpine and electroshock were employed to produce profound regression in schizophrenic patients. Both groups theorized that by such techniques they interrupted self-exciting circuits in the brain and facilitated reintegration of the patient. One group, however, viewed schizophrenia as an organic disorder and the other viewed it as a psychological disorder.

No matter what the theoretical viewpoint of the therapist, the tool most commonly used in the treatment of schizophrenia is the social milieu. In Europe, Canada and the U.S. mental hospitals universally stress the importance of work therapy, group therapy, the therapeutic community, open-door policies, television, dances and afternoon tea. There are few hospitals where the physicians do not attribute a large part of the efficacy of other kinds of treatment, including insulin-coma therapy as well as tranquilizers, to the interpersonal relations of patients and staff. The basic reorientation in the structure and function of the mental hospital throughout the nations of the West has had marked effect in eliminating what were regarded as usual symptoms of schizophrenia in former times—incontinence, smearing of feces and marked catatonic disorder of motility. Indeed, it seems to be fairly well recognized that medication of any sort supports the hospital staff in its traditional medical role and therefore has an important effect on therapy, whatever the direct action on the patient may be.

Progress in therapy, it is clear, has derived from the accumulation of empirical lore and not from theoretical foresight. If present attempts at therapy are to contribute to the improvement of therapy in the future, the therapist-investigator must emphasize the design and method of collecting data. Whatever his private persuasion, if he carefully reports his results, his colleagues and his successors in the work will learn something. As has been suggested in this discussion, the behavior of the investigator himself requires study in the investigation of so complex a subject as disturbed human behavior. The impulse of the organically oriented investigator to reduce the subject to a single cause, on the one hand, and the soul-saving tendencies of the psychotherapist, on the other, have on occasion muddied the waters. The chasm between them remains unbridged. But while it is my impression that the evidence for the psychosocial nature of schizophrenia has been mounting for the past 10 years, I see little reason to claim victory for either side, nor much sense in taking an either-or position. Such continuing conflict between polar positions is not strange in science. It is good evidence that serious effort is being made to study schizophrenia.

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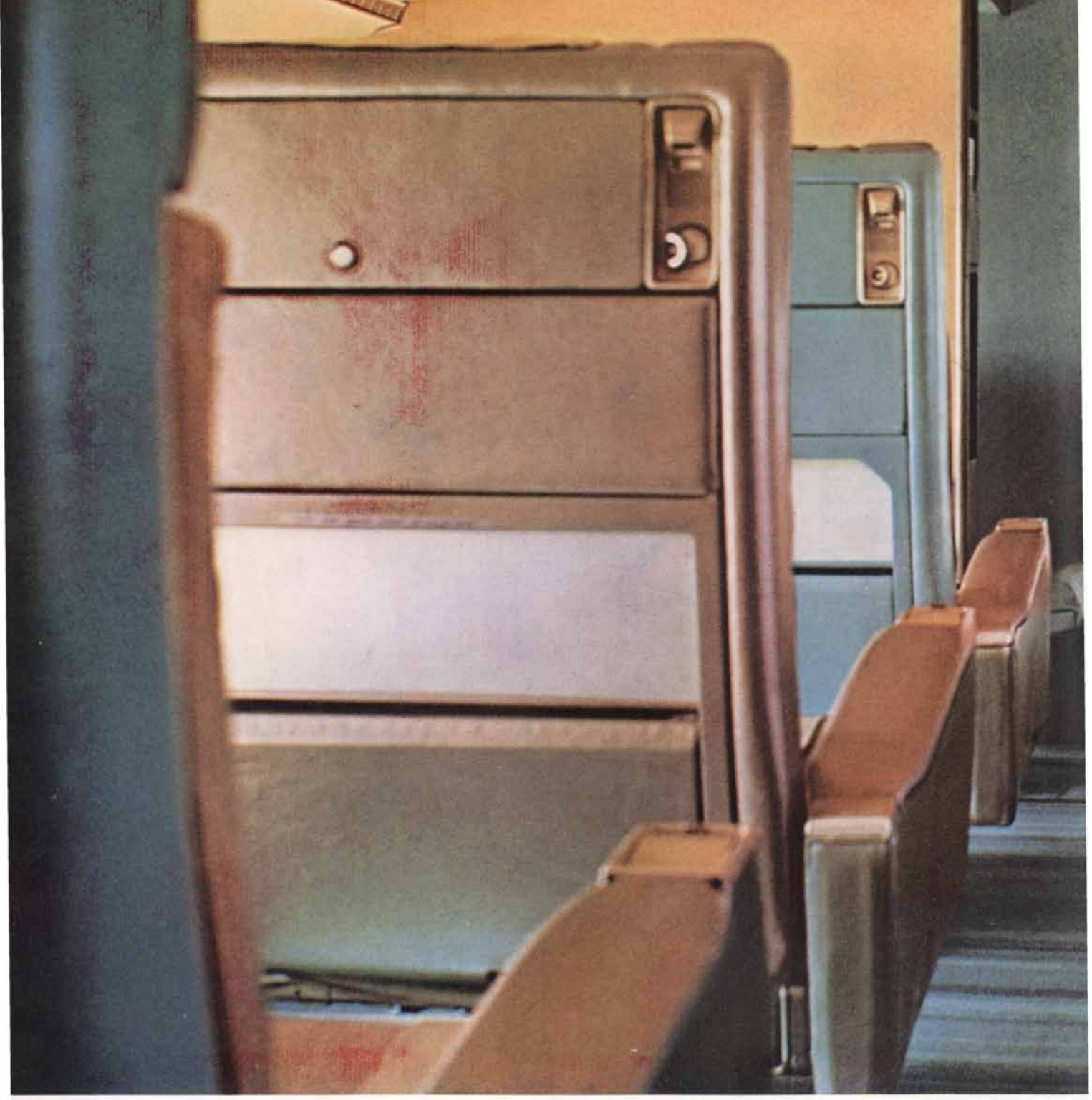

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For a moment, the Captain allowed himself to think of the many people who had been with him that day—but whom he had not seen.

The meteorologist in charge of the upper air. He had forecast the trends from Los

Angeles to New York—and hit them on the nose. The meteorologist who had forecast the terminal weather—just as precisely.

The dispatcher at the operations base. He and the Captain had authorized the flight plan by which the Captain had flown from coast to coast. And he had kept in touch with Flight 816 during the four hour and forty-five minute trip.

And then there were the experts of the operations planning center.

Aircraft routers who kept track of every United plane. Mechanical experts who knew his big jet like the backs of their hands. Operations planners who were in constant touch with every station on the line, ready to tell him where to go, should he need an alternate airport.

He hadn't needed them . . . today's trip across the country had been pleasantly routine . . . but, the Captain thought, it was good to know they were there.

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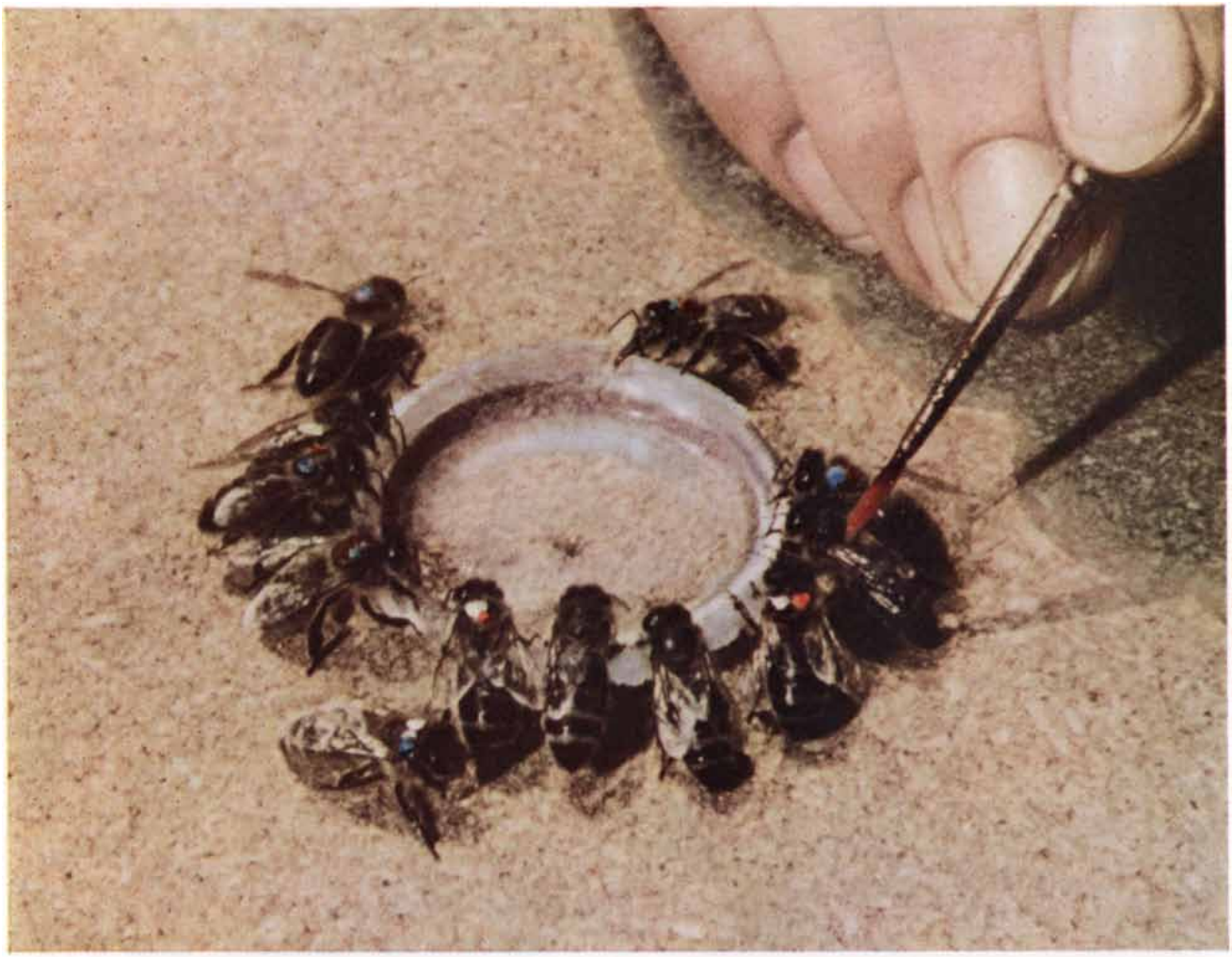


BEES ARE PAINTED with colored dots so that they can be identified during an experiment at the author's station near Munich. In this way the feeding station of a bee can be associated with its dance within the hive. The dish contains sugar water.

TWO VARIETIES OF BEE, the yellow Italian bee *Apis mellifera ligustica* and the black Austrian bee *A. mellifera carnica*, feed together. These two bees can live together in the same hive, but their dances do not have quite the same meaning. Accordingly one variety cannot accurately follow the feeding "instructions" of the other. Both of these photographs were made by Max Renner.

Dialects in the Language of the Bees

The dances that a honeybee does to direct its fellows to a source of nectar vary from one kind of bee to another. These variations clarify the evolution of this remarkable system of communication

by Karl von Frisch

For almost two decades my colleagues and I have been studying one of the most remarkable systems of communication that nature has evolved. This is the "language" of the bees: the dancing movements by which forager bees direct their hivemates, with great precision, to a source of food. In our earliest work we had to look for the means by which the insects communicate and, once we had found it, to learn to read the language [see "The Language of the Bees," by August Krogh; SCIENTIFIC AMERICAN, August, 1948]. Then we discovered that different varieties of the honeybee use the same basic patterns in slightly different ways; that they speak different dialects, as it were. This led us to examine the dances of other species in the hope of discovering the evolution of this marvelously complex behavior. Our investigation has thus taken us into the field of comparative linguistics.

Before beginning the story I should like to emphasize the limitations of the language metaphor. The true comparative linguist is concerned with one of the subtlest products of man's powerfully developed thought processes. The brain of a bee is the size of a grass seed and is not made for thinking. The actions of bees are mainly governed by instinct. Therefore the student of even so complicated and purposeful an activity as the communication dance must remember that he is dealing with innate patterns, impressed on the nervous system of the insects over the immense reaches of time of their phylogenetic development.

We made our initial observations on the black Austrian honeybee (*Apis mellifera carnica*). An extremely simple experiment suffices to demonstrate that these insects do communicate. If one puts a small dish of sugar water near a beehive, the dish may not be discovered for several days. But as soon as one bee has found the dish and returned to the hive, more foragers come from the same hive. In an hour hundreds may be there.

To discover how the message is passed on we conducted a large number of experiments, marking individual bees with colored dots so that we could recognize them in the milling crowds of their fellows and building a hive with glass walls through which we could watch what was happening inside. Briefly, this is what we learned. A bee that has discovered a rich source of food near the hive performs on her return a "round dance." (Like all the other work of the colony, food-foraging is carried out by females.) She turns in circles, alternately to the left and to the right [*see top illustration on next page*]. This dance excites the neighboring bees; they start to troop behind the dancer and soon fly off to look for the food. They seek the kind of flower whose scent they detected on the original forager.

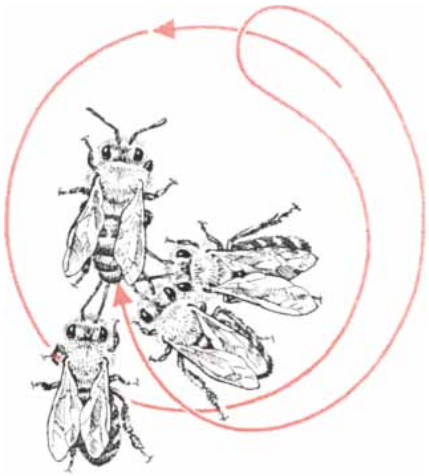
The richer the source of food, the more vigorous and the longer the dance. And the livelier the dance, the more strongly it arouses the other bees. If several kinds of plants are in bloom at the same time, those with the most and the sweetest nectar cause the liveliest dances. Therefore the largest number of bees fly to the blossoms where collecting is currently most rewarding. When the newly recruited helpers get home, they dance too, and so the number of foragers increases until they have drained most of the nectar from the blossoms. Then the dances slow down or stop altogether. The stream of workers now turns to other blossoms for which the dancing is livelier. The scheme provides a simple and purposeful regulation of supply and demand.

The round dance works well for flowers close to the beehive. Bees collect their nourishment from a large circuit, however, and frequently fly several miles from the hive. To search at such distances in all directions from the hive for blossoms known only by scent would be a hopeless task. For sources farther away than about 275 feet the round dance is replaced by the "tail-wagging dance." Here again the scent of the dancer points to the specific blossoms to be sought, and the liveliness of the dance indicates the richness of the source. In addition the wagging dance transmits an exact description of the direction and distance of the goal. The amount and precision of the information far exceeds that carried by any other known communication system among animals other than man.

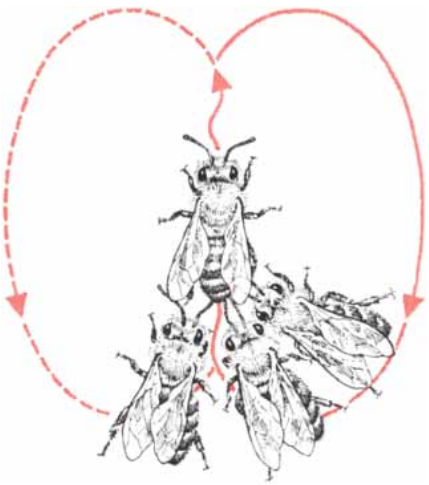
The bee starts the wagging dance by running a short distance in a straight line and wagging her abdomen from side to side. Then she returns in a semicircle to the starting point. Then she repeats the straight run and comes back in a semicircle on the opposite side. The cycle is repeated many times [*see middle illustration on next page*]. By altering the tempo of the dance the bee indicates the distance of the source. For example, an experimental feeding dish 1,000 feet away is indicated by 15 complete runs through the pattern in 30 seconds; when the dish is moved to 2,000 feet, the number drops to 11.

There is no doubt that the bees understand the message of the dance. When they fly out, they search only in the neighborhood of the indicated range, ignoring dishes set closer in or farther away. Not only that, they search only in the direction in which the original feeding dish is located.

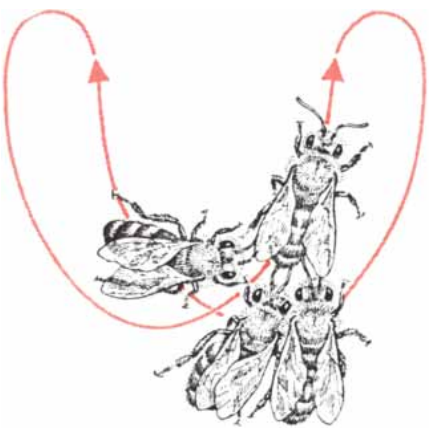
The directional information contained in the wagging dance can be followed most easily by observing a forager's per-



ROUND DANCE, performed by moving in alternating circles to the left and to the right, is used by honeybees to indicate the presence of a nectar source near the hive.



WAGGING DANCE indicates distance and direction of a nectar source farther away. Bee moves in a straight line, wagging her abdomen, then returns to her starting point.



SICKLE DANCE is used by the Italian bee. She moves in a figure-eight-shaped pattern to show intermediate distance. A dancer is always followed by her hivemates.

formance when it takes place out in the open, on the small horizontal landing platform in front of the entrance to the hive. The bees dance there in hot weather, when many of them gather in front of the entrance. Under these conditions the straight portion of the dance points directly toward the goal. A variety of experiments have established that the pointing is done with respect to the sun. While flying to the feeding place, the bee observes the sun. During her dance she orients herself so that, on the straight run, she sees the sun on the same side and at the same angle. The bees trooping behind note the position of the sun during the straight run and position themselves at the same relative angle when they fly off.

The composite eye of the insect is an excellent compass for this purpose. Moreover, the bee is equipped with the second navigational requisite: a chronometer. It has a built-in time sense that enables it to compensate for the changes in the sun's position during long flights.

Usually the wagging dance is performed not on a horizontal, exposed platform but in the dark interior of the hive on the vertical surface of the honeycomb. Here the dancer uses a remarkable method of informing her mates of the correct angle with respect to the sun. She transposes from the ability to see the sun to the ability to sense gravity and thereby to recognize a vertical line. The direction to the sun is now represented by the straight upward direction along the wall. If the dancer runs straight up, this means that the feeding place is in the same direction as the sun. If the goal lies at an angle 40 degrees to the left of the sun, the wagging run points 40 degrees to the left of the vertical. The angle to the sun is represented by an equal angle with respect to the upright. The bees that follow the dancer watch her position with respect to the vertical, and when they fly off, they translate it back into orientation with respect to the light.

We have taken honeycombs from the hive and raised the young bees out of contact with older bees. Then we have brought the young bees back into the colony. They were immediately able to indicate the direction of a food source with respect to the position of the sun, to transpose directional information to the vertical and to interpret correctly the dances of the other bees. The language is genuinely innate.

When we extended our experiments to the Italian variety of honeybee (*Apis mellifera ligustica*), we found that its innate system had developed somewhat differently. The Italian bee restricts her round dance to representing distances of only 30 feet. For sources beyond this radius she begins to point, but in a new manner that we call the sickle dance. The pattern is roughly that of a flattened figure eight bent into a semicircle [*see bottom illustration at left*]. The opening of the "sickle" faces the source of food; the speed of the dance, as usual, indicates the quality of the source.

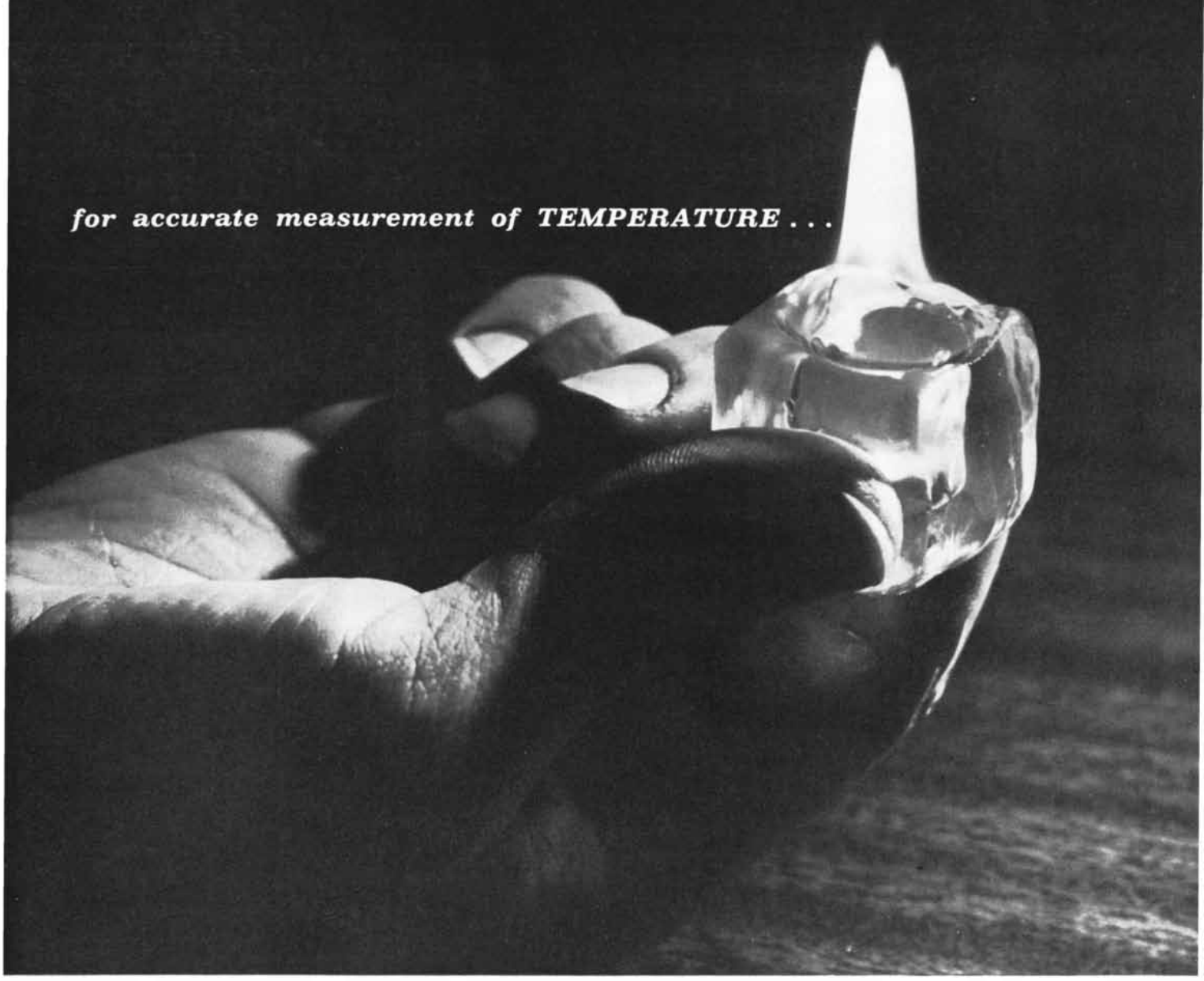
At about 120 feet the Italian bee switches to the tail-wagging dance. Even then she does not use exactly the same language as the Austrian bee does. The Italian variety dances somewhat more slowly for a given distance. We have put the two varieties together in a colony, and they work together peacefully. But as might be expected, confusion arises when they communicate. An Austrian bee aroused by the wagging dance of an Italian bee will search for the feeding place too far away.

Since they are members of the same species, the Austrian and Italian bees can interbreed. Offspring that bear the Italian bee's yellow body markings often do the sickle dance. In one experiment 16 hybrids strongly resembling their Italian parent used the sickle dance to represent intermediate distances 65 out of 66 times, whereas 15 hybrids that resembled their Austrian parent used the round dance 47 out of 49 times. On the other two occasions they did a rather dubious sickle dance: they followed the pattern but did not orient it to indicate direction.

Other strains of honeybee also exhibited variations in dialect. On the other hand, members of the same variety have proved to understand each other perfectly no matter where they come from.

Our next step was to study the language of related species. The only three known species of *Apis* in addition to our honeybee live in the Indo-Malayan region, which is thought to be the cradle of the honeybee. The Asian species are the Indian honeybee *Apis indica,* the giant bee *Apis dorsata* and the dwarf bee *Apis florea*. Under a grant from the Rockefeller Foundation my associate Martin Lindauer was able to observe them in their native habitat.

The Indian honeybee, which is so closely related to ours that it was for a long time believed to be a member of the same species, has also been domesticated for honey production. Like the European bees, it builds its hive in a dark, protected place such as the hol-



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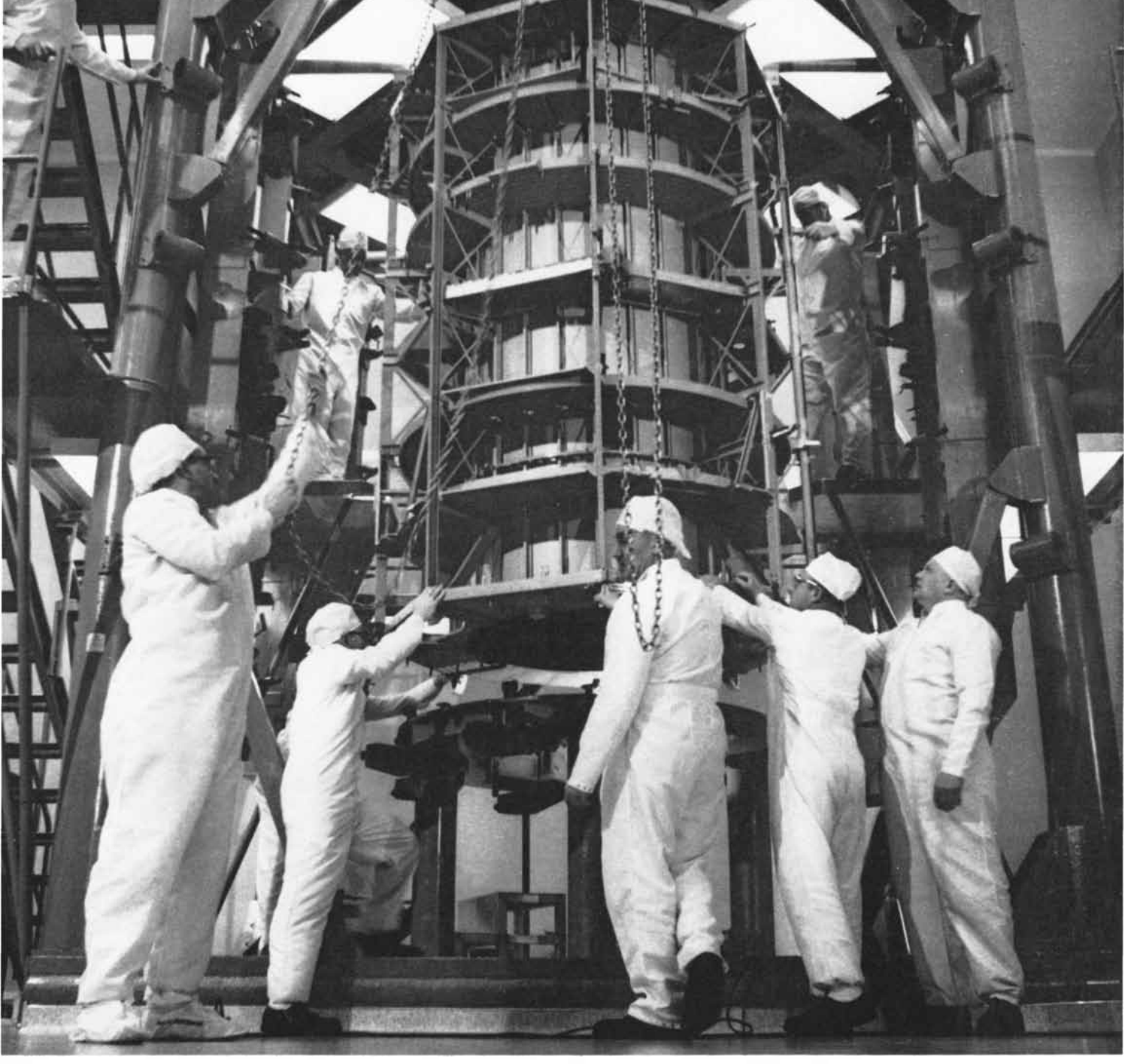

New window on the stars . . . by Grumman

The Orbiting Astronomical Observatory (OAO), when launched, will be the largest unmanned satellite to be put into orbit. Being developed by Grumman for the National Aeronautics and Space Administration, OAO will provide our scientists with a new window on the stars. The 3,000-pound satellite with its highly sophisticated equipment will relay to earth long-awaited information on cosmic phenomena. This prototype is one of the many important weapons and space systems being refined or already in production at Grumman. It is the product of Grumman's extensive facilities and human resources—Grumman capability. It is one answer to the challenges of a changing world—keeping the peace and exploring the unknown.

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Bethpage • Long Island • New York

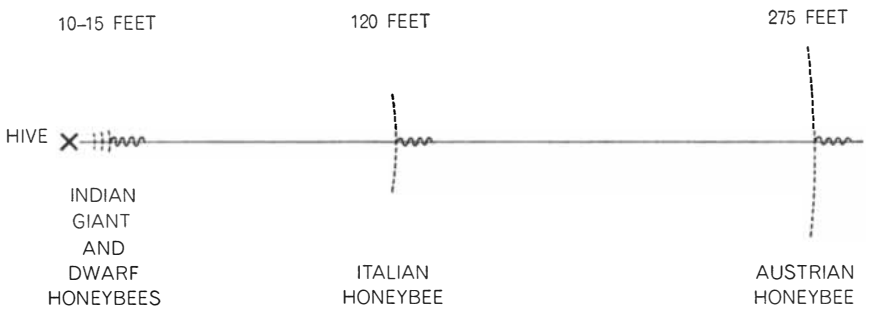
low of a tree. Its language is also much like that of the European bees. It employs the round dance for distances up to 10 feet, then switches directly to the tail-wagging dance. Within its dark hive the Indian bee also transposes from the visual to the gravity sense. The rhythm of the dance, however, is much slower than that of the European bees.

The giant bee also exhibits considerable similarity to its European cousins and to the Indian species in its communications. It changes from the round dance to the wagging dance at 15 feet. In its rhythm it moves at about the same rate as the Italian bee does. The hive of the giant bee, however, is built on tree branches or other light, exposed places. The inhabitants dance on the vertical surface of the comb, converting the angle with respect to the sun correctly into an angle from the vertical. But since the comb is out in the open, the dancers can always find a spot that commands a clear view of the sky. The fact that they do this indicates that the following bees can understand the instructions better when they have direct information about the position of the sun.

In the case of the dwarf bee, Lindauer found a clearly more primitive social organization and a correspondingly less highly developed language. The dwarf bees, which are so small that a layman would probably mistake them for winged ants, build a single comb about the size of a man's palm. It dangles from an upper branch of a small tree. When the dwarf bees return from feeding, they always alight on the upper rim of the comb, where their mates are sitting in a closely packed mass that forms a horizontal landing place for the little flyers. Here they perform their dances. They too use a round dance for distances up to 15 feet, then a wagging dance. Their rhythm is slow, like that of the Indian bee.

The dwarf bee can dance only on a horizontal platform. Lindauer obtained striking proof of this on his field trip. When he cut off the branch to which a comb was attached and turned the comb so that the dancing platform was shifted to a vertical position, all the dancers stopped, ran up to the new top and tried to stamp out a dancing platform by running about through the mass of bees. When he left the hive in its normal position but placed an open notebook over its top, the foragers became confused and stopped dancing. In time, however, a few bees assembled on the upper surface of the notebook; then the foragers landed there and were able to perform their dances. Then, to remove every possible horizontal surface, Lindauer put a ridged, gable-shaped glass tile on top of the comb and closed the tile at both ends. In this situation the bees could not dance at all. After three days in this unnatural environment the urge to dance had become so great that a few bees tried to dance on the vertical surface. But they continued to depend on vision for their orientation and did not transpose the horizontal angle to a vertical one. Instead they looked for a dancing surface on which there was a line parallel to the direction of their flight. They tried to make a narrow horizontal path in the vertical curtain of bees, keeping their straight runs at the same angle to the sun as the angle at which they had flown when they found food. Under these circumstances only a very few bees were able to dance. Obviously the dwarf bee represents a far more primitive stage of evolution than the other species. She cannot transpose from light to gravity at all.

In trying to follow the dancing instinct farther back on the evolutionary scale, we must be satisfied with what hints we can get by observing more primitive living insects. Whereas a modern fossil record gives some of the physical devel-

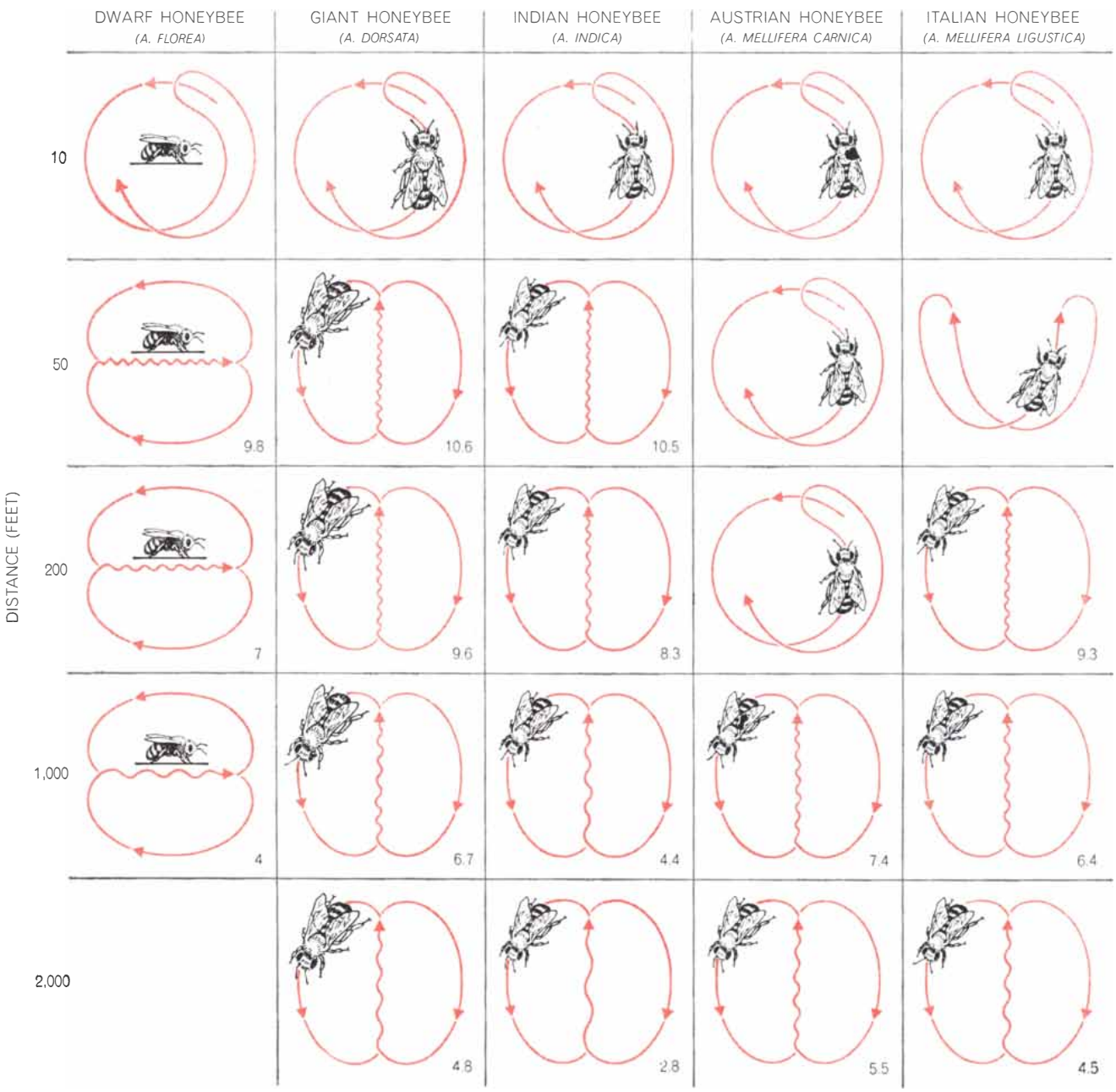


CHANGE FROM ROUND TO WAGGING DANCE occurs when nectar source lies beyond a certain radius of the hive. Change occurs at different distances among different bees. Because the wagging dance shows direction as well as distance, the Indian, giant and dwarf bees can give more precise information about a nearby source than the European bees can.

opment of insects, their mental past has left no trace in the petrified samples.

