SCIENTIFIC AMERICAN

MAYA WALL PAINTING

FIFTY CENTS

May 1955

. . . why they spell a better life for you

A CENTURY AGO, pioneering scientists learned to take apart water, air, and earth and put them together again . . . in completely different arrangements.

THE RESULT, very often, was *a synthetic*—a brand new material that didn't exist in nature, or a more abundant, more useful version of a nature-made product. Thus, through the years, synthetic has come to mean 'man-made and well-made.'

Science has developed nearly half a million synthetic materials since that time, and millions more are possible.

WHERE DO SYNTHETICS fit into your life? Nearly everywhere! The aspirin you take for a headache, the life-saving sulfa drugs and scores of other modern medicines are synthetics. So are today's remarkable plastics, new textiles, and many paints, dyes, adhesives, and valuable chemicals.

AN IMPORTANT PART of the work of the people of Union Carbide is discovering and producing synthetic materials that serve you and industry. From natural gas and oil, alone, they produce nearly 400 chemicals. Among them are chemicals that are vital to everything from synthetic rubber to cosmetics . . . and to the variety of plastics and resins made by UCC, which are used in nearly every home and industry today.

FREE: *Learn how ALLOYS, CARBONS, GASES, CHEMICALS, and PLASTICS improve many things that you use. Ask for the 1955 edition of "Products and Processes" booklet C.*

UNION CARBIDE
AND CARBON CORPORATION

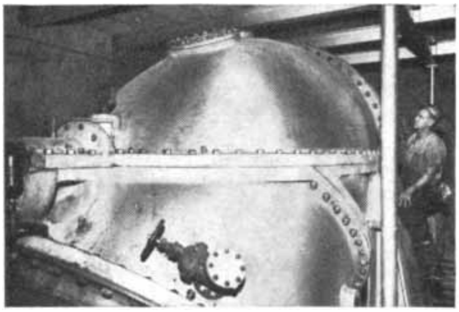
30 EAST 42ND STREET UCC NEW YORK 17, N. Y.

In Canada: UNION CARBIDE CANADA LIMITED

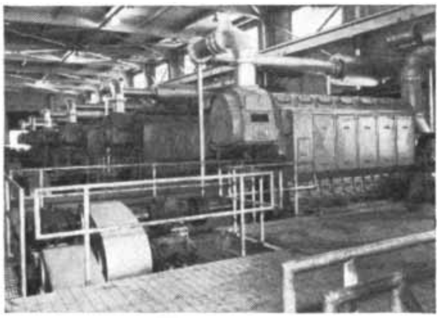
UCC's Trade-marked Products include

SYNTHETIC ORGANIC CHEMICALS PRESTONE Anti-Freeze EVEREADY Flashlights and Batteries PREST-O-LITE Acetylene
Dynel Textile Fibers ELECTROMET Alloys and Metals HAYNES STELLITE Alloys UNION CARBIDE LINDE Oxygen
LINDE Silicones BAKELITE, VINYLITE, and KRENE Plastics NATIONAL Carbons ACHESON Electrodes PYROFAX Gas

World's largest pumping station tames Everglades



Each giant 89-ton pump is equal to the floor space of the average-sized living room. The huge four-bladed, air-foil propeller moves water through the pump at the rate of 360,000 gallons a minute.



Six 1600-hp. Fairbanks-Morse Opposed Piston Diesel Engines insure uninterrupted power for the big pumps, especially during the hurricane season when they will be most urgently needed.

FAIRBANKS-MORSE

a name worth remembering when you want the best

PUMPS • DIESEL AND DUAL FUEL ENGINES • DIESEL LOCOMOTIVES • RAIL CARS • ELECTRICAL MACHINERY • SCALES • HOME WATER SERVICE EQUIPMENT • FARM MACHINERY • MAGNETOS

Floridians who have counted their flood loss in thousands of lives and millions of dollars bitterly refer to Lake Okeechobee as the Killer Lake.

Tomorrow, with the dedication of the world's largest self-powered pumping station, there is the promise of forever taming the Everglades' rampaging waters.

Located at the southern tip of the lake, the station houses six of the world's largest pumps . . . built by Fairbanks-Morse . . . powered by Fairbanks-Morse Opposed Piston Diesel Engines.

Each pump can deliver over 500 million gallons a day. That's more water than is consumed each day by the entire population of Florida. Put all six of these giant 89-ton pumps in operation and you can pump nearly three times the daily consumption of New York City.

In addition to flood control, this giant pumping installation will help maintain a high fresh water table in southern Florida during the dry season . . . prevent salt water contamination of water supplies in coastal cities . . . and even help stabilize the famous Florida climate.

It's a Big Day at 20-Mile Bend . . . a Big Day for the whole State of Florida. We at Fairbanks-Morse are proud to be a part of one of the greatest engineering projects on the face of the earth.

Fairbanks, Morse & Co., Chicago 5, Ill.

LETTERS

Sirs:

Your February article on the opposition of one town to fluoridation of drinking water is a much-needed case history of the tragic distrust and disregard of scientists and the scientific method which deprives a democratic community of a proven benefit. Unfortunately fluoridation is not the only scientific advance which is going unutilized because of groundless opposition.

Your readers may be interested to know that there is an organized opposition to the vaccination of dogs against rabies, the 100-per-cent fatal disease, which has been effective in limiting the protection of the American people against the threat of rabies epidemics. Those who object to the vaccination of dogs sometimes insist that there is no such disease as rabies in spite of hundreds of years of clinical evidence and indisputable laboratory proof that the disease can be induced by a virus. Others admit that rabies exists but oppose vaccination on grounds that would rule out all preventive inoculations.

Vaccination of dogs against rabies is a relatively safe immunological procedure, recommended by the U. S. Public Health Service, the World Health Organization, doctors and veterinarians. The hazard of post-vaccinal accident has always been as low or lower than that of many vaccinations routinely given hu-

Scientific American. May, 1955; Vol. 192, No. 5. Published monthly by Scientific American, Inc., 2 West 45th Street, New York 36, N. Y.; Gerard Piel, president; Dennis Flanagan, vice president; Donald H. Miller, Jr., vice president and treasurer. Entered at the New York, N. Y., Post Office as second-class matter June 28, 1879, under act of March 3, 1879. Additional entry at Greenwich, Conn.

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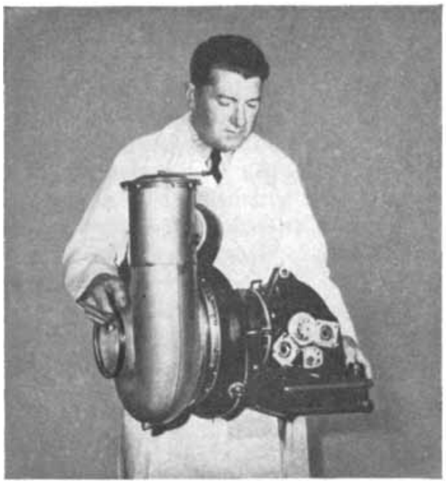
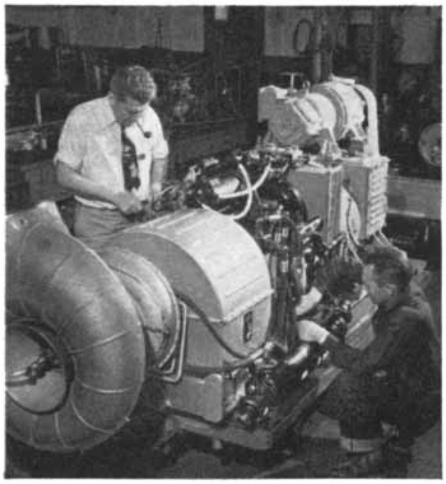
A Primer of Gas Turbine Engines





What is the man above holding?

He is holding a Solar "Mars" gas turbine engine. Its power output runs to 50 hp, but it weighs less than 100 lb and is smaller than a two-foot cube. It achieves this remarkable power-to-size ratio by running at a high speed: the shaft in this engine turns at 40,000 rpm!

What advantages do small gas turbines offer?

Gas turbines are extremely light and compact; they permit smaller space envelopes and easy transportation, so important in such applications as portable fire pumps and airborne generator sets (photo above). Gas turbines are simple and rugged, with low maintenance cost. They need no cooling system and will operate on a variety of fuels. Low initial cost is anticipated, when gas turbines reach volume production.

Where are gas turbine engines being used?

Gas turbines today are finding an increasing variety of uses: in boats, where compactness is important; in airplanes, where light weight is essential; in remote pumping stations, where portability counts; in electric power plants, where reliability must be assured.

What gas turbines are made by Solar?

Today in addition to the 50 hp Mars gas turbine, Solar is producing the 500 hp Jupiter gas turbine (photo above). Its weight installed is under 900 lb—less than one fourth that of a comparable diesel engine!

Mars engines have been adapted to many applications such as fire pumps, starter carts, and welding equipment, and they are in volume production for auxiliary generator sets used on the Douglas C-124C and Lockheed C-121C. Both constant speed Jupiter engines for generator sets and variable speed engines for ship propulsion have been built for the U.S. Navy.

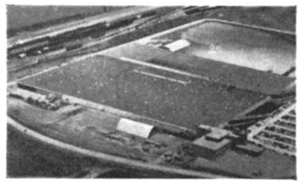
Solar gas turbines are not yet generally available as all current production is going into military uses. Field testing of commercial applications is underway and production for civilian use is anticipated in the near future. Further information is available on request.

SOLAR AIRCRAFT COMPANY SAN DIEGO DES MOINES

DESIGNERS, DEVELOPERS AND MANUFACTURERS OF METAL ALLOY PRODUCTS

This is What Solar Offers You

Solar specializes in the manufacture of precision products from alloys and special metals for severe service. Solar's experience since 1927 is unduplicated in this field. Solar skills and facilities range from research, design and development through to mass production. Wherever heat, corrosion or difficult specifications are problems, Solar can help you solve them.



PLANTS. *In San Diego and Des Moines (photograph above). A total of 1,400,000 sq ft of floor space. Approximately 5,000 employees. Annual sales over $65,000,000.*

EQUIPMENT. *Production equipment for all types of metal fabrication —forming, machining, welding, brazing, casting, coating. Extensive laboratory and testing equipment. Facilities for development, prototype, limited or mass production.*

SERVICES. *Research, design, development, tooling and production engineering staffs. Experienced with all alloy steels, stainless alloys, super alloys, and titanium and its alloys. Government source inspection and Solar quality control meet rigid aircraft and commercial standards.*

CONTRACT PRODUCTION

Current orders include aircraft engine and airframe parts, alloy castings, pneumatic ducting, atomic energy components. Customers include some of the most honored names among aircraft and industrial companies in the U.S. and Europe.

SPECIAL PRODUCTS

Bellows. *"Sola-Flex"® bellows and expansion joints in many designs from ½ in. up to the world's largest, 28 ft in diameter.*

Gas Turbines. *Solar "Mars" 50 hp engines for auxiliary generator sets, ground carts, portable fire pumps; Solar "Jupiter" 500 hp engines in variable and constant speed models.*

Ceramic Coatings. *"Solaramic"® is the Solar trade mark for a family of coatings that protects metals from heat, corrosion, galling and abrasion.*

Controls. *Complete control systems utilizing the new Solar "Microjet"® principle for control of gas turbines, jet engines and pneumatic devices.*

FURTHER INFORMATION
Your inquiry regarding any Solar product or service will receive prompt attention. Address
Solar Aircraft Company
Department B-12
San Diego 12, California

man beings. In the past seven years test of an attenuated virus vaccine grown in eggs has further reduced the small danger. To date the new vaccine has been used successfully on more than 2,000,000 dogs in various parts of the world. Further, there has never been a case in which an attenuated virus vaccine has reverted to infective virulence. Public health officers say that immunization of 70 per cent of the dogs in any community protects it from the threat of a rabies epidemic, and they can point to Israel, Malaya and other more enlightened areas which have suppressed rabies this way.

Meanwhile inadequate immunization of U. S. dogs exposes the entire population to the threat of rabies. Under prevailing conditions, doctors and public health officers have to recommend the painful and costly Pasteur treatment whenever there is the slightest suspicion that a biting dog may be rabid, and endemic rabies in our wild animals makes it impossible to eradicate the disease from the country by the heroic dog control and quarantine measures adopted for the British Isles.

The irony of the situation, of course, is that the dog population stands to gain more from vaccination than the human population. About 7,000 of our 22½ million dogs die of rabies every year compared with only about a score of our 160 million human beings. Yet the opposition to vaccination programs comes from those who say they love dogs and want to protect them against the discomfort or danger of vaccination.

JOSEPH STETSON

Gun Dog Editor
Field & Stream
New York, N. Y.

Sirs:

An excellent and timely article by James Marston Fitch on the curtain wall [SCIENTIFIC AMERICAN, March].

A popular misconception of fact has been restated, insignificant as far as this article is concerned, but perhaps worthy of bringing to your attention. Pietro Belluschi's Equitable Loan Building is glazed with a glass sandwich reported to be "two sheets separated by a hermetically sealed partial vacuum."

I believe Mr. Fitch will find the commercially available insulating glass units (Twindow, Thermopane, etc.) do not contain a partial vacuum, but rather just dry air at atmospheric pressure. Partial

from moraine:

METAL POWDER PARTS
MAKE DIFFICULT DESIGNS EASY

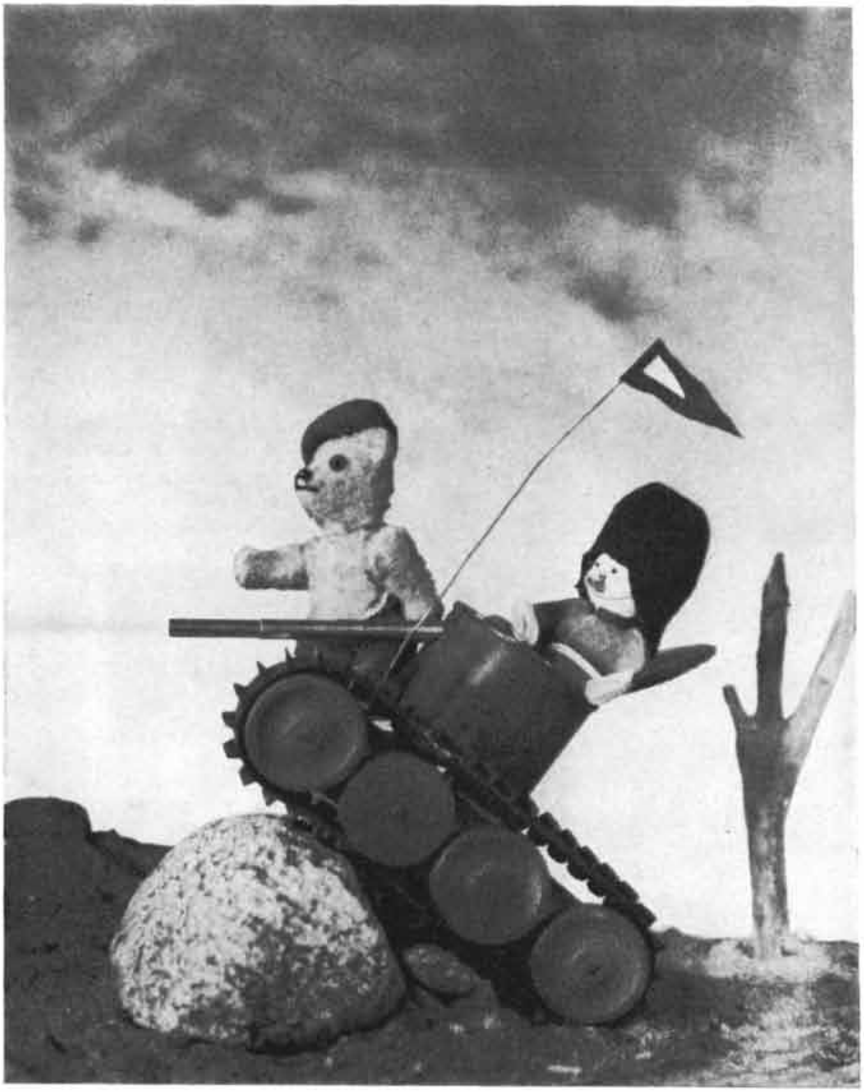
By conventional casting and machining methods, some of these parts couldn't be made, and the cost of others would be prohibitive. Yet Moraine makes them all, in only one press operation, using the metal powder process. Industries of all kinds get substantial product improvement benefits—and save money, too—by making use of Moraine's unexcelled skill and experience with metal powders. Another Moraine benefit is its ability to deliver in quantity, on schedule.

Typical examples of the wide variety of metal powder parts that Moraine produces for the automotive, appliance, and other industries.

Other Moraine products include: Moraine-400 bearings, toughest automotive engine bearings ever made—M-100 engine bearings and Moraine conventional bi-metal engine bearings—Self-lubricating bearings—Moraine friction materials—Moraine porous metal parts—Moraine rolled bronze and bi-metal bushings—Moraine power brakes—Delco hydraulic brake fluids, Delco brake assemblies, master cylinders, wheel cylinders and parts.

moraine products

DIVISION OF GENERAL MOTORS, DAYTON, OHIO



about tank gun stabilization

...AND FORD INSTRUMENT COMPANY

Modern tanks can cross almost any type of terrain, but the aiming of their guns while the tanks are pitching and bumping over rough ground has been a difficult task. Modern stabilizing devices make it possible to keep the gun steady on its target while the tank jolts and bounces forward.

For four decades the Ford Instrument Company has been working on stabilization problems. Early in its life, the company had to solve the problems of roll, pitch and yaw of warships to keep the naval guns steady for firing while the ship was in motion. Ford engineers today are applying their wealth of experience in solving the same sort of problem for tank guns.

Ever since 1915, when Hannibal C. Ford built the first gunfire computer for the U. S. Navy, Ford Instrument has been a leader in applying the science of automatic control to American defense and peacetime industry. For more information about Ford's products, services and facilities, write for free illustrated brochure.