The use of sunlight as a means of orientation is common to many insects. It was first observed among desert ants about 50 years ago. When the ants creep out of the holes of their subterranean dwellings onto the sandy and barren desert surface, they cannot depend on landmarks for orientation because the wind constantly changes the markings of the desert sands. Yet they keep to a straight course, and when they turn around they find their way home along the same straight line. Even the changing position of the sun does not disturb them. Like the bee, the desert ant can take the shift into account and use the sun as a compass at any hour, compensating correctly for the movement of the sun in the sky.

Perhaps even more remarkable is the fact that many insects have developed an ability to transpose from sight to gravity. If a dung beetle in a dark room is placed on a horizontal surface illuminated from one side by a lamp, the beetle will creep along a straight line, maintaining the same angle to the light source for as long as it moves. If the light is turned off and the surface is tilted 90 degrees so that it is vertical, the beetle will continue to crawl along a straight line in the dark; it now maintains the same angle with respect to gravity that it earlier maintained with respect to light. This transposition is apparently an automatic process, determined by the arrangement of the nervous system. Some insects transpose less accurately, keeping the same angle but placing it sometimes to the right and sometimes to the left of the vertical without regard to the original direction with respect to the light. Some are also impartial as to up and down, so that an angle is transposed in any of four ways. Since the patterns do not transmit in-



DIALECTS in the language of the bees are charted. The dwarf bee dances on a horizontal surface. All others dance on a vertical surface. The speed of the wagging dance carries distance instructions. The more rapidly the bee performs its wagging runs, the shorter is the distance. The figures in the squares represent the number of wagging runs in 15 seconds for each distance and kind of bee.

COST & LEAD TIME REDUCED

Development And Production Costs Cut 50%

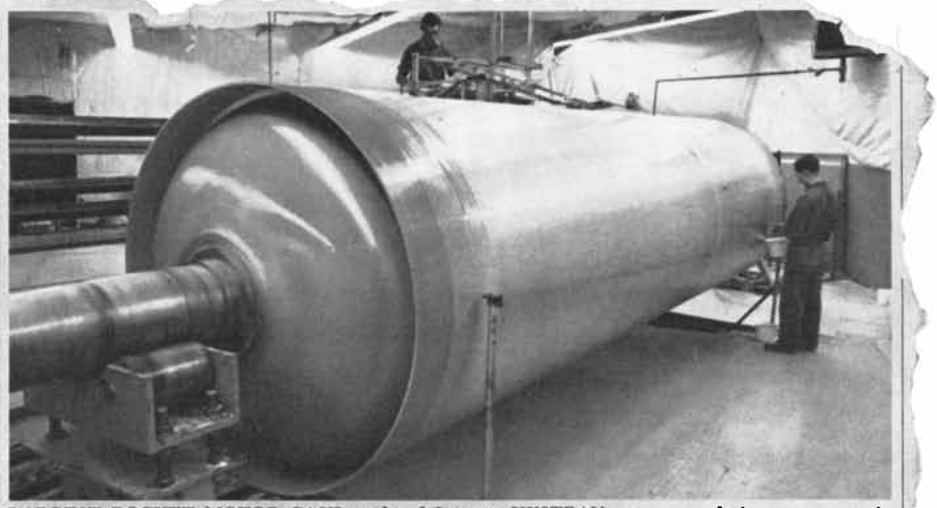
FARMINGDALE, L. I., N. Y.—The record-size rocket motor cases of HYSTRAN reinforced plastic made by Lamtex Industries, Inc. substantially reduce costs and delivery time as compared to conventional cases made of steel.

Development costs for a typical HYSTRAN case are one-quarter those for a similar steel case. Production costs for the plastic cases (after all development, tooling, and design modifications have been completed) are expected to be one-half those for comparable steel cases. Tooling costs for the HYSTRAN cases are approximately one-quarter those for steel cases.

Plastic: 5 Months
Steel: 24 Months

The large reinforced plastic cases produced at Lamtex were delivered five months after the start of the program, including all development, tool design, and fabrication. By contrast, the delivery lead time required for comparable steel cases is in the area of 24 months. While the delivery time for production-model steel cases (after all tooling and final designs have been completed) is about nine months after ordering, Lamtex can deliver production-run HYSTRAN cases in two to three months.

Wound in one piece, Lamtex's HYSTRAN rocket motor case includes precisely located, wound-in aft ports fitted with nozzle blast tube hardware.



LARGEST ROCKET MOTOR CASE made of Lamtex HYSTRAN nears completion as automatic filament winding machine applies final layers of fiberglass and epoxy resin to attach handling and supporting skirts at both ends of case.

Lamtex Produces Largest Fiberglass Reinforced Plastic Rocket Cases

FARMINGDALE, L. I., N. Y.—Solid propellant rocket motor cases of reinforced plastic larger than any previously produced have been developed and manufactured here by Lamtex Industries, Inc. The 22-foot long, 5½-foot diameter cases are made of HYSTRAN, Lamtex's exclusive filament wound reinforced plastic.

These lightweight structures were produced for Thiokol Chemical Corp. as part of a Process Development Program to investigate reinforced plastics for use in large rocket motor cases. The program is sponsored by the Air Force Systems Command, Manufacturing Technology Laboratory, Chemical Engineering Branch.

Greater Strength Per Pound

An outstanding advantage of the HYSTRAN reinforced plastic cases over conventional cases made of metal is their much higher strength-to-weight ratio. In a conservative, prototype design, Lamtex reinforced plastic cases carry a weight only 87% that of comparable steel cases. A more sophisticated, flight-weight design is expected to reduce weight further to just 60% of steel cases.

Design And Performance

Additional advantages resulting from the use of HYSTRAN for rocket motor cases include:

Thermal insulation, inherent in reinforced plastic, as contrasted to the conductivity of metals. During flight, HYSTRAN also resists scorching friction heat—usually without any special external insulating materials.

Superior corrosion resistance. The same resins used in HYSTRAN are frequently applied to metallic structures to improve corrosion resistance.

Safety lacking in metals, because this reinforced plastic is non-magnetic and non-sparking.

Impact and shatter resistance. A basic characteristic of HYSTRAN is its relative flexibility, providing high impact resistance to shocks and blows.

Built-in insulating liners are an integral part of HYSTRAN filament wound cases. Additional special inside liners are not required prior to casting of the propellant.

No notch sensitivity exists in HYSTRAN structures, alleviating a problem which plagues all high strength-to-density metallic structures.

Make Own Equipment

Lamtex Industries, producer of these record-size rocket motor cases, designed and built its own filament winding machines, since no standard machinery or proven procedures existed. As an industry recognized leader in this new field, Lamtex has pioneered the design of filament winding equipment, including new servo-controlled machines.

Quality And Reliability Are Important

With new materials and techniques being developed almost daily, continuous testing and quality control are necessary to insure the high degree of reliability required. A typical example of this involved the actual filament winding of a sub-scale model to test a new, super-high-strength fiberglass for use on the large case.

Other Plastic Products

Lamtex is currently producing high quality reinforced plastic products for a wide range of industrial, commercial and military applications. Included are such products as filament wound pipe and tubing, torpedo battery cases, radomes, nose cones, high voltage insulators, pressure vessels, high strength undersea structures, antenna towers, compression and vacuum molded parts, rocket launcher tubes. A host of vital space-age programs utilize Lamtex products — included are POLARIS, PERSHING, MERCURY, VORTAC, BOMARC, MINUTEMAN, RANGER, SCOUT, NIKE-ZEUS, LAW and a variety of NASA projects.

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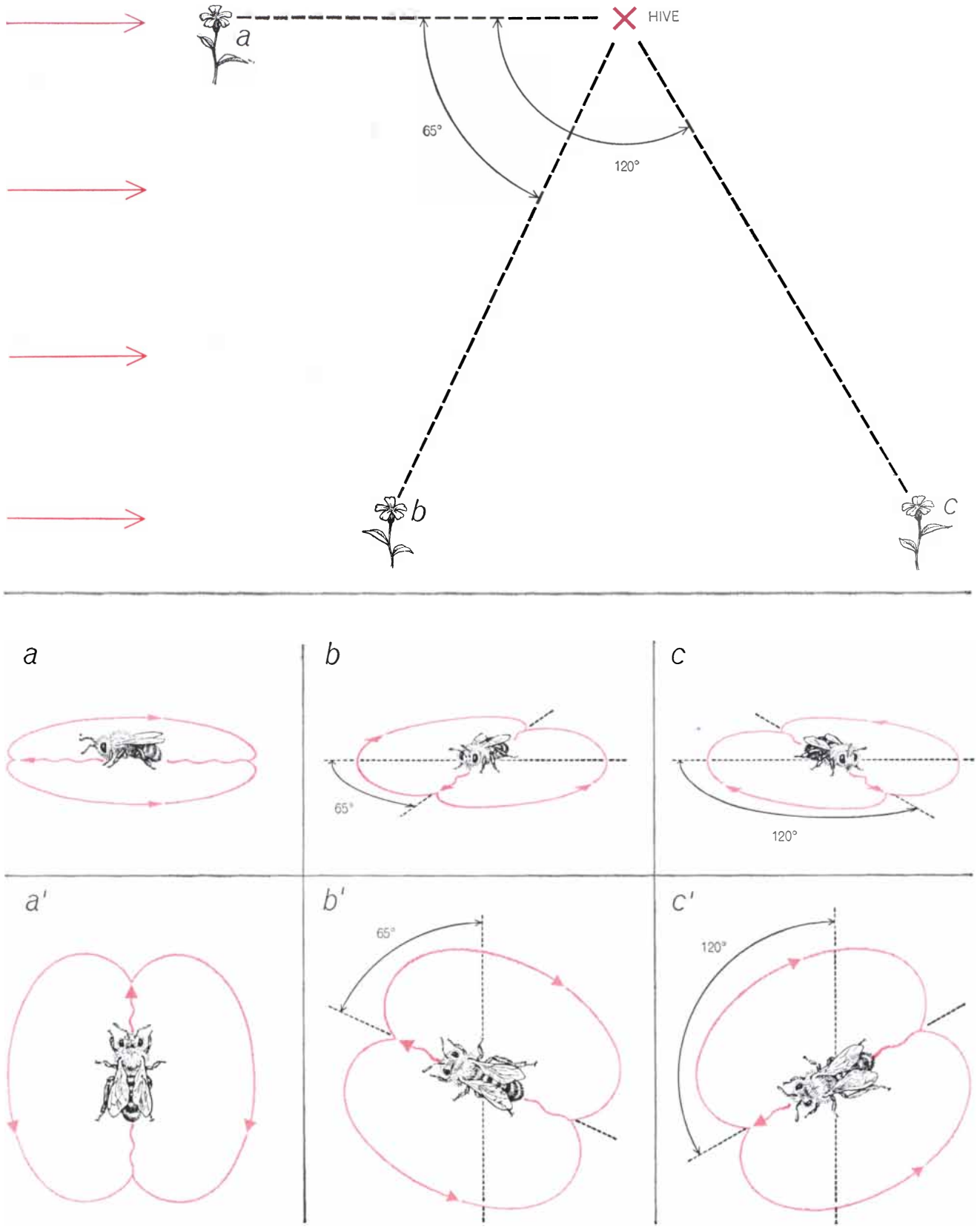


DIRECTION of a nectar source from the hive is shown by the direction in which a bee performs the straight portion of the wagging dance. The top section of the drawing shows flowers in three directions from the hive. The colored arrows represent the sun's rays. The middle section shows the dwarf bee, which dances on a horizontal surface. Her dance points directly to the goal: she orients herself to see the sun at the same angle as she saw it while flying to her food. The bottom section shows the bees that dance on a vertical surface. They transpose the visual to the gravitational sense. Movement straight up corresponds to movement toward the sun (*a'*). Movement at an angle to the vertical (*b'*, *c'*) signifies that the food lies at that same angle with respect to the sun.

formation, their exact form makes no difference. Among the ancestors of the bees transposition behavior was probably once as meaningless as it is in the dung beetle and other insects today. In the course of evolution, however, the bee learned to make meaningful use of this central nervous mechanism in its communication system.

Both navigation by the sun and transposition, then, have evolved in a number of insects. Only the bees can use these abilities for their own orientation and for showing their mates the way to food. The straight run in the wagging dance, when performed on a horizontal surface, indicates the direction in which the bees will soon fly toward their goal. Birds do something like this; when a bird is ready to take off, it stretches its neck in the direction of its flight. Such intention movements, as they are called, sometimes influence other animals. In a flock of birds the movements can become infectious and spread until all the birds are making them. It is possible that among the honeybees the strict system of the wagging dance gradually developed out of such intention movements, performed by forager bees before they flew off toward their goal.

The most primitive communication system we have found among the bees does not contain information about distance or direction. It is used by the tiny stingless bee *Trigona iridipennis,* a distant relative of the honeybee. Lindauer observed this insect in its native Ceylon. Its colonies are less highly organized, resembling bumblebee colonies rather than those of honeybees.

When a foraging *Trigona* has found a rich source of nectar, she also communicates with her nestmates. But she does not dance. She simply runs about in great excitement on the comb, knocking against her mates, not by chance but intentionally. In this somewhat rude manner she attracts their attention to the fragrance of blossoms on her body. They fly out and search for the scent, first in the nearby surroundings, then farther away. Since they have learned neither the distance nor the direction of the goal, they make their way to the food source one by one and quite slowly.

We probably find ourselves here at the root of the language of the bees. Which way the development went in detail we do not know. But we have learned enough so that our imagination can fill in the evolutionary gaps in a general way.

SEARCHLIGHT

NO. 5 IN A SERIES OF SCIENCE-FICTION ORIGINALS CREATED EXPRESSLY FOR HOFFMAN ELECTRONICS CORPORATION

By Robert A. Heinlein

"Will she hear you?"

"If she's on this face of the Moon. If she was able to get out of the ship. If her suit radio wasn't damaged. If she has it turned on. If she is alive. Since the ship is silent and no radar beacon has been spotted, it is unlikely that she or the pilot lived through it."

"She's got to be found! Stand by, Space Station. Tycho Base acknowledge."

Reply lagged about three seconds, Washington to Moon and back. "Lunar Base, Commanding General."

"General, put every man on the

Moon out searching for Betsy!"

Speed-of-light lag made the answer sound grudging. "Sir, do you know how big the Moon is?"

"No matter! Betsy Barnes is there somewhere—so every man is to search until she is found. If she's dead, your precious pilot would be better off dead, too!"

"Sir, the Moon is almost fifteen million square miles. If I used every man I have, each would have over a thousand square miles to search. I gave Betsy my best pilot. I won't listen to threats against him when he can't answer back. Not from anyone, sir! I'm sick of being told what to do by people who don't know Lunar conditions. My advice—my official advice, sir—is to let Meridian Station try. Maybe they can work a miracle."

The answer rapped back. "Very well, General! I'll speak to you later. Meridian Station! Report your plans."

Elizabeth Barnes, "Blind Betsy," child genius of the piano, had been making a USO tour of the Moon. She "wowed 'em" at Tycho Base, then lifted by jeep rocket for Farside Hardbase, to entertain our lonely missilemen behind the Moon. She should have been there in an hour. Her pilot was a safety pilot; such ships shuttled unpiloted between Tycho and Farside daily.

After liftoff her ship departed from its programming, was lost by Tycho's radars. It was . . . somewhere.

Not in space, else it would be radioing for help and its radar beacon would be seen by other ships, space stations, surface bases. It had crashed—or made emergency landing—somewhere on the vastness of Luna.

"Meridian Space Station, Director speaking——" Lag was unnoticeable; radio bounce between Washington and the station only 22,300 miles up was only a quarter second. "We've patched Earthside stations to blanket the Moon with our call. Another broadcast blankets the far side from Station Newton at the three-body stable position. Ships from Tycho are orbiting the Moon's rim—that band around the edge which is in radio shadow from us and from the Newton. If we hear——"

"Yes, yes! How about radar search?"

"Sir, a rocket on the surface looks to radar like a million other features the same size. Our one chance is to get them to answer . . . if they can. Ultrahigh-resolution radar might spot them in months—but suits worn in those little rockets carry only six hours' air We are praying they will hear and answer."

"When they answer, you'll slap a radio direction finder on them. Eh?"

"No, sir."

"In God's name, why *not*?"

"Sir, a direction finder is useless for this job. It would tell us only that the signal came from the Moon—which doesn't help."

"Doctor, you're saying that you might *hear* Betsy—and not know where she is?"

"We're as blind as she is. We hope

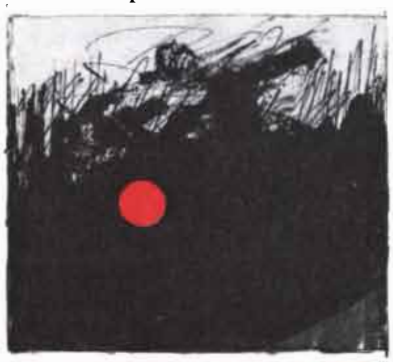
that she will be able to lead us to her . . . if she hears us."

"How?"

"With a Laser. An intense, very tight beam of light. She'll hear it——"

"*Hear* a beam of light?"

"Yes, sir. We are jury-rigging to scan like radar—that won't show anything. But we are modulating it to give a carrier wave in radio frequency, then modulating that into audio frequency—and controlling that by a piano. If she hears us, we'll tell her to listen while we scan the Moon and run the scale on the piano——"



"All this while a little girl is *dying?*"

"Mister President—*shut up!*"

"*Who was THAT?*"

"I'm Betsy's father. They've patched me from Omaha. *Please,* Mr. President, keep quiet and let them work. I want my daughter back."

The President answered tightly, "Yes, Mr. Barnes. Go ahead, Director. Order anything you need."

In Station Meridian the director wiped his face. "Getting anything?"

"No. Boss, can't something be done about that Rio station? It's sitting right on the frequency!"

"We'll drop a brick on them. Or a bomb. Joe, tell the President."

"I heard, Director. They will be silenced!"

"*Sh!* Quiet! Betsy—do you hear me?" The operator looked intent, made an adjustment.

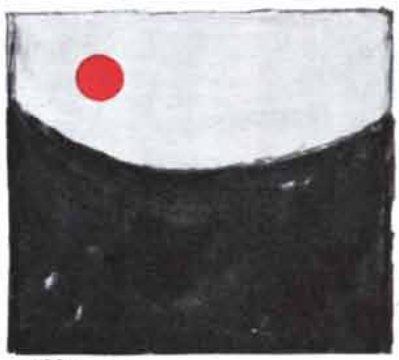
From a speaker came a girl's light, sweet voice: "—to hear somebody! Gee, I'm glad! Better come quick—the Major is hurt."

The Director jumped to the microphone. "Yes, Betsy, we'll hurry. You've got to help us. Do you know where you are?"

"Somewhere on the Moon, I guess. We bumped hard and I was going to kid him about it when the ship fell over. I got unstrapped and found Major Peters and he isn't moving. Not dead—I don't think so; his suit puffs out like mine and I hear something when I push my helmet against him. I just now managed to get the door open." She added, "This can't be Farside, it's supposed to be night there. I'm in sunshine, I'm sure. This suit is pretty hot."

"Betsy, you must stay outside. You've got to be where you can see us."

She chuckled. "That's a good one. I see with my ears."



"Yes. You'll see us, with your ears. Listen, Betsy. We're going to scan the Moon with a beam of light. You'll hear it as a piano note. We've got the Moon split into the eighty-eight piano notes. When you hear one, yell, '*Now!*' Then tell us what note you heard. Can you do that?"

"Of course," she said confidently, "if the piano is in tune."

"It is. All right, we're starting—"

"*Now!*"

"What note, Betsy?"

"E flat, the first octave above middle C."

"This note, Betsy?"

"That's what I said."

The Director called out, "Where's that on the grid? In Mare Nubium? Tell the General!" He said to the microphone, "We're finding you, Betsy honey! Now we scan just that part you're on. We change setup. Want to talk to your Daddy meanwhile?"

"Gosh! Could I?"

"Yes indeed!"

Twenty minutes later he cut in and heard: "—of course not, Daddy. Oh, a teensy scared when the ship fell. But people take care of me, always have."

"Betsy?"

"Yes, sir?"

"Be ready to tell us again."

"*Now!*" She added, "That's a bullfrog G, three octaves down."

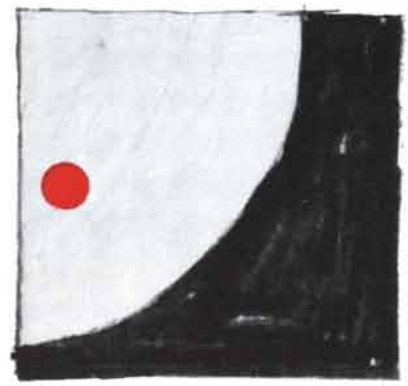
"This note?"

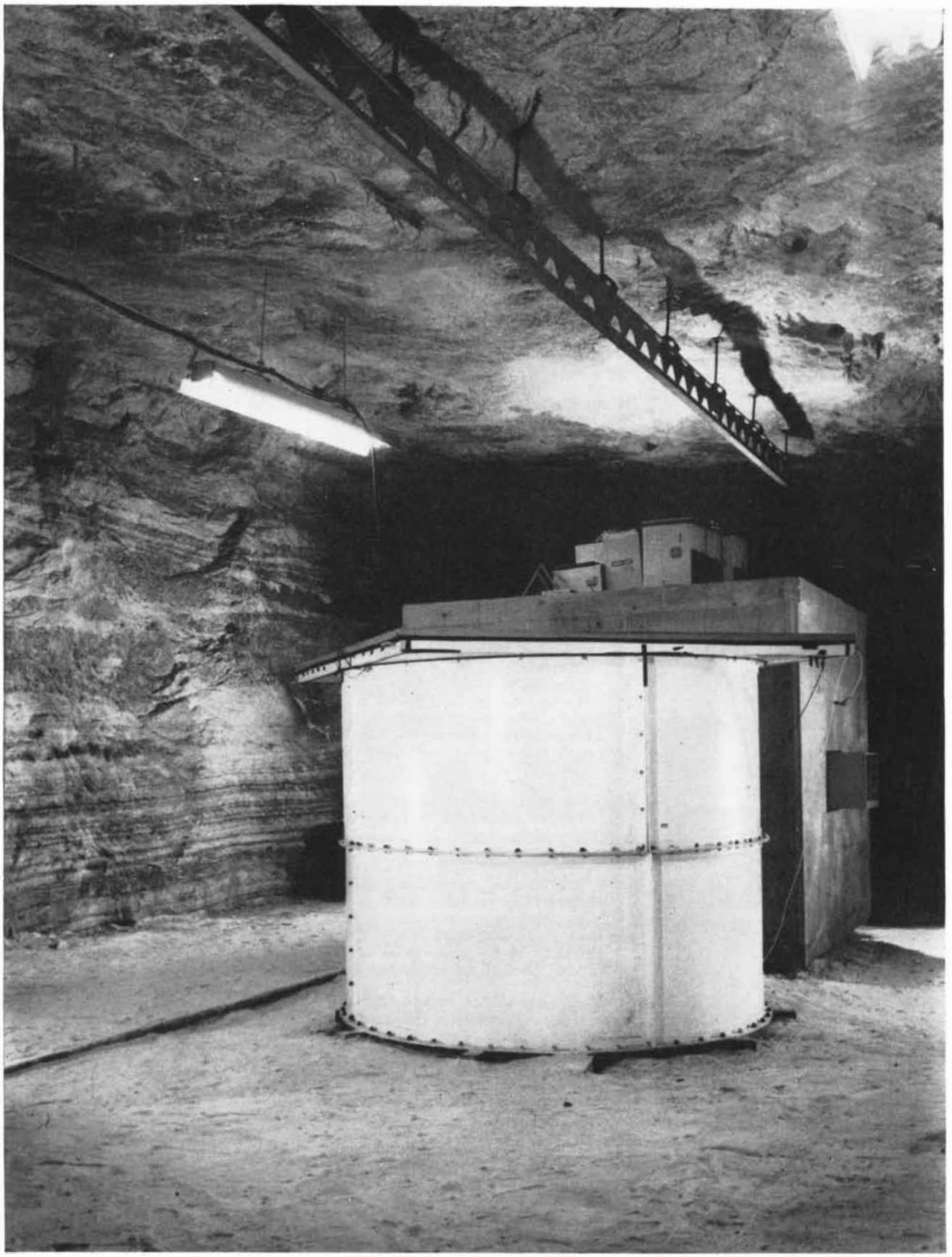
"That's right."

"Get that on the grid and tell the General to get his ships up! That cuts it to a square ten miles on a side! Now, Betsy—we know *almost* where you are. We are going to focus still closer. Want to go inside and cool off?"

"I'm not too hot. Just sweaty."

Forty minutes later the General's voice rang out: "They've spotted the ship! *They see her waving!*"





NEUTRINO DETECTOR ASSEMBLY was designed by Frederick Reines of the Case Institute of Technology to measure the flux of high-energy neutrinos in cosmic rays. It is photographed in position in the Fairport Harbor Mine of the Morton Salt Company near Cleveland. The detector is located 2,000 feet underground to shield out particles other than neutrinos. The tank in foreground, which is the detector proper, is eight feet eight inches high and eight feet in diameter. Structure behind it houses electronic apparatus.

NEUTRINO ASTRONOMY

A flood of the penetrating particles called neutrinos pours down on the earth from the sun and stars. If they could be detected, they would constitute a rich source of astrophysical information

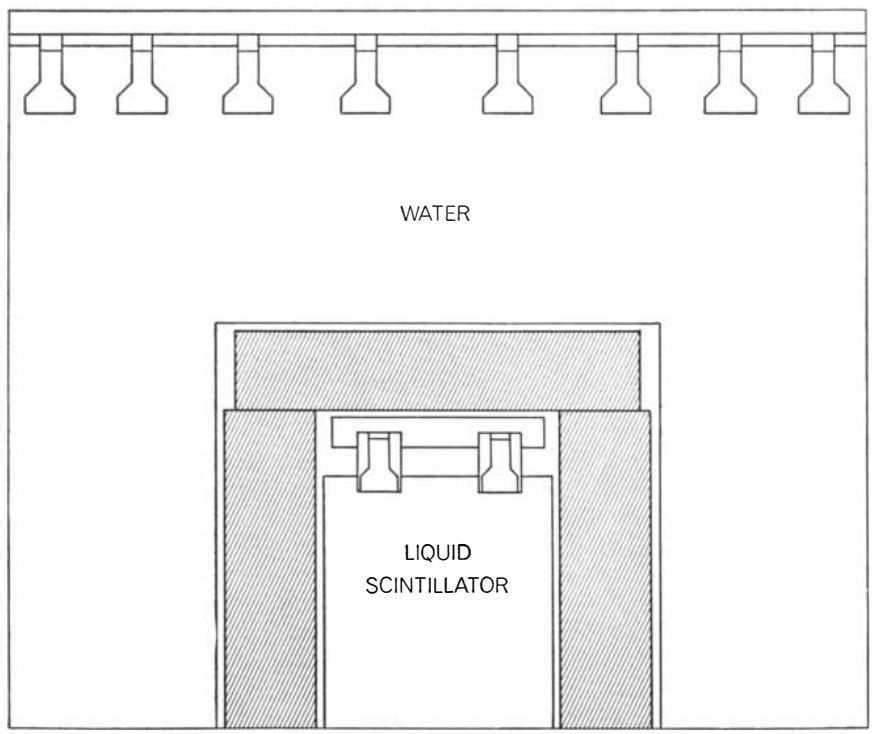
by Philip Morrison

Of the dozens of "fundamental particles" with which physics is seized, only two nowadays bear the name without any skeptics' quotation marks. These are the photon and the neutrino. Each stands at the base of one of the two hierarchies to which all known particles belong. The photon, or quantum of the electromagnetic field, is the simplest and lightest of the bosons: particles with an integral number of spin units. The neutrino occupies a corresponding place among the fermions: particles with half-integral spin. (The familiar proton, neutron and electron are all fermions.) Neither the photon nor the neutrino possesses a measurable mass, and they have energy only by virtue of their motion, which is always at the speed of light. The photon is familiar to everyone; all the light by which we live and know the world is nothing but a flood of photons. The neutrino lies almost entirely outside human experience. Yet it would be strange if nature's other most fundamental particle did not conceal a fair share of nature's secrets. Recent theoretical calculations indicate, in fact, that the unfamiliar neutrino may turn out to be the major actor in an unseen drama of the physical world.

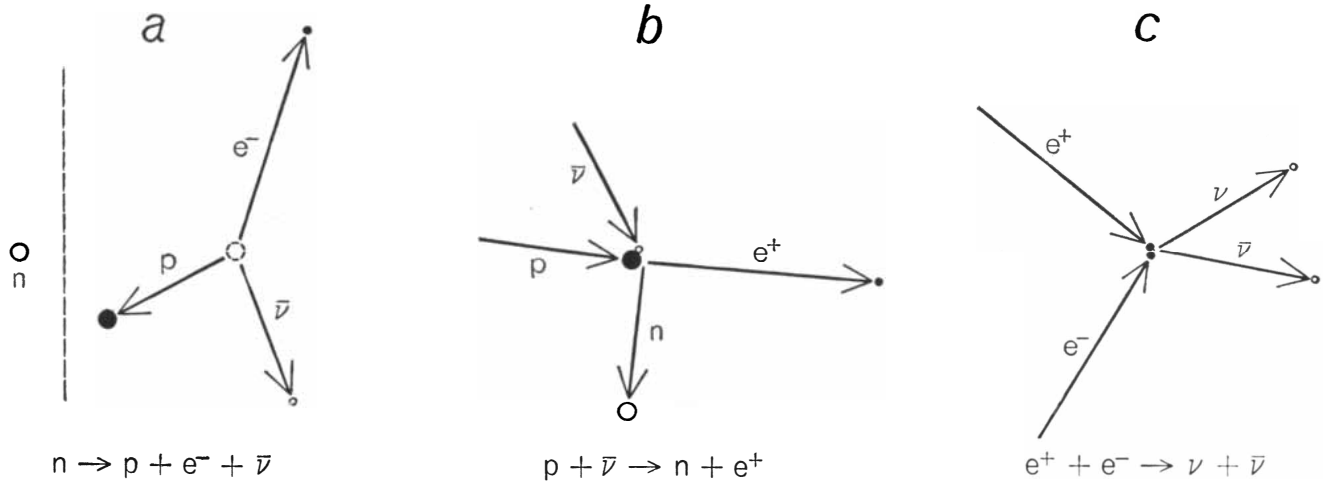
Everything the astronomer knows about the regions beyond the earth he has learned from photons. The faintest star that can be seen with the naked eye rains some 1,000 photons per second into the wide-open, dark-adapted pupil. Sunlight delivers to the same area a million billion times as many. The signals picked up by the radio astronomers' huge antennas are also photons, but photons of much lower energy.

Neutrinos, it is now realized, must also stream down on us out of the heavens. From the sun they bring a tenth as much energy as does the visible light. From many stars they convey vastly more energy than comes in the form of light. Yet this enormous flux of particles passes wholly unnoticed. Suppose that somehow we could build a neutrino telescope. What could we expect to see of the sun and stars? What might we hope to learn of the universe? This article will sketch some of the hopes.

The task of a would-be builder of a neutrino telescope is not to gather or concentrate the particles; there are plenty of them. What he must do is induce them to interact with the material of his instrument and deliver up their energy, as photons deliver theirs to the retina of the eye or to the photographic emulsion. The catch is that neutrinos interact practically not at all—with any kind of matter. At the most conservative estimate 10^{23} neutrinos pass through the body of a man during his lifetime. *Just one* is likely to interact and be absorbed there. Neutrinos from the sun come up through the solid earth at midnight as plentifully as they rain down from the



CROSS SECTION OF DETECTOR is shown schematically. The liquid scintillator responds to products of reactions between incoming neutrinos and nuclei in surrounding iron plate (*hatching*) or in scintillator itself. Scintillations are detected by photomultiplier tubes at top of inner chamber. If scintillation is accompanied by visible Čerenkov radiation in the surrounding water, the event is not counted because it was produced by a charged particle.



NEUTRINO REACTIONS are characterized by their extremely slow rate. Of the three reactions shown here, *a* and *b* have been observed, whereas *c* is known only from theory. In *a* a free neutron (n) disintegrates spontaneously into a proton (p), an electron (e^-) and an antineutrino ($\bar{\nu}$). In *b* a proton and an antineutrino ($\bar{\nu}$) combine to form a neutron and a positron (e^+). In *c* an electron and a positron combine to produce a neutrino and an antineutrino. This reaction is believed to occur in stars that become supernovae.

noonday sun. How then do we know them at all?

A generation ago the neutrino made its debut, not in the laboratory but in the mind of the theoretical physicist Wolfgang Pauli. He was concerned with the problem of beta decay: the emission of electrons by certain radioactive species of atomic nuclei. Quantum theory indicated that every nucleus of a given species has precisely the same set of discrete energy states. A beta ray electron carries away some nuclear energy, and accordingly all electrons ejected from nuclei in a given state were expected to have the same amount of energy. This was indeed true of the other two kinds of radioactive emission: alpha particles and gamma ray photons. But it was not true of the electrons. They exhibited not a single energy for each decaying nuclear type but a whole spread of energies, from zero up to the maximum that was characteristic of the nuclear state. There were three ways to account for this: (1) the product nucleus for each individual electron emitted had an energy content that depended on the energy of the electron its parent nucleus had emitted, which would imply that one electron or one nucleus is intrinsically different from another, (2) energy was not conserved in electron emission, (3) a varying portion of the energy of the decay went off in some undetected form.

Only the third alternative was less than revolutionary. So physicists, always conservative, began to look for the missing energy. It had to be carried in a neutral particle, since there was no missing charge. A gamma ray was the first guess, but it was simply not there. It was Pauli who realized that the comparative rates of electron and gamma emission furnished a clue to the elusiveness of the hypothetical particle. The release of energy by beta decay is unimaginably slower, or less probable, than the release of energy by gamma rays. The ratio is something like 10^{18} to one. If a new, light neutral particle were created with each beta ray electron, this particle would be almost impossible to detect: the slowness of its emission implied an analogous and matching improbability of absorption in the nuclei of any matter it penetrated. Enrico Fermi made detailed calculations showing that the shape of the electron spectrum agreed with these assumptions, and he gave the new particle the name neutrino (in Italian "little neutral one").

Physicists sighed with relief: energy conservation was safe. More and more indirect evidence piled up: momentum too was missing, but in just the way it would be missing if the elusive neutrino bore it away. Still, the profession was a bit uneasy. It is one thing to satisfy conservation laws; it is quite another to have a particle with some reality, a particle that could again be made to yield up the energy and momentum it had been given license to steal away.

It was not until modern skill and scale became available that the first neutrino was caught and the validity of the theory founded by Pauli and Fermi proved in a direct way. Six years ago Frederick Reines and Clyde L. Cowan, Jr., then at the Los Alamos Scientific Laboratory, set up an enormous detector and counter apparatus in the avalanche of neutrinos coming from one of the world's largest nuclear reactors in Savannah River, Ga. The neutrino density there was perhaps 30 times larger than the density of neutrinos from the sun and stars.

Once or twice an hour, on the average, the experimenters caught a neutrino interacting with a proton in the huge tanks of water of their detector. Then and there appeared the lost energy and momentum of beta decay, as had been calculated.

In June a second type of neutrino was detected [see "Science and the Citizen," page 52]. It is born not with an electron in beta decay but with a mu meson in the decay of a pi meson. I mention it here only to rule it out of the discussion. This article is concerned exclusively with the beta-decay neutrino.

In addition to its original function as a carrier of energy and momentum, the neutrino has come to play a wider role in the schemes of the theoretical physicist. There seems little doubt that all fermions (and their corresponding antiparticles) can emit or absorb a neutrino (or antineutrino) in any reaction that obeys the various conservation laws of physics: conservation of energy, of momentum, of electric charge and a few more. In the process any pair of fermions can turn into any other pair. Such transformations have a small but definite rate, depending very much on the energy released but not at all on which particular fermions are involved. Another rule of this particle game is that the birth, or emission, of any antiparticle is exactly equivalent to the death, or absorption, of the corresponding particle and vice versa.

As an example of a fermion transformation, consider the case in which a neutron and a neutrino are converted into a proton and an electron. In the shorthand of the particle physicist, in which the neutrino is designated by the Greek letter ν (nu), we can write

$$n + \nu \rightarrow p + e^-.$$

The equation states that a neutron absorbs a neutrino and changes to a proton and an electron. (The electron carries a minus sign to distinguish it from its antiparticle, the positron, which is written e^+.) Although the conversion is one of the most common of all neutrino reactions, it is usually not seen in this form but in the exactly equivalent form where the birth of an antineutrino (written as $\bar{\nu}$ replaces the death of a neutrino:

$$n \rightarrow p + e^- + \bar{\nu}.$$

This reaction is observed. It is the archetype of all beta decays, the neutron being the simplest radioactive nucleus. On the average it takes 10 minutes and releases about 750,000 electron volts of energy. A gamma emission with the same energy available would take place in some 10^{-16} second. That relative slowness is the clear mark of a neutrino reaction.

If we continue to follow the rule about particles and antiparticles, the transformation might also involve the absorption of a positron by the neutron rather than the emission of an electron:

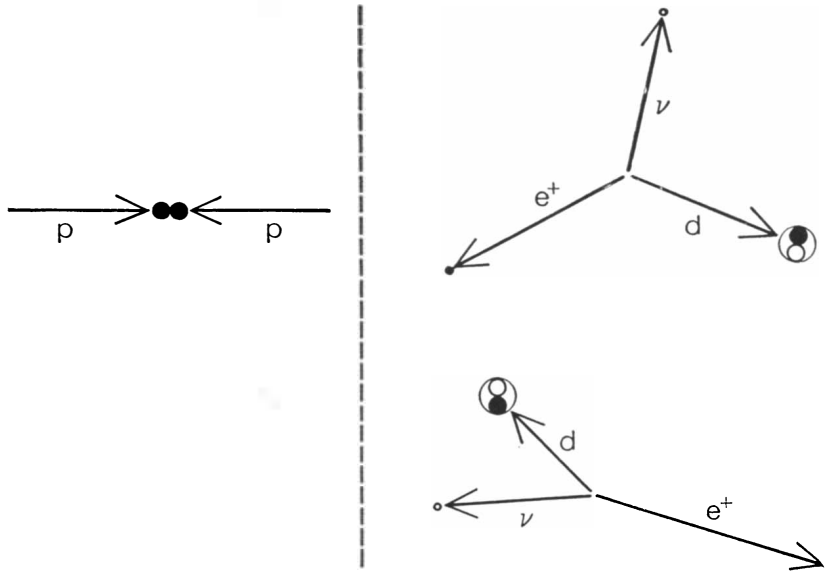
$$n + e^+ \rightarrow p + \bar{\nu}.$$

Moreover, like all particle reactions, this one can be reversed if the energy it releases is supplied from outside. If that were done, we would have a proton absorbing an antineutrino and turning into a neutron and a positron:

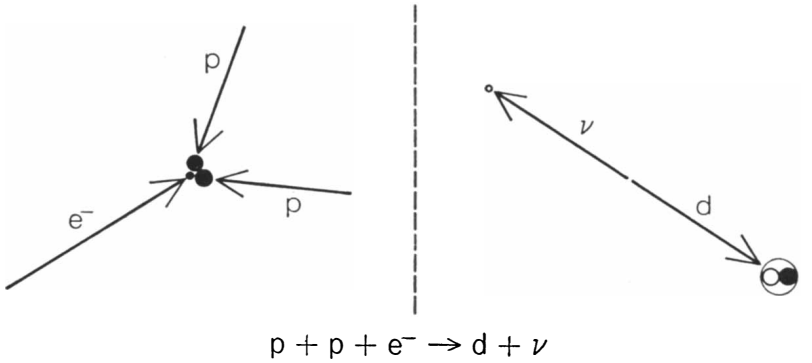
$$p + \bar{\nu} \rightarrow n + e^+.$$

This is the very process that Reines and Cowan observed in their Savannah River experiment. The necessary energy was supplied by the kinetic energy of the neutrinos coming out of the reactor.

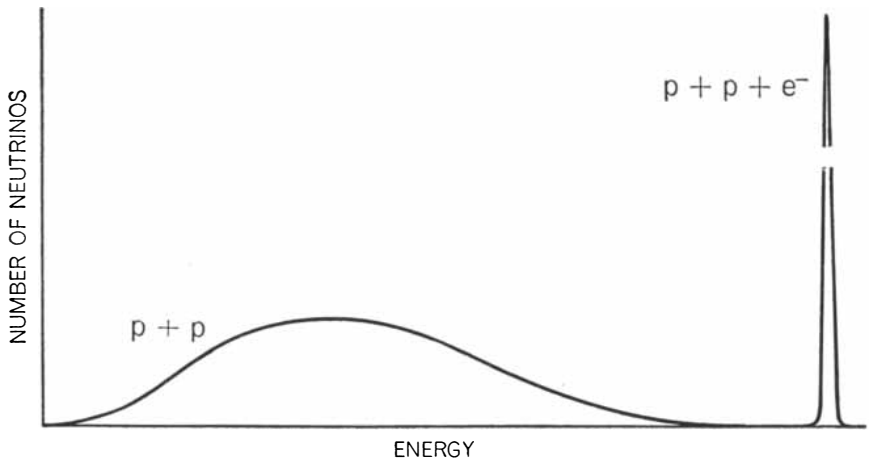
Physicists firmly believe there are many other neutrino reactions that have never been observed, because the theory suggests that any fermion pair can turn into any other. Which of the various processes would supply the material of neutrino astronomy? Armed with the rules of interaction already mentioned, and with more quantitative formulae from which the rates of each reaction can be predicted, some physicists have



REACTION IN CORE OF SUN, in which two protons (p) come together to form a deuteron (d), also releases a neutrino (ν) and a positron (e^+). Because three particles carry away momentum, the energy and direction of neutrinos vary. Two possible cases are shown.



RELATED REACTION, in which two protons and an electron (e^-) coalesce to form a deuteron and a neutrino, has a smaller but finite probability. With only two product particles, they can move off only in opposite directions, so that neutrinos have constant energy.



ENERGY SPECTRUM OF NEUTRINOS from the sun has two parts: a continuous band from the reaction shown at top of page and a line from the reaction shown in middle. The line has some width because of thermal motion of the electrons participating in the reaction. This chart is based on the work of Hubert Reeves of the University of Montreal.

set out to identify the neutrino sources in the stars.

The long-lived thermonuclear furnace that is our sun derives its heat from a neutrino-emitting reaction. For some years it has been clear that the combination of two protons to yield the lighter deuteron (a compound of one proton and one neutron) is the first step in the release of solar energy. The reaction is

$$p + p \rightarrow d + \nu + e^+.$$

Since d (the deuteron) is simply a close association of n and p, what has happened from the point of view of the elementary fermions is simply that one proton has turned into a neutron:

$$p \rightarrow n \text{ (in the deuteron)} + \nu + e^+.$$

The energy release is made possible only by the presence of a second proton. Occasionally two such protons, which cannot form a stable nucleus at all, collide and remain close together for a tiny fraction of a second. If during that time a neutrino is emitted, one proton has become a neutron, and the neutron and proton, still close together, *can* bind into the stable deuteron nucleus, releasing the needed energy. The process takes place, so to speak, *en passant*. And yet so numerous are the collisions at the 15-million-degree temperature and the density (10 times that of lead) of the hot hydrogen gas of the sun's core that this infrequent neutrino emission makes the sun glow. An average proton makes more than 10^{16} collisions each second under central solar conditions. Only once in a few thousand years will it have the luck to penetrate the electrostatic repulsive barrier so deeply that the collision will permit a try at the formation of a deuteron. And of these lucky close collisions, only one in 10 million will emit a neutrino and form a deuteron in actual fact. It is the neutrino emission that determines the time scale for the evolution of the sun and thus for the development of life on earth.

The turbulent, hot, dense core of the sun is, then, a source of neutrinos. In the first step of the nuclear reactions there—the formation of a deuteron—about half the energy leaves the sun at once in the straight flight of a neutrino. Subsequent steps rapidly burn the deuterons to helium without any neutrino emission. The over-all part of the nuclear energy spent in the form of the impalpable neutrinos is about 10 per cent. Even this tithe represents great power, and it would delineate the core of the

sun if we could only "see" the neutrinos.

The light of the sun is also born in the core, but it reaches us in quite a different way than do the neutrinos. The difference underscores some of the reasons for dreaming of a neutrino astronomy. Light originates as high-energy X-ray photons deep in the solar interior. Ricocheting again and again, it works its way out to the surface through the enormous bulk of the sun, taking about a million years. In the process each original photon has given birth to a couple of thousand progeny, all of which share the original energy. Neutrinos, on the other hand, interact so little that although they are born in the very core of the star they pass out as though the rest of the great mass were not present. In a neutrino telescope the sun would appear not as a disk but as a tiny hot spot, less than a hundredth the diameter of the sun we see, but emitting about a fourteenth of its power.

Hubert Reeves of the University of Montreal has given a still stronger reason for trying to build a neutrino telescope. He has reminded us that the reaction

$$p+p \rightarrow d+e^{+}+\nu$$

must always be accompanied by the less probable reaction

$$p+p+e^{-} \rightarrow d+\nu,$$

in which the protons absorb an electron instead of emitting a positron. This will take place only once in a couple of hundred of the standard neutrino emissions. But there is a remarkable difference. In each case the energy is shared among the final particles. The process

$$p+p \rightarrow d+e^{+}+\nu$$

produces three particles to share the energy. The motion of any two, say e^{+} and ν, is balanced by the motion of the third: the recoiling deuteron [*see top illustration on opposite page*]. Therefore the direction and energy of the output particles, including the neutrino, are variable. But in the case

$$p+p+e^{-} \rightarrow d+\nu$$

the two final particles, d and ν, can only have equal and opposing momentum. There is no angle to vary, so the emitted neutrino always carries off the same momentum and hence the same energy. This means that the neutrino energy spectrum is a line spectrum and not a continuous one. The neutrino spectrum

THREE YEARS and 39 DAYS

On January 12, 1959 the National Aeronautics and Space Administration (NASA) selected McDonnell Aircraft Corporation for the design and construction of a manned spacecraft to be launched by an Atlas booster, placed in a controlled orbit around the earth and returned safely. This project was called Mercury.

Twelve months and 3 days later the first spacecraft was delivered for flight testing.

On January 31, 1961 a chimpanzee was boosted into space in a Mercury Spacecraft. After a 418 mile flight down range, the spacecraft and Astro-Chimp, Ham, splashed into the Atlantic and were recovered safely.

Two years, three months and 23 days after the contract was announced, Astronaut Alan Shepard climbed into a Mercury Spacecraft for a down range flight witnessed by the world. Eleven weeks later, Astronaut Gus Grissom duplicated the feat.

On November 29, 1961, another high flying Chimpanzee, named Enos, rode twice around the earth and was successfully recovered.

. . . the Evolution of a Spacecraft

Three years and 39 days after the project began, a Mercury Spacecraft carrying Astronaut John Glenn was launched by an Atlas booster and placed in a controlled orbit. After three orbits, spacecraft and astronaut returned safely to the Earth and were recovered. It is significant to note that the initial assignment has been completed. The Mercury Spacecraft is now operational, a literal laboratory for astronauts as they continue the study of man's capabilities in space. McDonnell is now designing and building a two-man spacecraft for NASA. Called Gemini, it will be capable of long term orbital missions and rendezvous with another space vehicle while in orbit. Chapter 1, Book 1 of a great new American enterprise has now been written. Chapter 2 is just beginning.

MCDONNELL

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from the sun therefore contains both the continuous spectrum of neutrinos from p + p and the distinct line from p + p + e^- [*see bottom illustration on page 94*]. The line has a small energy width that depends on the thermal motion of the particles, and its height depends on the relative probability of the reaction producing it and therefore on the density of the gas where the reaction occurs. To observe the neutrino spectrum would be to determine experimentally the central solar conditions and to fix exactly which reactions are going on. The neutrinos provide the only possible experimental substitute for the "analytical boring machine" of which the British astrophysicist A. S. Eddington wrote, the only way to penetrate the massive shield of a star's body and see what the center is like. It is tantalizing that this message comes constantly to us riding a beam as bright, in order of magnitude, as sunlight itself, and yet we cannot detect it at all!

Evidently neutrino stellar astronomy, if it ever arrives, will bring from the cores of stars experimental information we can now obtain only by analysis of the emitted starlight, many generations removed from the source of energy. Here is an experimental challenge if there ever was one.

It is nearly 25 years since the role of beta-decay neutrinos has been understood in stellar energy release. On that basis alone the emission of neutrinos was a somewhat strange accessory to starlight, but only an accessory. To produce radioactive nuclei that could emit neutrinos nuclear processes were required, which themselves always emitted more energy in particle or photon form.

Some of the other neutrino reactions—recognized in the more powerful theory of recent years—are remarkably different. The simplest and most important process of this still unseen but firmly predicted type turns an electron-positron pair of fermions into a neutrino-antineutrino pair, at a rate easily calculated from the theory of the fermion transformations that are observed. The equation reads

$$e^- + e^+ \rightarrow \nu + \bar{\nu}.$$

All the conservation laws are fulfilled nicely. But if one were to look for this process in the laboratory he would notice an electron pair disappear with no detectable progeny once in about 10^{20} trials. No one will be that patient.

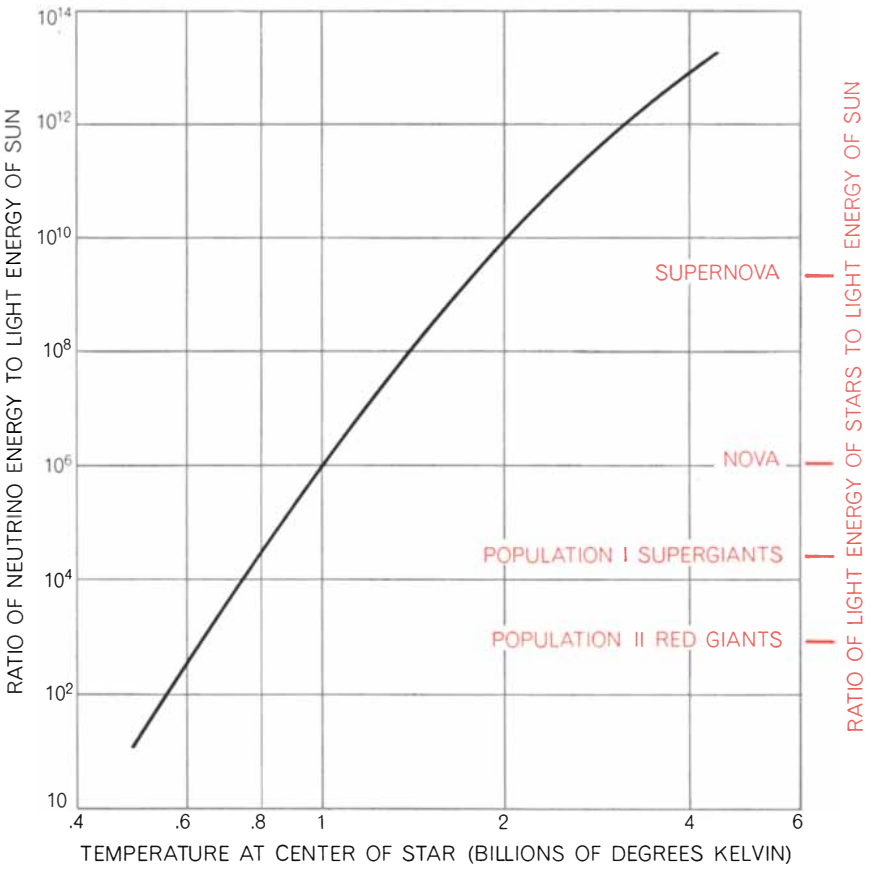
In such an emission of a neutrino-antineutrino pair no nucleus whatever is involved. The emission does require electron-positron pairs, which might seem an unusual constituent of stellar matter. In fact, however, the pairs are not rare. At high enough temperatures, beginning, say, with a few hundred million degrees centigrade, any volume whatever, even a good vacuum, is populated spontaneously with electrons and positrons. They come from the temperature radiation itself. The photons of this radiation, once they have energy enough, collide with one another to produce electron-positron pairs. Of course the pairs will quickly annihilate back to radiation again. The pair of equations that represent this sort of radiative chemistry are

$$\gamma + \gamma \rightarrow e^+ + e^-;$$

$$e^+ + e^- \rightarrow \gamma + \gamma.$$

Here the Greek letter γ (gamma) represents a high-energy photon. At thermal equilibrium one reaction takes place just as often as the other. The short lifetime of the electron pairs is a guarantee that there are not many present at any time, but they are constantly made and destroyed by collisions in obedience to the general laws of equilibrium. This would have very little importance for the behavior of hot matter and radiation if it were not for the neutrinos. What can it matter if such pairs are transiently formed in the deep stellar interior? Their presence is a mere detail.

The neutrino emission changes all this. Once in a great many collisions an electron pair will *not* annihilate back into the pair of gamma rays that made it but rather into a neutrino-antineutrino pair. Those particles will never again collide. They escape the region even if its walls are a star, and they seek the depths of space, robbing the hot region of their energy forever. The possibility of neutrino formation means that there is no way to retain thermal energy intact once high enough temperatures are reached to make this reaction important. There are related neutrino-photon processes too, important for somewhat lower and for still higher temperatures. Such energy loss is a newly recognized but fully general feature that the neutrinos give to hot matter of arbitrary composition; the matter loses heat at a definite and by no means negligible



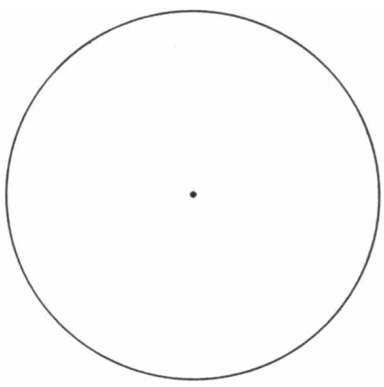
NEUTRINO "LUMINOSITY" of stars is plotted against the temperature at their centers. Luminosity is expressed as the ratio of energy emitted by stars in form of neutrinos to the light energy emitted by the sun. Some optical luminosities are shown at right. This chart is based on the work of Hong-Yee Chiu of the National Aeronautics and Space Administration.

rate. Any walled box at these extreme temperatures must lose all its thermal energy in a matter of minutes by neutrino loss.

In the latter stages of stellar evolution—those stages in which elements of medium weight are formed—temperatures suitable for the emission of neutrinos are expected. The stages are short-lived because the nuclear reactions that maintain the supply of energy are rapid, unlike the slow reactions at the coolish center of modest stars like the sun. Now we realize that they must be still more rapid than had been thought, because they must furnish not only the energy sent out as light but also that sent off in invisible neutrinos. The neutrino luminosity far exceeds the photon luminosity as the temperature rises.

Hong-Yee Chiu of the Institute for Space Studies of the National Aeronautics and Space Administration has shown that at a central temperature of a few hundred million degrees the energy shed by a star becomes dominantly neutrino energy. The hotter the star, the more it is a neutrino star and not merely a visible star. In the last centuries of their lives those few very hot stars headed for explosive death—presupernovae—seem likely to emit billions of times more power in the imperceptible neutrino than they send out as light. Indeed, it appears that the neutrino loss would of itself account for the pre-explosion collapse, although before the collapse can reach really explosive speeds other nuclear events regain control of the fate of hot compressed matter.

It is to be noted that the center of a massive star does not cool when it emits energy but rather collapses and heats. The tendency to cooling implied by energy loss is overbalanced by the gravitational pull, which causes the hot matter to contract whenever it loses energy. The contraction releases enough gravitational potential energy to supply the lost energy radiated—as light and as neutrinos—and a surplus to heat the compressed star-stuff still more. The heating increases the rate of energy loss by neutrino emission, so the collapse is faster and the loss still greater. Evidently the material has become unstable and is headed toward calamity, of which supernovae are one sign. It is quite possible that we still have not grasped the full meaning of supernovae collapse, which may go well beyond the formation of the most stable nucleus (iron) to produce strange new regions in which not matter but gravitational energy contributes most to the energy account.



"NEUTRINO SUN" would appear as a small, intense spot (*dot*) about one-hundredth the diameter of visible sun (*circle*).

We can now see that neutrinos will take away nearly all stellar energy released in the rare but important hotter stages of star evolution. Light removes the energy made available by the burning of hydrogen to helium, and that made by burning helium to carbon as the elements evolve. Neutrinos do almost all the rest, at least until supernova collapse. At that point we are unsure; it is not to be excluded that in gravitational collapse energies as great as all the energy of familiar matter are thrown off in still undetected neutrinos. We can surely assign at least a quarter of all the energy released by stars to neutrinos, and perhaps even the dominant part. The stars that became the supernovae of Tycho Brahe and his student Johannes Kepler, and the star that the Chinese astronomers of the Sung dynasty saw by day, had been invisibly "brightening" in the imperceptible glow of neutrinos for centuries before they finally grew bright for a few months in visible light when the slowly diffusing, much scattered photons finally worked their way to the surface. Neutrino detectors would make possible a supernova-early-warning service.

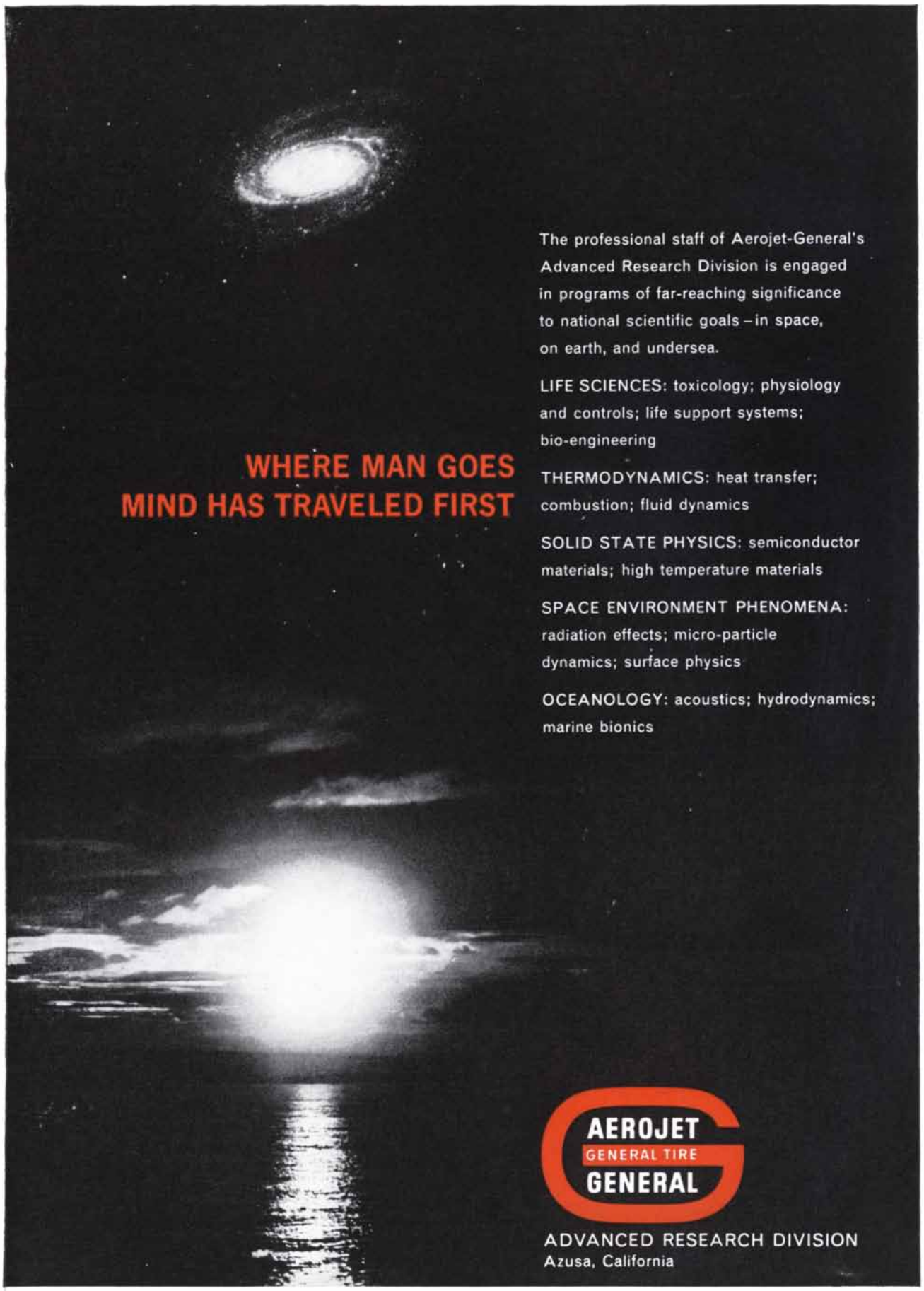
The end of the neutrino story is still uncertain. It may be that this newly discovered means of removing energy works even in the common smaller and cooler stars, allowing them to cool to the white-dwarf stage without ever reaching giantism and heavy-element-burning temperatures. It may be (as John A. Wheeler and his associates at Princeton University and Bruno M. Pontecorvo, I. B. Zeldovitch and Y. Smorodinsky in the U.S.S.R. have conjectured) that there is as much energy in the impalpable neutrino flux as in matter itself, placed there either by some supercollapse or by strange processes that go back to a possible explosive creation of all matter. It is even possible to see in the neutrino a relation with the very expansion of the universe, an expansion perhaps caused by the pull of an enormous total mass of very low-energy neutrinos. None of these matters is settled, and presumably none can be until the natural stream of neutrinos is detected. Then we might be able to reach some cosmological decisions in the nuclear laboratory.

At the present moment Reines, now at the Case Institute of Technology, and Cowan, now at Catholic University, are mounting schemes that at least point toward a neutrino astronomy. They are setting out to detect neutrinos produced not by stars but by cosmic rays and that have substantially higher energies than those treated in this article. The higher the energy of the neutrinos, the greater their probability of interacting with other matter.

Already Reines and his student Charles C. Giamati have been able to set a new limit on the higher energy cosmic ray neutrino flux that is close to the rate actually expected. The big detector with which this was accomplished was located 2,000 feet underground in a mine of the Morton Salt Company near Cleveland [*see illustration on page 90*]. Their next step, now in the design stage, is a counter containing 1,000 or more tons of the purest and most limpid water, set deep underground to shield out electrically charged cosmic ray particles and scanned by large photomultiplier tubes. They seek to detect the light radiated by fast particles secondary to the high-energy neutrinos entering the counter.

To be sure, even this heroic effort will fall short of revealing the still more elusive, star-born, electron-associated neutrinos. The experimenters are set too hard a task by the weakness of the neutrino interaction at low energy, the very weakness that allows the particles to signal us so directly from the center of the stars. But perhaps a way can be found. Maybe one day we can use as detectors not the nearly stationary protons and electrons of matter but fast-moving particles, made highly energetic in our own accelerating machines. Someday we may watch for events occurring from collisions of our fast particles against invisible partners, the neutrinos from the depths of space.

Suffice it to say for now that the message is there, bearing information on the cores of the stars and perhaps on the very bounds of space and time.



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Pumps in the Living Cell

One of the main activities of most animal cells and many animal tissues is the excretion of sodium. How is this "active transport" accomplished? Here the answer is sought in the kidney of the amphibian Necturus

by Arthur K. Solomon

One of the main tasks of the living cell is simply to maintain its physical integrity: to keep itself from bursting open. In its normal liquid environment the cell is subject to an inexorable force acting to push water across its enclosing membrane from outside to inside and thereby increase the pressure inside. Some plant cells resist the force by structural means. The strong outer wall of such a cell contains the pressure, which, incidentally, furnishes the rigidity that gives the cell its shape. Animal cells have evolved a different answer. In effect they hold back the water with pumps.

Biological pumping, or "active transport," plays other fundamental roles in the functioning of both individual cells and multicellular organisms. The process has attracted the interest of biophysicists in many laboratories. They have undertaken to isolate its mechanism and to identify the source of the energy that drives it.

In preventing the cell from bursting, the pump is working against the force of osmosis. This force results from the universal tendency of solutions on each side of a semipermeable membrane to reach equal concentration. The membrane of the cell is freely permeable to the molecules of water and to other small molecules, but not to large molecules such as those of proteins. In general the concentration of large molecules is higher inside the cell than it is in the surrounding liquid; therefore water tends to flow in to equalize the concentration. Almost all animal cells are thought to offset the effect by pumping out sodium. They expend a substantial fraction of their total energy budget in maintaining a lower sodium concentration inside the cell than outside. The result is that the total concentration of large and small molecules is the same inside the cell and out, and therefore there is no osmotic pressure.

Since the sodium is tranferred as positively charged ions, its outflow leaves the interior of the cell electrically negative with respect to the outside. The potential difference across the membrane is only about a tenth of a volt, but the membrane is only about a millionth of a centimeter thick. Hence the field amounts to 100,000 volts per centimeter, which is quite a respectable figure. Among its various physiological roles the electrical potential difference makes possible the transmission of impulses along nerve fibers and the triggering of contraction in muscle.

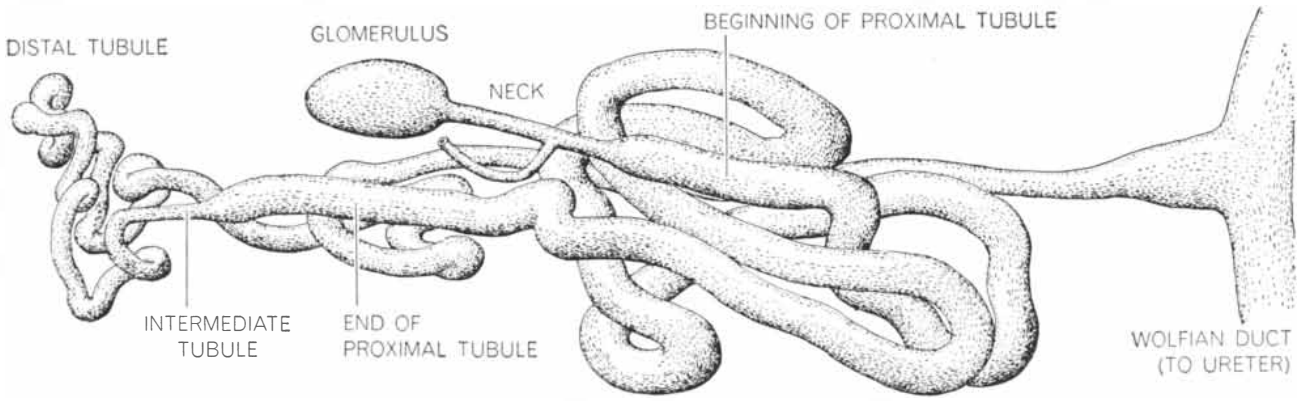
Under certain circumstances a system of cells pumps sodium to move water rather than to prevent it from moving. For example, approximately seven quarts of water enter the human intestinal tract every day, mostly in saliva and secretions of the stomach and pancreas. Here the problem is to return most of the water to the body fluids. It appears that the lining of the gut contains a pump that moves sodium, and water along with it, out of the intestine and back to the bloodstream.

In our laboratory at the Harvard Medical School we have been studying a somewhat similar system in the vertebrate kidney. The kidney is the organ that regulates the composition of the blood plasma and hence the extracellular environment of all the cells in the body. In an adult human being some 50 gallons of blood a day pass through the little capsules in the kidney called glomeruli. Here the proteins are filtered out, remaining behind in the blood, and the rest of the solution passes through the filter into the kidney tubules. In the first, or proximal, section of the tubule 80 per cent of the salt and water and all the glucose are pumped out and returned to the bloodstream. The rest of the material, which includes all the waste, travels on to the more distant segments of the tubule, which exercise fine control over the composition of the urine. Our interest has centered on the proximal section of the tubule, where the bulk of the work is done.

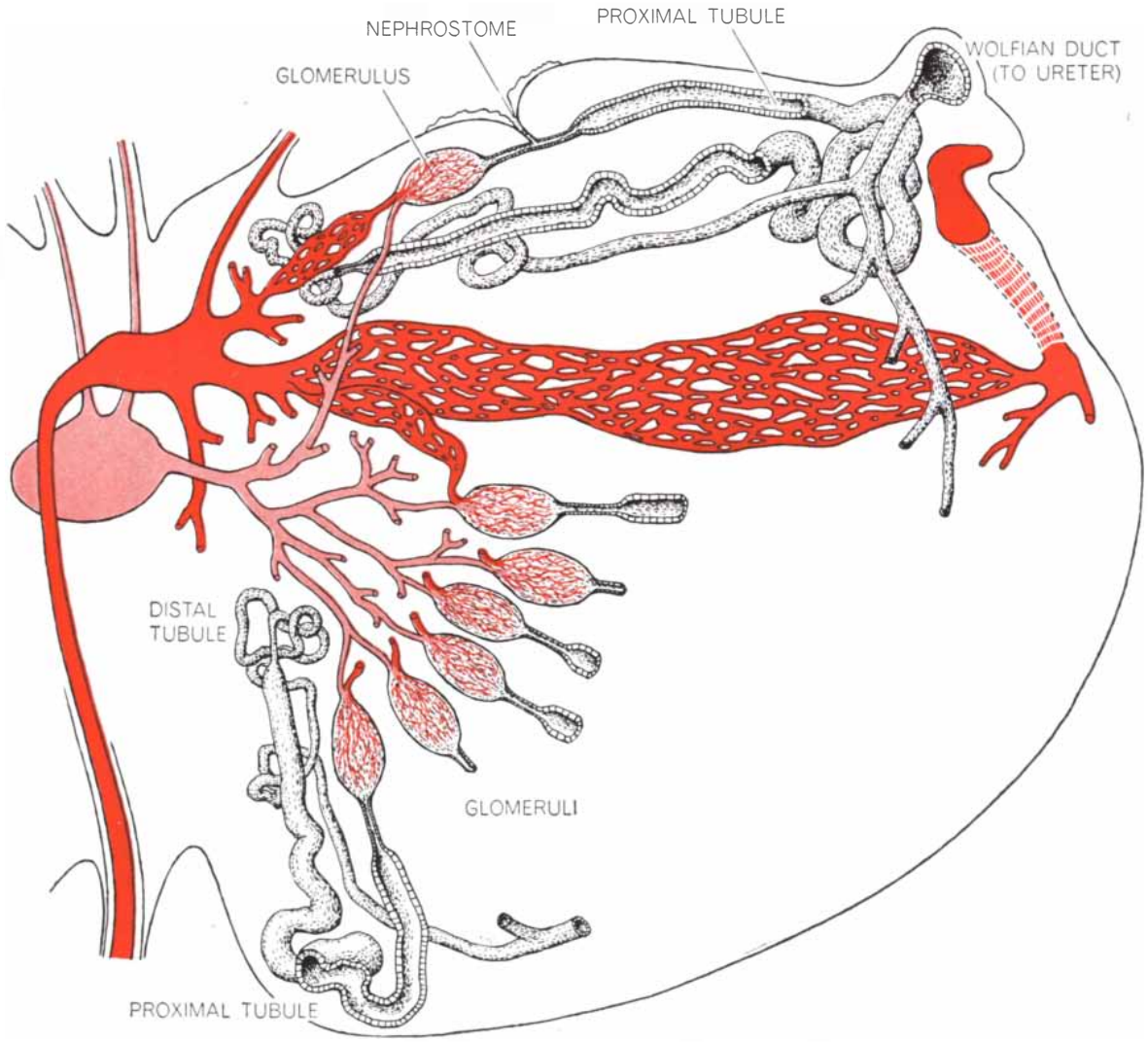
The experimental animal we have been using is the large fresh-water amphibian called *Necturus* or the mud puppy. The kidney tubule of *Necturus* is relatively large: its internal diameter of about a two-hundredth of an inch is big enough to admit a special micropipette. Moreover, the proximal section of the tubule starts and finishes near the surface of the kidney, providing access to both its ends even though its middle portion descends into the kidney and cannot be seen [*see illustrations on opposite page*]. These advantages have attracted a number of workers. The pioneers were Alfred N. Richards and his group at the University of Pennsylvania School of Medicine, who carried out a

AUTHOR'S NOTE

The author wishes to acknowledge the collaboration of his associates in the work reported in this article. They are: Irwin B. Hanenson, Joseph C. Shipp, Hisato Yoshimura, Erich E. Windhager, Hans J. Schatzmann, Guillermo Whittembury, Donald E. Oken, W. J. Flanigan, Nobuhiro Sugino, Francisco C. Herrera, Raja N. Khuri, Charles J. Edmonds and David L. Maude.



PROXIMAL TUBULE of the *Necturus* kidney runs from the glomerulus at one end to the narrower intermediate tubule at the other. For most of its length it is within the kidney. Both ends, however, are near the surface and are accessible to the experimenter.