52

FORD INSTRUMENT COMPANY

DIVISION OF THE SPERRY CORPORATION

31-10 Thomson Ave., Long Island City 1, N. Y.

ENGINEERS:

FORD IS CONSTANTLY ADDING TO ITS STAFF OF ENGINEERS. IF YOU CAN QUALIFY, THERE MAY BE A POSITION FOR YOU.

evacuation of the air space would cause the plates to bow toward each other.

R. D. Spencer

Pittsburgh, Pa.

Sirs:

In the January issue of *Scientific American*, Lewis M. Terman ("Are Scientists Different?") concludes by stating that the current friction between scientists and government officials is due to underlying personality differences between the two groups. This conclusion does not appear to be borne out by the data presented in the article.

Patterns of behavior that are more characteristic of scientists than nonscientists, which are well documented by this study, are an oversimplification of the problem in indicating that these differences are *the* basic reasons for the existence of this complex problem. There are additional social, political and technological factors involved.

In his sincere effort to contribute a constructive answer to the issue by applying the tools of the behavioral sciences, we feel that Professor Terman may have inadvertently given added force to the current wave of anti-intellectualism.

Herbert I. Harris

Chief Psychiatrist

Norman R. Bernstein

Assistant Psychiatrist
Homberg Memorial Infirmary
Massachusetts Institute of Technology
Cambridge, Mass.

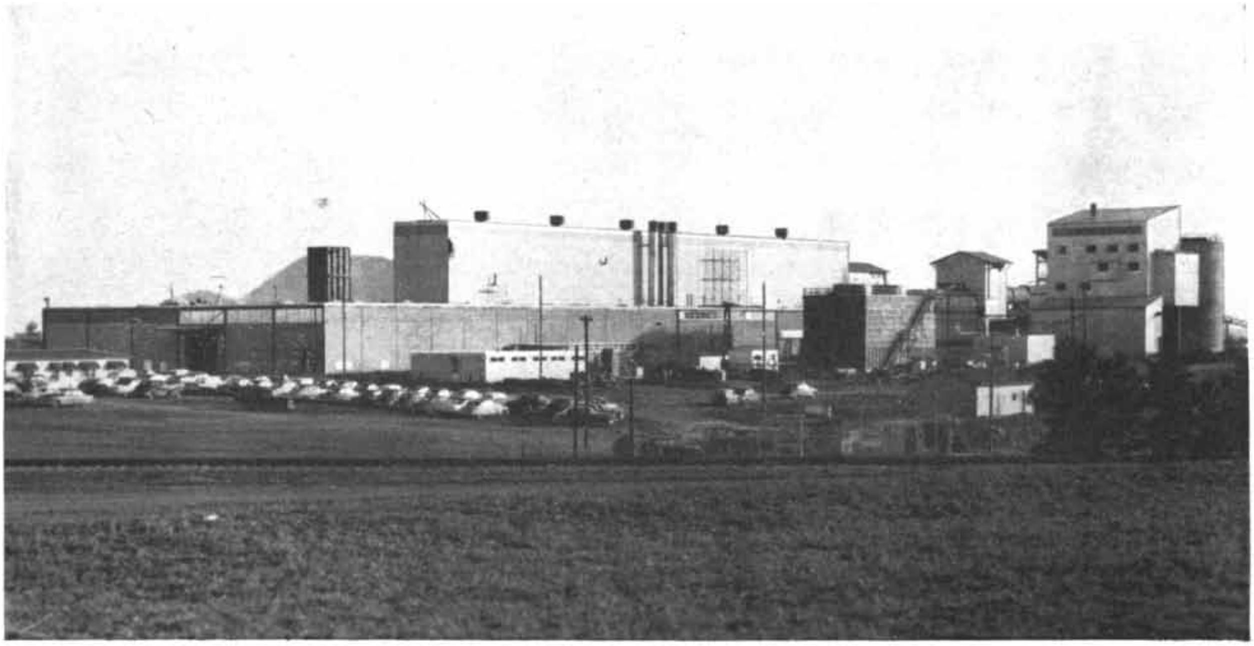
Sirs:

Cats, as even an amateur felinologist knows, are in a class by themselves and are not to be confused with any other creatures. The references in your January issue to Louis F. Fieser's "bevy" of cats reduces the level of these wonderful creatures to that of beautiful women. It is as if you referred to a "herd" of bathing beauties.

Cats come in clowders, like prides of lions or gaggles of geese. Large cats, that is. Kittens, when they are not in the same litter, are a kendle.

William Volk

Trenton, N. J.



Lithium

Putting the "prod" in^ production . . .

Here's a bird's-eye view of the biggest step yet in meeting industry's continuing demand for Lithium. Lithium Corporation has put on stream a lithium plant with the largest potential capacity in the world. The $7,000,000.00 project located at Bessemer City, North Carolina is producing Lithium Carbonate and Lithium Hydroxide for industry at large.

Unique in the Lithium industry, Bessemer City is processing run-of-mine ore directly through its chemical plant, as well as concentrates. The former eliminates the once necessary step of first concentrating the ore. The plant treats company-owned deposits of spodumene ore reserves in the adjacent King's Mountain area. The concentrates are from Canadian sources. Coupled with the company's original plant at St. Louis Park, Minnesota, a substantial increase in present productive capacity of the lithium industry is assured.

• • •

Why don't *you* look into Lithium? This miracle element is benefiting, cost-wise, many important industries. Organic chemicals, ceramics, air conditioning, greases, metallurgy, pharmaceuticals, brazing fluxes—all utilize Lithium to improve their products. It might well contribute untold profits for *your* company. A card or letter will bring you complete information.

. . . trends ahead in industrial applications for Lithium.

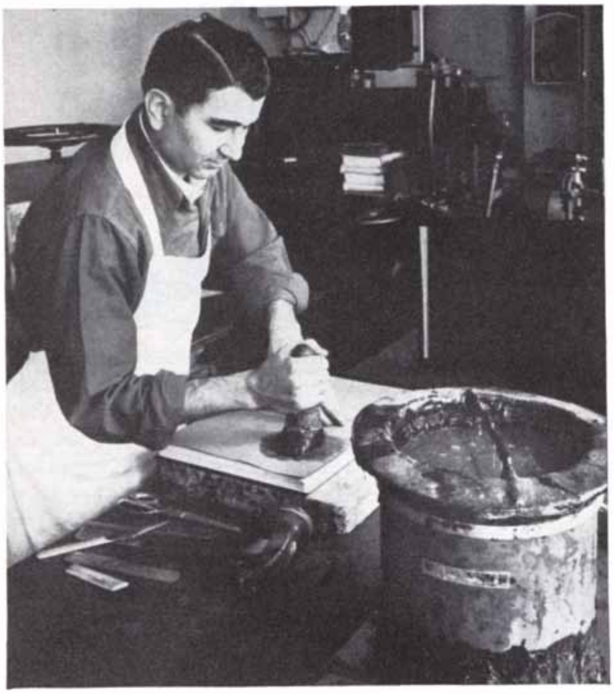
Life on the Chemical Newsfront

CHEMICAL PROGRESS WEEK-MAY 16-21

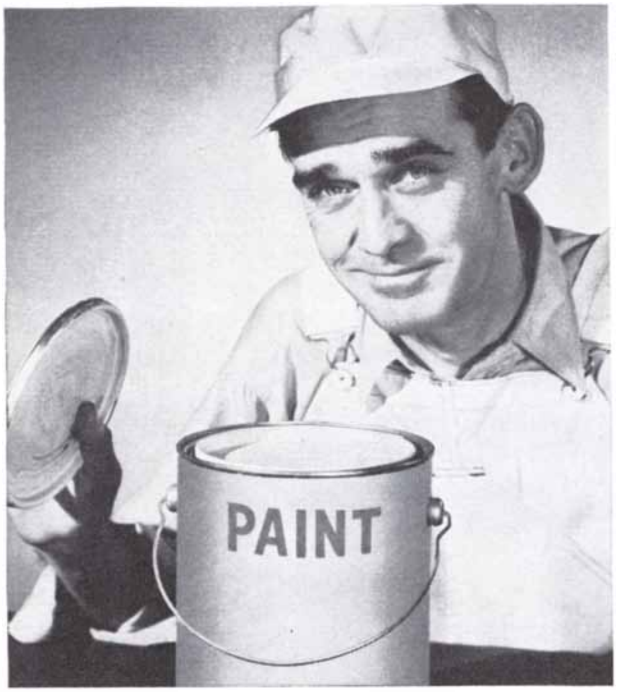
Photo courtesy American Fruit Grower

"ONE OF THE MOST USEFUL NEW INSECTICIDES." That's what State and Federal researchers say of Malathion, the versatile insecticidal chemical 0-0-dimethyl dithiophosphate of diethyl mercaptosuccinate, developed and manufactured by Cyanamid. For home garden use, Malathion is an all-purpose insecticide controlling a range of pests for which three or four insecticides were required previously. For agricultural use, the USDA accepts Malathion for control of more than 75 different insects on more than 40 crops, yet its toxicity to man and animals is very low, lower than DDT. Malathion residues disappear rapidly; usually less than one part per million remains ten days after application. It has a remarkable record of plant safety on practically all species of ornamentals, fruits and vegetables. **(No. 1)**

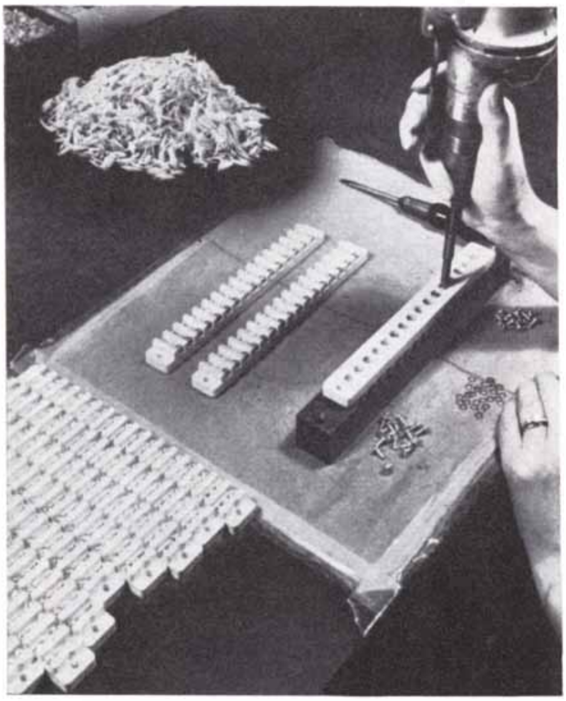
COAL MINERS STAKE THEIR LIVES on the blasting caps they use. At the Cleveland Coal Show, May 16-19, Cyanamid will exhibit to miners AMERICAN Electric Blasting Caps designed by Cyanamid research to assure maximum safety on every shot. The detonating power is more than sufficient to set off most insensitive explosives. Color-coded Organosol insulation on the leg wires is compounded of 5 layers of plastic having high electrical and mechanical strength. Timing-precision, water-tightness and handling-ease give high reputation to these blasting caps among men who know blasting best. **(No. 2)**



ANIMAL GLUES STAY FLUID FOR DAYS with less than 1% of Cyanamid's Dicyandiamide (based on dry solids) added as the fluidizer. This *non-progressive* property imparted by dicyandiamide, a property many other fluidizers lack, means glues stay workable and spread smoothly for days, give better results, cost less. **(No. 3)**



GUANYLUREA PHOSPHATE is an effective corrosion inhibitor in the new water-based latex-type paints. No rusting of the tin can or discoloration of the paint were observed when about 1.0% guanylurea phosphate was used at pH 8. Hot aqueous solutions of guanylurea phosphate for metal cleaning remove rust and passivate steel surfaces by forming a phosphate coating. **(No. 4)**



TERMINAL BLOCKS WITH EXCEPTIONAL STRENGTH, both electrical and mechanical, are being molded for the U. S. Navy from Cyanamid's new MELMAC® Molding Material 3135, shown in the inset. A unique melamine-glass high-impact molding material, MELMAC 3135 has very high arc and flame resistance. It can be compression- or transfer-molded into small or large parts, can be preformed and preheated, and flows so well that intricate and thin-sectioned parts can be molded without "shorts." **(No. 5)**

AMERICAN Cyanamid COMPANY
30 ROCKEFELLER PLAZA
NEW YORK 20, NEW YORK

SEND more information on the following items mentioned in the May, 1955 issue of LIFE on the Chemical Newsfront: S.A.

No. 1, 2, 3, 4, 5.

Literature ☐ **Price** ☐ **Samples** ☐ **of**__________

Name__________

Company__________

Address__________

City__________ Zone_____ State__________

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

MAY, 1905: "A new system of intercommunication telephone, the most salient characteristic of which is that absolute secrecy and privacy are secured while conversation is being maintained between two persons, has been introduced by the General Electric Company of Great Britain. In this latest device it is absolutely impossible for any tapping, interruption, overhearing, or leakage to take place. Secrecy is insured by the provision of a complete metallic circuit to each pair of stations. This system is particularly adapted to government offices or other similar conditions where secrecy between any two departments at time of conversation is a particular desideratum."

"Prof. Jacques Loeb of the Rudolph Spreckels Physiological Laboratory of the University of California has described a method by which it is possible to produce swimming larvae from the unfertilized egg of the sea urchin. This method consisted originally in putting the sea urchins' eggs for about two hours in hypertonic sea water. The development of these eggs, however, differed in certain points from that of the eggs fertilized with sperm. In particular, the number of larvae developing from fertilized eggs is, as a rule, practically 100 per cent, while in the case of artificial parthenogenesis a much smaller percentage of the eggs developed into swimming larvae. Prof. Loeb decided to combine two methods of artificial parthenogenesis, each of which alone imitated the process of sexual fertilization only partially. When he applied two methods in succession, namely the original osmotic method and a treatment with ethyl acetate, he obtained surprising results. Ninety to 100 per cent of the eggs developed. The rate of segmentation was practically the same as that of the eggs of the same female, fertilized with sperm. A large percentage of the blastulae originating from this combination of methods looked perfectly normal. Their further development occurred with the same velocity as that of the

control eggs, which had been fertilized by sperm. Prof. Loeb concludes that it is obvious that we are now able to imitate the process of sexual fertilization in the egg of the sea urchin in all its essential features by purely physical and chemical means."

SCIENTIFIC AMERICAN

MAY, 1855: "Last week a patent was granted H. K. McClelland, of Eldersville, Pa., for an improvement in fountain pens, the nature of which consists in providing the tube handle with a small India-rubber bag for containing the ink. In the tube there is a valve, which is operated by a spring key like that of a musical instrument, and there is a small piece of sponge at the neck of the tube, which gives out the ink to the pen. When writing, by pressing with the finger upon the key, the ink flows out to the sponge when wanted, and keeps up a supply to the pen, thus obviating the trouble of dip, dip, dipping into an ink bottle."

"A correspondent who has worked journeywork at coffin-making during the past four years informs us that a great many coffins are required of certain sizes, while but few are required of other sizes. He submits the following monthly averages from the sales book of his employer, James B. Richards:

Ft.	In.	Coffins	Ft.	In.	Coffins
–	20	20	4	8	1
2		20	4	10	1
2	4	20	5		1
2	6	19	5	2	2
2	8	20	5	4	4
2	10	20	5	6	9
3		18	5	8	10
3	6	9	5	10	12
3	8	8	6		12
3	10	7	6	2	4
4		3	6	4	4
4	6	1	6	6	3

Our correspondent notes that the last three are almost always required for the months of December and January."

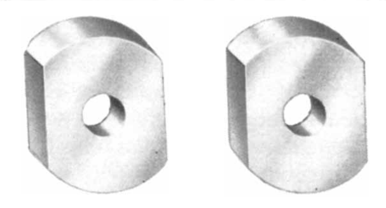
"John A. Roebling, C. E., has been trying to sound the Niagara River below the Falls. A 40 lb. weight attached to a No. 11 wire was dropped from a height of 225 feet from the bridge, but was only out of sight for a second when it was thrown up to the surface about 100 feet down the stream. The weight had a

Carboloy Trends and Developments for Design Engineers...

How to select permanent magnet materials
How to use Thermistors as a circuit element
High-temperature testing with chrome carbide

Change of magnet material improves rotor performance

Outwardly, these two magneto rotors are exactly the same. But in performance, there is quite a difference.



Original rotor (left) was Alnico 5. Then Carboloy magnet engineers demonstrated that the flatter, more stable demagnetization curve of Carboloy® Alnico 6 would provide more coercive force and greater stability . . . without increasing cost. The new rotor is exactly the same size and shape — but 15-20% more effective.

In this case, Carboloy magnet engineers helped the manufacturer improve product performance through the use of a more suitable magnet material. Carboloy engineers can call upon their extensive knowledge of magnet materials to reduce product size and weight, simplify design, or lower costs.

Carboloy magnet engineers, aided by new measurement and development facilities, can also assist you in design and magnetic circuit analysis, and with the associated problems of magnetization, testing, demagnetization and stabilization. For more information, write, today, outlining your problem.

Thermistors simplify circuit design and lower costs

Heat practically any material, and its resistance *increases*. But heat a Carboloy Thermistor, and its resistance *decreases* tremendously.

For a temperature range from −50°C to 200°C, resistance of copper or platinum, for example, doubles. Over the same temperature range, resistance of Carboloy Thermistors decreases by a factor of 10,000.

With some Thermistors, it is possible to reduce resistance 50% with a temperature increase of 17°C.

Large temperature coefficients and other nonlinear characteristics make Thermistors ideal low-cost circuit elements for the measurement and control of minute temperature changes. These electronic semi-conductors eliminate costly, fragile components. They never wear out, never need maintenance.

To help designers evaluate the circuit possibilities of Thermistors, Carboloy offers engineering assistance, a 54-page Technical Manual, and several inexpensive Thermistor engineering kits. Write today.

Grade 608 Chrome Carbide remains stable at 1800°F

High temperature metals are frequently tested at temperatures in the range of 1800°F. But before performance can be measured accurately, engineers must have structural materials for their testing devices that can withstand such elevated temperatures.