NECTURUS KIDNEY is estimated to contain approximately 800 tubules. In this schematic drawing the venous blood vessels are shown in dark red and the arterial in light red. Much of the water and salt flowing through the kidney returns to blood via tubules.

classic series of studies on the *Necturus* kidney in the 1930's.

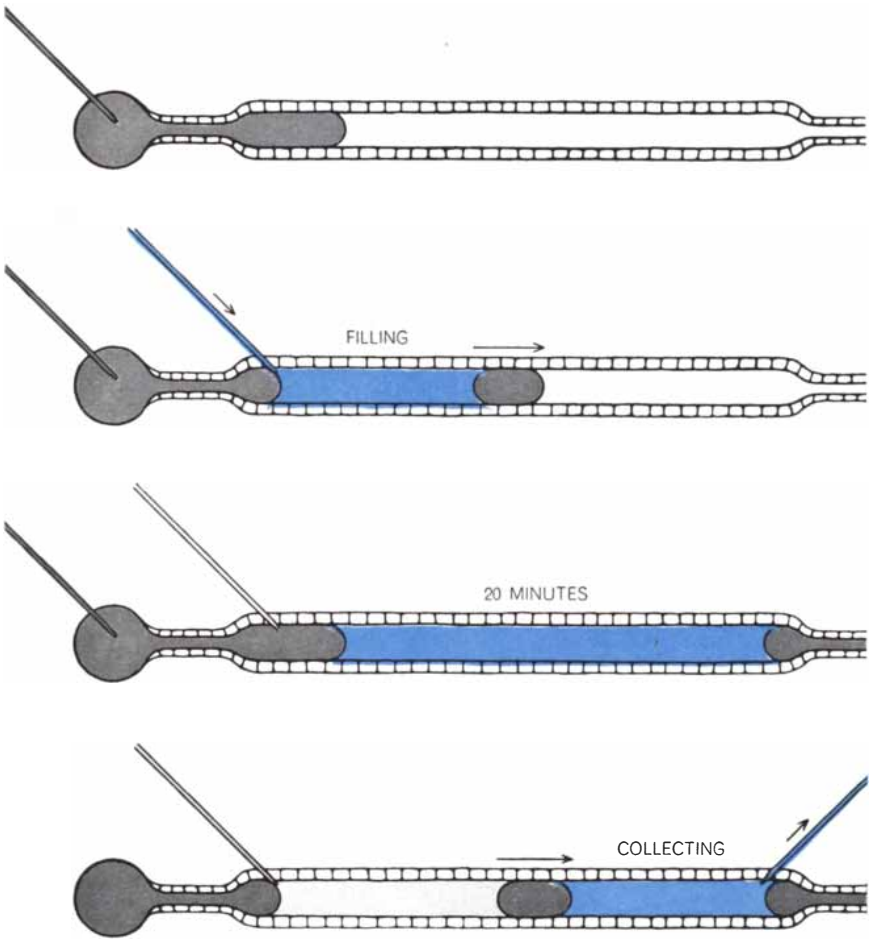
Taking up the investigation in 1953, we hoped to extend Richards' results with the help of certain new theoretical ideas on active transport and new methods, particularly the use of radioactive tracers. At first we were interested in the outward movement of solutions through the wall of the proximal tubule. It should be emphasized that we were not then studying the activity of the membrane of the individual cell but of a wall composed of a layer of cells.

By means of a technique known as stopped-flow microperfusion we can measure precisely the amount of water and dissolved molecules that are absorbed from a single kidney tubule. Working with the exposed kidney of an anesthetized living animal, we insert a micropipette into a glomerulus and inject colored oil until it enters the upper part of the proximal tubule. Then a second pipette is inserted into the drop of oil and a solution containing a radioactive tracer is injected, splitting the oil drop in two. As fluid begins to fill the tubule, it pushes the "front" part of the oil drop; this disappears from view, descending into the kidney, and finally reappears at the end of the proximal tubule. We can identify the end because at this point the tubule abruptly narrows, and the drop assumes a characteristic shape. Now the tubule is filled with fluid in the process of being perfused. We isolate the fluid completely by injecting a little more oil through the glomerulus to seal the hole by which the tubule was filled.

In 20 minutes a measurable amount of salt and water has disappeared from the tubule. Then another micropipette is inserted into the beginning of the tubule and a second drop of oil is sent through, pushing the perfusion fluid into a collecting pipette. The amount of fluid we collect is only about a ten-thousandth of a cubic centimeter, a quantity just visible to the naked eye. We measure the volume by transferring the fluid under the microscope to a small capillary tube of constant bore, a technique devised by Richards. Evaporation presents a problem in dealing with such small amounts of solution, and we have to be careful to keep the droplet away from the extreme ends of the capillary.

To determine how much water has been lost from the tubule, we put into a perfusion fluid the inert substance inulin, the molecules of which are too large to pass through the tubule wall. The increase in the concentration of inulin in the fluid collected from the tubule is then a measure of the decrease in water volume. Fortunately we were able to obtain inulin labeled with the radioactive isotope carbon 14. As a result we can measure changes in inulin concentration by radioactive techniques, which are simpler than chemical ones.

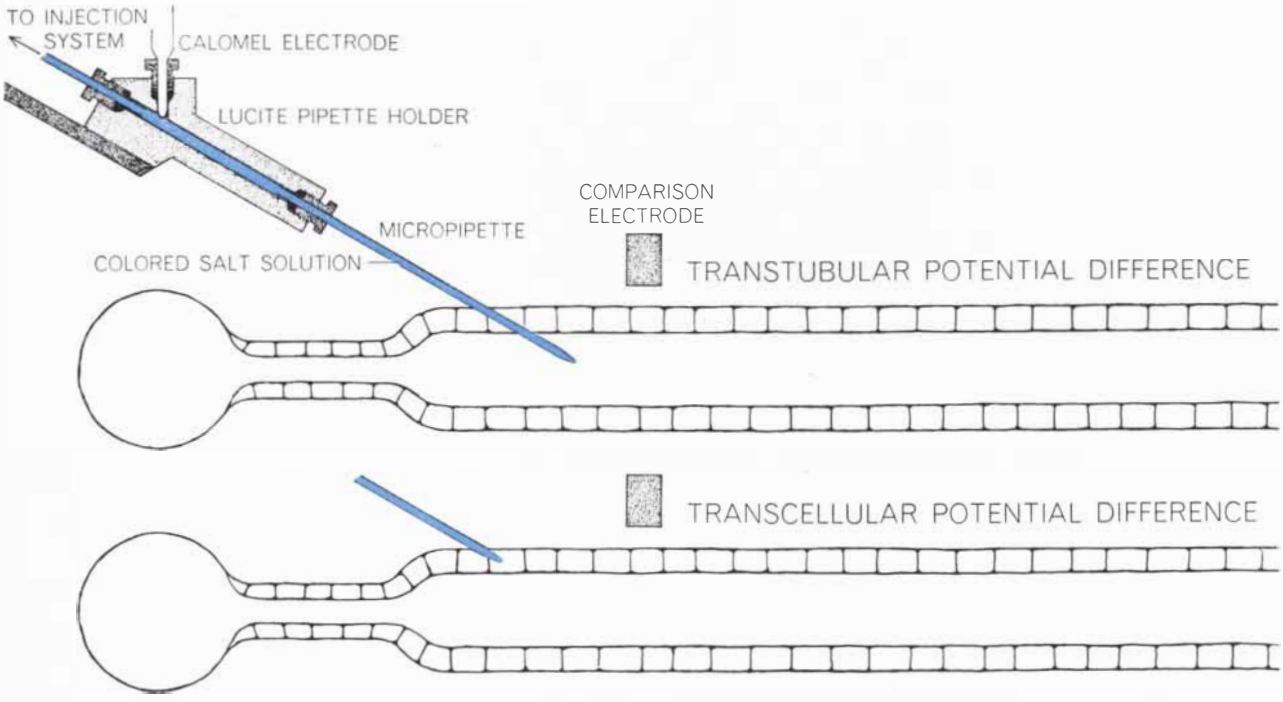
Richards had found that as fluid moves down along the tubule, some of it passing out through the wall, the concentration of dissolved salts (chiefly sodium chloride) remains almost constant. Evidently salt and water move together. But which is actively pumped and which follows along passively? It had generally been assumed that salt, or rather sodium, is the actively transported material in situations of this kind, but we wished to take nothing for granted.



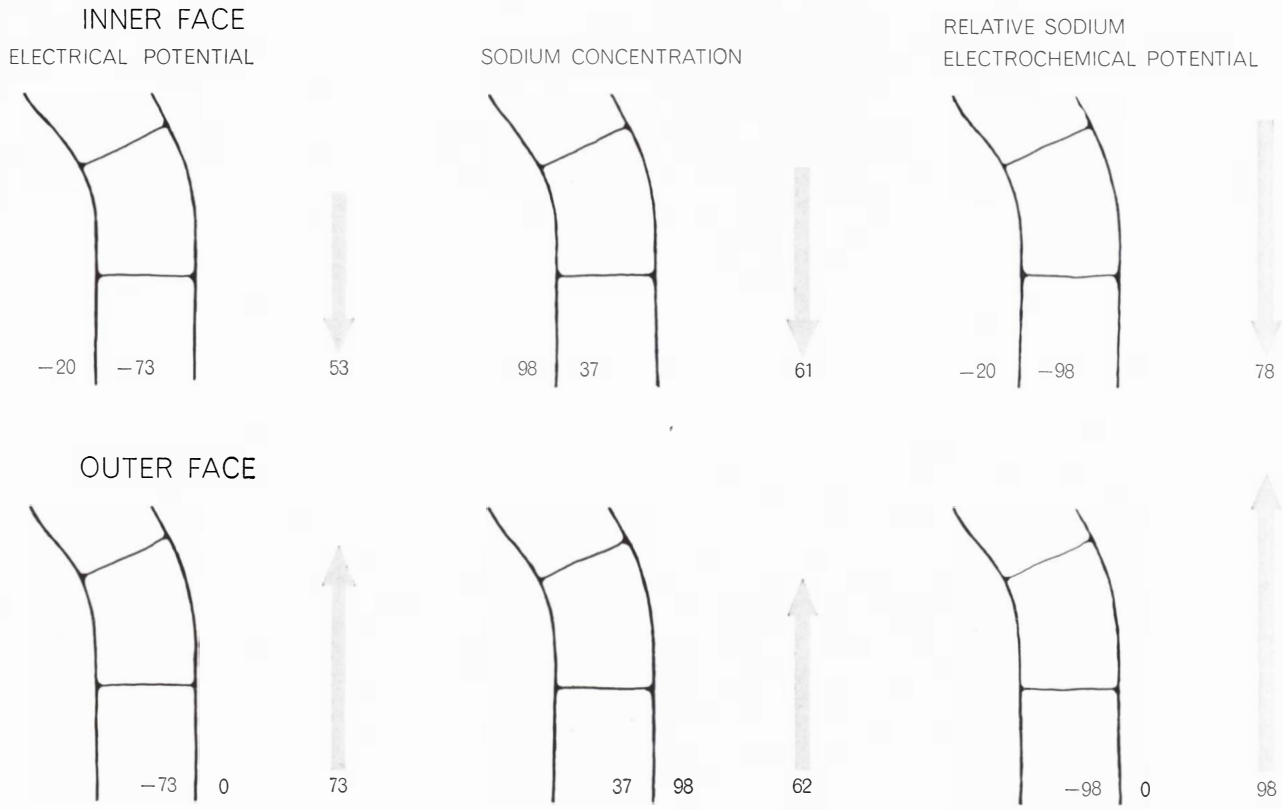
STOPPED-FLOW MICROPERFUSION technique, by which many of the results described in this article were obtained, is illustrated schematically. In drawing at top a micropipette is inserted into a glomerulus (*left*) and oil is injected until it fills the narrow neck and enters the proximal tubule. In second drawing from top perfusion fluid is injected through a second pipette into middle of oil, forcing a droplet ahead of it. Tubule is full when droplet reaches the far end of the tubule (*third from top*). After about 20 minutes the fluid is collected (*bottom*) by injecting a second liquid behind the oil remaining at near end of tubule.

It took three and a half years before we mastered the techniques sufficiently to conduct a successful experiment. We found that 27 per cent of our perfusion fluid water was absorbed in 20 minutes, a figure that agrees fairly well with the observation of Richards' group that 19 per cent is absorbed when fluid passes through the tubule under normal conditions.

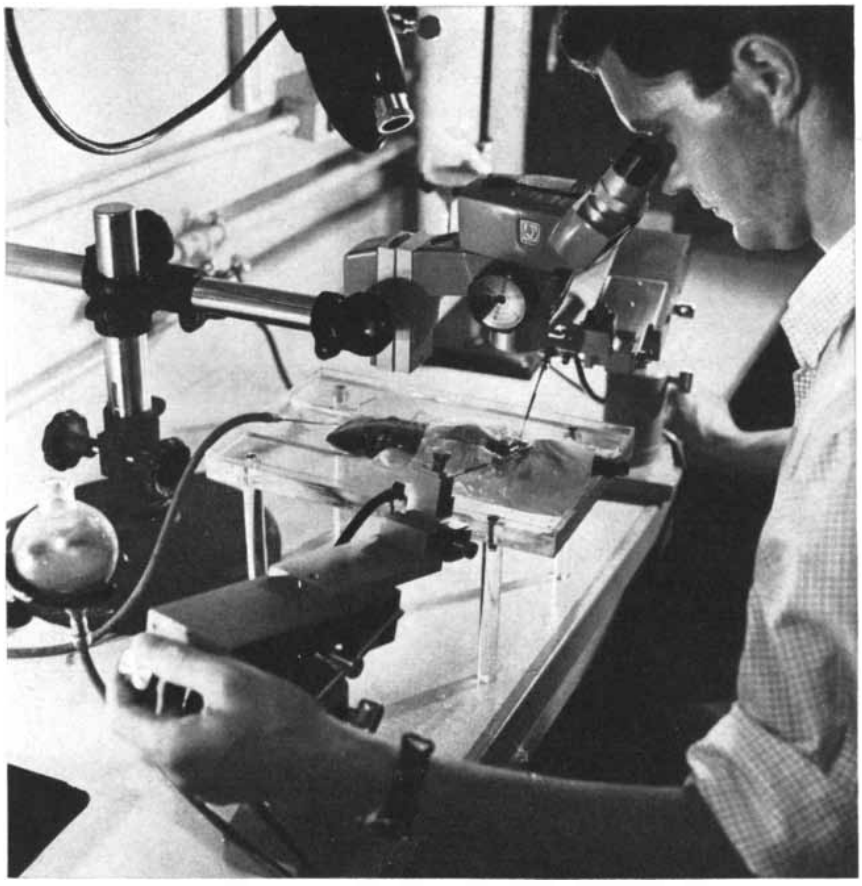
We attacked the problem of identifying the actively and passively transported materials by varying the salt concentration of the perfusion fluid. To offset osmotic-pressure effects from changes in salt concentration, any sodium chloride removed was replaced with mannitol, another inert substance. When the sodium chloride concentration inside the tubule was reduced (but the osmotic pressure held constant), the outflow of water also decreased. A further reduction stopped all water movement; at a still lower concentration water moved into the tubule. These results indicated



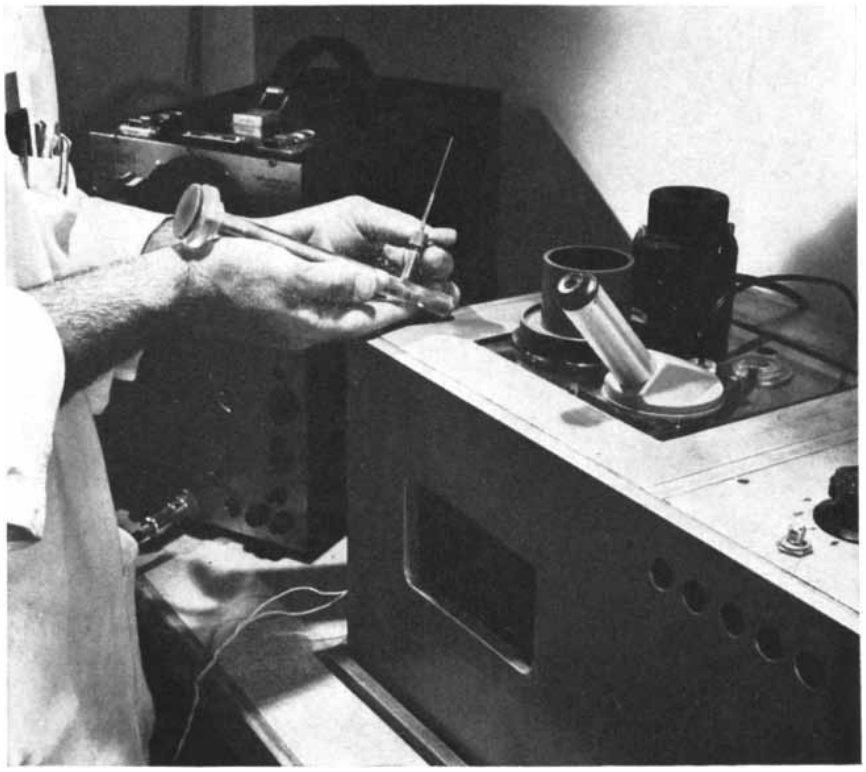
ELECTRICAL POTENTIAL DIFFERENCES across the inner and outer sections of the membranes of the tubule wall are measured by inserting microelectrodes into the tubule (*top*) and into the cells (*bottom*). Colored salt solution furnishes electrical contact through calomel electrode. After measurement colored solution is injected into tissue, where it marks the point of measurement.



POTENTIAL DIFFERENCES, both electrical and chemical, that sodium ion encounters at inner face (*top*) and outer face (*bottom*) of cells of tubule wall are indicated by gray arrows. Numbers are units appropriate to each type of potential or concentration.



INSERTION OF MICROPIPETTE into a kidney tubule is accomplished with the aid of a pair of micromanipulators located at each side of a tray on which the anesthetized animal is placed (*center*). The experimenter monitors the operation through binocular microscope.



FREEZING-POINT APPARATUS, designed by J. A. Ramsay and R. H. J. Brown of the University of Cambridge, is contained in the box at right. The experimenter is about to insert the sample-holder. Freezing is observed through microscope eyepiece at top of box.

that water movement is dependent on salt movement.

Although sodium chloride was by far the most abundant substance dissolved in the perfusion fluid, the fluid also contained other molecules, in particular mannitol, that might leak back and forth across the tubule wall. This or any other molecule would transport some water. To establish that water movement is completely passive we had to take into account the leakage of all molecular species, known and unknown. The simplest way to do this is to measure the freezing point, which is lowered by an amount proportional to the concentration of independent dissolved particles. In a series of experiments we varied the salt concentration of the perfusion fluid, causing water and dissolved molecules to move into the tubule in some cases and out of it in others. In each case we measured the small change in the freezing point of the fluid before and after the experiment, and the total water transferred. We were able to show that water movement is strictly proportional to solute movement: when there is no net transfer of dissolved substances, there is no flow of water. Therefore the movement of water through the wall of the tubule is entirely passive.

We were now ready to look for the pump; that is, to find the substance that is actively transported. Before describing the experiments let us consider in more detail what is meant by the term "active transport."

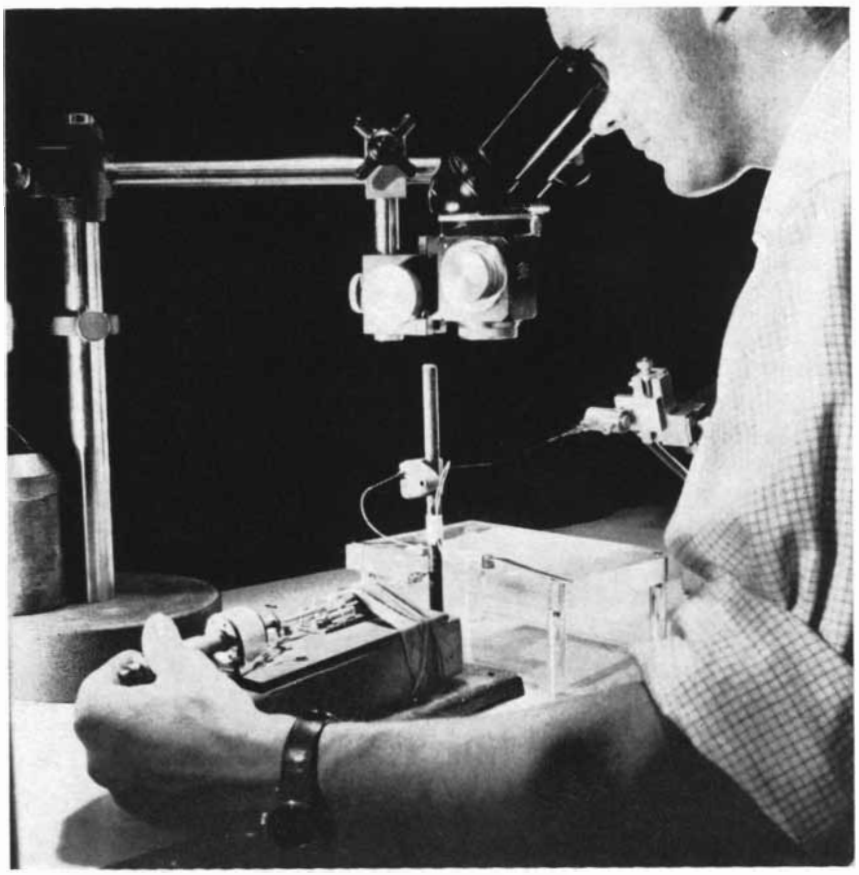
If a weight is moved uphill, it is moved from a lower gravitational potential to a higher one. Such a motion, which is opposite to the natural tendency of the weight, requires active transport. Now think of a sugar solution that is more highly concentrated at one side of its container than it is at the other. It is obvious that the transfer of sugar from the more concentrated to the less concentrated side is a downhill process. If sugar is seen to move en masse the other way, it must be actively transported against a chemical potential difference. In the case of charged atoms or molecules (ions) the electrical potential must also be considered. A positive ion moves downhill from a region of higher to a region of lower electrical potential; for it to move the other way implies active transport. The laws of physical chemistry show how to combine the two effects: at 37 degrees centigrade an electrical potential difference of 61 millivolts (thousandths of a volt) is equivalent to a 10-fold concentration difference. It is just as hard to move a positive ion such

as sodium "upward" across a 100-fold concentration difference as across a 10-fold concentration difference and an electrical potential difference of 61 millivolts. One student of active transport, Thomas Rosenberg of Denmark, defines it as net movement up an electrochemical potential gradient.

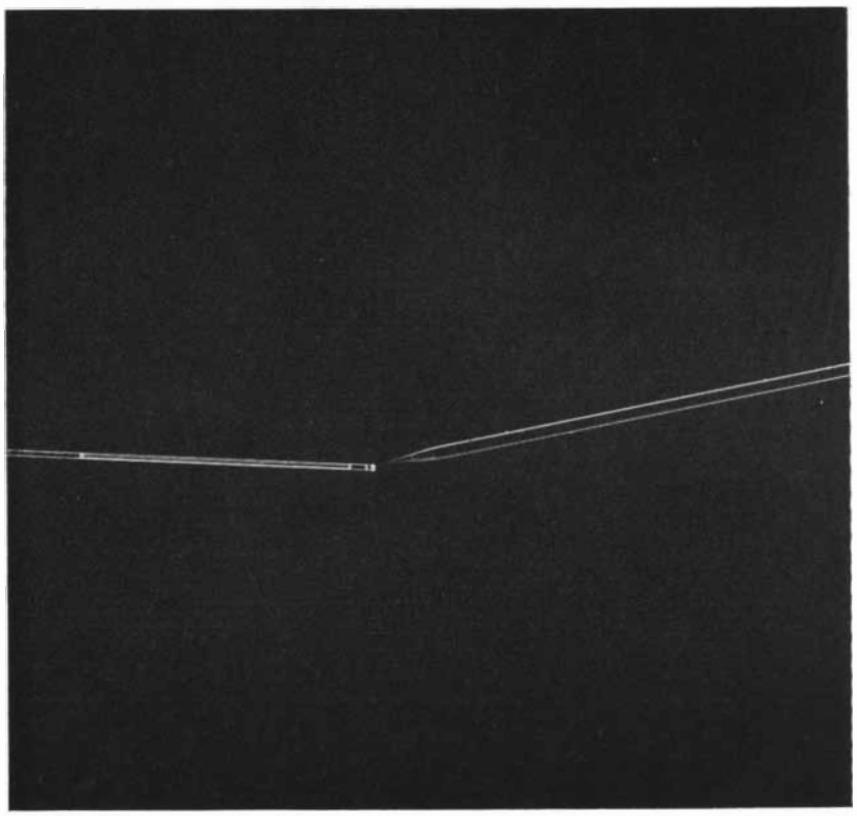
In view of what is known, or at least suspected, about sodium in many cellular systems, we first turned our attention to this element. Our first perfusion experiments, in which we progressively lowered the concentration of sodium chloride, had shown that water and presumably sodium moved out of the tubule even when the inside sodium concentration was only 67 per cent of the outside concentration. Evidently sodium is transported up a chemical concentration gradient.

Next we had to know about the electrical potential difference between the inside and the outside of the tubule. Gerhard H. Giebisch of the Cornell University Medical College had already measured the potential and found it to be 20 millivolts more positive outside than inside. Hence it appeared that the sodium ion also travels up an electrical potential gradient. Giebisch's determination, however, was made under conditions somewhat different from those of our experiments, so we thought we should make the measurement ourselves. We adopted his technique, inserting microelectrodes into the tubules [*see top illustration on page 103*]. The tips of the electrodes are much smaller than those of the micropipettes and cannot be seen under the microscope. Therefore we had no direct way of telling whether or not they were correctly placed in the tubule. To check their location we filled the hollow microelectrodes with colored salt solution (the solution served as an electrical conductor). When a measurement had been completed, we forced the colored liquid out of the electrode and into the tubule, a process that requires considerable pressure to overcome the capillary forces in the minute electrode tips. If the colored solution could be seen in the tubule, the measurement was accepted; if not, the figure was discarded. To our gratification we obtained a potential difference of 20 millivolts. We could now say unequivocally that sodium is actively transported through the tubule wall up an electrochemical potential gradient, in agreement with Rosenberg's definition.

A more thoroughgoing analysis of active transport has been made in the



TRANSFER OF FLUID from micropipette, extending from apparatus at right, to measuring capillary tube is also carried out under microscope with aid of a micromanipulator.

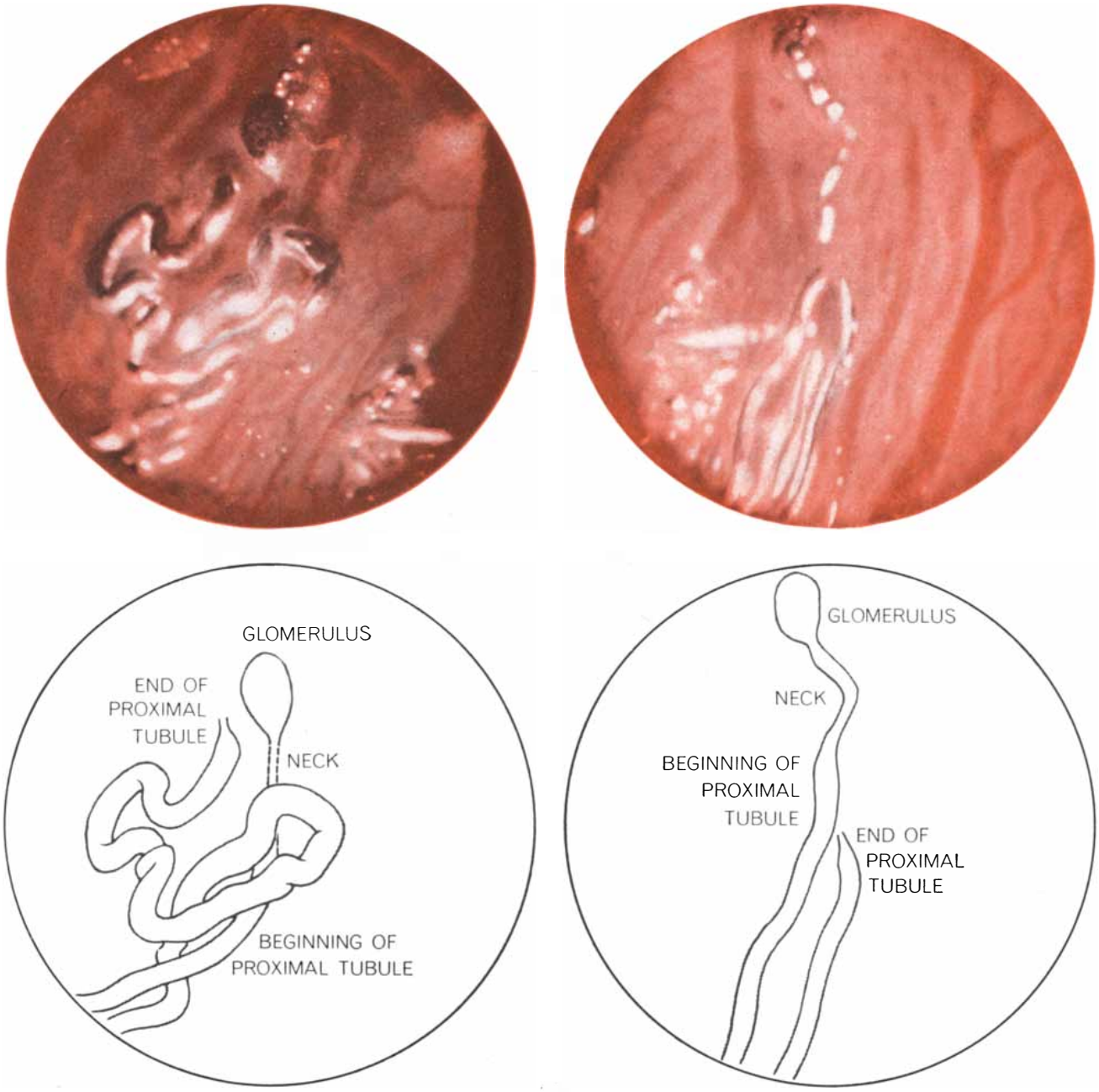


PIPETTE AND CAPILLARY are photographed in close-up, magnified three diameters. Bore of capillary (*left*) is uniform, so length of liquid column is measure of its volume.

past few years by Hans H. Ussing of the University of Copenhagen. He recognized that processes other than net uphill transport require an immediate energy supply. One example is downhill motion at faster than equilibrium rate. An automobile coasts downhill at a speed governed by the steepness of the grade and the various frictional forces involved. If it goes down faster, it must be taking power from the engine. To take this kind of motion into account Ussing derived an equation in which the ratio of uphill to downhill movement is compared with the known electrochemical potential difference.

In an attempt to apply Ussing's equation, we have tried to measure the backward flow of sodium in the tubule. By adding some radioactive sodium to the fluid injected into the tubule and determining the amount of radioactivity remaining in the fluid collected at the end of the experiment, we hope to get a direct measure of the outflow of sodium. Combining this figure with the net change in sodium content in the tubule would enable us to calculate a net return flow. But this method turns out to be incapable of showing whether or not individual ions have accumulated in the cells of the wall and then leaked back into the tubule several times during the course of the experiment, and so we cannot really say what the total uphill or downhill motion is. At present, therefore, we cannot subject our results to Ussing's more fine-grained analysis.

Although the results were disappointing, the quantitative methods required to deal with such small amounts of material are worth mentioning. It is easy



KIDNEY TUBULES in *Necturus* have been injected with mercury to make them visible in the two photomicrographs at top. The two drawings at bottom indicate what parts are seen. Photomicrographs were made by Bradford D. Pearson of Harvard Medical School.

enough to assay radioactive sodium by ordinary counting techniques; determining total sodium content less than a millionth of a gram is another matter. The measurements were made in a flame photometer specially adapted for ultramicro quantities. The solution is placed in a flame and the yellow sodium line is isolated by a spectroscope. The intensity of this line, which gives an indication of the amount of sodium present, is then measured with a photomultiplier tube.

The experiment did confirm, in any case, that the net movement of sodium in the *Necturus* kidney tubule is upward against an electrochemical gradient. It remained to find out if any of the other important ions in the system are also actively pumped. The migration of chloride ions has been studied by Giebisch together with Erich E. Windhager, formerly of our group. They found no need for active transport. The 20-millivolt potential difference across the wall is in the right direction to pull the negatively charged chloride ion out of the tubule.

In our laboratory we tackled the rather difficult problem of potassium. The concentration of this element in the blood of *Necturus* is about a thirtieth that of sodium. Like sodium, it passes through the glomerular filter and forms a part of the normal tubular fluid. Because of its much lower concentration, and because photomultiplier tubes are much less sensitive to the purple light it emits than they are to yellow light, potassium is harder to measure than sodium. Even with the flame photometer tuned to its highest efficiency, we were unable to determine the potassium concentration in the fluid collected from a single tubule; we had to pool several samples in order to obtain enough material for analysis. We found that as water passed out of the tubule, the potassium concentration inside rose in exactly the same ratio as the inulin concentration, indicating no net movement of potassium. We therefore concluded that potassium transport is also passive. This left sodium as the active component.

Now we could go on to the exciting task of localizing the transport process within the cells of the tubule wall. We assumed that the pumping is done somewhere on the cell membrane, either on the part that faces the inside of the tubule or on the part that faces outward. Giebisch had already measured the electrical potential difference across the separate faces of the cell in living animals. We now began to work with slices

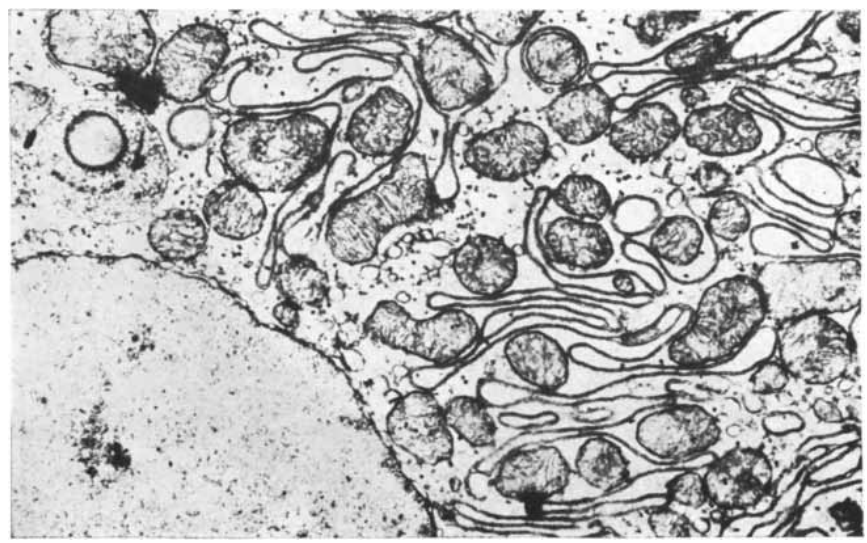
of kidney in which we could determine the concentration of sodium, potassium and chloride inside the cell. In this work the two groups collaborated very closely. When we checked the electrical potentials in the cells of our kidney slices, we obtained results in striking agreement with Giebisch's.

Combining the electrical and chemical measurements gave the following picture [*see bottom illustration on page 103*]. In the case of sodium the concentration inside the cell is much less than the normal tubular fluid concentration. In addition, the 53-millivolt potential difference across the inside face of the cell membrane is in the direction to pull sodium ions from the tubule into the cell. Therefore sodium moves into the cell down both an electrical and a chemical concentration gradient, and the process appears passive. At the outside face of the cell the electrical potential difference is 73 millivolts, but in a direction opposed to the motion of the sodium. The movement also goes against a chemical concentration gradient. Therefore sodium must be actively transported. The sodium pump, the only active process so far identified, appears to be located at the outside face of the cell. The beauty of this system is that it accounts for a host of apparently unrelated phenomena. The sodium pump at the outside face provides the force to pump the water out of the tubule and incidentally to preserve the cell's osmotic integrity. At the same time it controls the sodium concentration within the cell and the observed electrical potential differences.

Electron microscope studies have recently produced a picture consistent with our hypothesis. It has long been known that a major energy source for cellular reactions of all kinds are the small bodies called mitochondria. Since the sodium pump requires energy, our model suggests that there should be a concentration of mitochondria at the outer face in kidney proximal tubule cells. Recent electron micrographs show, most dramatically in frogs and to a lesser extent in *Necturus*, that this is indeed the case. Modern anatomy places the energy source just where it is needed according to our biophysical studies.