Conventional metals and alloys rapidly become unstable above 1500°F. As temperature goes higher, there is a tremendous decrease in resistance to oxidation and creep. And, while ceramics can take the heat, they are too brittle for most tests.

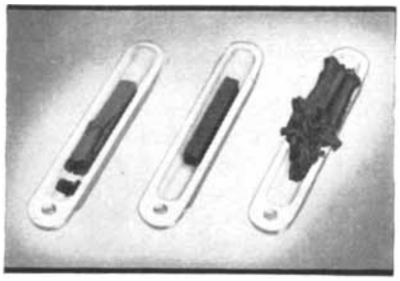
Today, however, test engineers are turning to a new structural material, Carboloy Grade 608 Chrome Carbide.

Chrome carbide combines all the requisites of high - temperature materials:

It retains strength at 1500°F or higher.

It resists oxidation at 1800°F or higher.

It resists creep and deformation at 1800°F or higher.



The photograph, above, demonstrates Carboloy Grade 608 Chrome Carbide's oxidation resistance at 1850°F, for 24 hours. At left, is 18-8 stainless steel; at right, tungsten carbide . . . both disintegrated. The chrome carbide in the center is untouched, except for a slight surface discoloration.

The transverse rupture strength of Carboloy Chrome Carbide is exactly the same at 1800°F as it is at room temperature — 100,000 psi.

These characteristics make chrome carbide ideal for load-applying members and sample grips for transverse rupture and tensile stress rupture testing, for anvil and Brale extensions, and for Brinell balls for hardness tests.

These same characteristics, plus chrome carbide's high abrasion resistance make it equally valuable for many wearproofing applications. For more information on the physical properties and applications of Carboloy Grade 608 Chrome Carbide, write today. A low-cost Grade 608 engineering appraisal kit is available.

Permanent magnets, Thermistors and chrome carbides are but three of the Carboloy Created-Metals now helping designers improve products and lower costs. Others include: *cemented carbides* for combating wear, *Hevimet* for high-density and radioactive shielding applications, and *vacuum-melted metals.*

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"A law suit is now going on between Morse and Smith, concerning their respective rights in the Telegraph Patent. Morse claims $500,000 from Smith—$200,000 of it for Amos Kendall's legal fees. Smith objects to paying such a nice little sum, and we don't wonder at it. It is not a question of infringement, but a dispute beween old friends and partners in the same patent."

"From a communication lately made to the Academy of Science, by one of the surgeons belonging to a French regiment in the East, it appears that chloroform has been very extensively employed in the cases of wounded soldiers in the Crimea, and with most successful results. The apparatus used was of a most simple character, consisting of a piece of twisted paper, of a conical shape, with the wide end large enough to cover the mouth and nostrils of a patient, and cut round at the sharp end, so as to admit the passage of air. A piece of lint placed at this narrow end served to receive the chloroform, of which from twenty to thirty drops were poured on it. The patient being then placed on his back, with a bandage over the eyes (light being found to materially impede the effects of the inhalation), the little paper bag was placed closer and closer to the mouth. This plan was employed in the case of every man in the French Army badly wounded at Alma and Inkerman."

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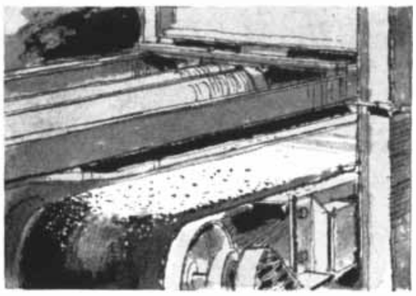
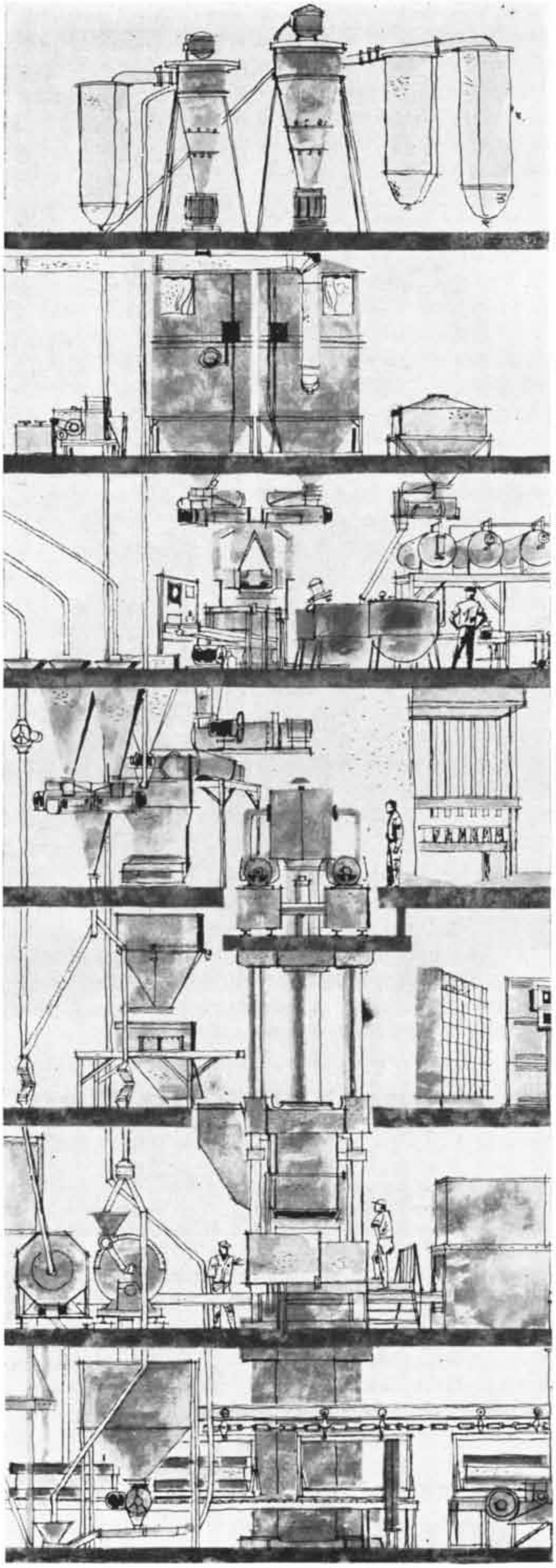
ELECTRONIC COMPUTER DEPARTMENT **Remington Rand** INC. ROOM 1514, 315 FOURTH AVE., NEW YORK 10

new automatic factory does 18-hour job in 4 minutes

•



A MOVING BELT starts ground cork on the journey that turns it into cork composition for industrial use. Mixed with binder, ground cork is compressed into mats and cured by a new dielectric method that takes advantage of the polar nature of cork and binder molecules.



Electronics and automation team up to produce better cork compositions for expanding industrial use

Today, in the Pittsburgh plant of the Armstrong Cork Company, a 7-story combination of automatic controls and electronic baking is turning ground cork into cork composition mats faster than ever before . . . and doing it better. Sheets sliced from these mats are far more uniform, make more dependable gaskets, clutch facings, and other cork products.

Cork is one of nature's best heat insulators. That's why, using steam heat, it used to take at least 6 hours of baking to set the binder of a 3-inch-thick mat. Often the outside of the mixture was "overcooked" before the center was done. Now, a mat three times as thick is baked electronically in about 4 minutes . . . 270 times as fast as the 18 hours required to bake three 3-inch mats by the old steam method.

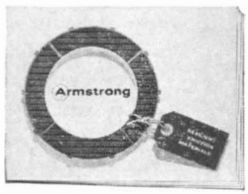
Uniformity in mixing, too, is assured by automatic machinery that thoroughly blends ground cork with binder ingredients. Extremely sensitive equipment is needed because cork is so very light. For example, 4 ounces is the average load metered by a continuous weighing belt that's accurate within 1%.

Cork's light weight creates blending problems, too. It's difficult to make the light particles rub against each other hard enough to spread the heavier binder. A specially designed, high-speed, continuous mixer solves the problem. It pours a large amount of energy into a small amount of cork—30 horsepower into only 10 pounds of mix. Mixing takes place under pressure in the confined area between a cylinder rotating within a slightly larger fixed cylinder. Every particle is coated with binder in 10 to 15 seconds.

To turn the mix into cork composition, it must be compressed into a mold and baked. For high density compositions, mix weighing 3 pounds per cubic foot must be compressed until it weighs 35 pounds per cubic foot. A hydraulic press three stories high does this job. On a 28″ x 50″ plate, it exerts pressures up to one million pounds.

After compression, the mix goes into a dielectric oven. While steam-cured cork composition varied as much as 18% in density, electronically cured mats vary less than 3%—a sixfold improvement.

To meet the changing needs of industry, Armstrong is continually developing new, more dependable types of cork composition. Among the more important are facings for automotive and appliance clutches. For a discussion of cork as a clutch facing, send for the new 20-page illustrated manual, "Armstrong Resilient Friction Materials." Write on your letterhead to Armstrong Cork Company, Industrial Division, 8205 Inland Rd., Lancaster, Pennsylvania.



Armstrong INDUSTRIAL PRODUCTS

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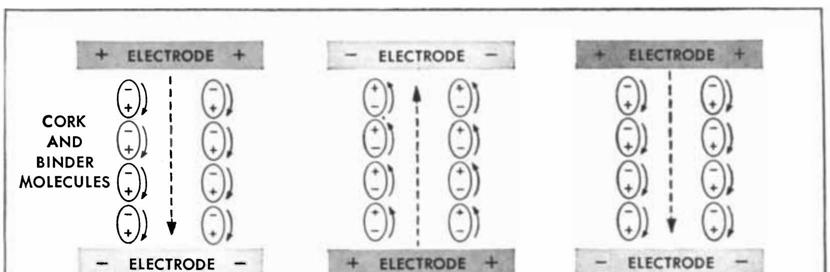
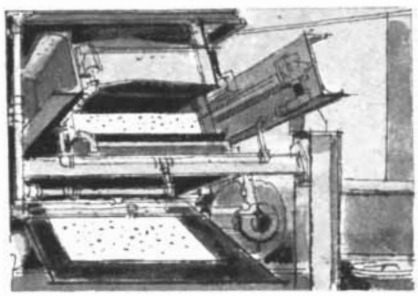
adhesives . . . cork composition . . . cork-and-rubber . . . felt papers . . . friction materials



MOLECULES SWING BACK AND FORTH LIKE THIS 13,000,000 TIMES A SECOND.

CORK AND BINDER MOLECULES are dipoles—that is, electrically positive at one end, negative at the other. When the cork mix is placed between two charged electrodes, the molecules always turn their positive poles toward the negative electrode. By alternating the electrodes from positive to negative at high frequency (13 megacycles), the dipolar molecules are made to swing violently back and forth 13 million times a second. Friction developed between these moving cork and binder molecules uniformly heats the 9-inch-thick mat from top to bottom in only 4 minutes.



THE CURED MAT IS SLICED into sheets varying from 1/32-inch to 1-inch thick. Because mixing is precise and dielectric heating cures the mats evenly, these cork composition sheets are exceptionally uniform in density, tensile strength, compression and recovery range, and in color.

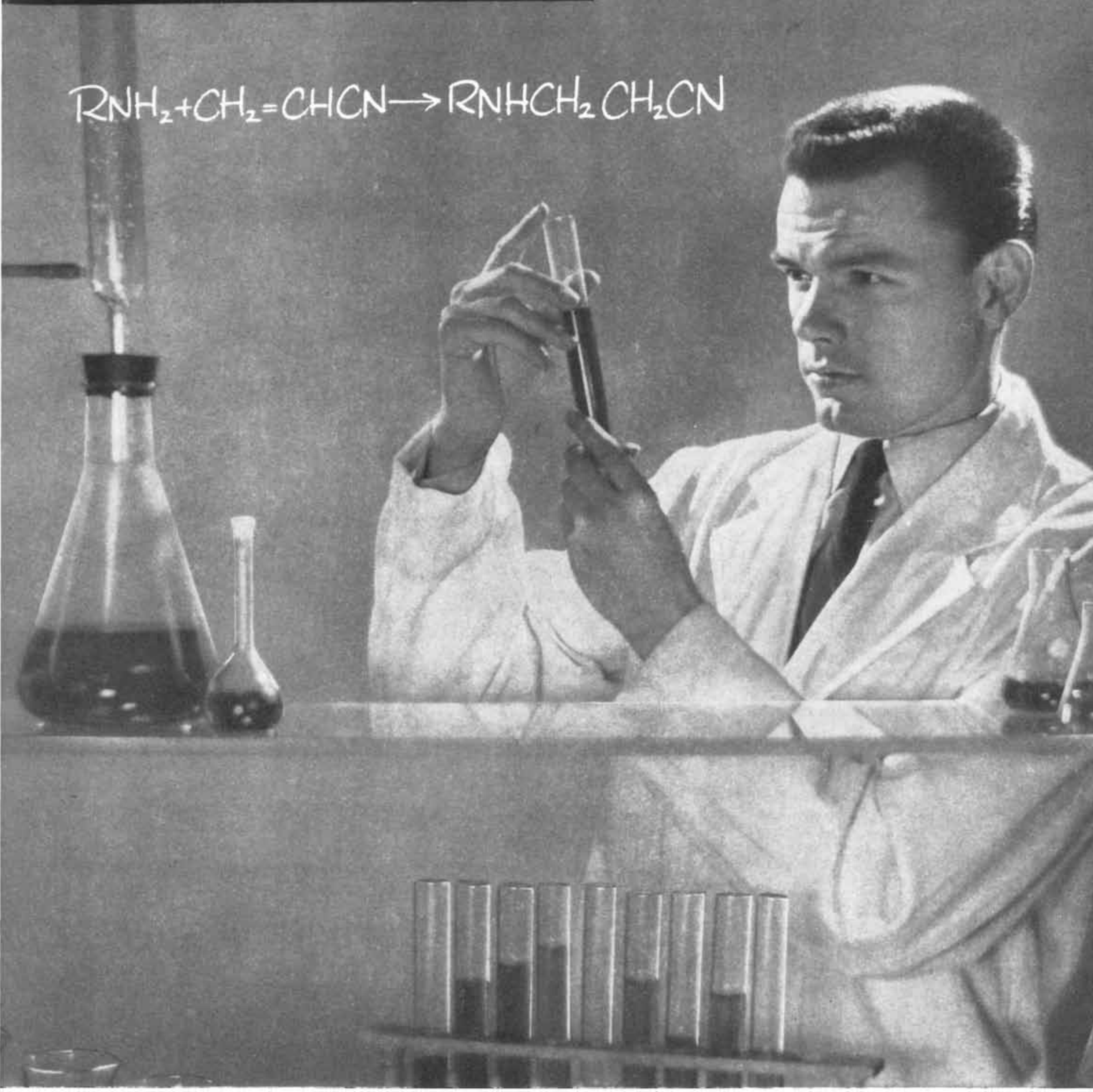
THE AUTHORS

RENE J. DUBOS ("Second Thoughts on the Germ Theory") is a member of the Rockefeller Institute for Medical Research in New York City. His career in microbiology dates from 1924 when, as a young assistant editor with the International Institute of Agronomy in Rome, he chanced to read an article by the émigré Russian microbiologist Serge Winogradsky. In his paper Winogradsky called for an ecological approach to the microbiology of the soil, rather than the study of its organisms one by one. Dubos, much impressed by the idea, later embarked for the U. S. to start some research of his own at Rutgers University. He took a Ph.D. at Rutgers in 1927, then joined the Rockefeller Institute where, except for two years spent teaching at Harvard University, he has been ever since. Dubos' early interest in the soil has turned out to be extremely productive. In 1939 he isolated the first antibiotic substance (which he first called gramicidin and later tyrothricin) in crystalline form from soil bacteria. His work in antibiotics won him a share in a 1948 Lasker Award of the American Public Health Association.

E. O. P. THOMPSON ("The Insulin Molecule") is a biochemist with the Commonwealth Scientific and Industrial Research Organization of Australia. Born in Sydney, he was graduated with first-class honors in organic chemistry from Sydney University in 1945 and after five years of teaching and research there obtained a fellowship which enabled him to go to England to work on insulin under Frederick Sanger at Cambridge University. Thompson carried out further studies on proteins during 1953 at the College of Medicine of the University of Utah at Salt Lake City. He is now investigating the chemistry of wool, "a complex protein material," in the Wool Textile Research Laboratories in Australia.

W. W. MORGAN ("The Spiral Structure of the Galaxy") is a professor of astronomy at the University of Chicago and Yerkes Observatory. He has been at Chicago since he took his Ph.D. there in 1931. His first research was on stars whose spectra indicate a wealth of the rare-earth elements, such as europium. In 1942 he began working out the distances of all the blue giant stars that can be observed with the 40-inch re-

THE CHALLENGE OF CYANOETHYLATION



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fractor at Yerkes, and as a result of this work discovered two spiral arms in the Milky Way not far from the sun. The astronomer Otto Struve, who was present at the 1951 meeting where Morgan announced his discovery, wrote later: "Astronomers are usually of a quiet and introspective disposition. Moreover, they tend to be cautious—more often than not they take plenty of time to weigh the evidence before they accept it. But in Cleveland, Morgan's paper on galactic structure was greeted by an ovation such as I have never before witnessed." Since then Morgan has turned to the optical exploration of still more distant parts of the galaxy.

FRITS W. WENT ("Air Pollution") is professor of plant physiology at the California Institute of Technology. His article on "The Ecology of Desert Plants" appeared in the April issue.

DANIEL H. FUNKENSTEIN ("The Physiology of Fear and Anger") is director of clinical psychiatry at Boston Psychopathic Hospital and an associate in psychiatry at the Harvard Medical School. After taking his M.D. at the Medical College of Louisiana in 1934, he trained in surgery at Barnes Hospital and Washington University in Saint Louis, but his work in the Air Force in World War II turned him from surgery to psychiatry. On his return to civilian life he obtained psychiatric training and began to investigate stress reactions in the laboratory. Most of the research he reports in his article was financed by grants from the 33rd-degree Scottish Rite in the U. S. Northern Masonic Jurisdiction through the National Association of Mental Health.

TATIANA PROSKOURIAKOFF ("The Death of a Civilization") is a member of the archaeological staff of the Carnegie Institution of Washington. She was born in 1909 in Tomsk, in western Siberia, where her parents were students at the university. The family came to the U. S. on a government mission during World War I and remained afterward. Miss Proskouriakoff grew up in Philadelphia and studied architecture at the University of Pennsylvania and at Pennsylvania State College. Finding architects not much in demand during the depression, she turned to free-lance drawing. Linton Satterthwaite of the University of Pennsylvania Museum, for whom she made a drawing of a shell inscribed with hieroglyphics ("It was this strange writing which first aroused my interest in the Maya," she says), in-

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vited her to join a museum expedition to Guatemala. She spent two field seasons there making drawings of the excavations. She joined the staff of the Carnegie Institution in 1946. From Yucatan, where she is now, she writes: "In my spare time I still play with Maya hieroglyphs. At present I am digging in an ancient Maya kitchen to learn something of the domestic life of those times. When all the technical work is done, I hope to make some sketches, reproducing not only the buildings at Mayapan, but also scenes of ancient activities."

DANIEL D. McCRACKEN ("The Monte Carlo Method") is a numerical analyst in the aircraft gas turbine division of the General Electric Company at Cincinnati. He joined General Electric in 1951 after graduating from the Central Washington College of Education with degrees in chemistry and mathematics. Most of his work has been in the field of electronic computing, and he is now on the staff that operates G.E.'s IBM 701 at Cincinnati. He is an amateur musician and, on vacations in the Northwest, a mountain climber.

BROTHER G. NICHOLAS, F.S.C. ("Life in Caves") is a science teacher at La Salle High School in Cumberland, Md., and a member of the Brothers of the Christian Schools (Fratres Scholarum Christianarum). He is a graduate of Catholic University and has an M.S. from the University of Pittsburgh. In spite of his teaching load of 34 hours a week, Brother Nicholas has managed to write some 25 articles, mostly on the biology and paleontology of caves, and at 27 is a vice president of the National Speleological Society. He writes: "I have explored some 200 caves, mainly in Maryland, Virginia, West Virginia and Pennsylvania. Being mainly a biologist, I became intrigued as to just how any life could possibly exist in such apparently desolate regions. This, plus the luck of stumbling over some important fossil remains near Cumberland, gained for me the opportunity of meeting several individuals willing to finance some large-scale excavations in the Cumberland Bone Cave. From this it was a natural step to explain the relationships of the animals found there. At times, after wading through cold water up to my chin and squeezing through rocky crevices fit for only a caterpillar, I have wondered whether it was worth all the trouble just to report on some crazy cave cricket. There is so little being done on the biology of caves, though, that I suppose somebody has to do it."

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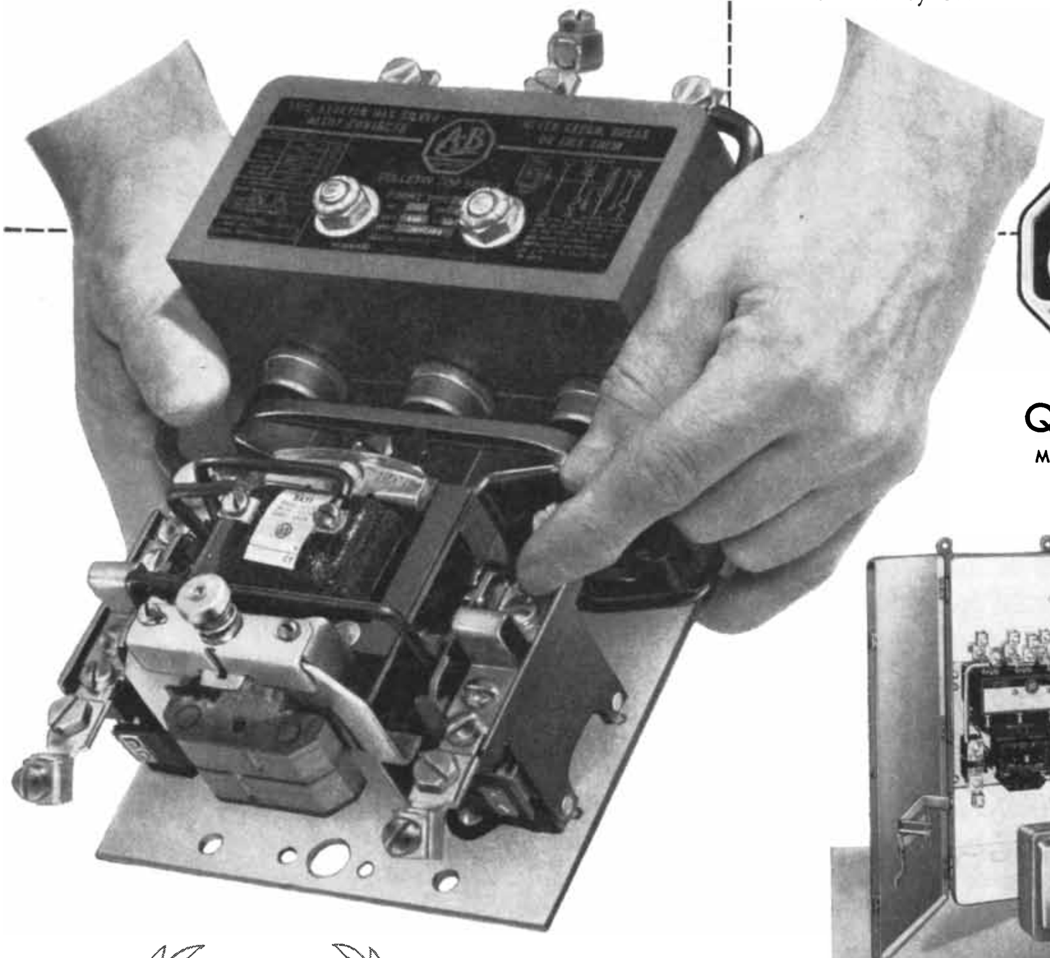

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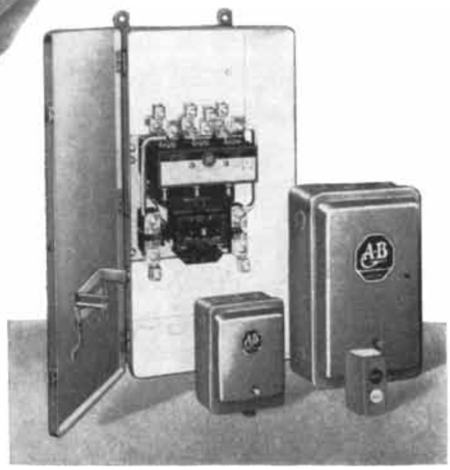

Allen-Bradley trouble-free, across-the-line, squirrel cage motor starters range from Size 0—1½ hp, 110 v; 2 hp, 220-440-550 v; to Size 7—300 hp, 220 v; 600 hp, 440-550 v. All are available in the various NEMA type enclosures.

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THE COVER

The photograph on the cover shows a small section of a mural in a Maya temple. Located at Bonampak near the southern border of Mexico, the temple was discovered only in 1946. The entire mural depicts the ceremonial torture and execution of prisoners by Maya dignitaries. The figure on the cover is one of the prisoners. At upper left is a Maya inscription. Mural was made during seventh and eighth centuries A.D., when the Maya culture was in full flower. By the 15th century it had declined to the state described in the article beginning on page 82.

THE ILLUSTRATIONS

Cover photograph by
Manuel Alvarez Bravo

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DESIGNING WITH ALUMINUM

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NO. 12

ROLL FORMING VS. EXTRUDING

ROLL FORMED SHAPES are produced by passing a continuous strip of material through a series of mating pairs of contoured rolls, each of which bends the strip a little closer to the desired form; the finished shape emerging from the last pair of rolls at a rate of from 75 to 300 feet per minute. The length of the shape is limited only by the length of coil stock available. The finished shape is straight and ready to be sawed to usable lengths as it leaves the roll former.

The process was originally a refinement of the draw bench. By adding a pair of contoured rolls to the bench it was found that the finish and shape of the resulting section could be improved and higher production rates attained. Additional stands of rolls were added until they were accomplishing the entire forming operation.

To produce an extruded shape, a die consisting of a flat steel plate containing an opening of the required shape, is clamped against one end of a container which ordinarily takes the form of a cylinder open at both ends. A cast billet pre-heated to a temperature well within the plastic range is placed in the container and pressure is applied through the open end by the ram of a hydraulic press. Hot metal is slowly forced out through the die opening, assuming the shape of the opening. The rate of extrusion varies from one or two feet per minute to as much as one hundred feet per minute, depending on the composition and temperature of the alloy being extruded. Extruded shapes may be twisted as they come from the extrusion press and must be straightened before they are ready for use. Straightening is ordinarily accomplished by stretching. A variety of other equipment such as roll straighteners, gag presses and detwisters is employed to straighten heat treated sections.

Fig. 1. Multiple hole extrusion die.

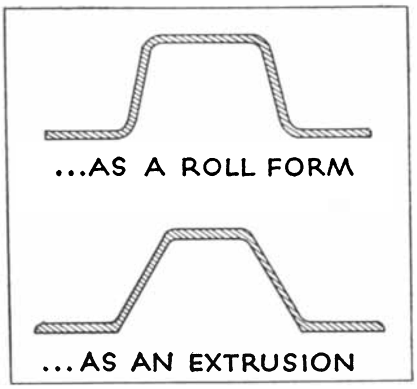

Fig. 2. Trailer side post design. Note more efficient distribution of metal possible with extruded post.

Typical sections produced by the two methods are illustrated in the above drawing. At first glance these sections appear to be quite similar, but closer study reveals several important differences. Since the roll formed section is produced from strip stock it follows that the metal thickness must be uniform throughout the cross section. Extrusions are not subject to such limitations and it is possible to vary the thickness of adjoining sections abruptly through rather wide limits, though the difficulty of obtaining a satisfactory extrusion increases with the disparity in thickness. This fact makes it possible to distribute the metal more efficiently and the stiffness/weight ratio of a properly designed extrusion will equal or exceed that of the corresponding roll formed section.

The thickness of metal which can be extruded is limited by a number of factors having to do with the shape of the section and the alloy to a minimum in the neighborhood of 0.040 in. Roll formed sections can be successfully produced from strip as thin as 0.005 in. and the only restriction imposed by the alloy is that of the minimum corner radius which can be produced without cracking the strip. Even in the most readily formed materials the minimum radius of an outside corner would be the thickness of the material. The corresponding minimum for an extruded section would be about 1/64th inch and would be entirely independent of section thickness.

Extrusions are generally preferred for hollow sections. In certain cases it is possible to produce closed sections by adding an induction welding head to the roll forming machine. This technique is restricted to the production of circular tubing, but will undoubtedly be applied to more complex shapes in the future.

By the very nature of the process, it is inevitable that an extruded section will carry a pattern of fine scratches parallel to its length, which may detract from its appearance in certain applica-

PLEASE TURN TO NEXT PAGE

tions. Roll formed sections begin as a strip of highly finished sheet and if properly handled this finish will not be marred. In fact the normal forming operation improves the finish to the extent that the completed product is more or less polished by the surface of the rolls. This fact leads to a preference for roll formed sections for many applications in the truck body, automotive, building and furniture fields and for many sheet metal, aircraft and household articles where the finish of the formed section is important.

Fig. 3. Roll forming produces an almost unlimited variety of shapes.

Again because they start as sheet, already a fully wrought product, roll formed sections develop higher tensile properties than do extrusions. Because the forming takes place gradually, strain is more uniformly distributed in the roll formed section. Subsequent forming operations required to fabricate the finished product are more easily accomplished than in sections produced by other methods. Where a customer requires a bending or a joggling operation in his finished part, he will find that a cold roll formed part is more easily worked than an extrusion, drawn section or a brake formed part.

It is possible to perform several additional operations by adding suitable attachments to the roll forming machine. By adding a set of coiling rolls at the exit end it is possible to form the section into rings of any reasonable diameter without additional handling operations. Numbering, printing or embossing rolls may be incorporated in the tooling. With embossing rolls, such objects as picture frames, automobile scuff plates, and even jewelry may be formed with the roll design imprinted in the metal.

Rolled sections with inserts of wood, fabric, wire, powdered material, paper and any other substance which can be fed to the machine continuously, are easily formed.

While extrusions do not lend themselves to the application of a repeated pattern while being produced as do the roll formed sections, they may be easily and economically designed to meet specific product requirements. It is easy to add metal from which ribs, lugs and pads may be produced with little or no additional machining.

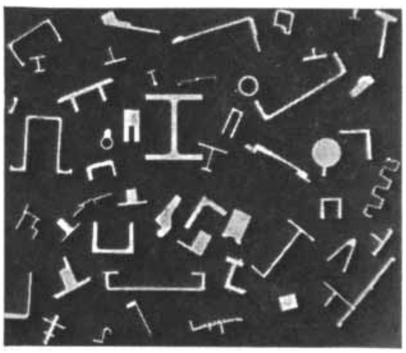

Fig. 4. Cross sections of typical extruded shapes.

The contoured rolls required for the production of cold roll formed shapes are relatively expensive since they require a considerable amount of hand work to match the male and female rolls in each pair exactly. The number of pairs or "stands" of rolls required to produce a given section is directly proportional to the complexity of the section. As many as thirty stands have been used on an especially intricate shape, although this must be considered unusual. Most sections may be formed on machines designed for a maximum of sixteen stands. Once the dies have been made and adjusted, production proceeds at a relatively high rate.

In contrast, extrusion dies are simple and much less costly but production is generally slower. The choice of production method will then be considerably influenced by the total quantity and rate of production which is desired. Relatively long runs are required to amortize the cost of roll dies.

When all properties of the two types of section are considered, it becomes apparent that the title of this article is somewhat misleading. "Roll Forming *and* Extruding" would be more appropriate for each has its special field of application in which the other simply cannot do the job as well.

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CONTENTS FOR MAY, 1955 VOL. 192, NO. 5

ARTICLES

DEPARTMENTS

Dry pre-coated adhesive film speeds rubber-to-metal bonding

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Reactivation of the dry film is easy. Fresh adhesive is applied to the metal surface and the rubber part pressed firmly into place. The dry D-280 film absorbs solvent from the fresh adhesive and is reactivated by it. The result is a quick grab that holds the pad firmly in position. The final bond is usually stronger than the rubber itself.

For more information on D-280 and other Armstrong Adhesives, write Armstrong Cork Company, Industrial Division, 8005 Inland Road, Lancaster, Pennsylvania. In Canada, please write to 6911 Decarie Boulevard, Montreal.

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SCIENTIFIC AMERICAN

MAY, 1955 VOL. 192, NO. 5

Second Thoughts on the Germ Theory

Everyone harbors disease germs, yet not everyone is sick. This is ascribed to "resistance," suggesting that germs are less important in disease than other factors affecting the condition of the host

by René J. Dubos

The germ theory of disease has a quality of obviousness and lucidity which makes it equally satisfying to a schoolboy and to a trained physician. A virulent microbe reaches a susceptible host, multiplies in its tissues and thereby causes symptoms, lesions and at times death. What concept could be more reasonable and easier to grasp? In reality, however, this view of the relation between patient and microbe is so oversimplified that it rarely fits the facts of disease. Indeed, it corresponds almost to a cult—generated by a few miracles, undisturbed by inconsistencies and not too exacting about evidence.

Historians usually give a biased account of the heated controversy that preceded the triumph of the germ theory of disease in the 1870s. They barely mention the arguments of those physicians and hygienists who held that clinical observations could not be completely explained by equating microbe with causation of disease. The critics of Louis Pasteur and Robert Koch pointed out that healthy men or animals were often found to be harboring virulent bacteria, and that the persons who fell victim to microbial disease were most commonly those debilitated by physiological disturbances. Was it not possible, they argued, that the bacteria were only the secondary cause of disease—opportunistic invaders of tissues already weakened by crumbling defenses?

It is entertaining to note that this doctrine was recently revived in an English court of justice. According to an account published in *The Lancet* of November 6, 1954, a lacquer sprayer, aged 36, sued his employers on the ground that he had contracted pneumonia and pleurisy because the spraying room in which he had worked was cold and drafty. His lordship the judge found that the plaintiff's work place was indeed cold, drafty and damp in the early morning. He accordingly awarded damages totaling 401 pounds, feeling satisfied that the plaintiff's illness was caused by the absence of heating. There is little doubt that the pneumonia and pleurisy of which the workman complained were manifestations of the activities of some microbial agent—virus or bacterium or probably both. Furthermore, it is probable that the workman had not contracted infection in the shop but had been harboring the guilty microbes in his organs for weeks, months or perhaps even years. The ruling that the deficient heating had *caused* the pneumonia brings to mind the view expressed by George Bernard Shaw in the preface to *The Doctor's Dilemma:* "The characteristic microbe of a disease might be a symptom instead of a cause."

Louis Pasteur, founder of the germ theory

Fortunately for the prestige of the germ theory, another case involving a microbial disease was being tried at the same time before a French court. Readers of SCIENTIFIC AMERICAN will recall that the myxomatosis virus, which has killed off immense numbers of rabbits in Australia, was recently introduced in France by a doctor who wished to get rid of the rabbits on his estate, and that the disease soon spread over most of Western Europe [see "The Rabbit Plague," by Frank Fenner; February, 1954]. The too-enterprising French doctor was sued for huge sums of money by enraged hunters, fur dealers, rabbit breeders and others whose interests had been affected. The trial brought out many fine points of legal responsibility, but there was no doubt in anyone's mind that the myxomatosis virus—not some climatic or physiological factor—was the cause of the destruction of rabbits. The germ theory had been vindicated.