By way of conclusion I might point out that the term "active transport" in a sense betrays ignorance. A naïve member of a primitive society, seeing an automobile climb a hill, might conclude that the body of the car is somehow endowed with the energy to move it. We can trace the energy to the engine, to the cylinder and to the chemical bonds in the fuel. The body of the automobile moves passively under the power of the drive shaft. The drive shaft is in turn passively actuated by the cylinders. They are passively pushed by the expansion of burning gases, and so on.

Our results, then, represent only a first step. The localization of the sodium pump within the cell is exciting, but the major problem still faces us. What is the detailed molecular mechanism by which sodium is transported, and how is this mechanism coupled to its energy supply? When these questions are finally answered, we shall be able to drop the phrase "active transport" from our vocabulary.



CELL OF FROG KIDNEY TUBULE shows rich concentration of mitochondria (*dark objects*) near the outside face (*curved line at bottom left*). This electron micrograph, magnification 18,000 diameters, was made by Morris J. Karnovsky of Harvard Medical School.

In tank warfare . . . how much advantage goes to the force that fires first? ■ Combat tank units in Korea were six times as effective when they fired first as when they returned fire. This is one of many conclusions drawn from scientific examination of disabled tanks by our operations research teams in Korea. Typical additional determination: a true measure of the combat effectiveness of various anti-tank weapons.

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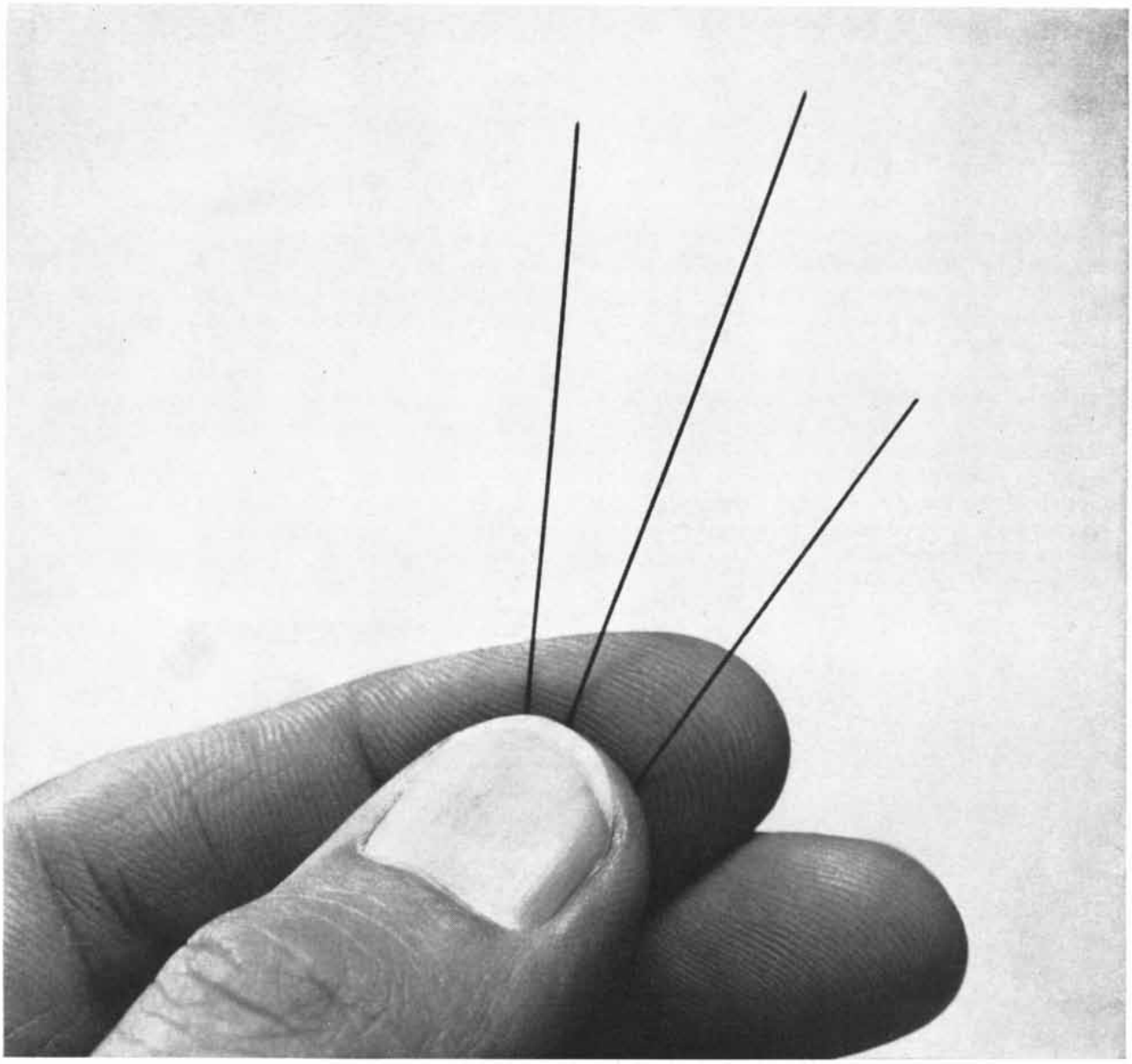

New NCR rod switches computers in billionths of a second

The essential action that takes place in man's most complicated machine, the computer, is a simple one.

An electric current turns on . . . and off . . . that's all.

But in solving a typical problem, the computer performs this switching operation millions and billions of times. That's why computer technicians speak of millionths of a second when they discuss switching speeds.

Under the ever pressing need for greater speed and capacity they are now coming to talk in terms of nano-seconds—literally ***billionths*** of a second.

The NCR thin film rod memory element you see here can switch in billionths of a second — an unprecedented speed — many times faster than core memories in existing computers.

Developed in NCR's Research and Development division, it is going to work in new computers — increasing capacity, reliability and flexibility . . . shrinking size and multiplying speed. Since this amazing rod operates efficiently over a wide range of temperatures, it will find use in applications other than business computers.

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KININS

They are a class of local hormones, produced in blood or tissues where and when needed. They dilate the blood vessels and move smooth muscles. They also give wasp venom much of its sharp sting

by H. O. J. Collier

It has been known for half a century that the smooth functioning of the body depends in large measure on hormones, the "chemical messengers" secreted by particular glands and transported to their site of action in the bloodstream. More recently physiologists have discovered that various substances with hormone-like properties are in effect manufactured on the spot, from the blood or other fluids, precisely when and where they are needed. These active substances, made without the aid of special glands, have been called local hormones. Because local hormones are released near their sites of action and are usually destroyed rapidly, their physiological roles have been hard to establish. In the past few years, however, good progress has been made in defining the activity and nature of a number of these elusive hormones. Among them is the group of substances called kinins.

Kinins can be regarded as miniature proteins. Ordinary proteins are giant molecules built up of hundreds or thousands of amino acid subunits, of which there are 20-odd varieties. The properties of a protein depend on the number and kind of amino acids it contains, on the order in which they are linked together and on the cross links between them. Proteins containing fewer than 100 or so amino acid units are commonly called polypeptides, or simply peptides. The kinins are peptides, but because the study of kinins is so new there is no general agreement as yet on the number and kind of amino acid units that characterize a kinin. Until more kinins have been thoroughly investigated the outline of the group will probably remain vague. The core of the group is nonetheless already formed by several well-defined peptides with similar biological properties. These are kinins that were first obtained from the plasma of mammalian blood and from mammalian urine. Later, surprisingly, similar substances were found in the venom of wasps. Study of a few of these substances provides most of what is so far known of the genesis, nature and action of kinins. The knowledge growing around this core should lead to the definition of a group of highly active peptides and to an explanation of their role in the working of the body.

Kinins were discovered as biologically active products of blood many years before their chemistry was known. They were revealed by an experimental technique familiar in physiology. A segment of intestine, cut from an animal's body immediately after death, is suspended in a warm, oxygenated solution resembling blood in salinity and alkalinity. The segment is suspended from a lever; this transmits the movements of the intestine to a stylus that rests on a revolving drum covered with a sheet of smoked paper. As the intestine contracts and relaxes, the stylus draws a curved trace on the paper. A number of biologically active substances will make the intestine contract or relax. These responses are exquisitely sensitive and their amplitude varies directly according to the dose of active substance applied.

In 1937, using this technique, E. Werle, W. Götze and A. Keppler, then at the Düsseldorf Academy of Medicine, first demonstrated that such a thing as a kinin existed. When they treated a segment of guinea pig colon with human blood serum or an extract of salivary gland, nothing happened. But if the two fluids were mixed and applied immediately, the tissue contracted sharply [*see illustration on page 116*]. If the mixture was left standing for a few minutes, it lost its activity. The German workers concluded that an enzyme in salivary gland released from some component in blood a highly active but unstable substance. Eleven years later, in 1948, Werle named the substance kallidin. (The generic term "kinin" came later.)

The enzyme in salivary gland that released kallidin from blood was kallikrein, a protein that had been studied in Germany even before the discovery of kallidin. Kallikreins had been extracted from pancreas, urine, the wall of the gut and other sites, and were known by their ability to lower blood pressure when injected into the veins of an animal. This effect, it is now believed, is due to the release of kallidin within the body.

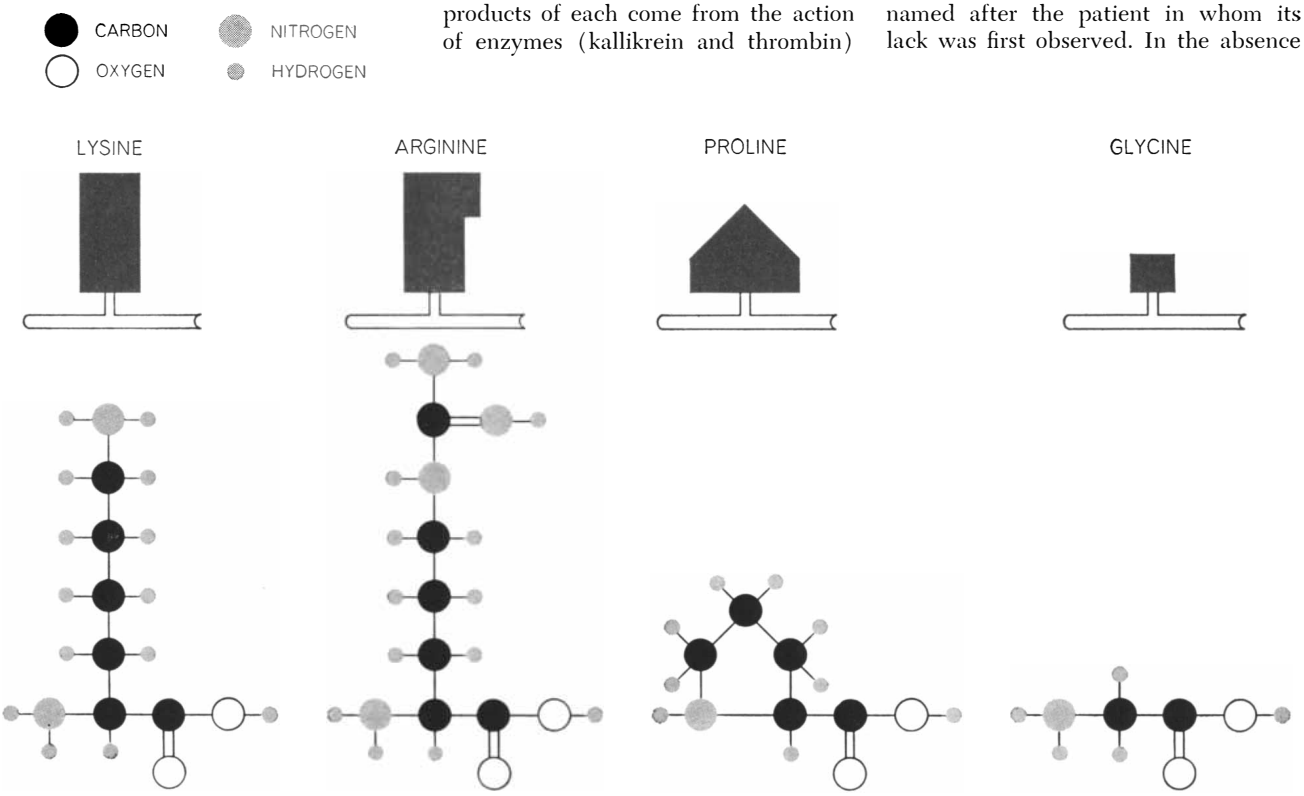
We owe to Werle and his group not only the first demonstration of a kinin but also the concept of how it is released in the blood. Normally no kallidin can be detected in the bloodstream of man or other animals. But the release mechanism can be set off by a variety of physical or chemical changes, such as acidification, dilution with salt solution, addition of acetone or papain (an enzyme derived from the papaya plant) or by allowing the blood to come in contact with glass. Some, if not all, of these treatments activate the kallikrein, which is normally present in blood in an inactive form. The kallikrein in turn chops off molecules of kallidin as peptide fragments of one of the large plasma proteins (alpha-two globulin). These events take place in plasma or serum obtained from blood, and they can also be set off in the body by injecting kallikrein or one of the agents that activate it [*see illustration on page 115*].

When a mechanism exists in the body for release of a highly active substance, a second substance is usually provided to destroy or inactivate the

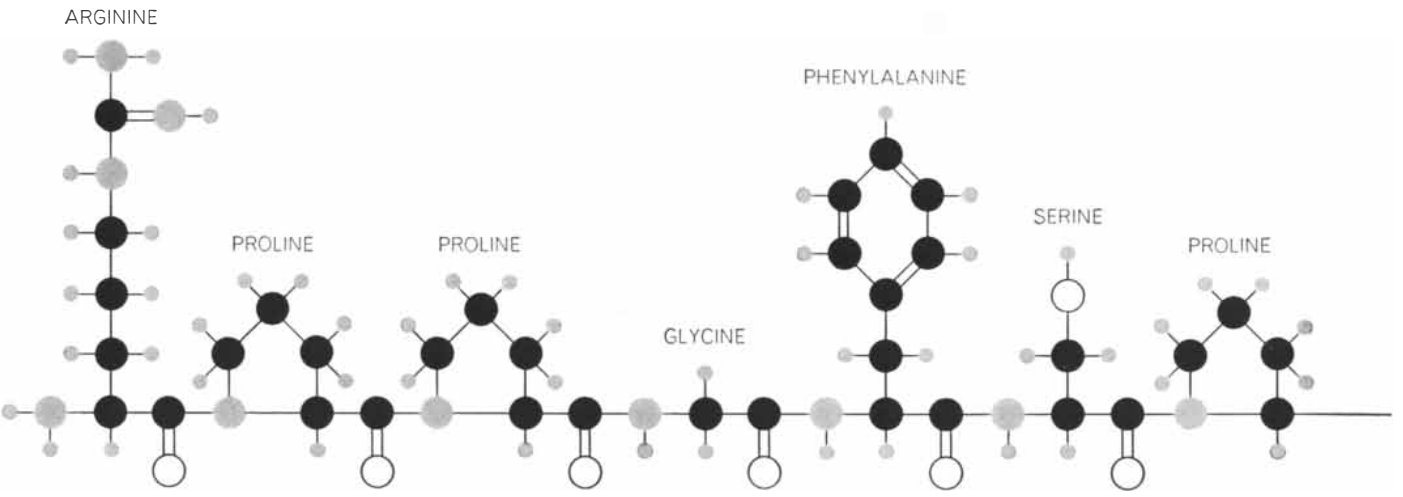
first. Such inactivating agents are enzymes that are often given names with the suffix "-ase." For example, blood and tissues contain potent esterases that quickly destroy acetylcholine, a substance that stimulates the contraction of a muscle when liberated from a certain kind of nerve ending. It is not surprising, therefore, that blood contains inactivators of kallikrein and enzymes—carboxypeptidases—that destroy kallidin. For this reason stored plasma or serum does not contain much free kinin.

There is a striking similarity between the release of kallidin and the deposition of fibrin, which is the main event in blood clotting. In both cases there exists a natural mechanism that is set in motion by abnormal conditions. The end products of each come from the action of enzymes (kallikrein and thrombin) on globulins normally present in plasma. Both of these end products may later be destroyed by other enzymes present or released in blood—kallidin by carboxypeptidase and fibrin by plasmin (sometimes called fibrinolysin).

The mechanism that releases kallidin and that which forms fibrin not only seem modeled on a similar pattern but also share some of the same cogwheels. One of these is the Hageman factor, named after the patient in whom its lack was first observed. In the absence



SIX AMINO ACIDS, of 20-odd found in proteins, appear as subunits in the two kinins whose structure has been established within the past two years. Bradykinin (kallidin I) is a peptide chain that is created from the linkage of nine amino acids, as shown below.



BRADYKININ (KALLIDIN I) is a peptide that appears in the bloodstream as a "local hormone." Related peptides are also found free in the venom of certain wasps. A peptide linkage is formed between two amino acids when the hydroxyl (OH) group of one acid links up with a hydrogen (H) atom in the amino group (NH_2) of a second acid to form water. The water splits away, allow-

of the Hageman factor, blood brought into contact with glass fails to clot at a normal rate and also fails to yield kinin. Both clotting and kinin release can be brought about by adding the Hageman factor from normal blood. The part this factor plays in both processes underlines their likeness and shows how complex is the system of activators and inhibitors that make it likely that clots and kinin will form when a blood vessel is broken.

Probably because of World War II, the first studies on kinins passed almost unnoticed outside Germany. Then in 1949 M. Rocha e Silva, W. T. Beraldo and G. Rosenfeld of the University of São Paulo published an unexpected observation. They were studying the effects of the venom of the South American snake *Bothrops jararaca* on the dog. They noticed that the venom released from dog's blood a substance that was highly active on pieces of intestine isolated from the guinea pig. At first they suspected that the venom had triggered the release of histamine, a substance frequently produced when tissues are irritated and undergo an allergic reaction. They found, however, that the effect of the substance was not abolished by antihistamines and that the response took about seven times as long to reach a peak as did the response to histamine [*see top illustration on page 117*]. They called the new substance bradykinin from the Greek words *bradys*, meaning "slow," and *kinein*, meaning "to move." The relation between bradykinin and kallidin was not to be clarified until 1961.

The São Paulo group showed that bradykinin could be liberated by the action of the digestive enzyme trypsin on plasma globulin; this meant that bradykinin could be made from raw materials available in bulk. Bradykinin was therefore the first of the kinins to be prepared pure, to have its chemical structure worked out and to be synthesized from the amino acids that compose it, but this is getting ahead of the story.

Globulins that yield kinins exist not only in blood but also in other fluids of the body, such as lymph, ascites (an abnormal accumulation of fluid in the abdomen), amniotic fluid (which surrounds the fetus in the uterus) and colostrum (the first milk after childbirth). Little is known as yet about the kinins that can be liberated from these fluids. They are a mine in which investigators may still strike rich deposits.

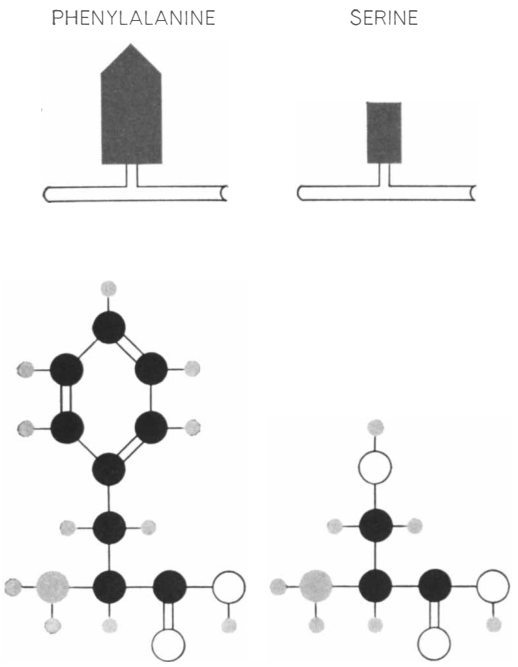
The discovery of kallidin and bradykinin showed that salivary glands and snake venom both contain enzymes that can release kinins from blood. Since the poison glands of snakes are modified salivary glands, this is understandable. More surprising is the fact that the venom of some insects contains free, active kinins.

In 1954 R. Jaques and M. Schachter, then at the National Institute for Medical Research in London, found the first venom kinin in the common wasp (*Vespa vulgaris*). The London workers removed the sting apparatus from hundreds of wasps to get enough material to show the main properties of the new substance. Schachter's group coined the word "kinin" by chopping "brady" from "bradykinin," which the wasp substance most closely resembled. Although Schachter and his colleagues have been unable to find a kinin in bee venom, they have just detected another kinin in the venom of the European hornet (*Vespa crabro*). In due course other species of the genus *Vespa* will no doubt yield kinins, and probably kinins will eventually be found in the venom of other genera and even of other orders.

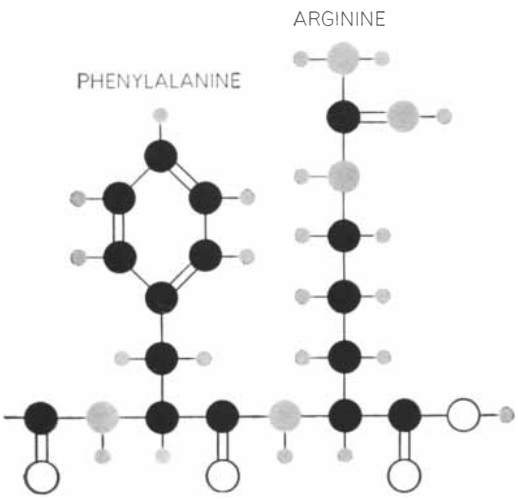
If wasp venom is kept for some time, the kinin disappears, but it stays active if the venom is first heated. This suggests that venom contains an enzyme that can destroy kinin. The kinins of the wasp and the hornet are highly concentrated in the fluid that these insects inject into their victims. Also contained in the fluid are other interesting substances: histamine and serotonin in the wasp fluid, and both these substances plus acetylcholine in the hornet fluid. The three substances, the molecules of which are smaller than those of the peptides, are also local hormones that occur naturally in the mammalian body. There they act on nerves, muscles and blood vessels, in some ways just as the kinins do.

The inactivation of kinins by enzymes such as chymotrypsin shows that kinin activity depends on a molecular structure containing peptide links. By means of such links the basic amino (NH_2) group of one amino acid joins the acidic carboxyl (COOH) group of another to make a larger molecule. This linkage scheme is common to both peptide molecules, which contain relatively few amino acids, and proteins, which contain hundreds. It is not difficult to show that kallidin and bradykinin are peptides and that they are smaller, for example, than the several varieties of insulin, each of which consists of 48 amino acid units. Two forms of the pituitary hormone corticotrophin have 39 amino acid units. Two other pituitary hormones, oxytocin and vasopressin, contain eight amino acid units and are comparable in size to the kinins.

Because living tissue can sometimes detect a single change in the type or even order of the amino acids in a peptide, the exact structure of each kinin is important and also bears on the ultimate definition of the group. Before the structure can be determined, the peptide must be completely purified. In 1959



Proteins are similar chains containing hundreds or thousands of amino acid subunits.

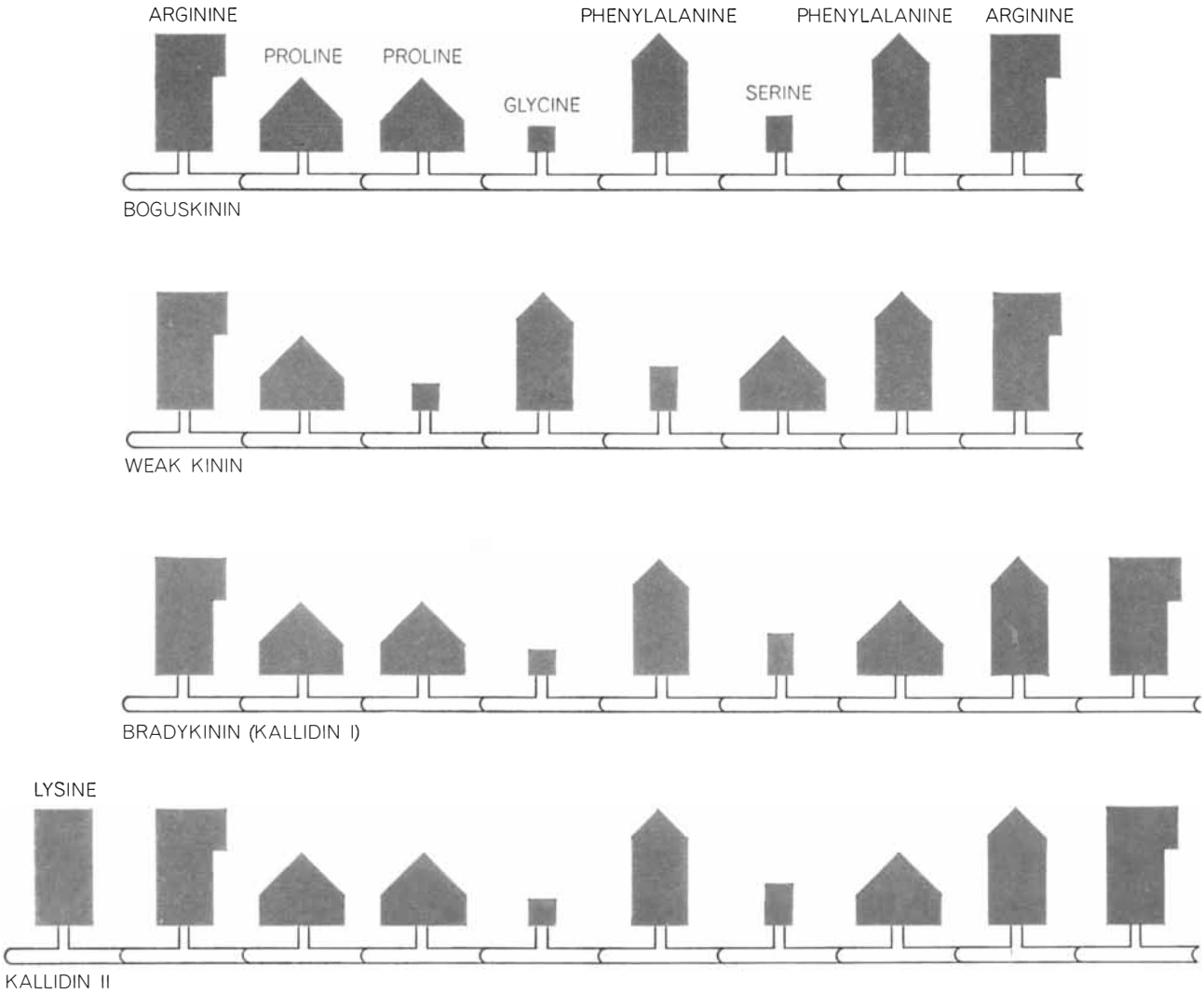


ing the two amino acids to be joined. Kallidin II and other kinin and kinin-like structures are illustrated on the next page.

D. F. Elliott, G. P. Lewis and E. W. Horton of the National Institute for Medical Research in London prepared pure bradykinin. Following the method of Rocha e Silva, they obtained their starting material by reacting crystalline trypsin with globulin from ox blood. After analyzing the pure compound, Elliott and his co-workers proposed, in April, 1960, that bradykinin consists of eight amino acid units in the following sequence: arginine-proline-proline-glycine-phenylalanine-serine-phenylalanine-arginine.

Within two months three independent teams of industrial scientists had synthesized this octapeptide and found it inactive. R. A. Boissonnas of the Swiss firm Sandoz Ltd. discussed this with Elliott. Boissonnas's group then began to make other peptides of related structure, while Elliott's group reviewed its own work, looking for errors. Boissonnas and his co-workers found that when one of the prolines of the inactive octapeptide was put in another position, the new compound had weak bradykinin-like activity. They then made a nine-amino-acid peptide with prolines present in both positions; this had all the activity of pure bradykinin. More or less simultaneously Elliott's group found that they had missed a third molecule of proline in reaching their proposed structure. They called the inactive octapeptide "boguskinin" and assigned to bradykinin the structure of the nonapeptide that Boissonnas had synthesized.

Meanwhile the chemical structure of the original kinin, kallidin, was still unknown, but it resembled bradykinin so closely in biological activity that many workers thought it must be the same substance. A year ago J. V. Pierce and M. E. Webster of the National Institutes of Health in the U.S. reported that they had obtained two different kallidins from human plasma treated with human urinary kallikrein. Their analysis showed that kallidin I was identical with bradykinin, whereas kallidin II was a 10-amino-acid peptide in which the amino acid lysine was attached to the arginine in position 1 of bradykinin. Soon afterward Ernest D. Nicolaides, Horace A. DeWald and Duncan A. McCarthy, Jr., of Parke, Davis & Co. synthesized this



SIGNIFICANCE OF STRUCTURE emerges from a comparison of four peptides closely resembling one another. The octapeptide at top was the first structure proposed for bradykinin. When it proved inactive, it was named "boguskinin." Moving one of the proline units to the right, between serine and phenylalanine, gave a peptide with weak kinin activity. Addition of a third proline, to replace the one moved, produced bradykinin, or kallidin I. Addition of lysine to left end of the chain produced kallidin II.

decapeptide, which showed high kinin activity.

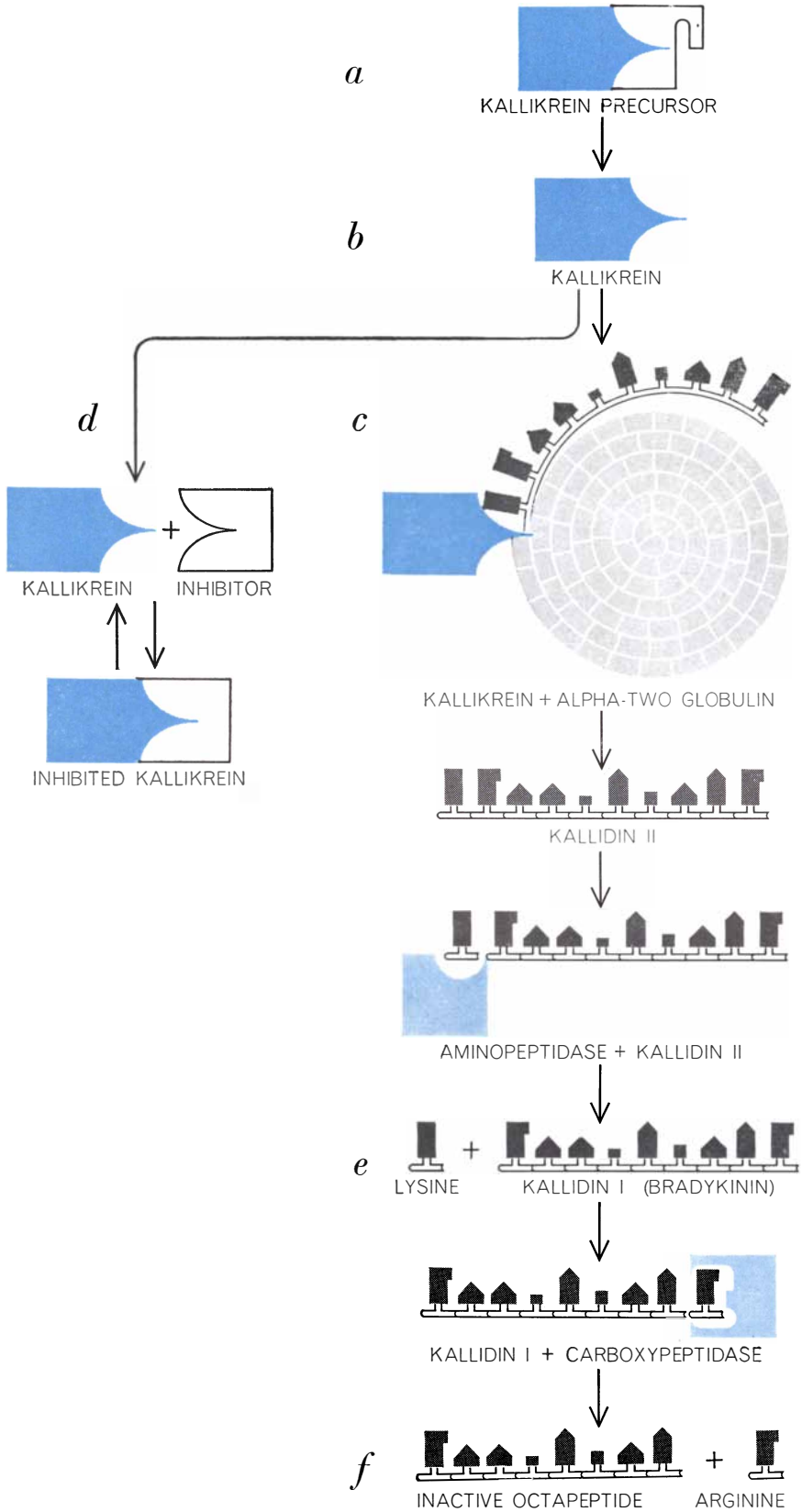
These adventures in peptide synthesis show not only the problems and surprises in this field of work but also the apparent capriciousness of living tissues in discriminating between chemical structures. Whereas the loss of a proline in position 7 inactivates bradykinin, the addition of a lysine to position 1 hardly affects its potency. Switching a proline from the position on the left of glycine to that on the right of serine makes a weak kinin from the inactive octapeptide [*see illustration on opposite page*].

The discovery that bradykinin, first detected as a product of the action of foreign enzymes on globulin, is released naturally in human plasma as one form of kallidin throws the terminology of plasma kinins into some confusion. While the difficulty stays unresolved, the term "kinin," qualified by site of release, provides a useful description.

Let us return, then, to the biological activity of the kinins. As we have seen, their profound effect on isolated pieces of intestine led to their discovery. The muscles that show such sensitivity belong to the category of smooth muscle. This type of muscle provides the motive power not only of the intestines but also of most of the other tubular systems of the body: the blood vessels (except capillaries), the air passages of the lungs and the ducts that carry the reproductive cells, urine and digestive juices. Isolated pieces of smooth muscle associated with such tubes usually respond sensitively to kinins, some by contraction, some by relaxation.

When injected into the bloodstream of man or animals, kinins also have powerful effects on the smooth muscles as they exist in the body. For example, in some species they affect the smooth muscles in the walls of the bronchioles of the lung. In the guinea pig less than one microgram (a millionth of a gram) of bradykinin, injected into a vein, will make the bronchioles constrict and so increase resistance to the flow of air into and out of the lungs. Injection of histamine, serotonin or acetylcholine has a similar effect, but the response to kinin develops more slowly [*see second illustration from top on page 117*].

In all mammals tested, kinins from blood and venom relax the muscles of the blood vessel walls, causing more blood to flow to the area involved and blood pressure to fall. In a recent experiment at the National Institute for Medical Research one microgram of

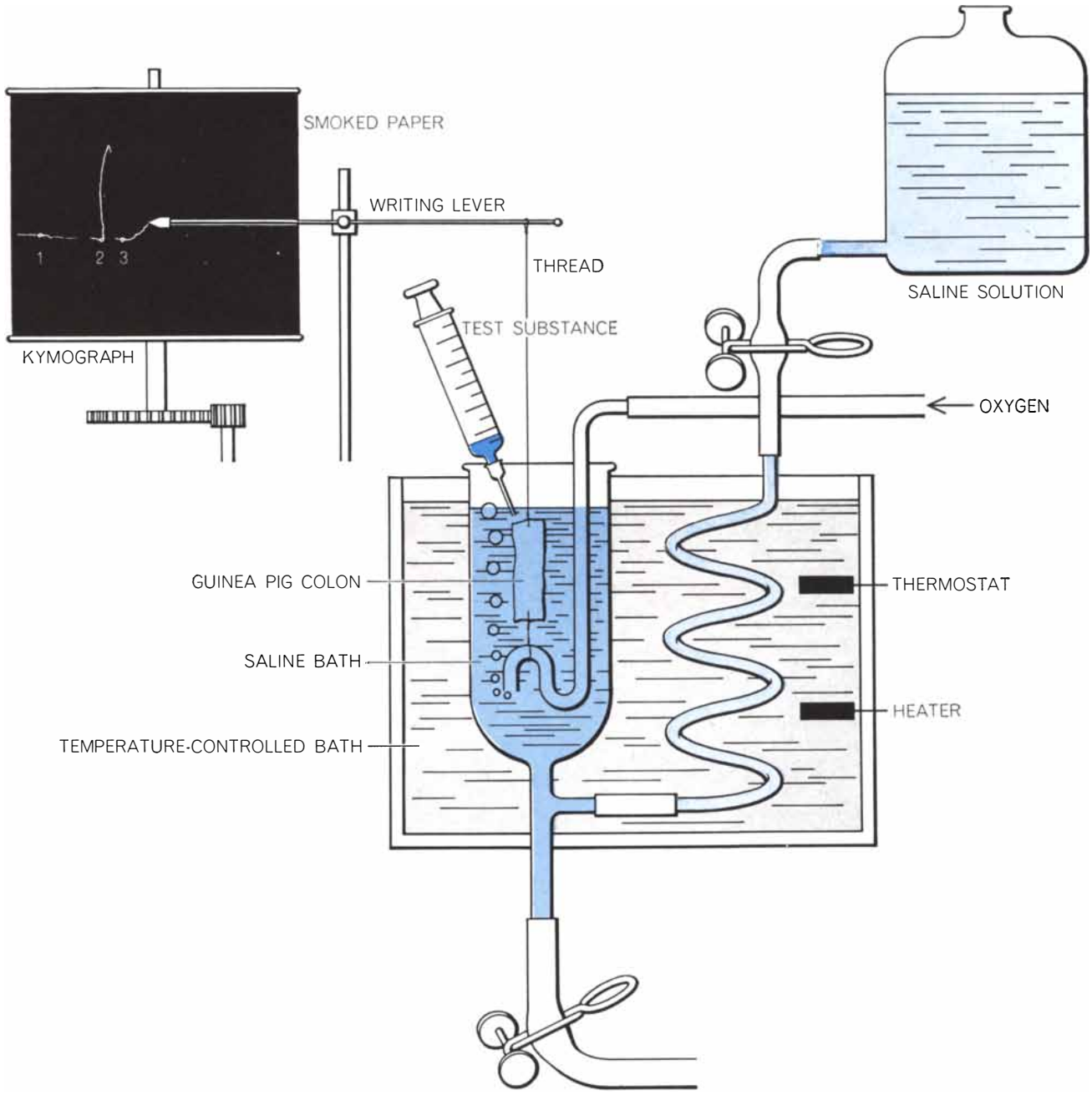


KININ RELEASE AND INHIBITION can occur rapidly in the blood in response to local requirements. Release of kallidin II is a two-step process. Blood contains a protein (*a*) that is a precursor of kallikrein. When kallikrein is released or activated (*b*), it chops a short peptide fragment, kallidin II, from one of the large globular proteins, alpha-two globulin (*c*). The blood also contains an inhibitor for kallikrein (*d*). Another enzyme, aminopeptidase, can remove lysine from kallidin II, producing kallidin I (*e*). Finally, kallidin I can be inactivated by carboxypeptidase, an enzyme that removes arginine (*f*).

pure bradykinin was injected into an artery in the arm of a healthy volunteer. For a short period after the injection blood flowed through the forearm more than six times faster than before.

Kinins can also dilate the capillaries to the point where they become leaky. This can be shown by injecting a dye such as Pontamine blue into a vein of a guinea pig. Normally the dye circulates in the blood without passing out into the tissues, but if a kinin is injected into the skin, a blue patch quickly appears because the capillaries become permeable to the dye. Such an increase in the leakiness of capillary walls is the direct cause of wealing in response to injury. A like effect is seen after the injection of histamine, but kinins are more potent.

Another characteristic of kinins is that they cause pain in human skin. C. A. Keele and his colleagues at Middlesex Hospital in London first showed this by a handy method. A small cantharidin plaster is left on the surface of the skin overnight and raises a blister. The loose skin over the blister is cut away and substances to be tested for their ability to cause pain are applied in dilute solution to the raw surface underneath. The subject presses on a rubber bulb with a force corresponding to the intensity of



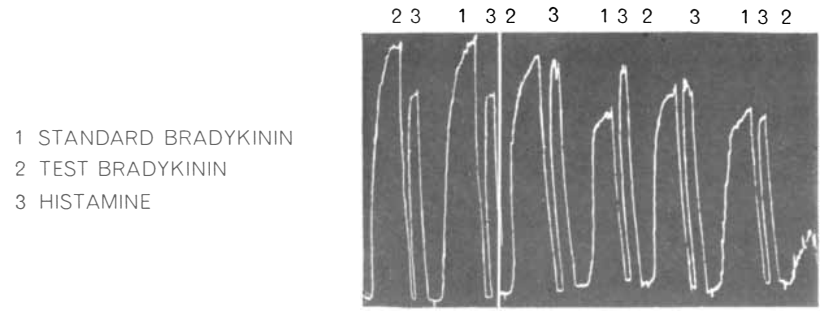
BIOLOGICAL ASSAY METHOD is the type used in 1937 by the discoverers of kallidin: E. Werle, W. Götze and A. Keppler of the Düsseldorf Academy of Medicine. They observed the reaction of a section of guinea pig colon suspended in a saline bath. Movement of the colon was recorded by a kymograph. When an extract of salivary gland was added to the bath, there was no response (*trace 1*). When the gland extract was mixed with human serum, the colon segment contracted sharply (*2*). When the mixture was left standing six minutes, the response was slight (*3*), showing that the active substance, later named kallidin, was being inactivated.

pain felt, and this pressure is transmitted to a pen writing on moving paper. By this method the Middlesex workers showed that blood plasma and fluids exuding into inflamed or injured tissues can yield a pain-producing substance. This is probably kallidin. They also found that weak solutions of acetylcholine, of serotonin and of several peptides, including bradykinin, cause pain. Needless to say, wasp kinin is also a potent pain provoker.

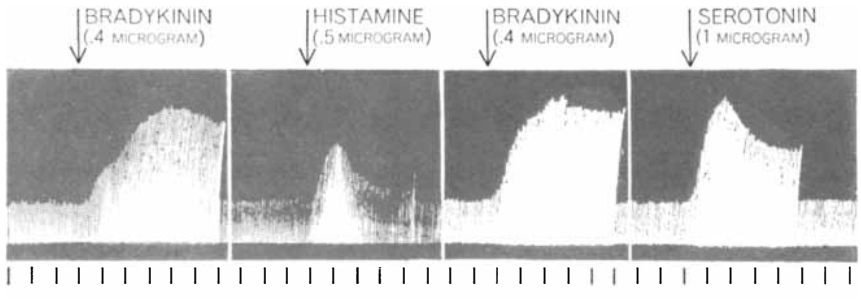
Most of the biological actions of kinins parallel those of histamine. But tests with pure bradykinin show that, molecule for molecule, it is a much more potent substance. The table on the next page lists a number of biological preparations together with the dose of bradykinin needed to evoke a response. One can see that for a sensitive tissue such as rat uterus, bradykinin is effective at a concentration of .1 nanogram (one-tenth of a billionth of a gram) per milliliter of solution.

So far kinins have shown one characteristic interaction with drugs. Aspirin, phenylbutazone, amidopyrine and phenazone, which belong to the group of agents variously described as analgesic-antipyretic, antirheumatic and anti-inflammatory, potently suppress the constriction of bronchioles that bradykinin evokes in guinea pigs. This action is selective, since the same drugs do not affect the constriction due to histamine, serotonin or acetylcholine [*see bottom illustration at right*]. Such studies are providing a clue to the mode of action of aspirin, which has so long remained a mystery. When we first observed this drug antagonism in the pharmacological laboratory of Parke, Davis & Co. in England, we thought it might explain in a simple way both what kinin does in the body and how these anti-inflammatory drugs act. Unfortunately our hopes of a simple explanation have been disappointed, because the drugs did not selectively antagonize other actions of kinins in experimental animals or in isolated organs.

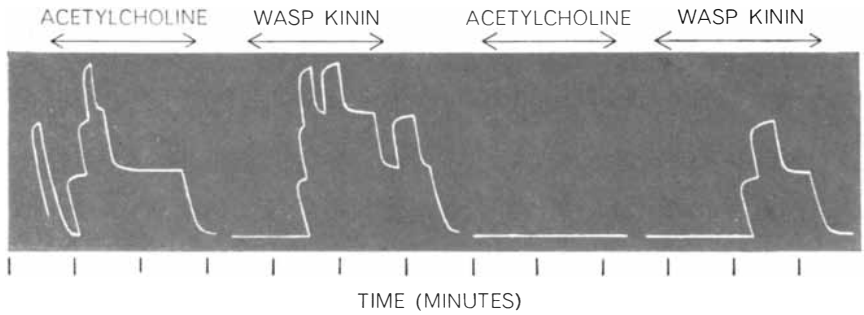
What research has revealed so far about kinins can be summarized in a paragraph. Applied at appropriate sites, these peptides cause pain, wealing, dilation of blood vessels and movement of smooth muscle. Within the body they are released as local hormones, where needed, when kallikrein circulating in the bloodstream is activated locally by the appropriate enzyme. Kinins can also enter the body in the venom injected by certain insects. Mechanisms that inacti-



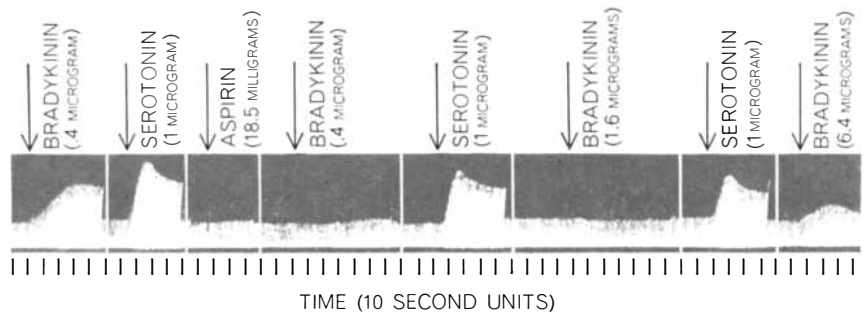
EFFECT OF BRADYKININ on isolated guinea pig intestine is compared with faster acting histamine. This kymograph trace was made by M. Rocha e Silva, W. T. Beraldo and G. Rosenfeld of the University of São Paulo, who discovered bradykinin in 1948. They found that the substance was released from dog's blood by the venom of a certain snake.



CONSTRICTION OF BRONCHIOLES in the lungs of a guinea pig is evoked by bradykinin, histamine and serotonin, administered intravenously. The constriction is measured by resistance of lungs to inflation, shown by height of trace. Experiment was performed by J. A. Holgate, M. Schachter, P. G. Shorley and the author at Parke, Davis & Co. in London.



RECORDS OF PAIN were made by a volunteer who pressed a series of switches indicating the intensity of pain produced by acetylcholine and wasp kinin, applied to an exposed blister base on his forearm. The first two test solutions contained one milligram per milliliter of active substance. The last two were only one-tenth as concentrated. Study was conducted by D. J. Holdstock, A. P. Mathias and Schachter at University College London.



EFFECTIVENESS OF ASPIRIN in suppressing the action of bradykinin and serotonin is determined by measuring resistance of guinea pig lungs to inflation. First two traces show normal rise in resistance after intravenous injection of the two substances. Aspirin is then injected intraperitoneally. Four minutes later bradykinin is again injected, followed by two injections of serotonin and two more larger doses of bradykinin. Aspirin suppresses action of bradykinin but not of serotonin. The study was made by the author and associates.

vate kinins exist in the blood and elsewhere. Kinins resemble some other physiological substances in action or in mechanism of release. For example, they are like histamine in many of their effects on living tissue; kallidin resembles fibrin in how it is produced and destroyed. Finally, anti-inflammatory drugs specifically antagonize kinins in their bronchiole-constricting action in guinea pigs.

Obviously there is much to be learned about the full role of the kinins as they come and go in blood and tissue fluids. Nonetheless, two minor parts played by these peptides can be discerned, and several reasonable suggestions have been made as to their major roles.

One minor part is that played by the kinins in wasp venom. Here they keep company with other pain substances, all of which are amply enough concentrated to hurt when injected into skin. Wasps and hornets display warning coloration, which may be expected to protect them, provided the warning is occasionally reinforced by a sharp pain. Although the individual insect that inflicts this pain may perish, most members of the species are thereby more likely to escape molestation.

More complicated is the possible role of kallikrein and kallidin in the mammalian body. So far only one part that they play has been elucidated. This is in the rare disease hereditary angioedema. People with this disease are subject to localized swellings in skin, muscle, larynx or digestive tract, which are transitory but liable to recur. These swellings are caused by fluid passing from the blood into the tissues, usually at places where pressure has been applied or a blow has been received. If the larynx is involved, there is danger that the passage of air will be blocked.

In 1960 N. S. Landerman, E. L. Becker and H. E. Ratcliffe of Walter Reed Army Hospital showed that the serum of a patient with this disease increased the permeability of blood capillaries more than normal serum did, when each was diluted in order to activate kallikrein and then was injected into the patient's own skin. They attributed this effect to an unknown factor in the patient's serum, which they and M. E. Webster have recently identified as the inherited lack of a natural kallikrein inhibitor. In short, hereditary angioedema results from an inborn defect in the mechanism of kallidin release.

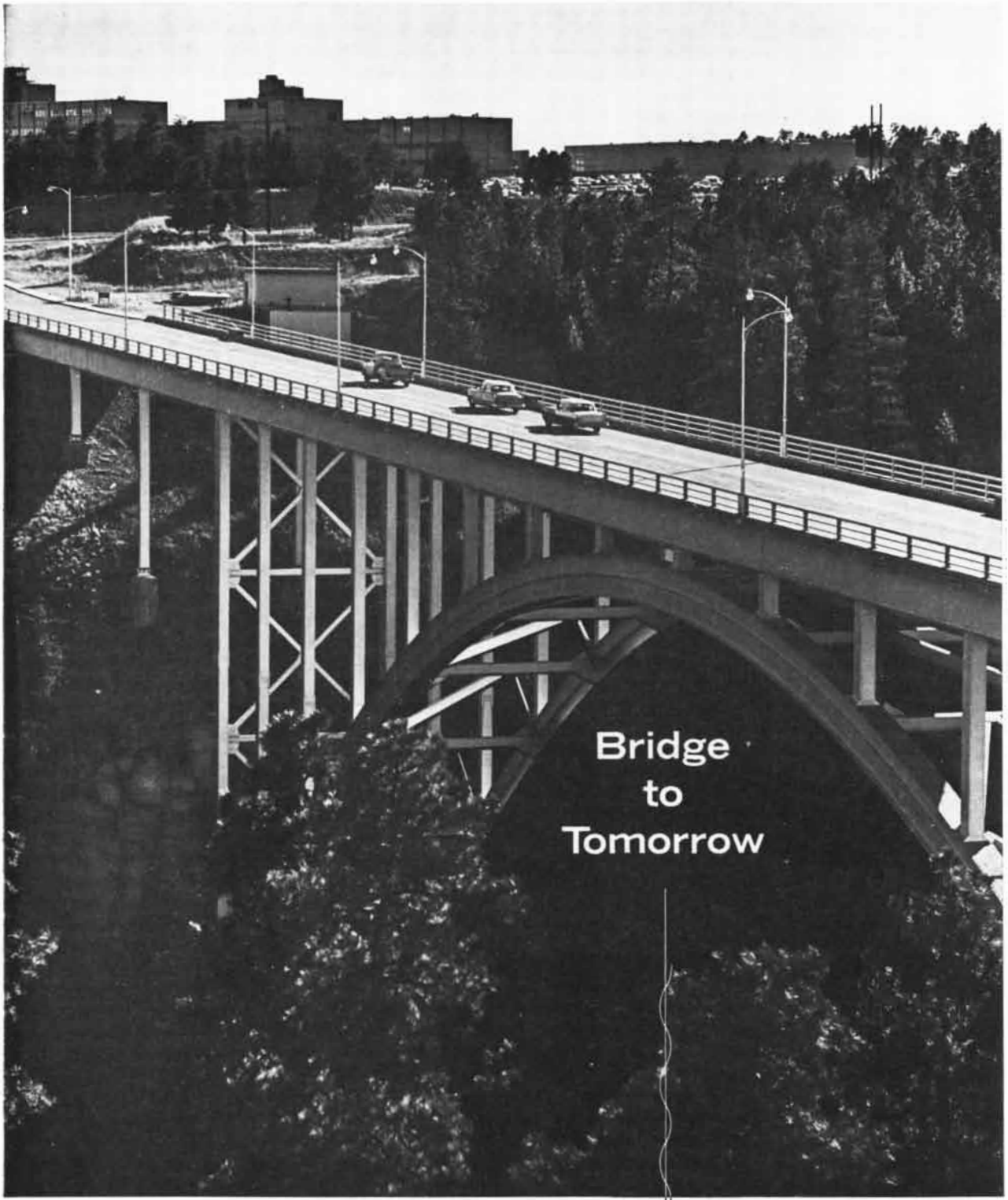
TEST OBJECT	ACTION	DOSE OR CONCENTRATION
 ISOLATED RAT UTERUS	SMOOTH-MUSCLE CONTRACTION	.1 NANOGRAM PER MILLILITER
 ISOLATED RAT DUODENUM	SMOOTH-MUSCLE RELAXATION	.8 NANOGRAM PER MILLILITER
 WHOLE GUINEA PIG	CONSTRICTION OF BRONCHIOLES	.5 MICROGRAM PER KILOGRAM (INTRAVENOUS)
 HUMAN FOREARM	DILATION OF BLOOD VESSELS	100 NANOGRAMS (INTRA-ARTERIAL)
 WHOLE CAT	LOWERED BLOOD PRESSURE	400 NANOGRAMS PER KILOGRAM (INTRAVENOUS)
 GUINEA PIG SKIN	INCREASED CAPILLARY PERMEABILITY	.1 TO 1 NANOGRAM (INTRADERMAL)
 HUMAN BLISTER BASE	PAIN	.1 TO 1 MICROGRAM PER MILLILITER

POTENCY OF PURE BRADYKININ is shown by the extremely small dosages or highly dilute concentrations needed to evoke its principal effects in a variety of test objects.

Apart from these two instances, the roles of the kinins remain uncertain. Some biologists have suggested that release of kallidin provides a way of increasing blood supply to parts of the body that need it, such as muscles or glands that are working hard or regions in which circulation is blocked. Another suggestion is that kallidin is released in allergic states such as asthma and urticaria, in which it contributes to some of the symptoms. A third hypothesis, which the work on angioedema makes particularly plausible, is that kallidin plays a part in the blistering or swelling of skin that commonly follows burns, blows or infections by microbes. The swelling arises from an increase in the leakiness of capillary blood vessels. This probably helps to combat injury by allowing protective antibodies (which are large molecules) and white cells (which are many times larger) to pass from the blood into the affected tissue.

Kallidin has the actions needed to fulfill these roles, and the mechanism for its release exists. The probability that it actually takes part is increased by the recent demonstration that kallikrein is activated during the natural event. Even so, it is still hard to prove that kallidin is essential, because a similar mechanism, such as the release of histamine, might work in parallel. In some important reactions the body has more than one means of achieving the required effect—like a man wearing both a belt and suspenders to keep his pants up. In this situation it is hard to say which is the essential device.

Research workers would be helped in getting the evidence needed to make the role of kallidin clear if they had drugs that more potently and specifically stopped its being inactivated in the body and others that antagonized its main biological actions. Meanwhile speculation on the possible role of kinins is a useful step toward finding the end of the main thread.



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MATHEMATICAL GAMES

A variety of diverting tricks collected at a fictitious convention of magicians

by Martin Gardner

Every summer, usually in July, several thousand members of the imaginary Brotherhood of American Magicians descend on a Middle Western hotel for their annual convention. This year it was the Sherman Hotel, at the northwest corner of Chicago's Loop. For three days and nights the hotel lobby was a phantasmagoria of riffling cards, clicking coins, cut and restored ropes, fluttering doves, vanishing bird cages and even one or two levitated ladies.

I attended the conclave partly because magic is my principal hobby, partly in search of offbeat material for this department. Many professional mathematicians are amateur conjurers and many conjurers have a lively interest in mathematics. The result is mathemagic, surely the most colorful of all the branches of recreational mathematics.

On the mezzanine floor about 20 magic dealers had set up booths for the purpose of hawking their wares. I paused in front of the booth where the Great Jasper (a Chicago magic dealer who performs under that name) was demonstrating a large-sized version of what magicians call "tumble rings." Thirty steel rings are linked together in the curious manner shown in the illustration on page 122. To operate the tumble rings, first hold the top ring of the chain in the left hand. Directly below the top ring is a pair of rings. With the right thumb and index finger take the *back* of the ring on the right exactly as shown in the illustration. When the ring held in the left hand is released, it appears to tumble from ring to ring all the way down the chain, finally linking itself to the bottom ring.

To repeat the effect, hold what is now the top ring in the right hand. With the left thumb and index finger hold the *front* of the ring on the left of the pair that links through the top ring. When the top ring held in the right hand is released, it tumbles down the chain as before.

"Do you suppose any of my readers could make a set of these rings?" I asked.

"Why not?" said Jasper. "Five-and-ten-cent stores sell steel key rings four for a dime. With 30 key rings and a strong thumbnail you can make a set of tumble rings in about 20 minutes. But don't tell any of the other dealers I said so."

Jasper was right. Key rings of the familiar coiled type make excellent tumble rings. To save your thumbnail, use a nail file to pry open the ends of the coils. A twist of the blade will keep a ring open until another ring can be slipped into the gap. The least confusing procedure is to start with the top ring, hanging it on a projection, then work down ring by ring, following the illustration. The rings tumble smoothly, with a pleasant clicking rhythm, unless you have made a mistake in the linkage.

While Jasper and I were chatting, Fitch Cheney, a mathematician at the University of Hartford, came over and joined us. "If you're interested in linkage effects," he said to me, "I've invented a new one that might be of interest to your readers."

From his pocket Cheney pulled a long piece of soft rope. Jasper and I each took an end, then with the index finger of our free hands we bent the rope into the shape shown at *a* in the illustration on page 125. Cheney tied a silk handkerchief tightly around the rope by making a single knot as shown at *b*. Both ends of the handkerchief were then tucked down through a loop, as indicated by the arrows, and the ends were tied twice below the rope to make a secure square knot [*c*].

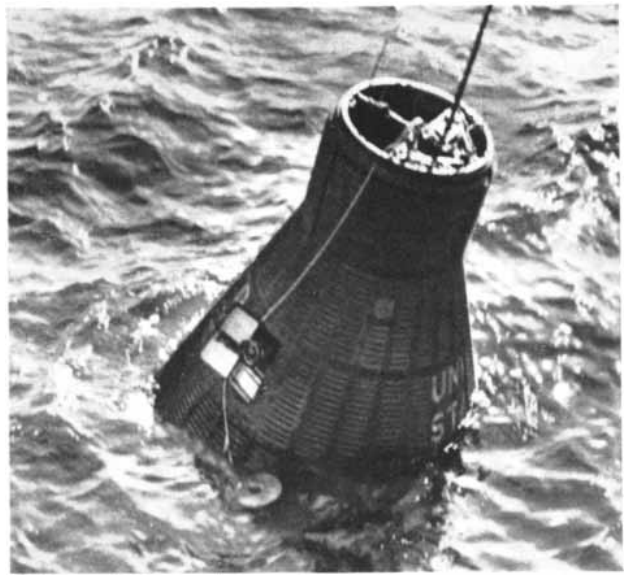
"Please release the loops you are holding with your index fingers," Cheney said, "and remove all the slack from the rope by pulling it straight." We did so, with the result shown at *d*. Cheney rotated the knotted silk 180 degrees to bring the square knot to the top.

"It's a strange thing," he said. "Although that handkerchief has been knot-

IBM asks basic questions in space

Where will it be next?

This plotting board, driven by an IBM computer, tells PROJECT MERCURY control personnel the exact location of the MERCURY spacecraft at any time in its orbit.



Throughout each orbital flight, the PROJECT MERCURY Control System continuously predicts the point where the MERCURY spacecraft will eventually return to earth.

Manned satellite tracking requires up-to-the-second information. To tell us where a MERCURY spacecraft is now and where we should look for it next, an IBM computer system at the NASA-Goddard Space Flight Center has been linked to ground tracking stations. This system connects sensors, real-time communications channels, data processors, and displays into an information network. It transforms data from space into continuous predictions of flight—from launching, through orbit, to impact.

Space information systems must squeeze thousands of complex computations into split seconds. To reduce computation time requirements, IBM engineers are investigating the application of advanced computing techniques—such as associative memory and auxiliary storage of precalculated data—to space systems. To enable tracking systems to operate in real time, they have developed special communications channels for PROJECT MERCURY and other projects, speeding data into central computers and back to tracking stations around the world. In another area, under contract to the Radio Division of the Bendix Corporation, IBM has designed a data processing system for real-time control of an Electronically-Steerable Array Radar (ESAR). This new approach to handling data in radar systems makes it possible to switch the direction of radar beams with far greater speed than was possible by using mechanical methods—so that one radar can track many satellites and space vehicles simultaneously.

Tracking systems will improve as we learn more about space. Present atmospheric models are static. Their failure to reflect the ebb and flow in the density of the air forces us to approximate orbital permutations due to atmospheric drag. By feeding data from satellites traveling through the atmosphere into an IBM 7090 computer at the Smithsonian Astrophysical Laboratory, IBM scientists are plotting air density as a function of deceleration. The dynamic atmospheric model which emerges from their work will make predictions of space flight in the region lying between 50 and several hundred miles from earth more accurate . . . an important step toward the precise control needed for the space systems of the future.

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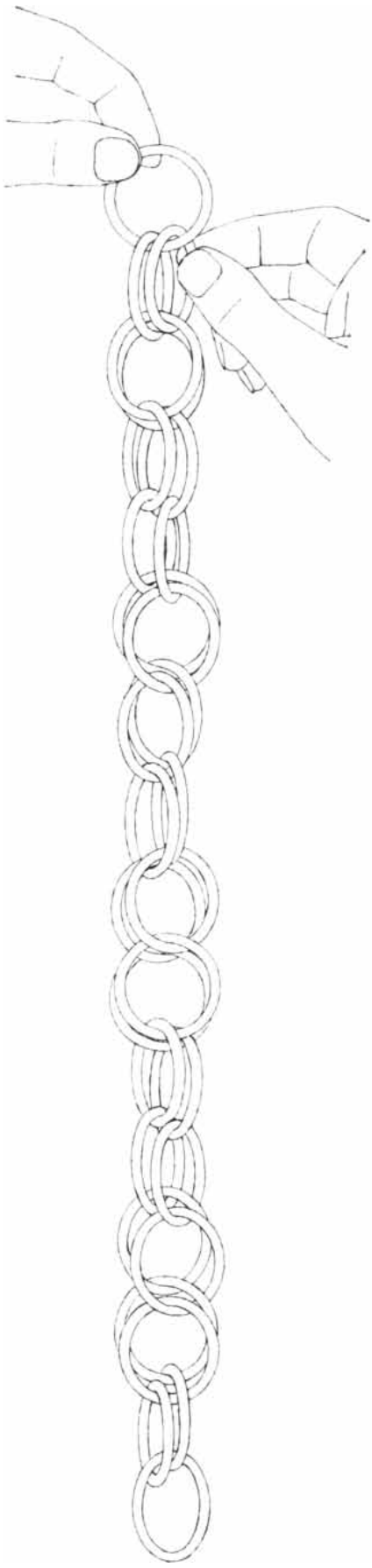


The tumble rings

ted tightly around the rope, the rope is now *outside* the closed curve formed by the cloth." He took hold of the knotted handkerchief, lifted it up and off the rope as shown at *e!* The effect is self-working if you follow the illustrations carefully.

The hotel's cocktail lounge before the dinner hour was noisy with prestidigitators. At the bar I ran into my old friend "Bet a Nickel" Nick, a blackjack dealer from Las Vegas who likes to keep up with the latest in card magic. The nickname derives from his habit of perpetually making five-cent bets on peculiar propositions. Everybody knows his bets have "catches" to them, but who cares about a nickel? It was worth five cents just to find out what he was up to.

"Any new bar bets, Nick?" I asked. "Particularly bets with probability angles?"

Nick slapped a dime on the counter beside his glass of beer. "If I hold this dime several inches above the top of the bar and drop it, chances are one-half it falls heads, one-half it falls tails, right?"

"Right," I said.

"Betcha a nickel," said Nick, "it lands on its *edge* and stays there."

"O.K.," I said.

Nick dunked the dime in his beer, placed it against the side of his glass and let it go. It slid down the straight side, landed on its edge and stayed on its edge, held to the glass by the beer's adhesion. I handed Nick a nickel. Everybody laughed.

Someone in the crowd took a small plastic top from his pocket. "Have you seen these 'tippy tops' that the dealers are selling? I'll bet you a nickel that if you spin it, it will turn upside down and spin on the tip of its pin."

"No bet," said Nick. "I bought a tippy top myself. But I'll tell you what I'll do. You spin the top clockwise. I'll bet *you* a nickel you can't tell me now in what direction it will be spinning after it flips over."

The man with the top pursed his lips and mumbled: "Let's see. It goes clockwise. When it turns over, it will have to keep spinning the same way. Obviously it can't stop spinning and start again in the other direction. But if the ends of its axis are reversed, the spin will be reversed when you look down on the top. In other words, after the top flips over it should be spinning counterclockwise."

He gave the top a vigorous clockwise spin. In a moment it turned upside down. To everybody's vast astonishment *it was still spinning clockwise when one looked down on it.* If the reader will buy a tippy top (they are sold in many dime stores and toy shops), he will discover that this is indeed what happens. As a particle physicist might say, the top actually alters its parity as it turns over. It becomes its own antitop or mirror image!

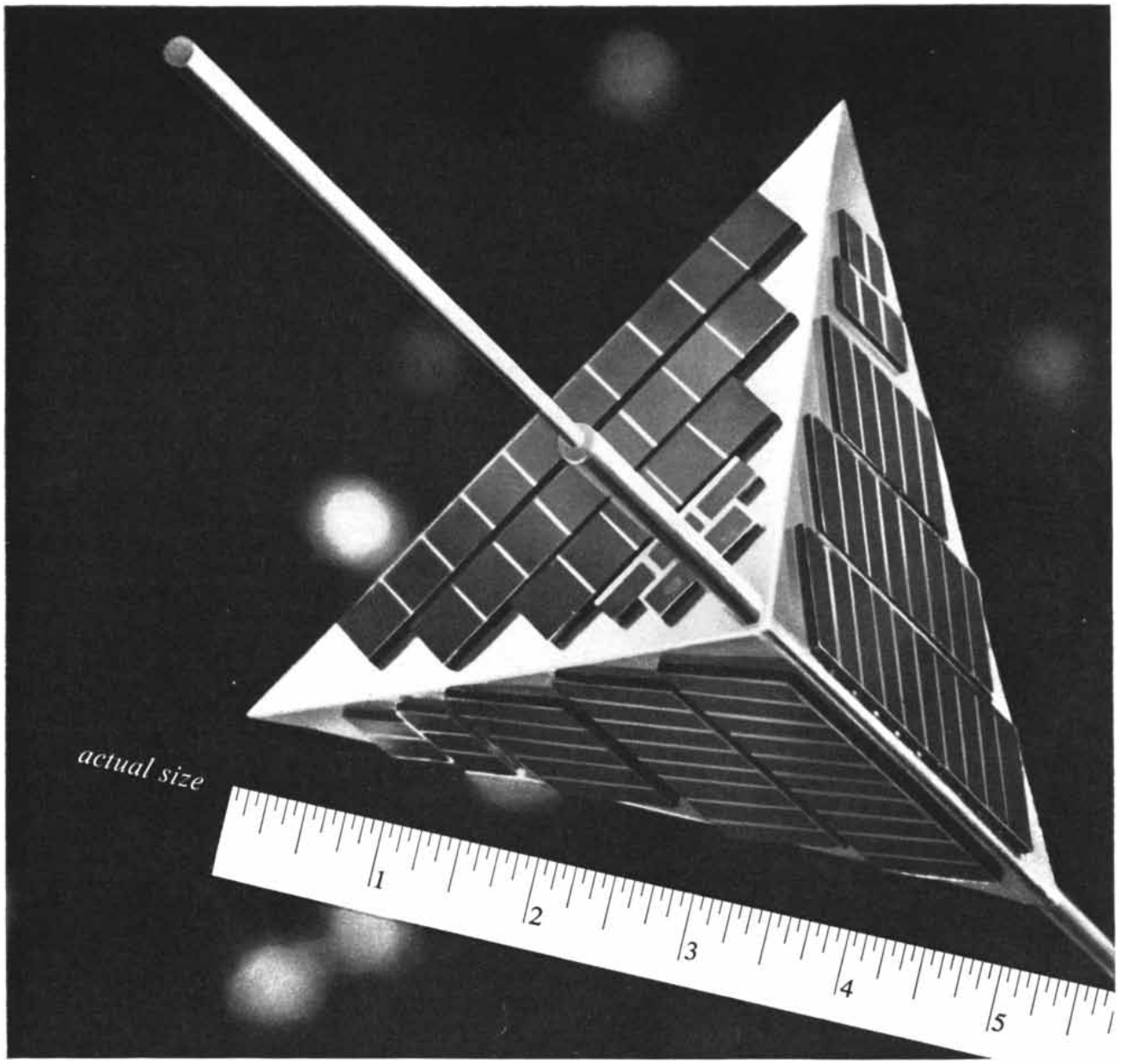
After the banquet and evening show, conventioners clustered in various hotel rooms to gossip, swap secrets and talk magic. I finally located the room in which the mathemagicians were in session. A friend from Winnipeg, Mel Stover, was explaining how the binary system could be applied to a familiar method of revealing a chosen card.

In many card tricks the selected card is disclosed when the spectator is handed a small packet of cards and asked to shift the top card to the bottom of the packet, deal the next card to the table, shift the next card to the bottom, deal the next to the table, and so on, until only one card remains. It proves to be the selected card. At what position in the packet must this card originally be placed so that it will become the last card? The position will vary, of course, with the number of cards in the packet. It can be determined by experiment, but for large packets experimenting is tedious. Fortunately, Stover explained, the binary system provides a simple answer.

This is how it is done. Express the number of cards in the binary system, shift the first digit to the end of the number, and the resulting binary number will indicate the position that the chosen card should be in from the top of the original packet. For example, suppose an entire deck of 52 cards is used. The binary expression for 52 is 110100. We move the first digit to the end: 101001. This new number is 41, therefore the chosen card must be the 41st card from the top of the deck.

What size packets can be used if we want the top card of the packet to be the card that remains? The binary number for the position of the top card is 1, so we must use packets with binary numbers of 10, 100, 1000, 10000... (in decimal notation packets of 2, 4, 8, 16... cards). If we want the *bottom* card of the packet to be the remaining card, then the binary numbers of the packets must be 11, 111, 1111, 11111... (or 3, 7, 15, 31... cards).

Is it possible for the second card from the top of a packet to be the remaining card? No. In fact, no card at an *even* position from the top can ever be the remaining card. The position of the chosen card, expressed as a binary number, must end in 1 (because after the



The world's smallest satellite has been developed by Space Technology Laboratories. Its shape will be different from all other satellites before it. STL engineers and scientists have used a tetrahedral configuration to bring about some remarkable characteristics in a space vehicle. There will be no need for batteries nor regulators in flight. The satellite will have no hot side, no cold side. It will require no attitude control devices. No matter how it tumbles in space it will always turn one side toward the sun to absorb energy, and three sides away from the sun to cool instrumentation and telemetry equipment inside. It can perform isolated experiments in conjunction with other projects. Or it can be put into orbit by a small rocket to make studies of its own, up to five or more separate experiments on each mission it makes.