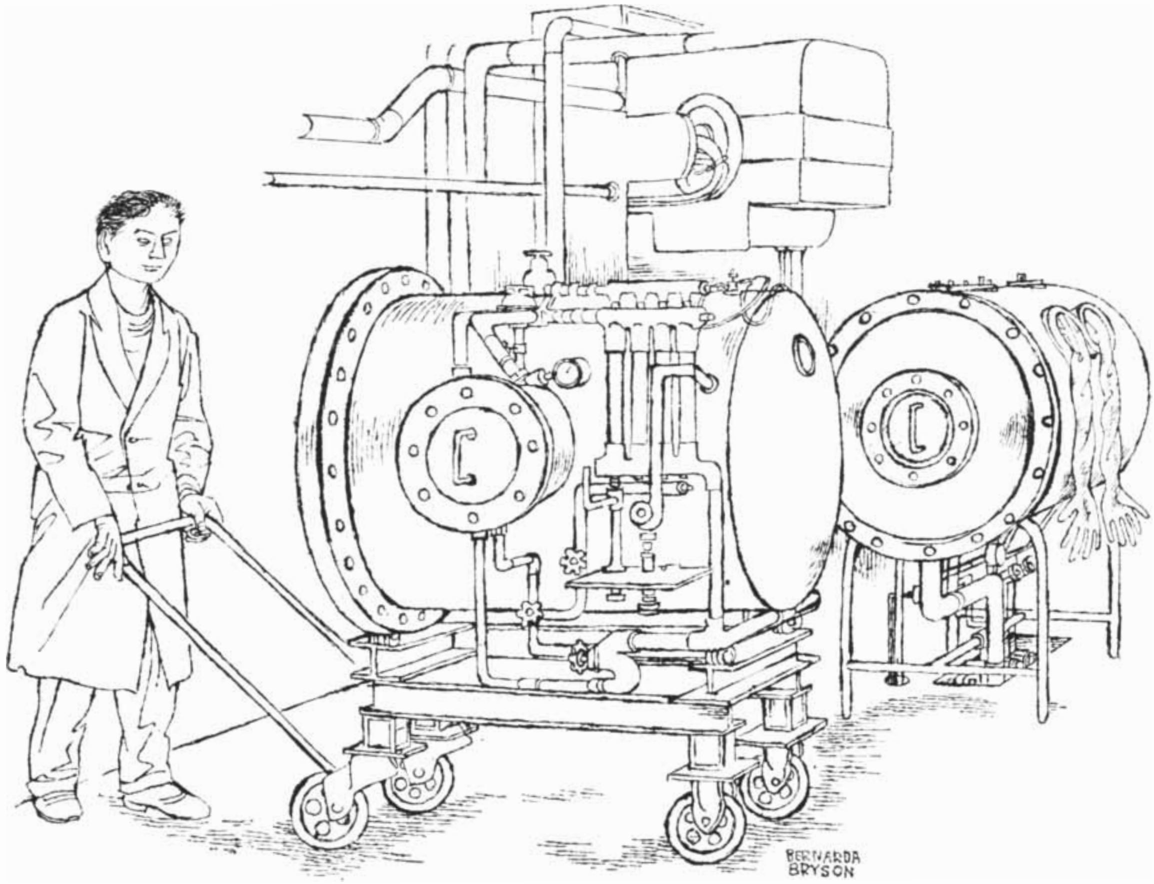
History offers many examples which, like myxomatosis, illustrate the operation of the germ theory of disease in its simplest and most direct form. The epidemic that ravaged Athens during the Peloponnesian War has not been convincingly identified, but Thucydides' vivid description makes clear its immensely destructive power. According to Edward Gibbon, the Justinian plague killed most of the European population during the 6th century, and plague reappeared with the same virulence in Western Europe under the name of "The Black Death" in the 14th century. Other illustrations could be selected from more recent historical events: the immense mortality caused by smallpox among the American Indians when they came into contact with the disease, introduced first accidentally, then willfully, by the European invaders; the decimating effect of measles in the Sandwich (Hawaiian) Islands in 1775, in the Fiji Islands a century later and among the Columbia River Indians in 1830; the death from tuberculosis of some 90 per cent of the Indians of the Qu'Appelle Valley in Western Canada within a decade. These instances, selected at random, provide tragic evidence that a microbial agent may strike down the weak and the healthy alike when newly introduced in a susceptible population.

Robert Koch, another early exponent of the germ theory

Yet what shall we say of the case of pneumonia that came before the English court? There are many situations in which the microbe is a constant and ubiquitous component of the environment but causes disease only when some weakening of the patient by another factor allows infection to proceed unrestrained, at least for a while. Theories of disease must account for the surprising fact that, in any community, a large percentage of healthy and normal individuals continually harbor potentially pathogenic microbes without suffering any symptoms or lesions. This type of dormant infection seems to occur widely, not only among men and animals, but also probably among plants and even microscopic cells. Only a few examples need be quoted to illustrate the theoretical interest and practical importance of the phenomenon.

All the healthy-looking mice raised for medical research under highly standardized and hygienic conditions carry a multiplicity of viruses capable of causing in them severe and often fatal pulmonary disease. Under normal circumstances the viruses remain dormant in the form of so-called "latent infections." But they can be "evoked," as the expression goes, by the simple artifice of dropping certain sterile fluids into the nasal cavity of the mouse. There is another disease, called pseudotuberculosis, which can be evoked in normal mice by subjecting the animals to radiation, to certain nutritional deficiencies or to a number of other stresses. Pseudotuberculosis results from the unrestrained multiplication of a diphtheria-type bacillus, which exists in a latent form in normal mouse tissues.

Like the mouse, normal man carries throughout life a host of microbes which now and then start proliferating and cause disease—under the influence of factors rarely if ever well understood. For example, a large percentage of the readers of this article harbor virulent tubercle bacilli and staphylococci, but very few will ever become aware of the microbes' presence. Most likely the infections will remain dormant unless brought into activity by some other intervening factor causing a "loss of general resistance"—an expression useful by



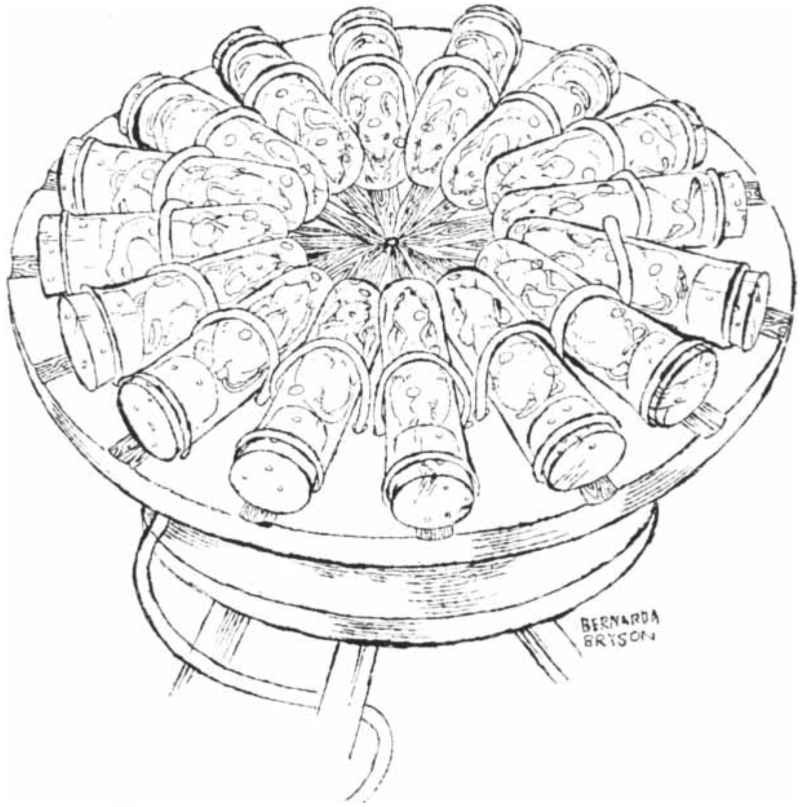
At the University of Notre Dame sterile chambers were used to raise germ-free animals

virtue of its vagueness. Uncontrolled diabetes, life in a concentration camp, overwork, overindulgence, even an unhappy love affair, may precipitate an attack of disease, much as exposure to drafts and to damp air was judged by the English court to be the cause of pneumonia. An example familiar to most of us is provided by the benign but recurrent lesions known as fever blisters or cold sores, caused by the herpes virus. Many people contract the herpes infection early in life, and the virus persists somewhere in the tissues from then on. It lingers idly until some provoking stimulus causes it to manifest its presence in the form of blisters. The stimulus may be a fever of unrelated origin, excessive irradiation, certain types of surgery, menstruation or improper food. Thus the herpes virus is merely the agent of *infection:* the instigator of the *disease* is an unrelated disturbance of the host.

It has been easy to demonstrate experimentally that the tubercle bacillus, the staphylococcus and the herpes virus are capable of causing progressive disease and even death in animals without the apparent participation of other contributory factors. For this reason these microbes are said to be virulent. But there are many other types of microbes not regarded as virulent which also can play an important part in the causation of disease under special circumstances. C. P. Miller of the University of Chicago School of Medicine has shown, for example, that some of the manifestations of radiation sickness are due to invasion of the blood and certain organs by bacteria normally present in the intestinal tract; indeed, he succeeded in protecting experimental animals from radiation death by controlling this infection of intestinal origin with antimicrobial drugs. In contrast, it has been repeatedly observed that vigorous treatment with drugs of almost any type of virulent infection in a human being may have the paradoxical effect of bringing about another type of infection, caused by the proliferation of otherwise innocuous fungi and bacteria. We are beginning, in fact, to witness the appearance of man-made diseases, caused by the rapid changes in human ecology brought about by the new therapeutic procedures.

The classical doctrines of immunity throw no light on precisely what mechanisms determine whether dormant microbes will remain inactive or begin to act up. What is needed to analyze this problem is some understanding of the agencies responsible for natural resistance to infection, and of the factors that interfere with the operation of these agencies. Fortunately interest in this area of research is increasing rapidly. Several independent trends of thought appear clearly in current programs of investigation.

One approach is a search of normal animal tissues for substances possessing antimicrobial activity. There are many such substances. One of the best known is lysozyme, discovered some 30 years ago by the late Alexander Fleming of penicillin fame. But the difficulty is not to discover antimicrobial substances; it is rather to gain information as to what role, if any, they play in the body's resistance to infection. The most interesting information on this point has come from studies at Western Reserve University Medical School by a group of



At the University of Chicago mice exposed to radiation on a turntable developed infections

immunologists under the leadership of Louis Pillemer. They have separated from human and animal sera a peculiar protein, "properdin," which can destroy or inactivate a few types of bacteria and viruses under certain conditions in the test tube. They have established, furthermore, that the concentration of properdin in serum is not constant. Particularly exciting is the finding that when animals are exposed to weakening radiation, properdin disappears almost completely within four to six days, precisely at the time when the animals become highly susceptible to the bacteria normally present in their intestinal tract.

Another determinant of susceptibility and resistance is the individual's nutritional state. History shows that famine and pestilence commonly ride together, but the links that bind them are neither obvious nor simple. This has been well demonstrated by a thoughtful analysis carried out by Howard Schneider at the Rockefeller Institute for Medical Research. I should like to cite the effect of diabetes, a metabolic disorder. It has long been known that patients with uncontrolled diabetes are extremely susceptible to certain bacteria, notably staphylococci and tubercle bacilli, whereas diabetics receiving proper insulin treatment are just as resistant to these bacteria as are normal individuals. In other words, susceptibility to infection in these cases appears to be linked in a reversible manner to the metabolic state. It is tempting to postulate that the biochemical abnormalities brought about by uncontrolled diabetes create an environment favorable for the activities of the bacteria. In fact, experiments carried out at Bryn Mawr College and at the U. S. Air Force School of Aviation Medicine by J. Berry and R. B. Mitchell, and in our own laboratory at the Rockefeller Institute, have shown that one can increase the susceptibility of mice to microbial disease by metabolic manipulations as simple as temporary deprivation of food, or feeding an unbalanced diet rich in citrate. Furthermore, resistance can be brought back to normal within two to three days by correcting the nutritional disorder.

It is clear, therefore, that susceptibility to infection is not necessarily inherent in the tissues, or dependent on the presence of antibodies, but is often the temporary expression of some physiological disturbance.

All in all, a new look at the biological formulation of the germ theory seems warranted. We need to account for the peculiar fact that pathogenic agents sometimes can persist in the tissues without causing disease and at other times can cause disease even in the presence of specific antibodies. We need also to explain why microbes supposed to be nonpathogenic often start proliferating in an unrestrained manner if the body's normal physiology is upset.

To guide one's thinking on these problems it is well to keep in mind a fact so simple that it is never talked about—namely, that the tissues of man and animals contain everything required for the life of most microbes. This is well shown by the ability of tissue cells to support the growth of bacteria and viruses in the test tube. It is therefore surprising that microbial disease is the exception rather than the rule, for we continually come into contact with all kinds of microbes. The problem, in other words, is not merely, "How do some microbes cause disease?" but rather, "Why are not all microbes capable of causing disease?"

We have already cited evidences of the tendency for a new kind of microbe to run riot in a population exposed to it for the first time. Even more striking in this regard are the observations made by James Reyniers and his colleagues at the University of Notre Dame. They found that animals born and raised in a sterile environment died when they were exposed to common bacteria such as are always present in a normal environment. For example, some of the banal microorganisms present in ordinary food products were virulent for them.

Thus the simple fact that a population survives and flourishes in a given environment implies that its members are endowed with a high degree of natural resistance to the microbes normally present in that environment. This natural resistance stems in part from evolutionary selection of the strains best endowed with mechanisms for withstanding the infections, and probably in part from the development of adaptive eactions in response to early exposure to the microbes. We cannot discuss here the workings—still very obscure—of these various protective mechanisms. Suffice it to say that their over-all effect is the establishment of a state of biological equilibrium between man or animals on the one hand, and the microbes endemic in the community on the other.

Whatever their nature, the mechanisms responsible for natural resistance are in general most effective under the narrow range of conditions constituting the "normal" environment in which the population has evolved. Any shift from the normal is likely to render the equilibrium unstable. I have already mentioned examples of disturbances that may upset the equilibrium—irradiation, metabolic abnormalities, treatment with antimicrobial drugs and so on. Psychosocial factors could have illustrated the point just as well. Although the precise mode of these factors is still unknown, there is no reason to doubt that they act by changing the environment, especially the *milieu intérieur*, in which higher organisms and microbes have evolved to a state of biological equilibrium.

During the first phase of the germ theory the property of virulence was regarded as lying solely within the microbes themselves. Now virulence is coming to be thought of as ecological. Whether man lives in equilibrium with microbes or becomes their victim depends upon the circumstances under which he encounters them. This ecological concept is not merely an intellectual game; it is essential to a proper formulation of the problem of microbial diseases and even to their control.

To be sure, there are situations where a microbe itself is a sufficient cause of disease irrespective of the physiological state of the exposed individual. Infancy exemplifies one such situation. The child, arriving so to speak as an immigrant in the human herd, comes into contact with certain microbes which are not yet fully integrated in human life by evolutionary forces and with which he as an individual has not had any experience. We have noted another type of situation where people may be defenseless against the disease agent: namely, the introduction of a new microbe in a previously unexposed population. This type of relationship is certainly in the mind of all scientists concerned with bacteriological warfare. Untold harm might follow the introduction of types of infectious agents to which we have never been exposed as a group in the past. Our farm animals or our crops would prove equally susceptible to plagues and pests so far kept at bay by unending vigilance.

However, dramatic as these special cases of complete lack of resistance may be, they do not constitute the main problem of microbial disease in ordinary life. As we have seen, practically all the common microbes already present, though ordinarily harmless, are capable of producing disease when physiological circumstances are sufficiently disturbed. These ubiquitous microbes rarely cause death, but they are certainly responsible for many ill-defined ailments—minor or severe—which constitute a large part of the miseries and "dis-ease" of everyday life. They establish a bridge between communicable and noncommunicable disease—a zone where presence of the microbe is the prerequisite but not the determinant of disease, a situation in which the fact of infection is less decisive in shaping the course of events than the physiological climate of the invaded body. For reasons that cannot be discussed here, it is unlikely that antimicrobial drugs can control this aspect of the relationship between man and microbe. What is most needed at the present time is some knowledge of the physiological and biochemical determinants of microbial diseases. For we cannot possibly hope to eliminate all the microbes that are potentially capable of causing harm to us. Most of them are an inescapable part of our environment.

The views of those who still deny the microbial causation of disease altogether are epitomized in a saying they are fond of repeating: "If the germ theory of disease were correct, there would be none on earth to believe it." I have attempted to show that this statement implies a narrow and incomplete understanding of the germ theory. Much more perceptive—indeed prophetic—was the conclusion reached by John Caius in his essay on the English "sweating sickness" in 1552: "Our bodies cannot . . . be hurt by corrupt and infective causes, except ther be in them a certein mater apt . . . to receive it, els if one were sick, al shuld be sick."

The variable host in a constant environment of germs

THE INSULIN MOLECULE

Last year, after a full decade of intensive work at Cambridge University, Frederick Sanger and his colleagues for the first time totally described the chemical structure of a protein

by E. O. P. Thompson

Proteins, the keystone of life, are the most complex substances known to man, and their chemistry is one of the great challenges in modern science. For more than a century chemists and biochemists have labored to try to learn their composition and solve their labyrinthine structure [see "Proteins," by Joseph S. Fruton; SCIENTIFIC AMERICAN, June, 1950]. In the history of protein chemistry the year 1954 will go down as a landmark, for last year a group of investigators finally succeeded in achieving the first complete description of the structure of a protein molecule. The protein is insulin, the pancreatic hormone which governs sugar metabolism in the body.

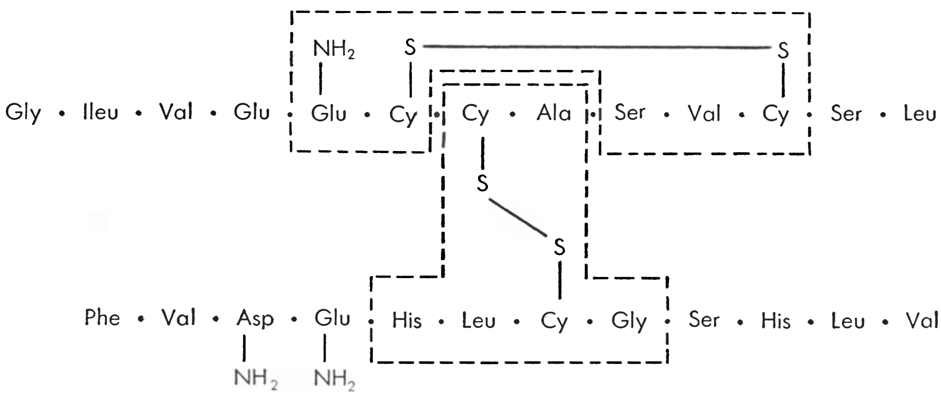
Having learned the architecture of the insulin molecule, biochemists can now go on to attempt to synthesize it and to investigate the secret of the chemical activity of this vital hormone, so important in the treatment of diabetes. Furthermore, the success with insulin has paved the way toward unraveling the structure of other proteins with the same techniques, and work on some of them has already begun.

The insulin achievement was due largely to the efforts of the English biochemist Frederick Sanger and a small group of workers at Cambridge University. Sanger had spent 10 years of intensive study on this single molecule. When he commenced his investigation of protein structure in 1944, he chose insulin for several reasons. Firstly, it was one of the very few proteins available in reasonably pure form. Secondly, chemists had worked out a good estimate of its atomic composition (its relative numbers of carbon, hydrogen, nitrogen, oxygen and sulfur atoms). Thirdly, it appeared that the key to insulin's activity as a hormone lay in its structure, for it contained no special components that might explain its specific behavior.

Insulin is one of the smallest proteins. Yet its formula is sufficiently formidable. The molecule of beef insulin (from cattle) is made up of 777 atoms, in the proportions 254 carbon, 377 hydrogen, 65 nitrogen, 75 oxygen and 6 sulfur. Certain general features of the organization of a protein molecule have been known for a long time, thanks to the pioneering work of the German chemist Emil Fischer and others. The atoms form building units called amino acids, which in turn are strung together in long chains to compose the molecule. Of the 24 amino acids, 17 are present in insulin. The total number of amino acid units in the molecule is 51.

Sanger's task was not only to discover the over-all chain configuration of the insulin molecule but also to learn the sequence of all the amino acids in the chains. The sequence is crucial: a change in the order of amino acids changes the nature of the protein. The number of possible arrangements of the amino acids of course is almost infinite. One can get some notion of the complexity of the protein puzzle by remembering that the entire English language is derived from just 26 letters (two more than the number of amino acids) combined in various numbers and sequences.

Sanger followed the time-honored method used by chemists to investigate large molecules: namely, breaking them down into fragments and then attempting to put the pieces of the puzzle together. A complete breakdown into the amino acid units themselves makes it possible to identify and measure these components. But this gives no clue to how the units are combined and arranged. To investigate the structure a protein chemist shatters the molecule less violently and then examines these larger fragments, consisting of combinations of two, three or more amino acids. The procedure is somewhat like dropping a pile of plates on the floor. The



COMPLETE MOLECULE of insulin is depicted in this structural formula. Each amino acid in the molecule is represented by an abbreviation rather than its complete atomic structure. The key to these abbreviations is in the chart on page 39. The molecule consists

first plate may break into 10 pieces; the second plate may also give 10 pieces but with fractures at different places; the next plate may break into only eight fragments, and so on. Since the sample of protein contains billions of molecules, the experiment amounts to dropping billions of plates. The chemist then pores through this awesome debris for recognizable pieces and other pieces that overlap the breaks to show how the broken sections may be combined.

An amino acid consists of an amino group (NH_3^+), a carboxyl group (COO^-) and a side chain attached to a carbon atom. All amino acids have the amino and carboxyl groups and differ only in their side chains. In a protein molecule they are linked by combination of the carboxyl group of one unit with the amino group of the next. In the process of combination two hydrogen atoms and an oxygen atom drop out in the form of a water molecule and the link becomes CO–NH. This linkage is called the peptide bond. Because of loss of the water molecule, the units linked in the chain are called amino acid "residues." A group of linked amino acids is known as a peptide: two units form a dipeptide, three a tripeptide and so on.

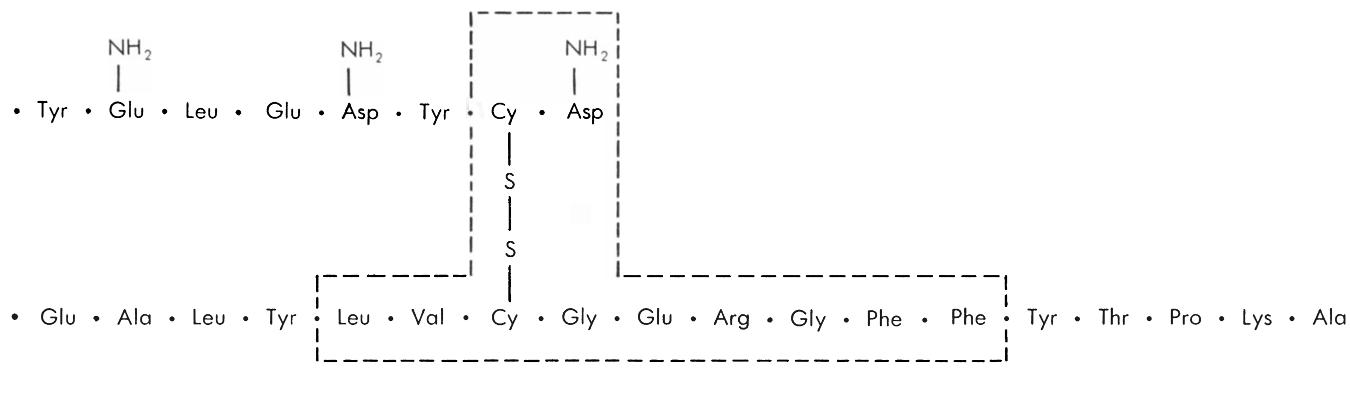
When a peptide or protein is hydrolyzed—treated chemically so that the elements of water are introduced at the peptide bonds—it breaks down into amino acids. The treatment consists in heating the peptide with acids or alkalis. To break every peptide bond and reduce a protein to its amino acids it must be heated for 24 hours or more. Less prolonged or drastic treatment, known as partial hydrolysis, yields a mixture of amino acids, peptides and some unbroken protein molecules. This is the plate-breaking process by which the detailed structure of a protein is investigated.

One of the key inventions that enabled Sanger to solve the jigsaw puzzle was a method of labeling the end amino acid in a peptide. Consider a protein fragment, a peptide, which is composed of three amino acids. On hydrolysis it is found to consist of amino acids *A*, *B* and *C*. The question is: What was their sequence in the peptide? The first member of the three-part chain must have had a free (uncombined) amino (NH_3) group. Sanger succeeded in finding a chemical marker which could be attached to this end of the chain and would stay attached to the amino group after the peptide was hydrolyzed. The labeling material is known as DNP (for dinitrophenyl group). It gives the amino acid to which it is attached a distinctive yellow color. The analysis of the tripeptide sequence proceeds as follows. The tripeptide is treated with the labeling material and is then broken down into its three amino acids. The amino acid which occupied the end position, say *B*, is now identified by its yellow color. The process is repeated with a second sample of the tripeptide, but this time it is only partly hydrolyzed, so that two amino acids remain as a dipeptide derivative colored yellow. If *B* is partnered with, say, *A* in this fragment, one knows that the sequence must be BA, and the order in the original tripeptide therefore was BAC.

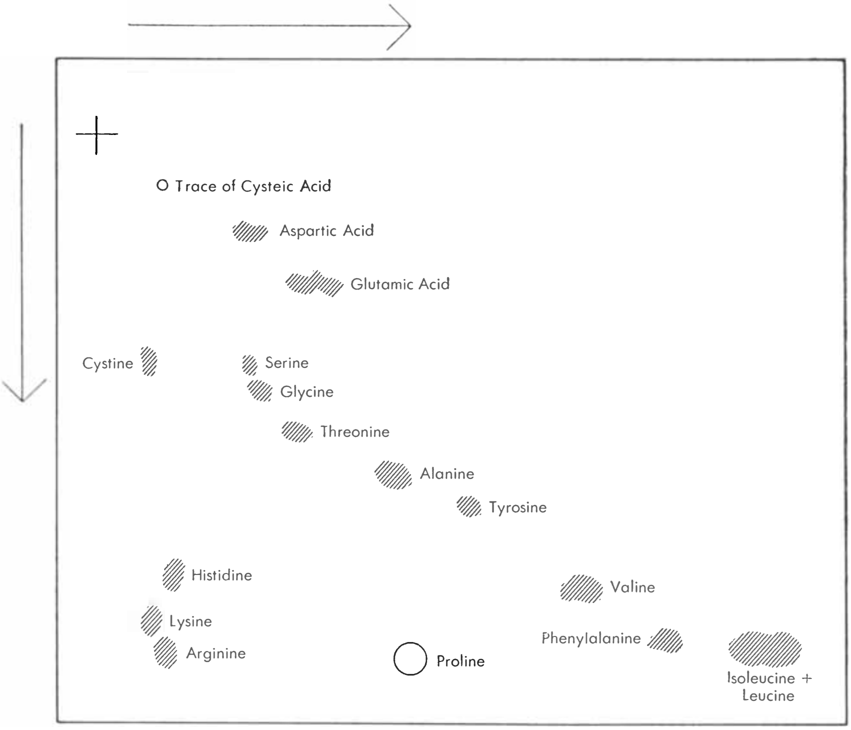
Another tool that played an indispensable part in the solution of the insulin jigsaw puzzle was the partition chromatography method for separating amino acids and peptides, invented by the British chemists A. J. P. Martin and R. L. M. Synge [see "Chromatography," by William H. Stein and Stanford Moore; SCIENTIFIC AMERICAN, March, 1951]. Obviously Sanger's method of analysis required separation and identification of extremely small amounts of material. With paper chromatography, which isolates peptides or amino acids in spots on a piece of filter paper, it is possible to analyze a mixture of as little as a millionth of a gram of material with considerable accuracy in a matter of days. As many as 40 different peptides can be separated on a single sheet.

With the knowledge that the insulin molecule was made up of 51 amino acid units, Sanger began his attack on its structure by investigating whether the units were strung in a single long chain or formed more than one chain. Among the components of insulin were three molecules of the amino acid cystine. The cystine molecule is unusual in that it has an amino and a carboxyl group at each end [*see its formula in table on page 39*]. Since such a molecule could cross-link chains, its presence in insulin suggested that the protein might consist of more than one chain. Sanger succeeded in proving that there were indeed two chains, which he was able to separate intact by splitting the sulfur links in the cystine molecule. Using the DNP labeling technique, he also showed that one chain began with the amino acid glycine and the other with phenylalanine.

Sanger proceeded to break each chain into fragments and study the pieces —especially overlaps which would permit him to build up a sequence. Concentrating on the beginning of the glycine chain, Sanger labeled the glycine with DNP and examined the peptide fragments produced by partial hydrolysis. In the debris of the broken glycine chains he found these sequences attached to the labeled glycine molecules: glycine-isoleucine; glycine-isoleucine-



of 51 amino acid units in two chains. One chain (*top*) has 21 amino acid units; it is called the glycyl chain because it begins with glycine (Gly). The other chain (*bottom*) has 30 amino acid units; it is called the phenylalanyl chain because it begins with phenylalanine (Phe). The chains are joined by sulfur atoms (S-S). The dotted lines indicate the fragments which located the bridges.



PAPER CHROMATOGRAPHY separates the 17 amino acids of insulin. In the chromatogram represented by this diagram insulin was broken down by hydrolysis and a sample of the mixture placed at the upper left on the sheet of paper. The sheet was hung from a trough filled with solvent which carried each amino acid a characteristic distance down the paper. The sheet was then turned 90 degrees and the process repeated. The amino acids, with the exception of proline, appear as purple spots when sprayed with ninhydrin.

valine; glycine-isoleucine-valine–glutamic acid; glycine-isoleucine-valine–glutamic acid–glutamic acid. Thus it was evident that the first five amino acids in the glycine chain were glycine, isoleucine, valine and two glutamic acids. Similar experiments on the phenylalanine chain established the first four amino acids in that sequence: phenylalanine, valine, aspartic acid and glutamic acid.

Sanger and a colleague, Hans Tuppy, then undertook the immense task of analyzing the structure of the entire phenylalanine chain. It meant breaking down the chain by partial hydrolysis, separating and identifying the many fragments and then attempting to put the pieces of the puzzle together in proper order. The chain, made up of 30 amino acids, was by far the most complex polypeptide on which such an analysis had ever been attempted.

The bewildering mixture of products from partial breakdown of the chain—amino acids, dipeptides, tripeptides, tetrapeptides and so on—was much too complicated to be sorted out solely by chromatography. Sanger and Tuppy first employed other separation methods (electrophoresis and adsorption on charcoal and ion-exchange resins) which divided the peptide fragments into groups. Then they analyzed these simpler mixtures by paper chromatography. They succeeded in isolating from the fractured chain 22 dipeptides, 14 tripeptides and 12 longer fragments [*see chart on pages 40 and 41*]. Although these were obtained only in microscopic amounts, they were identified by special techniques and the sequences of their amino acids were determined.

These were the jigsaw pieces that had to be reassembled. Just as in a jigsaw puzzle there are key pieces around which the picture grows, so in this case there were some key pieces as starting points. For instance, the chain was known to contain just one aspartic acid. Six peptides with this amino acid were found in the debris from partial breakdown of the chain [*see chart*]. The aspartic acid was attached to from one to four other amino acids in these pieces. Their sequences showed that in the original make-up of the chain the order must have been phenylalanine-valine–aspartic acid–glutamic acid–histidine.

Other sequences were pieced together in a similar way until five long sections of the chain were reconstructed. But this still left several gaps in the chain. Sanger and Tuppy now resorted to another method to find the missing links. They split the phenylalanine chain with enzymes instead of by acid hydrolysis. The enzyme splitting process yields longer fragments, and it leaves intact certain bonds that are sensitive to breakage by acid treatment. Thus the investigators obtained long chain fragments which bridged the gaps and revealed the missing links.

After about a year of intensive work Sanger and Tuppy were able to assemble the pieces and describe the structure of insulin's phenylalanine chain. Sanger then turned to the glycine chain and spent another year working out its structure, with the assistance of the author of this article. The glycine chain is shorter (21 amino acids) but it provided fewer clues: there were fewer key pieces that occurred only once, and two amino acids (glutamic acid and cystine) cropped up in so many of the fragments that it was difficult to place them unequivocally in the sequence.

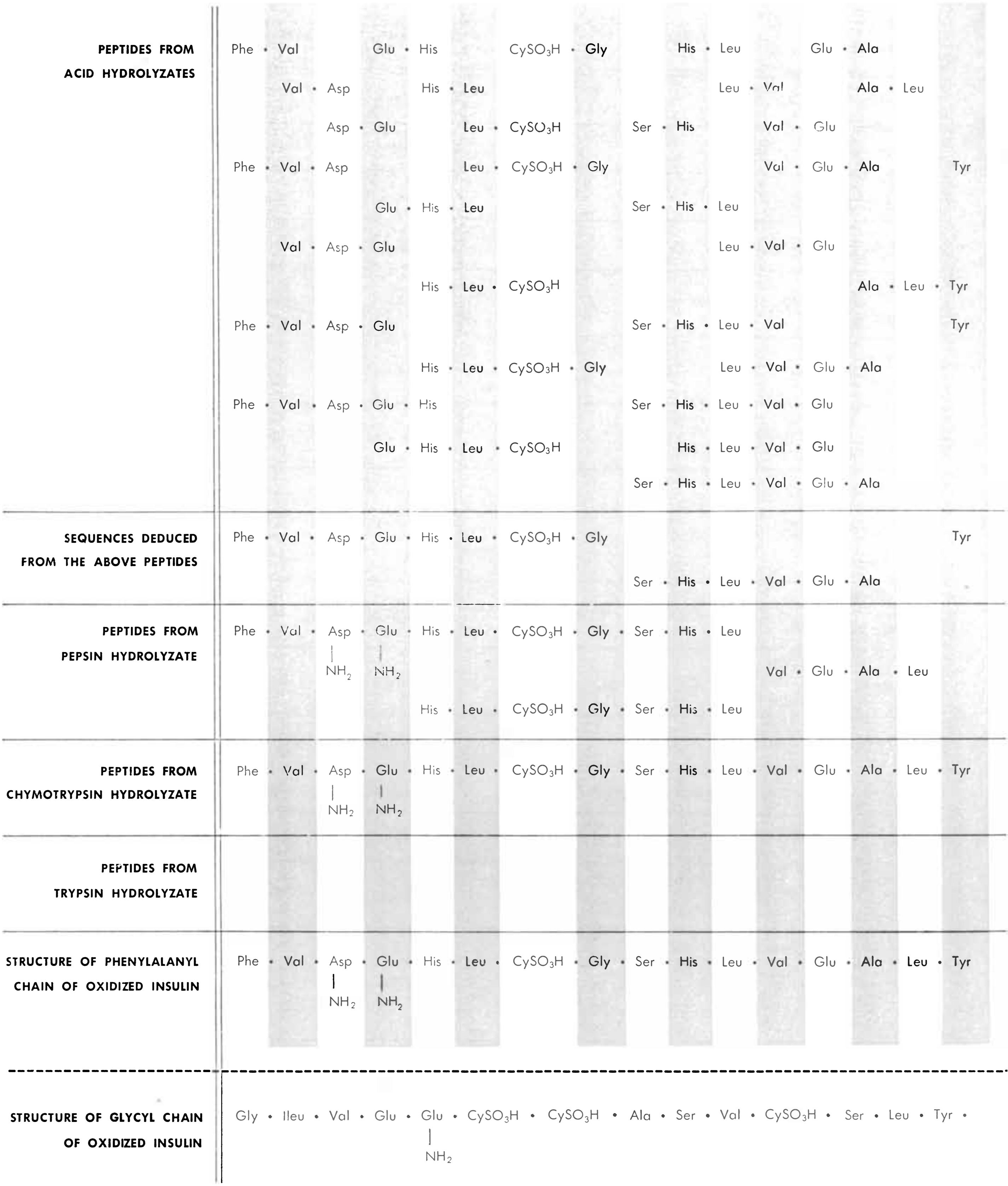
One detail that remained to be decided before the structure could be completed was the actual composition of two amino acids in the chain. Certain amino acids may occur in two forms: *e.g.*, glutamic acid and glutamine. Glutamic acid has two carboxyl (COO^-) groups, whereas glutamine has an amide ($CONH_2$) group in the place of one of the carboxyls [*see opposite page*]. The difference gives them completely different properties in the protein. Similarly there are aspartic acid and asparagine. Now acid hydrolysis changes glutamine to glutamic acid and asparagine to aspartic acid. Consequently after acid hydrolysis of a protein one cannot tell which form these amino acids had in the original chain. The question was resolved by indirect investigations, one of which involved comparing the products obtained when the same peptide was broken down by acid hydrolysis and by enzymes which do not destroy the amide groups.