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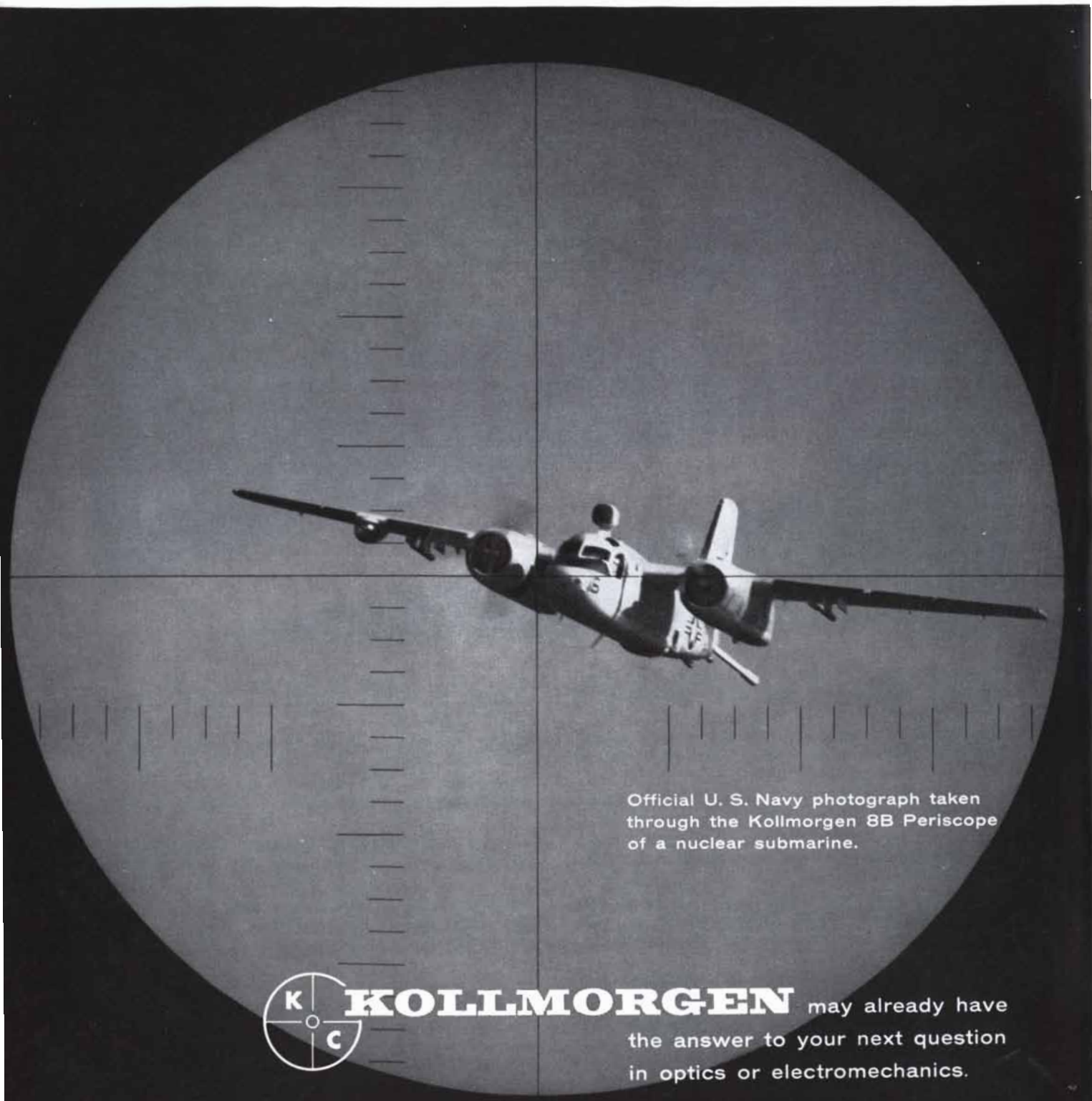
Q.

Who has the facts about looking things over from down under?

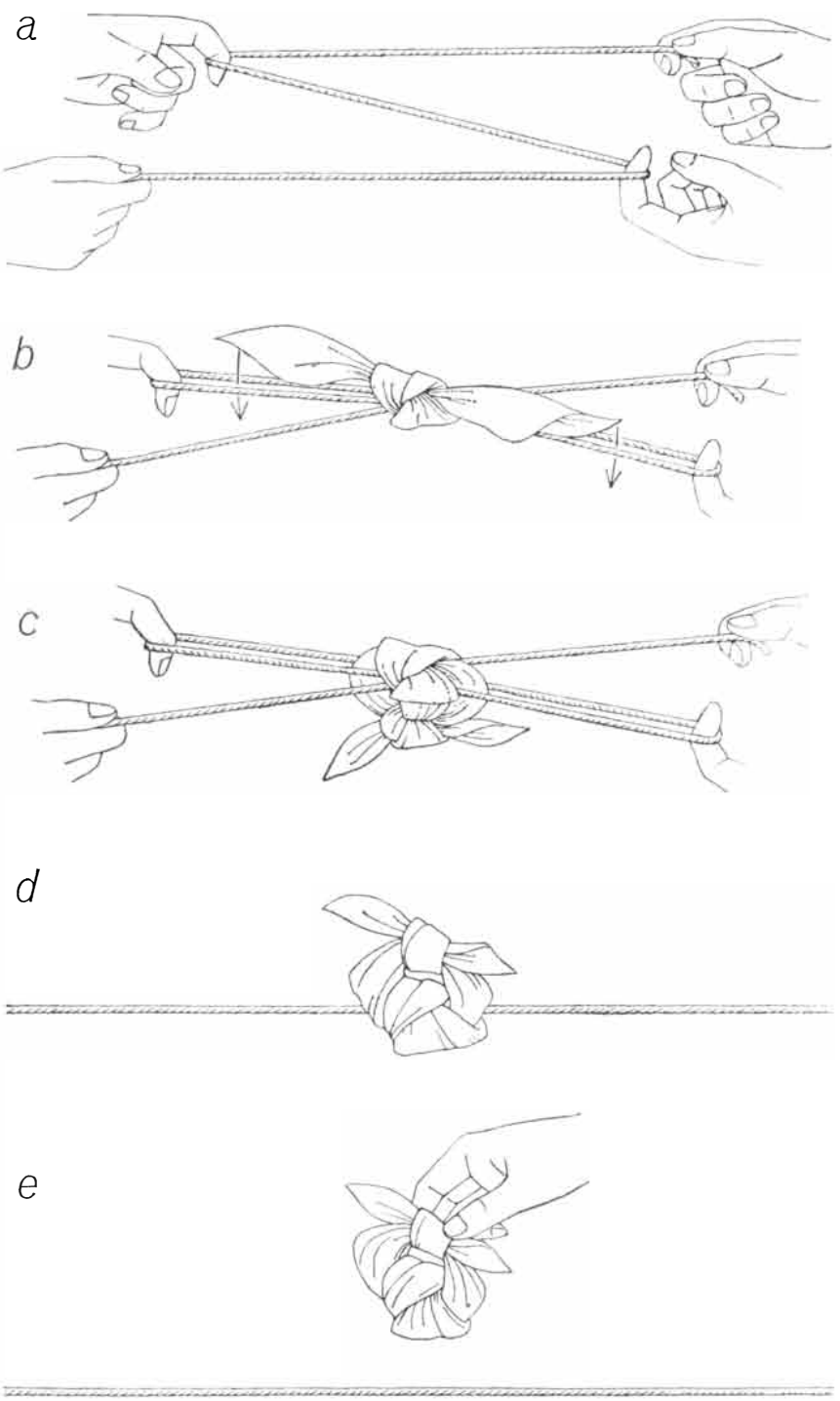


Official U. S. Navy photograph taken through the Kollmorgen 8B Periscope of a nuclear submarine.

KOLLMORGEN may already have the answer to your next question in optics or electromechanics.

first digit, which must be 1, is moved to the end it forms a number ending in 1). All binary numbers ending in 1 are *odd* numbers.

Victor Eigen (whose tricks were discussed in this department in August, 1960) took the floor to demonstrate a remarkable new card trick that involves the coding of information. "I want to explain in advance exactly what I intend to do," he said. "Anyone may shuffle his own deck of cards and from it select any five cards. From those five he must choose one. I am allowed to arrange the remaining four cards in any order I please. These four cards, squared into a packet, are to be taken to my hotel room by whoever selected the card. My wife is in the room, waiting to assist in the trick. The person carrying the packet will knock three times on the door, then push the packet of four cards, held face down, under the door. No words will be spoken by either person. My wife



Steps in performing Fitch Cheney's rope-and-handkerchief trick

will examine the packet and name the selected card."

I asked permission to do the selecting. The procedure was carried out exactly as Eigen had directed. I took five cards from my own deck and selected from them the six of spades. Eigen did not touch the cards. He wanted to rule out the possibility that he might mark them in some way and so provide additional information. Moreover, most cards have backs that vary in minute details when turned upside down. By taking advantage of these "one-way backs" (as magicians call them) it would be possible to arrange the cards in a pattern—some turned one way, some the other—that would convey a large amount of information. If the cards had been placed in a container of some sort, say an envelope, still more information could be coded. For example, the cards could be put in the envelope either face up or face down, the envelope could be sealed or left unsealed, and so on. Even the choice of a container or no container could convey information. It was to rule out all these possibilities that Eigen had described the procedure in advance and had been careful not to touch the cards in any way.

After I had arranged the four cards in an order specified by Eigen, I asked for his room number and was about to leave when Mel Stover spoke up. "Hold on a minute," he said. "How do we know that Eigen isn't sending information by the *time* he picks to send you to his room? By conversation he delays your leaving until the time is within a certain interval that is part of the code."

Eigen shook his head. "No time intervals are involved. If you like, wait awhile and let Gardner go whenever he wishes."

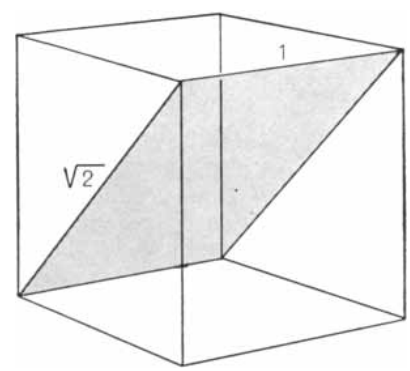
We delayed about 15 minutes, watching with awe while Ed Marlo, a Chicago card expert, showed how a flawless series of eight faro shuffles would bring a full pack back to its original order. A faro shuffle—in England it is called a weave shuffle—is a perfect riffle shuffle in which single cards alternate from left and right halves, each half containing 26 cards. If the first card to fall is from the former bottom half, it is called an out-shuffle. If the first card is from the former top half, it is an in-shuffle. Eight out-shuffles or 52 in-shuffles will restore the deck's original order. Only the most skillful card hustlers and magicians can execute such shuffles rapidly and without error. In recent years many articles analyzing the faro shuffle in the binary system have been published in both magic and mathematical journals. Ed Marlo has published two books about the shuffle and the brilliant mathematical card tricks that can be based on it.

After Marlo's demonstration I carried my packet of four cards to Eigen's room, knocked three times, pushed the face-down packet under the door. I heard footsteps. The packet was pulled out of sight. A moment later Mrs. Eigen's voice said: "Your card is the six of spades."

Exactly how did Eigen convey this information to her? He later explained his method, and I will pass it on in this department next month.

Last month's problem of slicing a cube to obtain a plane section of maximum area is answered as shown in the illustration below. The shaded section is a rectangle with an area of $\sqrt{2}$, or 1.41+. It is possible to slice a cube so that the section is a regular hexagon, but the area is only 1.29+. The largest hexagonal cross section is an irregular hexagon with an area of 21/16, or 1.31+.

The answer to the flatcar problem is that only one circle will roll over the flatworm. When there are n equally spaced circles and n is even, the number of circles that roll over a flatworm placed anywhere on the track (except at spots where a circle goes directly on the worm) is $n/2$. When n is odd, the situation is more complex. The track ahead of the front circle must be divided into segments that are each equal in length to the spacing between two adjacent circles. A worm on any alternate segment, beginning with the segment immediately ahead of the front circle, will be run over by $n/2 + 1/2$ circles. A worm on any of the other alternate segments will be run over by $n/2 - 1/2$ circles. Again, one assumes that the worm is not at a spot where a circle is placed directly on top of it; or, as the mathematician would say, one ignores "boundary conditions."



Answer to last month's cube problem

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THE AMATEUR SCIENTIST

How streams of water can be used to create analogues of electronic tubes and circuits

Conducted by C. L. Stong

Experimenters and physics teachers traditionally use mechanical models as aids in making abstract concepts concrete. Direct electric current, for example, is often seen in the mind's eye as water flowing through a pipe. Alternating current can similarly be visualized as the cyclic flow of water in a loop of pipe attached to a cylinder fitted with a double-acting piston. Few experimenters or teachers actually reduce such analogies to hardware. Even fewer develop analogues in the absence of an immediate need. Why fiddle away time on purposeless gadgets, real or fancied? One interesting reason is suggested by the experience of Murray O. Meetze, Jr., a high school student in Heath Springs, S.C.

Meetze set out to devise an improved analogue of the triode vacuum tube. Although triodes have no moving parts, all triode analogues he had encountered (or that have come to my attention) consist of assemblages of motor-driven pumps, valves, tanks and pipes, or of such imaginary arrangements as air guns that shoot pellets at fluttering Venetian blinds. Meetze sought a working model in which nothing moved except a fluid representing the electric current. He not only designed and built such a model but also used it in a series of experiments that led to the construction of a fluid diode, a fluid oscillator and a variety of hydraulic "circuits," including one that has no electronic counterpart. As a result he was invited to the National Science Fair, held this year at the Seattle Century 21 Exposition. There his project won an award.

Meetze writes: "A substantial number of pure fluid amplifiers have been devised. Most of them consist of channels or holes in blocks of metal, plastic or ceramic, depending on the application. The technology of designing pure hydraulic circuits was announced a few years ago by the Army's Diamond Ordnance Fuze Laboratories, but most of the work is classified. To qualify as a pure fluid device a design must have no moving parts. The hydraulic ram does not qualify, because it requires a pair of flap or ball valves, nor does the automatic clothes washer, because its cycles are governed by valves actuated by electric or hydraulic motors. The active elements of my circuits consist of nozzles and the passive elements of tubes and chambers. The pure fluid analogue of the triode vacuum tube, for example, is an arrangement of three nozzles. A jet of water issuing under a head of pressure from one nozzle corresponds to the evaporation of electrons from a heated cathode; the pressure corresponds to the electric potential set up by the B battery. A second nozzle pointing toward the first nozzle receives the jet and corresponds to the plate of the triode. A third nozzle located in the plane of the first two but at right angles to the jet functions as the grid of the triode. In the absence of a jet from the control (grid) nozzle, water flows from the power (cathode) nozzle and enters the output (plate) nozzle. Because the nozzles are located in the same plane, a jet issuing from the control nozzle collides with the jet from the power nozzle and diverts it away from the output nozzle, thus interrupting the transfer of fluid between the power and output nozzles. This action is analogous to the effect of a negatively charged grid on the plate current of a vacuum tube. A pure fluid triode connected for operation as an oscillator is shown in the accompanying illustration [*top of opposite page*]. Here the conducting phase is at the left and the nonconducting phase at the right.

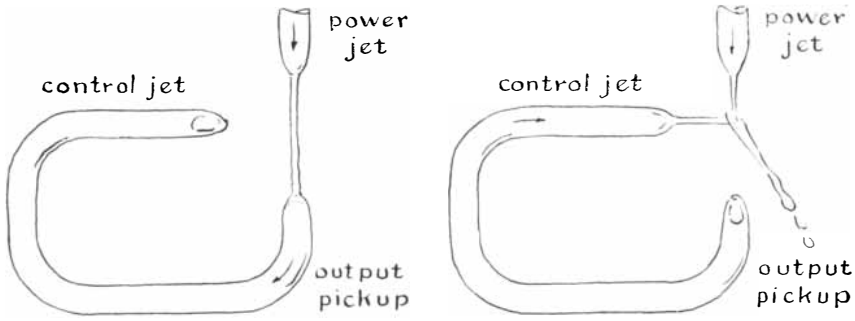
"The operation of a pure fluid oscillator is much easier to grasp than its electronic analogue. Water entering the power nozzle under pressure and flowing from it as a jet is received by the output nozzle and fed back through circuit tubing to the control nozzle. The resulting jet from the control nozzle momentarily deflects the power jet away from the output nozzle. The action is not instantaneous. Initially the control circuit is empty and a little time is needed for it to fill up. Even a full control tubing contains a few bubbles of air that must be compressed before the jet forms. The springiness of the bubbles corresponds to capacitance in the electrical analogue. In addition, the column of water in the control circuit has mass and is therefore characterized by inertia. The column cannot be instantaneously accelerated from rest to maximum velocity. The inertia corresponds to electrical inductance. As a result the power jet flows into the output jet for a finite interval and is then diverted for another finite interval, depending partly on the momentum of the control stream and partly on the energy stored in the compressed bubbles. The cycle is then repeated. The output consists of a series of unidirectional pulses, as does the output of a triode oscillator. I have not attempted to couple the oscillator to a 'tank' circuit for converting the unidirectional pulses into alternating flow. Such a tank might consist of a U-shaped tube. The output of the pure fluid oscillator would be fed into one arm of the U. Periodic pulses of incoming water would make water standing in the U tube oscillate at a frequency determined by the 'inductance' represented by the mass of the water column and the 'capacitance,' in this case represented by the force of gravity.

"When these experiments were first undertaken, I spent a lot of time trying to design completely enclosed systems. It seemed obvious that a jet of water could not possibly enter a facing nozzle without excessive splashing, particularly if it had to work against a head of pressure in the facing nozzle. One day I directed a small stream from one eyedropper nozzle into another nozzle about two inches away. The diameters of the nozzles were about equal. To my surprise

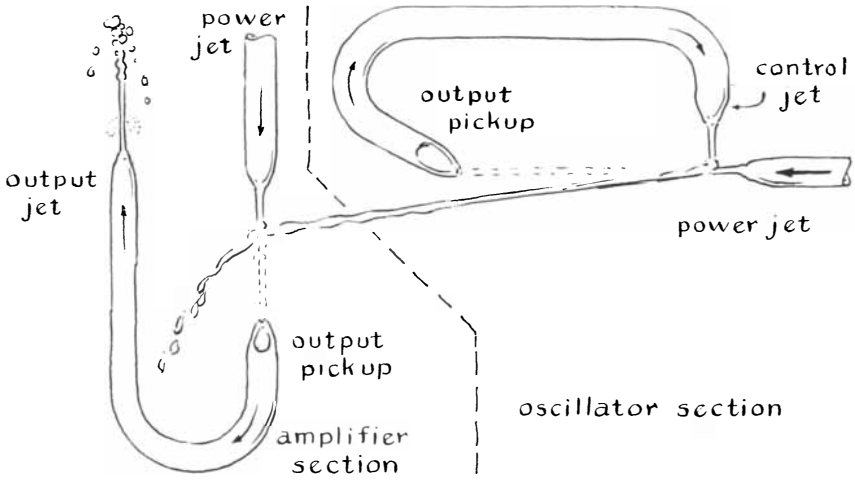
the arrangement worked about as efficiently as a closed system. When the stream is laminar, the jet narrows somewhat as it comes from a nozzle. Hence it readily enters an opening with the same diameter as that of the exit nozzle. On entering the second nozzle the jet is capable of building up a head of pressure because of its momentum. The disadvantage of using a receiving nozzle with a diameter smaller than that of the exit nozzle is obvious. On the other hand, pressure will not develop in a receiving nozzle so large that the jet simply splashes off the inner wall and runs out.

"I use the glass parts of eye droppers for nozzles, the kind without the little glass bulb at the dropping end. Pairs of nozzles with apertures of matching size could be made by softening a short length of glass tubing at the middle in a gas flame, removing the tubing from the flame and quickly pulling the ends apart. The narrow portion could then be nicked lightly with a three-edged file and broken to form two nozzles of identical diameter. I connect the nozzles into circuits by means of transparent plastic tubing and interconnect sections of tubing with copper L's, T's and straight couplings as required. These details are omitted in the accompanying illustrations. The nozzles and associated tubing can be mounted on any firm support, such as an apparatus stand or a vertical grid made of wooden dowels. The tubing can be wired to the supports, but clamps of the thumbscrew type make adjustment easier. Glass parts should be slipped into a sleeve of rubber tubing for protection at points where they are clamped. A basin equipped with a drain must be provided to catch the spent water. Any watertight box with low sides will do. The experimenter can make one of wood easily. Mine is made of sheet metal with soldered corners.

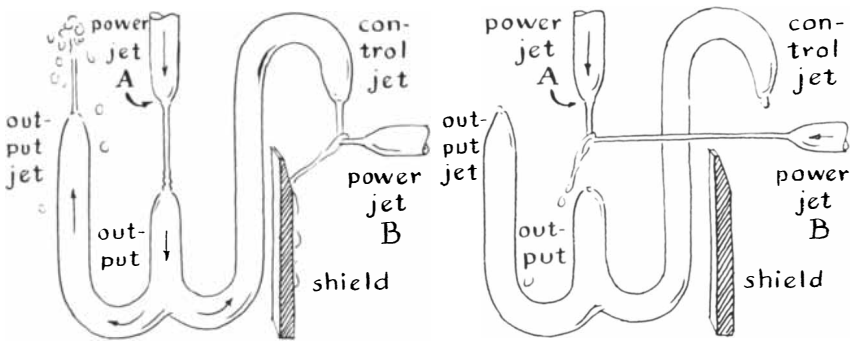
"In the course of experimenting with the oscillator I found that the deflected power stream could be used to control another power stream. Thus an oscillator operating from a source of low pressure can exert direct control over a second triode operating from an independent power supply, as shown in the accompanying illustration [*second from top at right*]. Amplification is observed if the pressure of the second power supply is higher than that which drives the oscillator. A pinchcock of the screw type installed on the tubing of the second power supply will function as a 'volume' control. The action of the oscillator is entirely independent of the am-



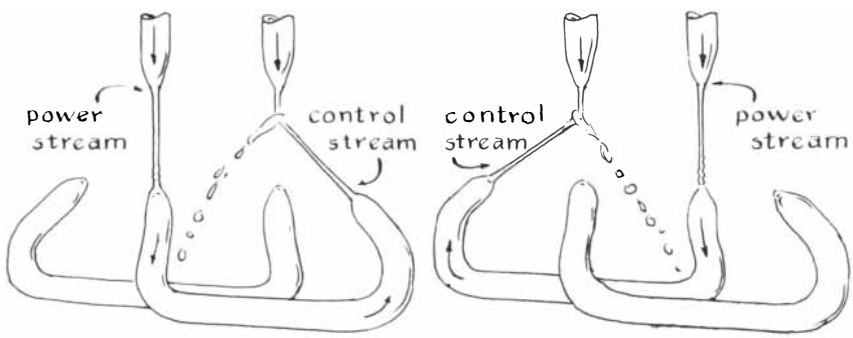
Pure fluid oscillator



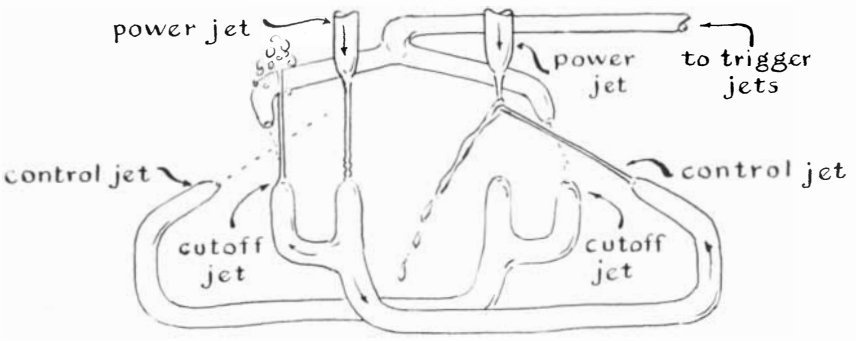
Pure fluid oscillator-amplifier



Asymmetrical flip-flop



Symmetrical flip-flop



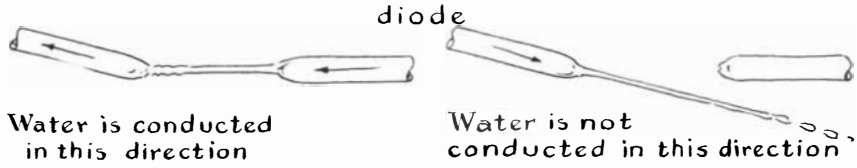
Positive-acting flip-flop

plifier. The frequency remains constant at all settings of the volume control.

"While experimenting with the oscillator-amplifier circuit in an attempt to make a hydraulic motor control itself, I hit on a bi-stable circuit, an analogue of the electronic 'flip-flop.' In one of the two stable states a power jet drives a control jet that deflects a second power jet against a shield, as shown at the left in the accompanying illustration [*third from top on preceding page*]. An output jet connected to the control circuit of the first power jet delivers output, in the form of a miniature fountain, as long as the circuit remains in this state. If you interrupt the first power jet, for instance by sticking your finger momentarily into the stream, the circuit flips to its alternate stable state. The second power jet deflects the first power jet from the control circuit. Interrupting the second power jet returns the circuit to its initial stable state. The switching intervals are approximately equal, although the circuit is asymmetrical.

"After learning that electronic flip-flops are symmetrical I undertook the development of a symmetrical analogue. This proved to be rather easy: it is simply a pair of triodes cross-connected so that the output of one controls the input of the other and vice versa [*see bottom illustration on preceding page*]. Observe that the control nozzles are directed upward toward the power jets from the same level as that of the output nozzles. This makes the circuit change state quickly when the operating power jet is interrupted, because water stands in the feedback tubes even when they are not conducting. The switching time can be increased (frequency lowered) by adding the analogue of capacitance to the control circuits. Just tip the feedback tubes so that the output nozzles are higher or lower than the control nozzles. The resulting bubbles in the control branches after each operating cycle will introduce delay.

"Both versions of the flip-flop were triggered, or flipped, by interrupting the power jet by hand. Electronic counterparts use a triggering circuit. My next series of experiments was aimed at developing a pure fluid analogue of the electronic trigger circuit. The problem appeared to be rather simple at first: a pair of triggering nozzles powered from a common source would be positioned so that jets of short duration could divert either the control jets or the power jets. The first triggering pulse would 'flip' the circuit for conduction by one stage; the following pulse would 'flop' conduction to the alternate stage. I decided to trigger the control jets. Experiment quickly showed that the problem was not so simple. At certain times the circuit flipped and at other times it remained in the initial state, depending on the duration of the triggering pulse. A sufficiently short pulse triggered a change in state every time. A long pulse would in effect trigger both the flip and the flop, because the twin jets of the trigger could divert either or both of the control jets. Positive action was provided



Pure fluid diode

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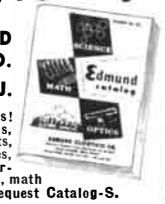

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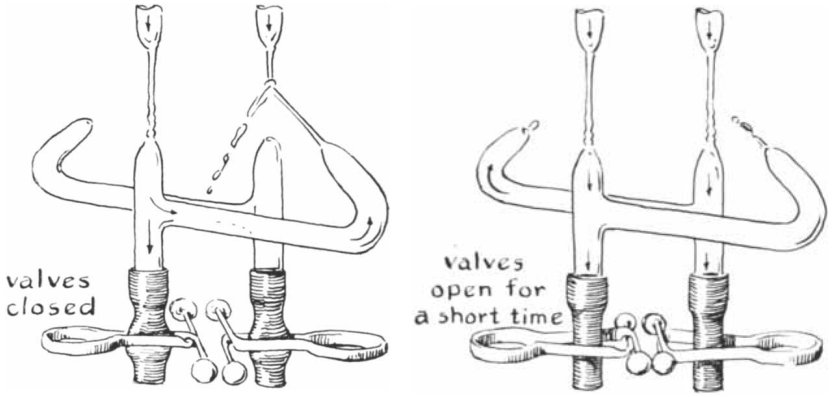
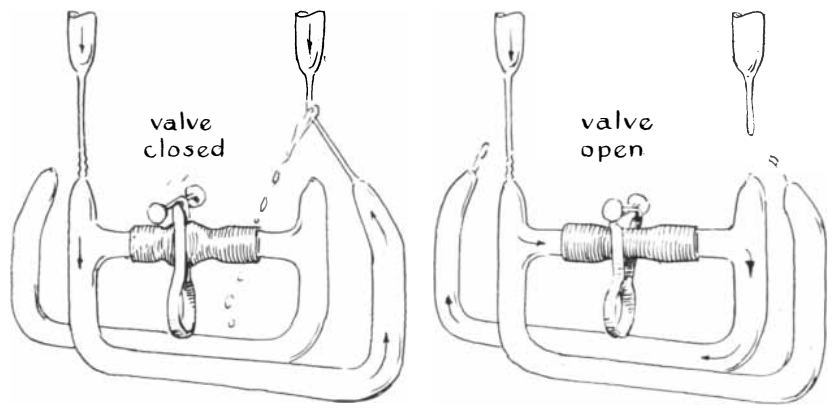


Negative-pulse flip-flop

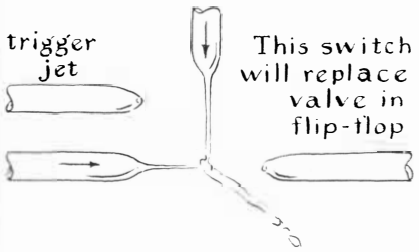
by a second pair of jets located between the triggering jets and their corresponding control jets. These can be thought of as cutoff jets. Their location is shown in the accompanying illustration [*top of page 130*]. The cutoff jets block the triggering pulse on the conducting side and prevent its twin from hampering the action of the 'off' control jet. Observe that the output pickup nozzles, the control and cutoff nozzles are located on a common level to prevent the circuits from draining in the flipping interval.

"One can construct a variety of flip-flops, some that require diodes as their electronic counterparts do. Although these are interesting both as analogies and as experiments, they do not operate more effectively than the circuits described earlier. Diodes are interesting and simple to construct, but the nozzles must be almost perfectly matched and aligned or they will not operate reliably. Diodes consist of two nozzles, one aimed directly toward the other and the second canted slightly. In the accompanying illustration [*bottom of page 130*] conduction is shown at the left and nonconduction at the right. The sensitivity of the circuit to adjustment can be lowered somewhat by flaring the canted nozzle so that the tip resembles a miniature funnel. The flaring can be done easily with the aid of a special tool. Remove the carbon rod from a size C flashlight battery, insert it into the chuck of an electric drill and, with the drill running, file the uncapped end of the carbon to a tapered point. Then soften the glass tip in a gas flame, remove the glass from the flame, quickly insert the carbon point into the opening of the nozzle and spin the glass between finger and thumb until it cools. With a bit of practice it is possible to produce a symmetrical flare about an eighth of an inch long with an outer diameter about twice that of the bore of the nozzle. By blowing a small bulb in one side of the flared nozzle it should be possible to make a pure fluid analogue of the variable-capacitance diode and set up a parametric oscillator.

"While examining electronic circuits closely I concluded that triggering involves a negative pulse: taking energy away from the circuit rather than add-



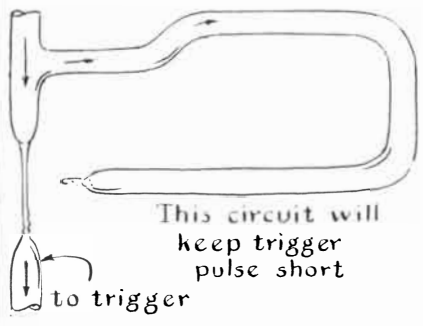
Single-trigger flip-flop



Pure fluid trigger

ing it. With this in mind I returned to the symmetrical bi-stable circuit and equipped the control feedbacks with drains in the form of pinchcocks placed so that they can be opened simultaneously, as shown in the accompanying illustration [*top of preceding page*]. Operating the pinchcocks reduces the pressure of the conducting control jet but has no effect on the nonconducting branch. (Incidentally, it will be observed that when conduction is initiated in a circuit, the first pulse from a nozzle is much more forceful than that of the steady stream. The effect is explained by the momentum gathered by the water as it rushes through an empty tube; it is analogous to inductive effects in electronic circuits that generate pulses of high voltage, such as 'kick' coils and induction coils.) The initial circuit operated well enough to demonstrate that I was on the right track. The device is highly sensitive to input pressure at the power jets, however, and tended to go into uncontrolled oscillation rather than to flip.

"A variation of the arrangement resulted in my most effective flip-flop. Two feedback drains are coupled through a single-trigger valve, or pinchcock [*see bottom illustration on preceding page*]. Opening the valve greatly decreases pressure at the presently conducting control jet, and the water drains into the presently nonconducting control jet. The 'off' power stream thereupon activates the 'off' control jet, completing the flip. The second operation of the valve re-



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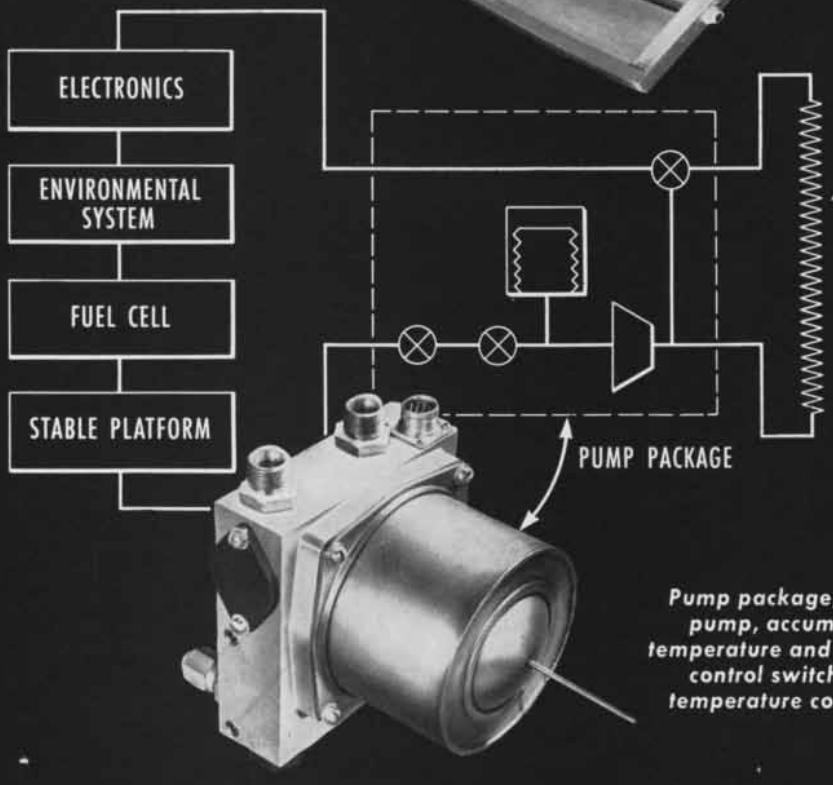

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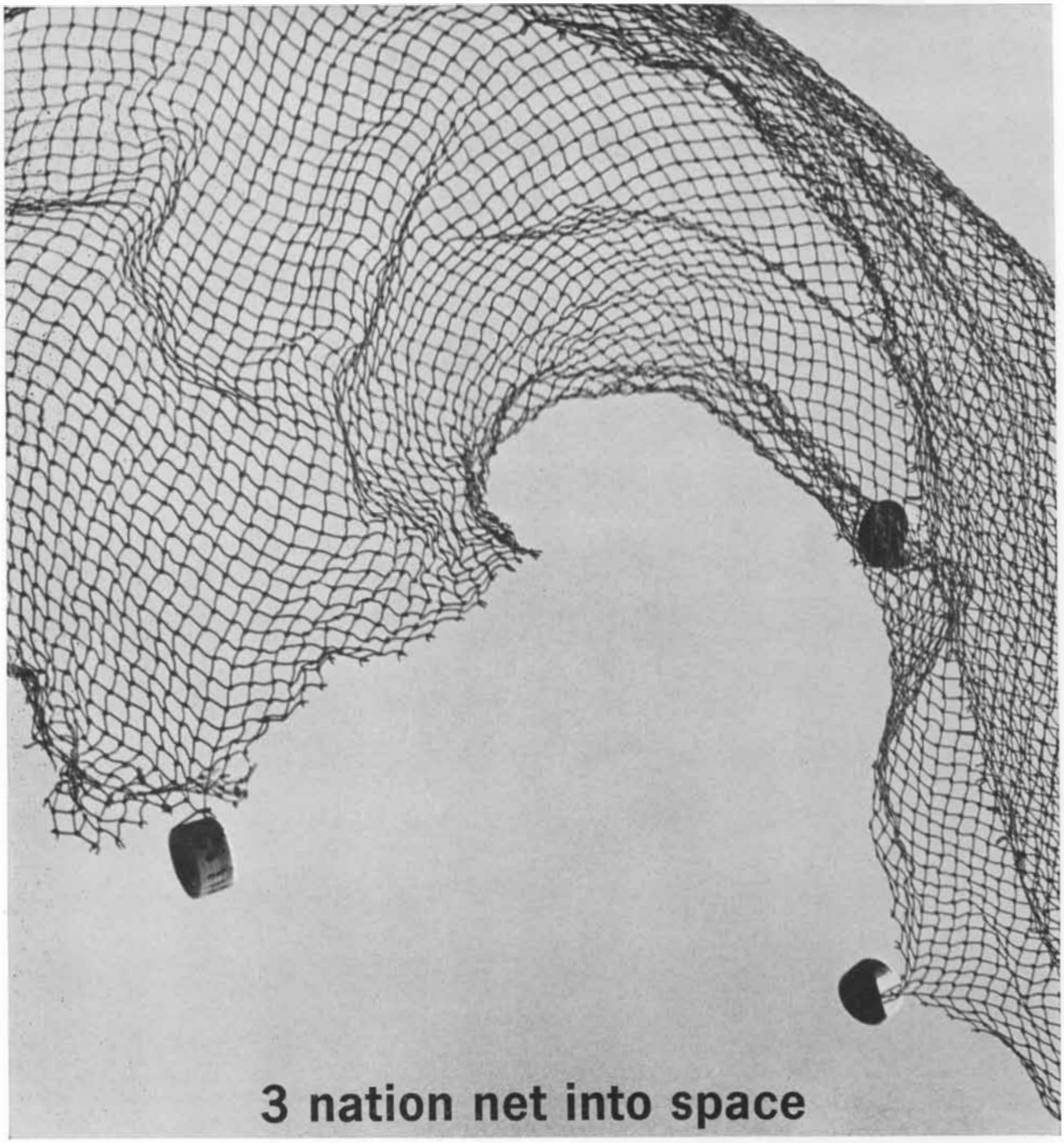

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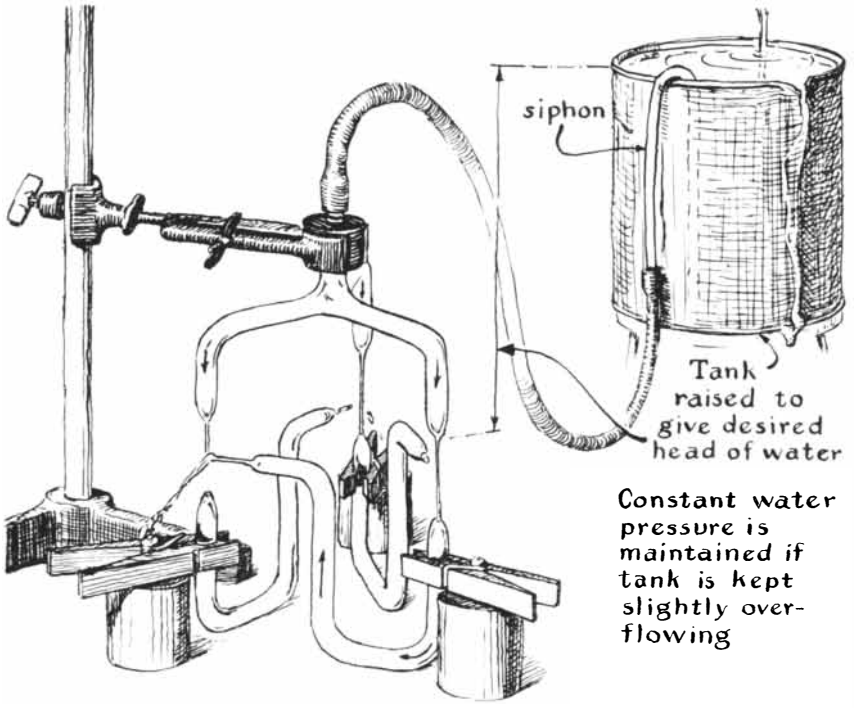
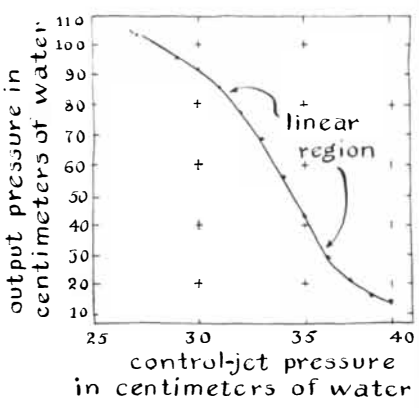


Three-phase oscillator

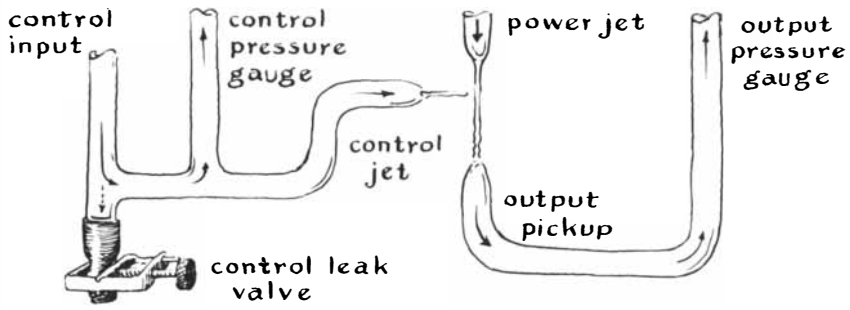
turns the circuit to its initial state. Actually, even when the valve is opened momentarily, the circuit oscillates for a half-cycle. This constitutes the 'flip.' The circuit has one disadvantage: it is sensitive to variations in power pressure and tends to go into uncontrolled oscillation. The mechanical valve can be replaced by a pure fluid switch. One version is shown in the accompanying illustration [*top of page 134*]. Unwanted oscillation can be prevented by using triggering pulses of short duration. A circuit for generating short pulses automatically is assembled by coupling a cutoff nozzle to the triggering nozzle through a short length of feedback tubing [*see bottom illustration on page 134*].