By the end of 1952 the two chains were completely assembled. There remained only the problem of determining how the two chains were linked together to form the insulin molecule. But this was easier said than done. As so often happens, what looked simple in theory had complications in practice.

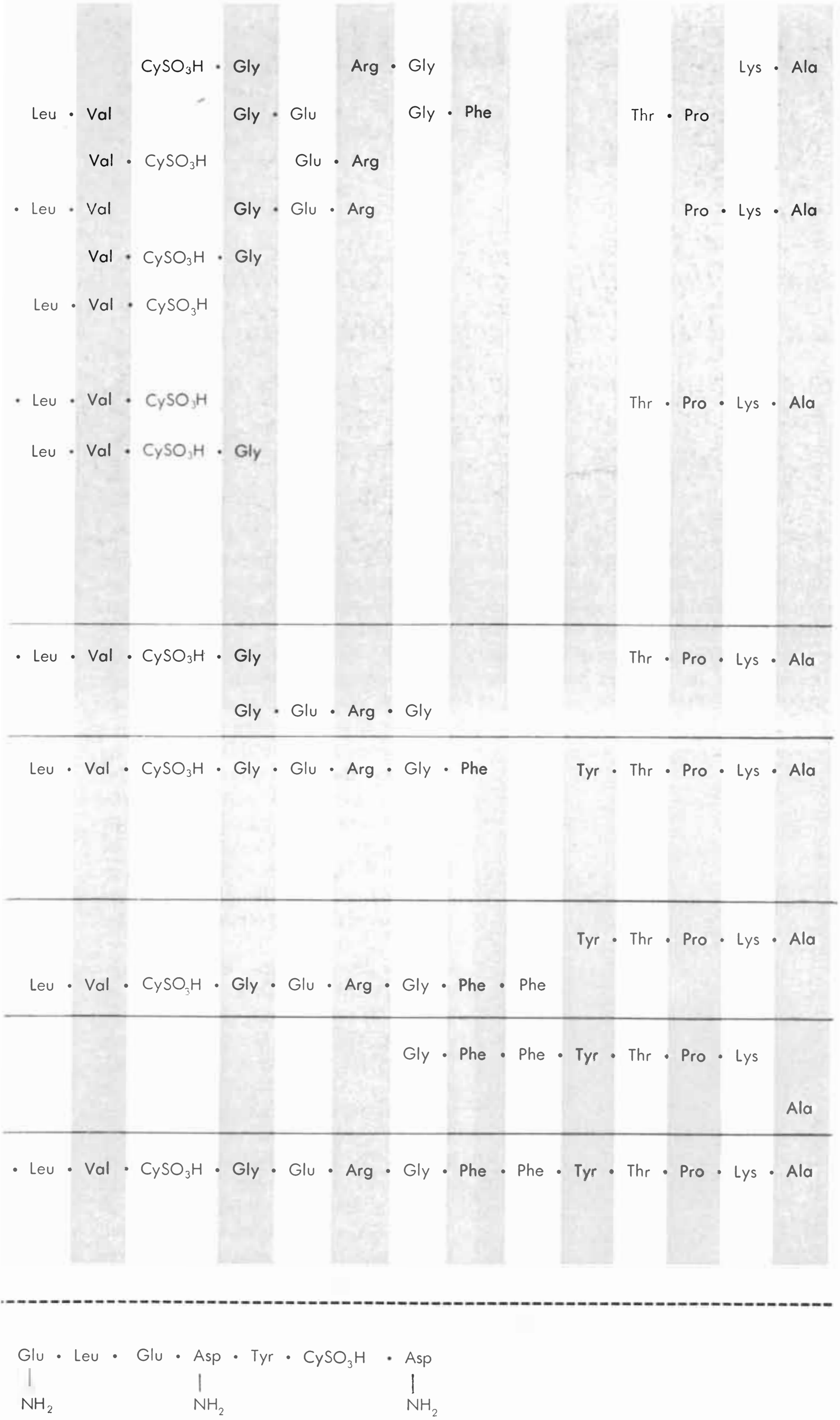
The bridges between the chains, as we have noted, must be cystine, because this amino acid has symmetrical bonds at both ends. The fact that insulin

FORMULA	NAME	ABBREVIATION	PHENYLALANYL	GLYCYL
$CH_2(NH_3^+) \cdot COO^-$	Glycine	Gly	3	1
$CH_3—CH(NH_3^+) \cdot COO^-$	Alanine	Ala	2	1
$CH_2OH—CH(NH_3^+) \cdot COO^-$	Serine	Ser	1	2
$CH_3 \cdot CHOH—CH(NH_3^+) \cdot COO^-$	Threonine	Thr	1	0
$(CH_3)(CH_3)>CH—CH(NH_3^+) \cdot COO^-$	Valine	Val	3	2
$(CH_3)(CH_3)>CH \cdot CH_2—CH(NH_3^+) \cdot COO^-$	Leucine	Leu	4	2
$(CH_3 \cdot CH_2)(CH_3)>CH—CH(NH_3^+) \cdot COO^-$	Isoleucine	Ileu	0	1
$CH_2—CH_2$, CH_2 $CH—COO^-$, NH^+ (ring)	Proline	Pro	1	0
$CH{=}CH$, CH $C \cdot CH_2—CH(NH_3^+) \cdot COO^-$, $CH—CH$ (ring)	Phenylalanine	Phe	3	0
$HO—C$ ($CH{=}CH$, $CH—CH$ ring) $C \cdot CH_2—CH(NH_3^+) \cdot COO^-$	Tyrosine	Tyr	2	2
$NH_2CO \cdot CH_2—CH(NH_3^+) \cdot COO^-$	Asparagine	Asp (NH_2)	1	2
$COOH \cdot CH_2 \cdot CH_2—CH(NH_3^+) \cdot COO^-$	Glutamic Acid	Glu	2	2
$NH_2 \cdot CO \cdot CH_2 \cdot CH_2—CH(NH_3^+) \cdot COO^-$	Glutamine	Glu (NH_2)	1	2
$NH_2—C({=}NH)—NH \cdot CH_2 \cdot CH_2 \cdot CH_2—CH(NH_3^+) \cdot COO^-$	Arginine	Arg	1	0
$CH{=}C \cdot CH_2—CH(NH_3^+) \cdot COO^-$, NH N, CH (ring)	Histidine	His	2	0
$CH_2NH_2 \cdot CH_2 \cdot CH_2 \cdot CH_2—CH(NH_3^+) \cdot COO^-$	Lysine	Lys	1	0
$(COO^-)(NH_3^+)>CH—CH_2—S—S—CH_2—CH<(COO^-)(NH_3^+)$	Cystine	CyS–CyS	2	4
			30	21

AMINO ACIDS of insulin are listed in this chart. Their chemical formulas are at the left. The dots in the formulas represent chemical bonds other than those suggested by the atoms adjacent to each other. The number of amino acid units of each kind found in the phenylalanyl chain are listed in the fourth column of the chart. The fifth column comprises a similar listing for the glycyl chain.



SEQUENCE OF AMINO ACIDS in the phenylalanyl chain was deduced from fragments of the chain. The entire sequence is at the bottom above the dotted line. Each fragment is indicated by a horizontal sequence of amino acids joined by dots. The fragments are arranged so that each of their amino acids is in the vertical column above the corresponding amino acid in the entire chain.



The shorter fragments (*group at the top*) were obtained by hydrolyzing insulin with acid. The longer fragments (*groups third, fourth and fifth from the top*) were obtained with enzymes. The same method was used to deduce the sequence in the glycyl chain (*bottom*).

contains three cystine units suggested that there might be three bridges, or cross-links, between the chains. It appeared that it should be a simple matter to locate the positions of the bridges by a partial breakdown of the insulin molecule which gave cystine-containing fragments with sections of the two chains still attached to the "bridge" ends.

When Sanger began this analysis, he was puzzled to find that the cystine-containing peptides in his broken-down mixtures showed no significant pattern whatever. Cystine was joined with other amino acids in many different combinations and arrangements, as if the chains were cross-linked in every conceivable way. Sanger soon discovered the explanation: during acid hydrolysis of the insulin molecule, cystine's sulfur bonds opened and all sorts of rearrangements took place within the peptides. Sanger and his associate A. P. Ryle then made a systematic study of these reactions and succeeded in finding chemical inhibitors to prevent them.

By complex analyses which employed both acid hydrolysis and enzyme breakdown, Sanger and his co-workers L. F. Smith and Ruth Kitai eventually fitted the bridges into their proper places and obtained a complete picture of the structure of insulin [*see diagram at bottom of pages 36 and 37*]. So for the first time the biochemist is able to look at the amino-acid arrangement in a protein molecule. The achievement seems astounding to those who were working in the field 10 years ago.

To learn how insulin's structure determines its activity as a hormone is still a long, hard road. It will be difficult to synthesize the molecule, but once that has been accomplished, it will be possible to test the effect of changes in the structure on the substance's physiological behavior. Evidently slight variations do not affect it much, for Sanger has shown that the insulins from pigs, sheep and steers, all equally potent, differ slightly in structure.

The methods that proved so successful with insulin, plus some newer ones, are already being applied to study larger proteins. Among the improvements are promising new techniques for splitting off the amino acids from a peptide chain one at a time—clearly a more efficient procedure than random hydrolysis. The rate of progress undoubtedly will be speeded up as more biochemists turn their attention to the intriguing problem of relating the structure of proteins to their physiological functions.

The Spiral Structure of the Galaxy

Like most other galaxies, the Milky Way is a vast flattened whirlpool of gas, dust and stars. In recent years radio and stellar astronomy have begun to map the location of its arms

by W. W. Morgan

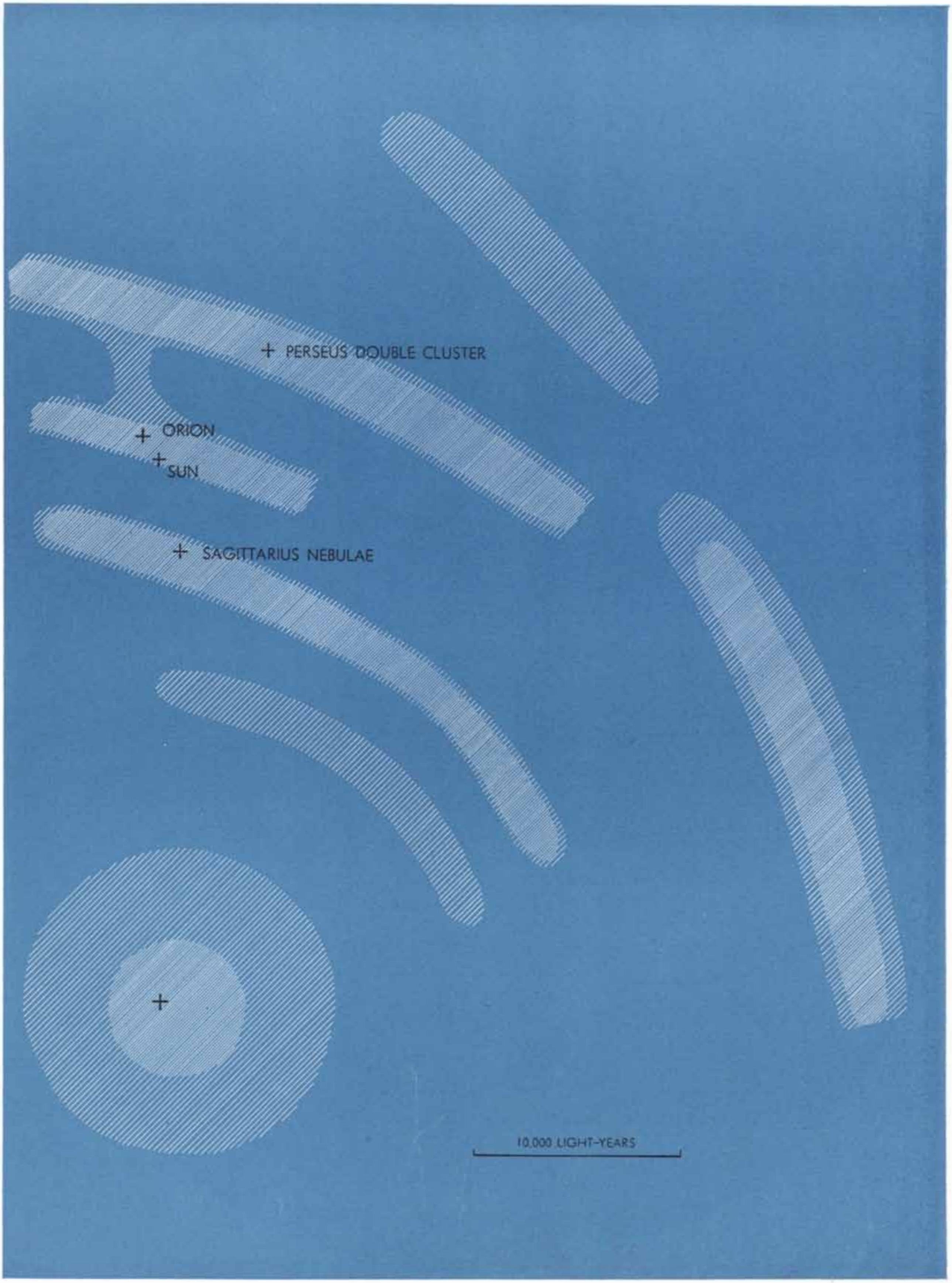
Thirty years ago the great U. S. astronomer George Ellery Hale published a small book outlining the picture of our galaxy, the Milky Way, as it looked to astronomers at that time. The galaxy was believed to be a gigantic disk in the shape of a watch, with star systems more or less evenly distributed throughout the disk and our own sun embedded in it about halfway between the flattened faces. Astronomers could not agree on the size of the galaxy (estimates of its diameter ranged from 30,000 to 300,000 light-years), and there was sharp dispute about whether the spiral nebulae observed in the heavens were part of our own system or separate galaxies.

GREAT NEBULA IN ANDROMEDA gave many clues to the structure of the Milky Way. Its spiral is not clearly visible because its central plane is greatly tilted to our line of sight.

Today we have a very different picture of our galaxy, which illustrates in a dramatic way the great advances in astronomy that have taken place within a single generation. Without attempting to review those advances, already discussed in detail in a number of articles in Scientific American [see especially "A Larger and Older Universe," by George W. Gray; June, 1953], this article will describe the present picture and some of the discoveries that revealed it.

Two developments started astronomers toward their new conception of our galaxy's structure: (1) the discovery that the Milky Way is rotating in space like a giant wheel, and (2) close examination of the great nebula in Andromeda, a neighboring galaxy which is about the same size as ours and also rotates. The Andromeda nebula was seen to have a spiral shape, with brilliant arms like those of a whirling Fourth-of-July pinwheel. If this system had spiral arms, should not our own rotating galaxy also be spiral in structure? We cannot see our galaxy whole, because we are looking at it from the inside. But investigation of the details of the Andromeda nebula's structure gave clues to astronomers concerning what to look for in our system.

One of the most beautiful features of the Andromeda nebula is its long spiral arms, marked by great strings of blue supergiant stars [*see photograph at left*]. Surrounding these hot stars are im-



SPIRAL ARMS OF THE MILKY WAY are located on this preliminary map, principally based on radio observations made in the Netherlands. The center of the galaxy is at the lower left. The arm at the top center is probably the outer arm of the Milky Way.

mense halos of ionized, luminous hydrogen gas measuring 80 to 250 light-years in diameter. And along the edges of the bright arms are great clouds of dust. All these features are now recognized to be characteristic of spiral galaxies. Consequently when astronomers began to seek signs of spiral structure in our galaxy, they searched for such objects.

That many hot stars in the Milky Way are surrounded by regions of luminous hydrogen had been observed a long time ago by Otto Struve in the U. S. and by other astronomers in Europe. The existence of such regions of ionized gas around very hot stars had been predicted earlier by the Danish astronomer Bengt Strömgren, who reasoned that the stars should ionize the hydrogen gas around them for a distance depending on the temperature of the star. And at the Mount Wilson and Palomar Observatories Walter Baade had discovered that the outer spiral arms of the Andromeda nebula were defined by long rows of gaseous emission regions, or luminous hydrogen clouds.

In 1951 a group at the University of Chicago undertook to study ionized regions of this type in our galaxy to see if they were arranged in definable patterns in space. To determine whether they formed any pattern, we had first of all to find the distance of each luminous cloud from the earth. This could be determined by measuring the distance of the hot star with which each ionized halo was associated. The measurement

GREAT HYDROGEN CLOUD in Orion is located in the same arm of the Milky Way as the sun. The well-known Orion nebula is at upper left center. This photograph was made by H. Abt with an eight-inch Schmidt telescope at the McDonald Observatory in Texas.

method used was observation of the stars' spectra—a powerful tool first developed at Mount Wilson some 40 years ago and refined since then. From the spectral nature of the light emitted by a star it is possible to estimate its intrinsic brightness, and its distance can then be calculated by comparing this with the amount of light that reaches us after its travel through space—that is, the star's apparent brightness.