"Pure fluid flip-flops can be ganged in series to make frequency dividers, binary counters and related devices used in digital computers. One output branch is tapped to trigger the succeeding flip-flop. The second branch functions as an indicator of state.

"Of the several devices that emerged from the experiments, one that seemed insignificant at first eventually gave me the most satisfaction because it led to a novel electronic circuit: a three-phase oscillator. In the case of simple flip-flops two pure fluid triodes are interconnected so that conduction in one blocks conduction in the other. When a third triode is added to form a closed ring, the device becomes unstable and oscillates. The arrangement is shown in the accompanying illustration [*above*]. Three power jets operate continuously. In the state illustrated the first control jet has cut off the second power jet. Accordingly the third control jet is also cut off. This enables the third power jet to activate the first control jet and, at the end of a time interval that depends on the constants of the system, to cut off the first power jet. As a result the jet action progresses around the ring at a phase angle, with respect to time, of 120 degrees. Further experiments demonstrated that triodes can be cascaded in this configuration without limit. Configura-



Graph of fluid amplification



Apparatus for measuring characteristics of pure fluid amplifier

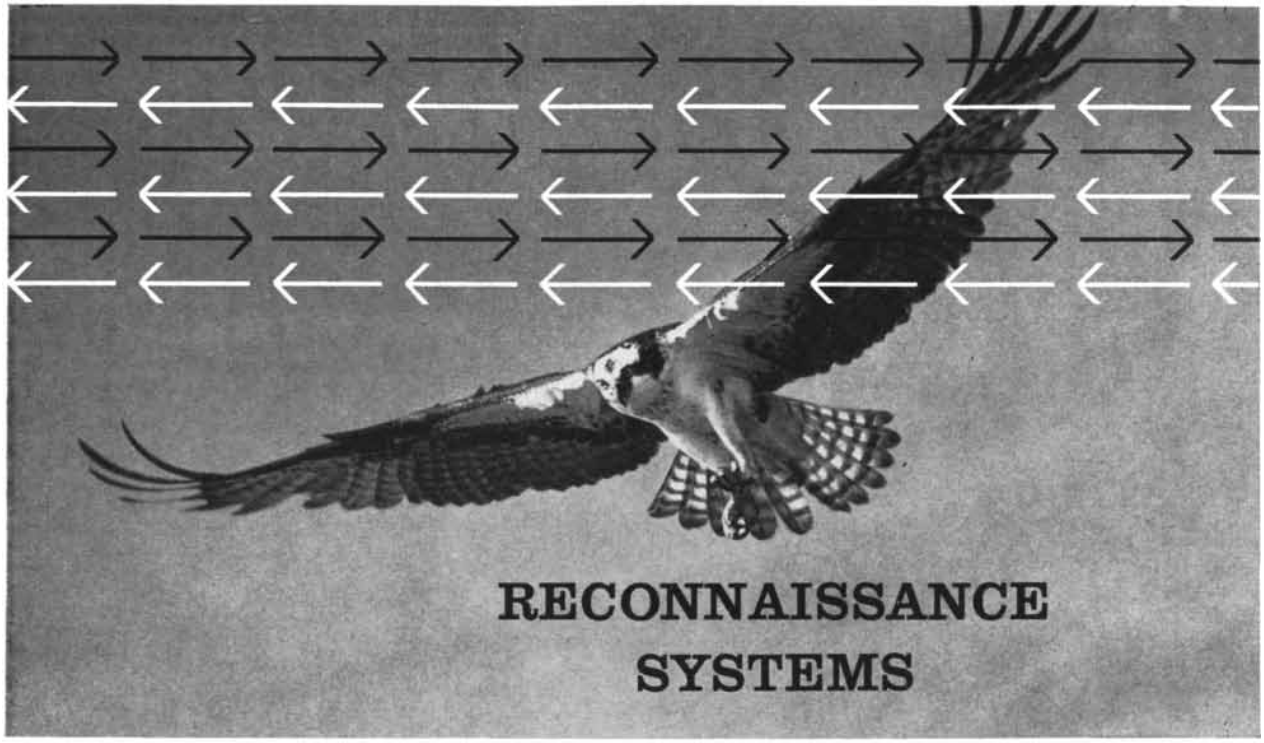
tions containing any even number of triodes are stable and configurations containing any odd number oscillate.

"There appears to be an electronic analogue for each of the pure fluid circuits and vice versa; any scheme should be transferable from one system to the other. The analogies are not perfect, however, and it is not always easy to devise an analogue even though a model representing one of the two systems is at hand. I have dreamed of constructing a pure fluid audio amplifier, for instance, ever since the experiments got under way. In contrast to the output signal of flip-flops and other all-or-nothing devices that in effect are little more than automatic switches, the amplitude of an amplifier's output signal must bear a constant proportional relation to amplitude of the input signal. Careful measurements indicate a region through which the pressure of the output circuit of a pure fluid triode varies directly with the pressure of the control jet. Although the gain in pressure is small in regions approaching complete conduction or nonconduction, it varies from sixfold to 20-fold between these extremes, depending on the pressure of the power jet, and is substantially linear. A curve of the characteristic gain can be drawn by plotting a series of simultaneous measurements of output pressure and control-jet pressure. My measurements are made in terms of centimeters of water head by means of a simple water manometer. The pressure of the power jet is maintained at constant value during the run. The accompanying graph [*bottom of preceding page*] is typical. With nozzles of optimum size output pressure approaches the pressure of the power supply within a few centimeters, in spite of the fact that the jets are not enclosed. A convenient setup for making simultaneous measurements is shown in the accompanying illustration [*above*]. Pressure of the control jet is varied by a pinchcock of the screw type. The control gauge and output gauge tubes are calibrated against a standard meter stick. The measurement is equivalent to plotting the grid voltage of a vacuum tube against plate voltage.

"Pure fluid devices, like all experimental apparatus, are obedient to Murphy's law: If something can go wrong, it will. Success comes easiest when certain precautions are observed. Faulty operation is most often traced to air that is inadvertently trapped in one circuit or another. Usually the symptoms show up as unstable jets, or sputtering. Unwanted air often enters the circuit with the power jet, particularly when the power jet is misaligned or improperly designed. The use of glass tubing or transparent plastic tubing is recommended because streams of bubbles in circuits such as feedback loops are easy to see. Air can be trapped in any loop, particularly a loop that operates in a vertical plane, and this must be taken into account in the design of a circuit.

"Variations in the pressure of tap water can present problems when you are experimenting with the more sensitive devices. I solve this problem by drawing water from a small tank located about five feet above the apparatus. My tank was equipped with six outlet valves from an old gas stove. They were soldered around the base of a one-gallon antifreeze can; two short nipples of copper tubing soldered into the can about an inch from the top provided input and overflow connections. A siphon arrangement should work just as well, although perhaps not so conveniently.

"Amateurs who enjoy solving mechanical puzzles will find a stimulating field in the design and construction of these analogues. The application of pure fluid devices appears to be limited only by the imagination of the experimenter. The fluid is by no means confined to water. With some modification of nozzle configuration it should be possible to devise a triode that works on compressed air. We will probably never have the opportunity to listen to an air-driven stereo phonograph, but nothing in my experiments suggests that one cannot be built."



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BOOKS

Two new works on the early history of the nuclear age

by James R. Newman

THE NEW WORLD, 1939/1946, by Richard G. Hewlett and Oscar E. Anderson, Jr. The Pennsylvania State University Press ($5.50).

NOW IT CAN BE TOLD, by Leslie R. Groves. Harper & Row, Publishers ($6.95).

These two books tell the story of an advance in technology comparable to none in its potential impact on every living person and on future generations. The story is of course not yet ended. Its full meaning will be unfolded in future chapters. If they are bright, mankind will gain much; if they are dark, mankind may perish.

Hewlett and Anderson's narrative, which gets its title from Arthur Compton's rather stagy telephone report to James Conant on the successful operation of Fermi's chain-reacting pile at Stagg Field ("Jim," he said, "you'll be interested to know that the Italian navigator has just landed in the New World") is the first volume of what is to be a multivolume history of the U.S. Atomic Energy Commission. The period covered here is from 1939 through 1946. When the story opens, scientists in the U.S. were just beginning to reckon the results of the epochal breakthrough of Hahn, Strassmann and Meitner. They were confirming, exploring and charting paths into unknown territory. Seven years later controlled atomic energy was a reality; the proof was the dead of Hiroshima and Nagasaki. The process of scientific digestion had gone forward at an astonishing rate; that of social digestion had scarcely begun.

Official histories are often more official than historical, especially when they are written so close in time to the events they purport to describe that large portions of the archives are still closed and the feelings of many living persons have to be protected. On the whole, however, the authors of this book, who are on the staff of the Atomic Energy Commission, have treated their subject frankly, openly and in considerable detail.

Two major themes constitute the survey of this period. The first concerns the scientific, technical and industrial aspects of separating uranium 235, making plutonium and designing and constructing the bomb; the second deals with the postwar period during which a legislative policy was evolved for the domestic control of atomic energy and attempts were made to achieve international control. The political theme is undoubtedly the more difficult to handle. It is one thing to tell how a plant came to be built, another to describe how a policy evolved and Congress made a law. Anyone who has spent some time in the Government and has tried to discover how things get done and who does them, to make sense of the crazy quilt of executive and legislative interaction, of lobbyists and pressure groups, of high officials who are short on time and ideas but make the decisions, of assistants who do the donkey work but remain anonymous, of nosy and cynical journalists who sometimes do harm and sometimes do good but rarely lubricate the processes of government—in short, anyone who has had the misfortune and the exhilaration of taking part in a legislative jamboree will appreciate the reportorial task that confronted Hewlett and Anderson. They write with verve and a lively appreciation of the difficulties, crosscurrents and tense conflicts that marked this first political phase of the atomic age. They re-create effectively the atmosphere of this exciting time when many different groups, with scientists in the vanguard, strove to educate the U.S. public, the press and members of Congress in the somber and challenging implications of the atomic bomb, in the importance of incorporating "an incredibly dangerous, mysterious force into the life of a nation" and in the beneficent possibilities of this force.

One of the most colorful and vehement struggles was over the civilian control of atomic energy. The control bill drafted by the War Department and approved by a group of prominent outside advisers had been perfunctorily inspected in the White House and then sent to Congress as the Administration's program. This was called the May-Johnson bill. It was seriously defective in many respects. It was essentially indifferent to the right of the American people to reap the fruits of a technological advance they had paid for. Its patent provisions were drafted so as to endow private and not public interests. Its administrative structure was almost incredibly naïve in envisaging ultimate control over atomic energy by a group of part-time consultants. It failed to establish proper safeguards against the possibility that military men might become the effective atomic energy decision makers. The bill that superseded the May-Johnson bill (introduced by Senator Brien McMahon and Congresswoman Helen Gahagan Douglas), which gained the President's support and which, after many vicissitudes, was finally enacted into law, was the product of many hands. It was threaded with compromises, some small, some serious, but it was a much better piece of legislation than that which the Administration had first offered. A large part of the credit for pushing McMahon's bill through Congress belongs to a group of energetic young scientists, most of whom for the first time found themselves in the political arena and for the first time deeply sensed their social responsibility. All this is ably described by Hewlett and Anderson.

It is likely, to be sure, that some of those who participated in the legislative battle will fault the authors, partly for inaccuracies, more for their interpretations. I was on the scene myself, and I would criticize the book's evaluation of several of the political skirmishes. But I would prefer not to put too fine a point on the matter. Facts and details are pale, poisonous little things. If you get one wrong, your critics will hang you; even if you get all the others right, they will not cut you down. When I compare material in my own files with the authors' account, I note discrepancies; but I can-

not always be certain where the error lies, and in any case only trivial items are at issue. As regards interpretations, thornier questions arise; in a few instances I am convinced that the authors have not caught quite the right note. A sequence of events did not follow the causal chain attributed to it, a decisive turning did not take place for the reasons given. But this represents only my point of view, and just as a mountain or a feature of the landscape may look radically different to observers at different vantage points, so may a series of events be interpreted differently by historians standing in different places or making their judgments at different times. Considering the mass of material that had to be sifted in preparing this work, the complexity of the issues, the fallibility of human memory, the effects of individual bias and the almost insuperable difficulty of describing accurately what happens in the smoke and swirl of battle—the reporters have done admirably. I have learned much from their account, and although I was involved in many of the happenings they describe and felt I had as complete a grasp of them as anyone, Hewlett and Anderson have broadened my perspective. By any reasonable standard theirs is an honorable and worthy accomplishment and must form the basis for future historical appraisals.

This cannot be said for General Groves's book, a singularly self-important account of his role in directing the Manhattan Project. *Now It Can Be Told,* I wish to emphasize, is not a dull book. It is clearly written. It presents a good deal of material that illuminates the growth of this horridly fascinating project and its culminating success. It has amusing cloak-and-dagger stories about the activities of the "Alsos" agents in Europe, whose task it was to discover how much progress the Nazis had made in building a bomb. But Groves's limitations and prejudices intrude at every turn.

His function in the Manhattan Project was that of administrator and expediter. Trained as an Army engineer, he makes no claim to any real understanding of the scientific side of the project. It is surprising, however, how imperfectly he seems to have grasped even the technological side. This is revealed more plainly in his postwar testimony before Congressional committees than it is in his book. Groves's myopia manifested itself not only in his opinions on how the atomic energy project should be run after the war but also in his wrongheaded notions about the possibility of the U.S. maintaining a monopoly in bomb making and the capacity of the U.S.S.R. for making its own atomic weapons.

Obsessively concerned with secrecy and proud of his policy of compartmentalization (pursuant to which no one working in any division of the enterprise was permitted to know about the work in other divisions), Groves was faintly—and not always so faintly—contemptuous of the majority of the project scientists, except for the Nobel prize winners, J. Robert Oppenheimer and a handful of others highly placed. Resentful and egotistical, he neither understood the issues of the legislative battle nor has he to this day forgiven those who had the temerity to challenge him. The following paragraph exemplifies his attitude:

"In spite of the record, since the very start of the postwar period there has been a continuous stream of propaganda calculated to lead the American people and the people of the world to believe that the War Department—and General Groves in particular—was determined to retain close control of atomic energy. The effect of this propaganda has been truly remarkable, despite the fact that it was entirely false, and was known to be false by those who first originated it and by many of those who constantly repeated it. It made no difference how many times they were corrected to their faces, often quite bluntly, or in writing; they continued to put the idea forward. Even today many of them keep up the sham and appear likely to do so as long as they live. In retrospect, this seems to have been one of the most perfect brainwashing operations in modern times, and it has been particularly effective among the better-educated Americans. Those who continued to spread it even after the facts were brought to their attention were obviously doing so deliberately with the intent of gaining political advantage from propaganda that they could not help but know was absolutely without foundation."

Groves had great energy and determination and was bent on succeeding in the task assigned him. He was given extraordinary powers and an almost unlimited budget. He brought into the program not only the industrial corporations that planned, constructed and operated the huge plants at Oak Ridge and Hanford but also the best-qualified scientists and technicians. He never lost sight of the main objective; he spared no effort to get supplies and priorities; he brooked no opposition. His significant contributions to the making of the "Little

Boy" and the "Fat Man" (respectively the uranium bomb detonated over Hiroshima and the plutonium bomb detonated over Nagasaki) were his singleness of purpose, his drive and the fact that he was never fazed by the immensity of the job. Had he been more sympathetic, more modest, more reflective, more concerned with the human problems of the scientists under his control, he might not have reached the goal as quickly as he did. Some think it would be a better world if he had not succeeded. The complexion of his qualities colors his writing and makes his book at times very hard to take. But both as a self-portrait and as the story of an almost incalculably fateful undertaking it is worth reading.

Short Reviews

THE COLLECTED PAPERS OF LORD RUTHERFORD OF NELSON: VOL. I, published under the scientific direction of Sir James Chadwick. John Wiley & Sons, Inc.—Interscience Division ($19.50). This volume, a fitting tribute to one of the great figures of science, comprises Rutherford's work from 1894 to April, 1907, papers describing his researches in New Zealand, at the Cavendish Laboratory and at McGill University. The entire scheme—three other volumes are to follow—is to include all Rutherford's papers, published either alone or with collaborators, a number of general articles, formal public lectures, letters to editors, personal recollections and appreciations by some of his friends and colleagues, and a bibliography. As is often the case with men of prodigious ability in science, mathematics or music, their earliest efforts carry their inimitable signature. In a basement of Canterbury College in New Zealand, Rutherford began his experimental career with studies of the magnetization of iron by high-frequency discharges. The "laboratory was rudimentary," the apparatus was simple, homemade, of the Faraday kind, but the work was skillful, ingenious, imaginative and directly to the point. After the New Zealand period he worked at Trinity College, Cambridge, under the direction of J. J. Thomson and devised a magnetic detector of radio waves; then, in collaboration with Thomson, he studied questions of the passage of electricity through gases exposed to X rays. At McGill he pursued with great intensity the entire field of radioactivity, just recently opened up. The volume concludes with papers on the velocity and energy of the alpha particles from radioactive substances and

on some cosmic aspects of radioactivity. The experiments and the speculations are of the highest interest, not only for their contributions to scientific knowledge but also as forerunners and promises of the brilliant future researches at Manchester and Cambridge. The volume is well made and is illustrated by 15 plates and many diagrams. One looks forward to the continuation of this fine project.

THE PEACE RACE, by Seymour Melman. George Braziller, Inc. ($3.95); Ballantine Books (50 cents). Melman, who is an industrial engineer on the staff of Columbia University, and who edited the valuable study *Inspection for Disarmament* (reviewed in these columns three years ago), offers an alternative to the deadly dangerous stumbling and fumbling of the arms race. No progress has been made in disarmament negotiations; perhaps where fear and suspicion are sovereign none is intended and therefore none can be achieved. Melman's proposal for breaking out of the dark forest is a new direction: we must "challenge" the U.S.S.R. to a competition in industrializing the great underdeveloped areas of the world. Since our economy has ample resources for this task (he estimates that the cost of the "peace race will amount, at maximum, to about 10 per cent of America's gross national product") and the U.S.S.R. has no reserves of production capacity, being forced as it is to endure drastic shortages in housing, food and consumer goods to keep up armaments, this is a competition we would be likely to win. But the competition is not conceived as merely another episode in the cold-war serial; for as Melman reasons, the U.S.S.R. cannot afford its political and economic consequences, and they "will be compelled to seek disarmament in order to compete in a peace race." Any number of objections to this hypothesis leap to mind. For one thing, if the U.S. can make both guns and butter for itself *and* others, it is hard to see why we would give up the guns so as to make more butter; and since we are unlikely to disarm, why would the U.S.S.R. disarm? Second, it is hard to imagine that the Russians will agree to compete with us in a sphere where they clearly have the worst of it. Third, the book grossly oversimplifies the problems of world industrialization. All the same, Melman supports his thesis with many relevant facts and argues it with sincerity, and the sections that expose the fatuities and evils of the arms race are particularly effective. This is a decent and responsible proposal that deserves attention, and whatever its defects, it is far more attractive than many of the policies now being followed.

JOHN VON NEUMANN: COLLECTED WORKS, VOL. I, edited by A. H. Taub. Pergamon Press ($14). The first of six volumes of the collected works of the noted mathematician, presenting papers on logic, theory of sets and quantum mechanics. When completed, the set will contain reprints of all von Neumann's published articles, some of his reports to Government agencies and other organizations, reviews of unpublished manuscripts found in his files and a bibliography. Von Neumann's intellectual gifts, quests and wide-ranging achievements deserve a memorial of this kind. Yet doubts arise as one examines this volume and the prospectus for the others still to come whether or not the enterprise is altogether worthy of its subject. The papers are presented without any editorial comment. No biographical memoir of von Neumann's life is to be included, and no appraisal of his work (although later volumes are to give certain evaluations of unpublished material). In fact, the only contact one is likely to make in these pages with von Neumann's personality is in the reprint of his excellent essay "The Mathematician." Typographically the volume is a kind of rag bag, as the papers are evidently reproduced photographically from the various journals and proceedings in which they first appeared.

LIVING AMPHIBIANS OF THE WORLD, by Doris M. Cochran. Doubleday & Company, Inc. ($12.50). The seventh volume in this publisher's illustrated "World of Nature Series" deals with the caecilians, the salamanders (from the hynobiids, giants and moles to the mud puppies and sirens), the frogs, toads and their relatives (including the leiopelmids, the tongueless, the fire-bellies, and midwives, the spadefoots, the tree frogs, the true frogs, the narrow-mouthed toads and the phrynomerids). Miss Cochran covers courting, mating, breeding, range distribution, coloration, defense mechanisms, feeding and adaptation. Among the spectacular specimens are the bird-voiced tree frog (*Hyla avivoca*); the giant tree frog, which looks like a frazzled and begoggled driver coming off the Indianapolis Speedway; Boulenger's platymantis, which comes from New Guinea (and for the rest of the world's peace of mind should stay there); the silver-striped sedge frog, an exquisite little chap obviously designed by Cartier's; the spotted hylambates, which feeds on moths in places like Mozambique and Zanzibar; the Cape short-head (*Breviceps gibbosus*), which usually lives in termite nests in the Cape Peninsula of Africa; Burmeister's frog (*Phyllomedusa burmeisteri*), obviously a Disney contrivance; the barking tree frog (*Hyla gratiosa*), which likes to swing on a trapeze; Budgett's frog, resembling a tiny rhinoceros; Zetek's frog, a bizarre, long-legged, sharp-nosed amphibian that has perfectly solved the problem of deterrence—its skin is so poisonous that no other animal tries to eat it (Miss Cochran notes that a "well-treated captive does not secrete the poison"); the three-striped arrow-poison frog, which secretes the venom that South American Indians use to tip their arrows; the Oriental fire-bellied toad, which lives in mountain streams near the seacoast of northeastern China, Manchuria and Korea, and which with its gorgeous red and green markings resembles a Chinese dragon; and White's tree frog, one of the jolliest and most benign-looking creatures in the animal kingdom. Two hundred and twenty-two illustrations, 77 in full color.

THE COMPLETE BOOK OF BIRTH CONTROL, by Alan F. Guttmacher, with Winfield Best and Frederick S. Jaffe. Ballantine Books (50 cents). A plain-spoken little book on all aspects of birth control: medical techniques, the rhythm method, the new pills, contraceptive methods, the views of organized religions, the puncturing of popular myths. Guttmacher, who is director of obstetrics and gynecology at Mount Sinai Hospital of New York and a leading figure in Planned Parenthood programs, presents a plethora of practical information for married couples who want children but want to exercise intelligent control over their own lives. Recommended.

THE COLUMBIA LIPPINCOTT GAZETTEER OF THE WORLD, edited by Leon E. Seltzer. Columbia University Press ($65). This excellent reference work, first published in 1952, now appears in a second printing. The main text is unaltered but there has been added a supplement identifying the new nations that have appeared during the past decade, fresh geographical data and a report of the 1960 U.S. census. Among the new nations covered in the supplement are Cambodia, the Central African Republic, the Republic of Chad, the republics of the Congo, Cyprus, Dahomey, Ghana, Iraq, the Ivory Coast, Malagasy, Mali,

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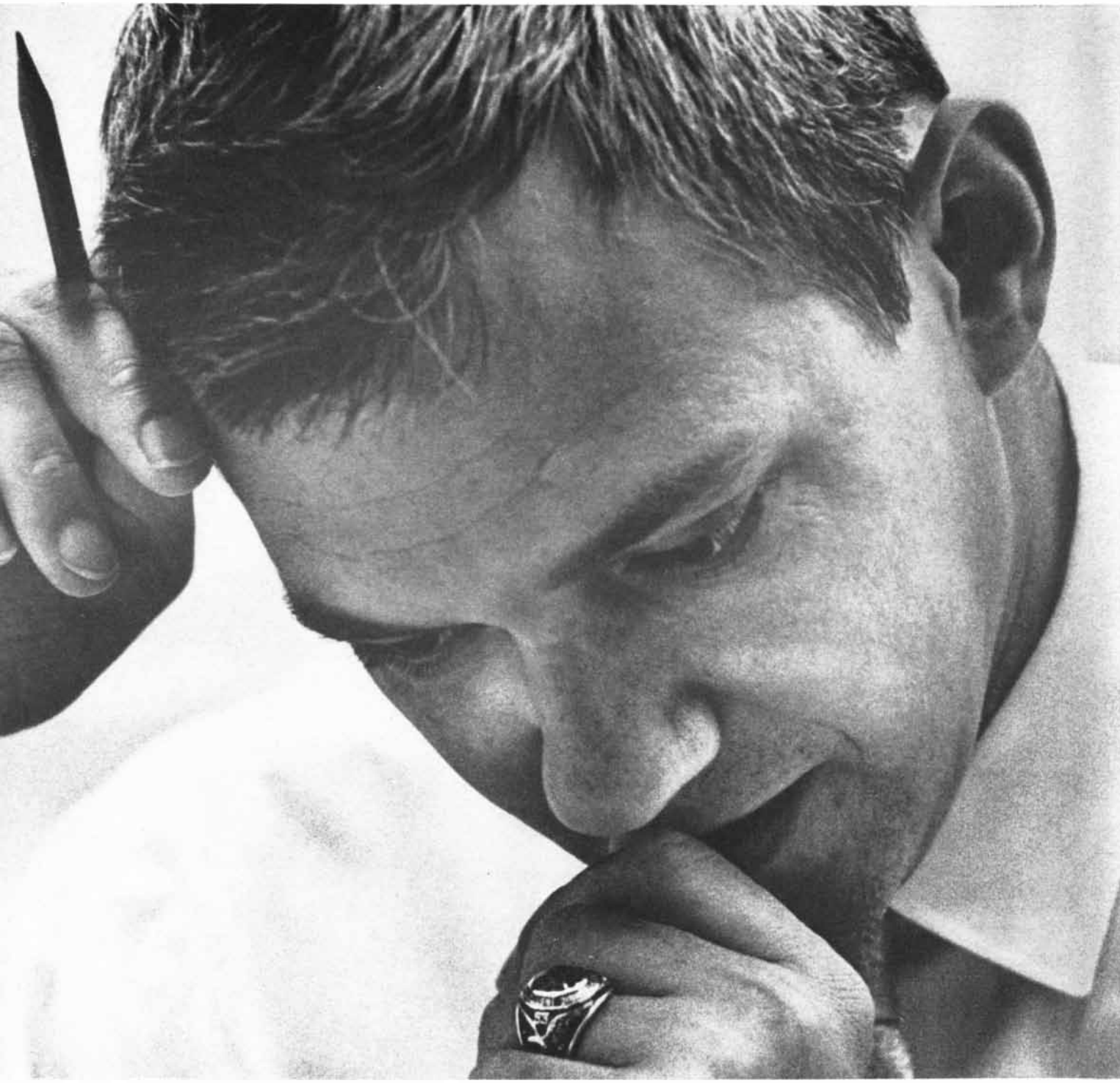

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THALIDOMIDE AND CONGENITAL ABNORMALITIES. G. F. Somers in *The Lancet*, Vol. 1, No. 7235, pages 912–913; April 28, 1962.

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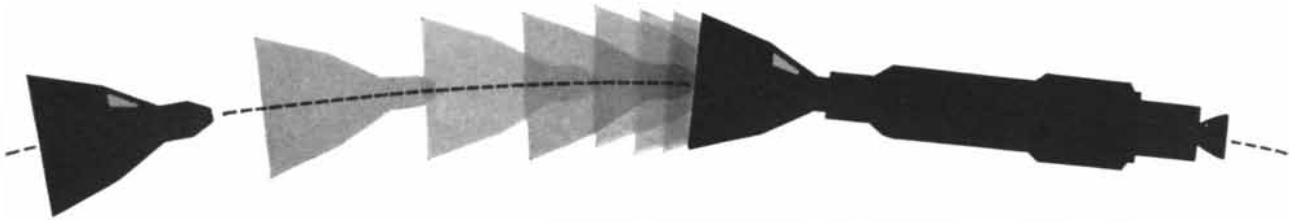

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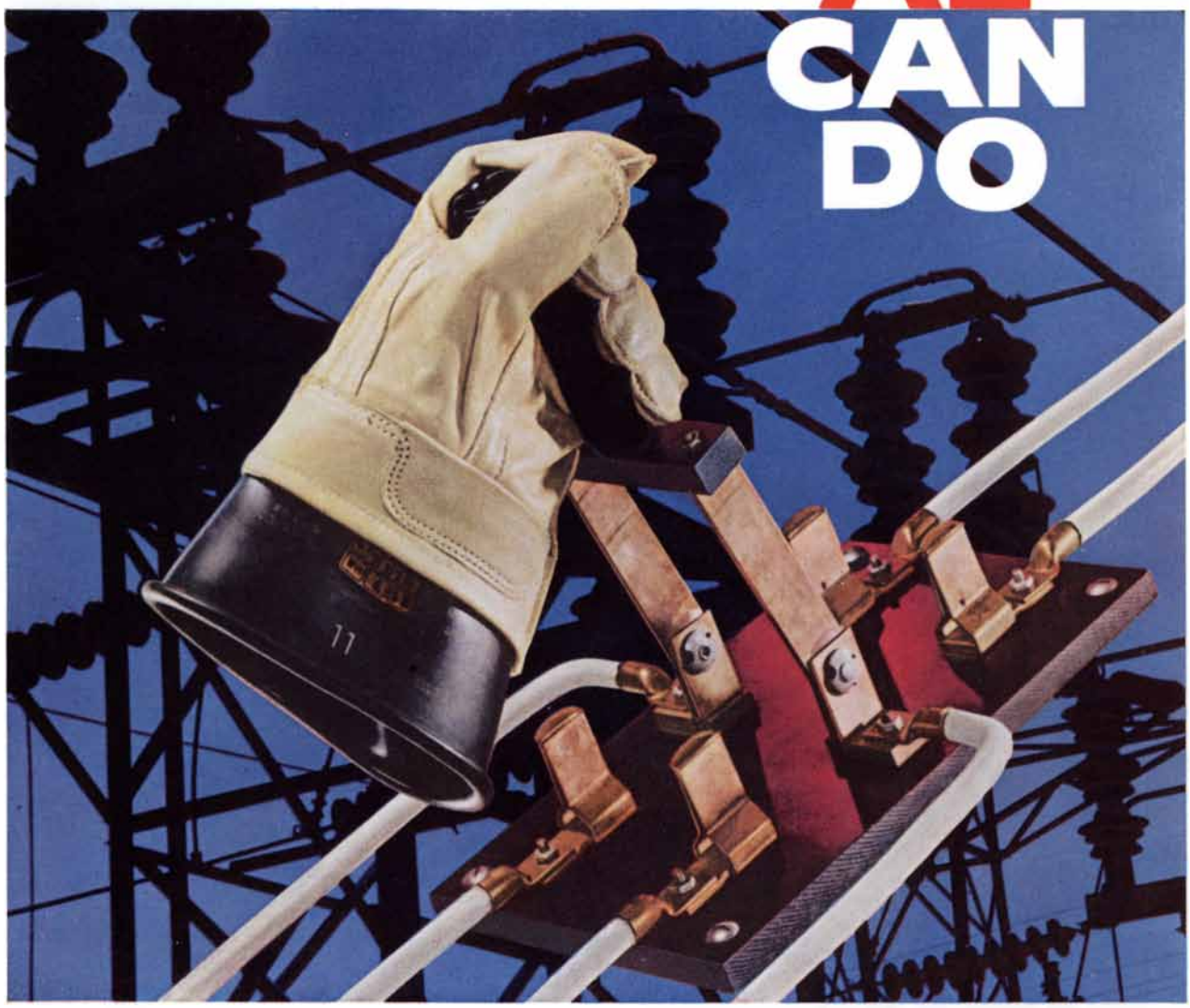

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