In the fall of 1951 the work of locating the positions of ionized hydrogen clouds in our galaxy was rewarded with discovery of the first outlines of a pattern. In the neighborhood of the sun were located two well-defined groups of luminous hydrogen clouds; each group formed a long, narrow band, and the two bands were separated by a dark space. Comparison of these bands with photographs of the spiral arms in the Andromeda nebula showed conclusively that they were segments of two spiral arms in our galaxy. The two segments, each about 10,000 light-years long, were parallel to each other and about 7,000 light-years apart. Our own sun lay near the inner edge of the arm that was nearer to the center of our galaxy.

Both arms were studded with blue supergiant stars. Further confirmation that they were indeed spiral arms was provided by the well-known fact that dense dust clouds, which are characteristic of spiral arms, lie not far from us.

The arm in which the sun is located also includes the blue supergiants and hydrogen clouds of the constellation of

TWO HYDROGEN CLOUDS in Monoceros are also located in the same arm as the sun. The cloud in the center is about 3,000 light-years away. The cloud at lower right is more distant. This photograph was made by H. Abt with the eight-inch Schmidt telescope.

Orion and the North America nebula. In the arm farther from the center of the galaxy is the giant double star-cluster in Perseus.

Our studies gave an indication of a third spiral arm, closer to the galactic center than the one embracing the sun. A later investigation, carried out jointly by the University of Chicago and A. E. Whitford and Arthur D. Code of the University of Wisconsin, confirmed the existence of this arm. It is about 4,500 light-years from us in the direction of the center of the galaxy. It includes some of the most brilliant gaseous clouds known, located in the constellation of Sagittarius.

These discoveries were soon confirmed and extended by a totally different means of investigation—the powerful new tool of radio astronomy. Within a few months after our Chicago group (Stewart Sharpless, Donald Osterbrock and the writer) announced the location of the first two spiral arms, an Australian team reported that they had located concentrations of hydrogen atoms evidencing the spiral structure with a radio telescope. And this report, by W. N. Christiansen and J. V. Hindman of the Commonwealth Scientific and Industrial Research Organization, was followed by further discoveries by a Netherlands group headed by J. H. Oort.

Hydrogen atoms in space broadcast radio energy at a wavelength of 21 centimeters [see "Radio Waves from Interstellar Hydrogen," by Harold I.

NORTH AMERICA NEBULA is at left in this photograph made by H. Abt with the eight-inch Schmidt. These hydrogen clouds are at various distances along the spiral arm that contains the sun. They are in a direction nearly opposite that of the Orion clouds.

Ewen; SCIENTIFIC AMERICAN, December, 1953]. With this hydrogen line it is possible to detect concentrations of hydrogen gas and determine their direction from us, but gauging their distances is more difficult. Clues to the distances were found in observations involving the Doppler effect. If a mass of hydrogen gas is moving toward us, its radio "spectral" line should shift toward shorter wavelengths; if it is moving away, the line should shift toward longer wavelengths. The radio astronomers observed a number of such shifts, and in some cases detected two separate shifts in the same line of sight, indicating two different clouds moving at different velocities. By constructing a model of our rotating galaxy showing what the rotational velocities should be at varying distances from its center, they were able to determine the positions of the hydrogen concentrations.

With a radio telescope Oort and his Dutch co-workers confirmed the existence of the spiral arm in which the sun lies and also of the second arm, about 7,000 light-years farther from the center of the galaxy, which contains the Perseus double cluster. They were able to trace the latter arm for a distance covering about half the circumference of the galaxy.

A great advantage of the radio telescope is that it can "see" much farther than optical instruments, because it penetrates through dust clouds in space. Thus the Dutch astronomers extended the exploration and succeeded in discov-

DOUBLE CLUSTER of stars in Perseus is at lower right center. This object, and the hydrogen clouds at top center, are located in the arm next outward from the arm that contains the sun. This photograph was made by H. M. Johnson with the same Schmidt.

LAGOON NEBULA is a hydrogen cloud in the constellation of Sagittarius. This nebula is located in the spiral arm next inward from the arm that contains the sun. The photograph was made with 200-inch telescope of Mount Wilson and Palomar Observatories.

ering more distant spiral arms. They found a faint outer arm 20,000 light-years from us in the direction away from the center of the galaxy, and very recently they have located two arms between us and the galactic center. In addition they explored the region of the center itself and learned that it is in a very turbulent state, with hydrogen atoms moving at far higher velocities than those in our neighborhood.

Our current picture of the galaxy is summed up in the diagram on page 43. At the center of the galaxy is a brilliant region, some 20,000 light-years in diameter, filled with hydrogen gas in a high state of turbulence. About 15,000 light-years out from the center lies the first spiral arm. There is a second arm about 21,000 light-years out, and the third, in which the sun is located, is about 27,000 light-years from the center. Beyond that, some 35,000 light-years out, lies a great spiral arm approximately circular in shape. Still farther out is a faint, highly-inclined arm at a distance of the order of 40,000 light-years from the center. This is probably the outermost arm of our galactic system.

The spiral structure is superposed on a smooth, featureless, disk-shaped system, increasing in brightness toward the center. At the center itself there is a brilliant, small nucleus. Because of heavy dust clouds, this nucleus has not been observed visually or photographically; it was discovered by radio astronomy.

This picture is, of course, incomplete. With each year of further exploration the details will become clearer and the over-all structure of our galaxy will be more precisely delineated.

Kodak reports to laboratories on:

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Set of tools

"Kodak Retina" designates a system of 35mm still photography built around a new camera we are just introducing into the United States. We have no illusions about the number of people in a position to make full use of such a set of photographic tools. (Not that the *Retina IIIc* outfit is particularly costly. It'll hardly be noticed in a capital equipment budget.)

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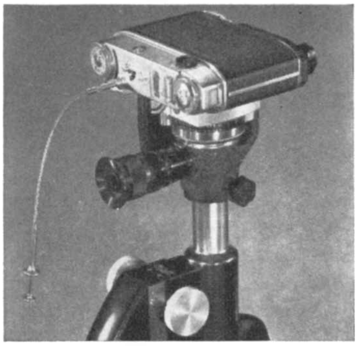
This is no Sunday-in-the-park job. True, it will catch your boy in action at a ball game, but it will also



enter into marriage with a fine microscope to do some much-needed photomicrography that has been put off because a full-scale installation has seemed a little overexpansive. Or, if exquisitely detailed, larger-than-life photographs of small specimens or parts would be helpful in your records or reports, the Kodak dealer can provide details about the *Retina* equipment that has been designed for these purposes, too.

You can't expect to find Retina IIIc *cameras distributed as widely as mass market merchandise. What counts is that a world-wide organization stands behind the camera with accessories and readily available, detailed counsel on their use.*

Greaseless fat

Thus we shout to the great industry that ministers percutaneously to the psyche. The cosmetic industry is as basic as can be, for mankind has long daubed itself with grease when it has wanted to feel extra good. As the veneer of civilization thickens, we acquire a tactile distaste for "grease." Cosmeticians abandon the term to lubrication engineers. The public wants its emollients non-greasy, and it knows what it wants.

Enter the chemist. He has made monoglycerides a commodity of commerce after having been for all time up to then only a passing phase of fat digestion in the alimentary canal. Lately he has found that the more of the hydroxyls in a monoglyceride that are replaced by acetyl groups, the more the melting point is depressed and the more the resistance to oxidative rancidity is raised. This is quite different from the effect of another variable at the disposal of the fat chemist, degree of unsaturation. Unsaturation makes for lower melting point with *poorer* stability.

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On a hunch we engage cosmetics-experienced consultants to evaluate them in lipstick, baby oil, electric shaving lotion, hair dressing, and any other cosmetic preparation worth mentioning. They find that every one of them should be better off for at least one of the benefits conferred by distilled acetylated monoglycerides. We assign the trade-mark "Myvacet" and spread the word. The orders start coming in. We step up production from experimental to semi-commercial. The psyche prospers.

If there is anything you want to know about Myvacet Distilled Acetylated Monoglycerides, *write to Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company).*

Spectral wisdom

Let drop a hint that your budget provides for a new spectrograph and shortly you will make several new friends who happen to represent leading manufacturers of laboratory instrumentation. They will be knowledgeable fellows brimming with ideas for making spectrography quicker, easier, less costly, and more significant. Plates and films won't be mentioned in much detail. It will be assumed that somebody up in Rochester, N. Y., will, in the course of frying other fish, toss off a little sensitized goods suitable for use in these instruments. After all, what author concerns himself with the paper on which he puts down his thoughts?

The metaphor, if so drawn, is unfair. For better or worse, a serious spectrographer can never consider plates and film as purely passive media. He has learned many facts about the subtle interactions between the exposing radiation, the emulsion, the latent image, the processing parameters, and the viewing light; but there is always the problem of passing his wisdom on to the young and impatient who have so many other things to learn.

Let him therefore spend half a buck for a copy of the new Second Edition of the data book "Kodak Materials for Spectrum Analysis," which brings straight from the horse's mouth the late word on specific characteristics of these products of ours, as well as general background on their behavior and handling.

There *are* changes. We have brought matters as up to date as they'll ever be and have added some succinct new material on photographic adjacency effects and the relationship between resolving power, sharpness, and granularity. Perhaps it wouldn't hurt even you to look it over.

If your Kodak dealer doesn't have the new edition of "Kodak Materials for Spectrum Analysis," he can sure enough order it for you.

This is one of a series of reports on the many products and services with which the Eastman Kodak Company and its divisions are . . . *serving laboratories everywhere*

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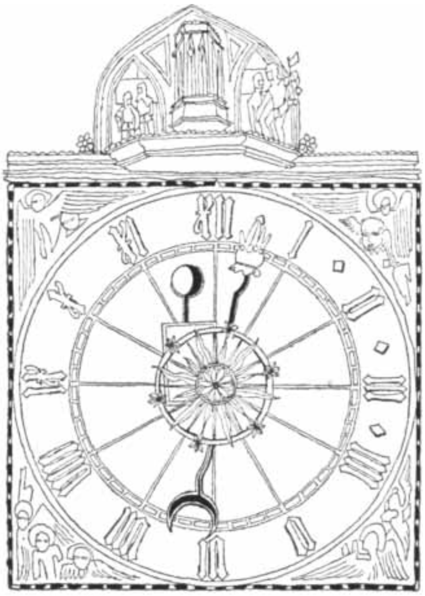

SCIENCE AND

Atomic Energy Appointments

Last month President Eisenhower filled out the membership of the Atomic Energy Commission by nominating Allen Whitfield, a Des Moines lawyer, to the last vacancy. Other members of the present Commission appointed by President Eisenhower are the chairman Lewis L. Strauss, Willard F. Libby and John von Neumann. Thomas E. Murray, whose term expires June 30, 1957, was appointed by President Truman.

The Joint Congressional Committee on Atomic Energy named a citizens' advisory board to counsel it on development of peaceful uses of atomic energy. The board will be headed by Robert McKinney, a New Mexico newspaper publisher and former Assistant Secretary of the Interior. Other members are Ernest R. Breech, chairman of the Ford Motor Company; George R. Brown, a Texas building contractor; Sutherland C. Dows, chairman of the Iowa Light and Power Company; John R. Dunning, dean of engineering at Columbia University; Frank M. Folsom, president of the Radio Corporation of America; T. Keith Glennan, president of Case Institute of Technology and former member of the AEC, and Samuel B. Morris, general manager of the Los Angeles Department of Water and Power.

Senator Clinton P. Anderson, chairman of the Joint Committee, said the panel would pursue a "continuing study" of nuclear progress, particularly in the power field. He said its investigations would be "in no way competitive with the Atomic Energy Commission." The board is to report to the Joint Committee by January 31, 1956, and may recommend legislation.

Changes at CERN

The *Conseil Européen pour la Recherche Nucléaire* (European Council for Nuclear Research) has announced that Felix Bloch, its first director general, is resigning on August 31 of this year. Bloch found that "unexpectedly heavy" administrative duties left him too little time for research. He will return to Stanford University, where he had been professor of physics before going to Geneva last year.

C. J. Bakker, professor of physics at the University of Amsterdam, will replace Bloch in the cooperative research organization. The Dutch physicist has been in charge of a group that is designing a synchrocyclotron for the CERN laboratory.

The Nautilus

Some of the history and engineering details of the world's first nuclear propulsion system were made public last month. An article on the power plant of the submarine U.S.S. *Nautilus* appeared in the *Westinghouse Engineer*.

The reactor uses ordinary water under high pressure as both moderator and coolant. This design has been under study since 1947. It had first been suggested a year earlier by Alvin M. Weinberg, research director of the Oak Ridge National Laboratory.

As in any nuclear power plant, one of the greatest problems in the *Nautilus* engine was heat transfer. Because of the difficulties created by high temperature, the engine was designed to work at "just about the minimum temperatures that would allow the generation of useful power." In the development and building of the engine some 28 per cent of the money was allocated to mechanical engineering, including heat transfer; 37 per cent to metallurgy and metallurgical engineering; 11 per cent to electrical engineering; 11 per cent to theoretical and experimental physics; 7 per cent to chemical engineering; 6 per cent to operational engineering and testing.

The reactor, the pressurized water circuit and the steam generator to which the circuit delivers its heat occupy a single shielded compartment near the center of the submarine. The shielding is pierced only by pipes carrying non-radioactive steam to the turbines and by electric control cables. Detectors monitor radioactivity levels both in the compartment and at points throughout the rest of the ship. The level of radiation outside the shield is said to be so low that a crew member exposed to it during the full life of the reactor would receive less radiation than from the ordinary lifetime of exposure to cosmic rays, natural radioactivity, chest and dental X-rays, television screens and luminescent instrument dials.

The *Nautilus* reactor not only drives its screws but also generates the ship's electricity supply. Part of the electricity is used to charge auxiliary batteries. For surface operation Diesel power also is available.

Soviet Nuclear Physics

The U.S.S.R. has recently provided the first glimpse into its work in atomic physics since World War II. A series of papers in the *Proceedings* of the Soviet Academy of Sciences showed that Soviet physicists are interested in the same problems as those in the West and have developed some instruments of their own.

The papers describe experiments, dating back to 1950, on high-energy collisions between protons and neutrons. The angles at which these particles bounce off each other give information about the mysterious forces that act between them in the atomic nucleus. In the Soviet experiments the bombarding particles were accelerated in a synchrocyclotron reaching an energy of 660 million electron volts, a higher energy than was available in the U. S. until 1952, when the Cosmotron went into operation at the Brookhaven National Laboratory.

Luke Yuan, a physicist at Brookhaven who has translated the papers, described the Russian results as highly accurate. In particular, the energies of the bombarding particles were determined more closely than in comparable U. S. experiments. If all the results were obtained by 1952, which the papers imply (but about which Yuan is somewhat dubious), the work was in some respects more precise than that being done in the U. S. at the time.

The most surprising news in the articles was a description of a solid recorder of particle tracks. The particles are tracked in scintillating crystals. Scintillation counters are in common use in the U. S., but they record each particle's passage simply as a single burst of light. The Soviet physicists have developed an amplifying system that works fast enough to follow the trail of successive flashes produced by a particle as it streaks through a cesium iodide crystal. The amplified track is displayed on a cathode ray tube. Photographs in the *Proceedings* showed the track of a pi meson decaying into a mu meson and several "stars" formed by fast particles smashing atoms of the crystal.

Solid track-detectors offer several advantages over cloud chambers and bubble chambers [see "The Bubble Chamber," by Donald A. Glaser; SCIENTIFIC AMERICAN, February, 1955]. They contain no moving parts. They do not have to be expanded and hence are continuously sensitive. They are very fast: each track lasts only an instant. The solid's density increases the chances that interesting collisions will take place in the detector. Several U. S. laboratories have been trying to develop this type of instrument but none has yet reported success.

The first U. S. physicist to notice the important Soviet papers was Freeman J. Dyson, now at the Institute for Advanced Study. He reported them to Robert Serber of Columbia University who in turn showed them to Yuan. Serber has described the work reported as "technically very good." Since it has no bearing on weapons, the fact that it has only now been published shows that Soviet secrecy is tighter than that in the U. S., Serber pointed out.

Perils of Radioactivity

Public debate about the hazards of nuclear weapon tests increased last month.

The magazine *U. S. News & World Report* published an article, said to have been "cleared for publication as factually accurate" by the Atomic Energy Commission, which declared that the tests created no danger. H-bombs could be tested once a week indefinitely, said the article, without "raising the amount of strontium 90 to a dangerous level." It added that children of parents exposed to radiation at Hiroshima and Nagasaki have not shown an abnormal number of defects, and that a strain of fruit flies

which has gone through 128 generations in highly radioactive containers has become "a much improved race of fruit flies with more vigor, hardiness, resistance to disease, better reproductive capacity." The article concluded: "The fear that people are supersensitive to mutations through radioactivity is not borne out. There is agreement among geneticists working with AEC that some changes in future generations are likely to result only from heavy or successive doses. . . . Some experts believe that mutations usually work out in the end to improve species."

From other quarters came other opinions.

The Nobel-prize-winning British physicist Frederick Soddy asserted that hydrogen explosions are "fouling the air with radioactivity. . . . It is nonsense to say it is harmless. . . . Politicians and technicians are rushing into experiments without the faintest idea of what the results may be."

Linus Pauling, professor of chemistry at the California Institute of Technology, said: "Continued dispersal of radioactive materials into the atmosphere is creating a critical situation. Irradiation may have started a new cycle of leukemia victims or new hereditary mutations."

According to Joseph Rotblat, professor of physics at the University of London, "we are sailing much closer to the wind than any of us thought" so far as genetic effects of H-bomb tests are concerned. Writing in the *Atomic Scientists Journal*, Rotblat estimated that a radioactivity level double the present natural background rate might be genetically tolerable. Any higher rate would be "rather risky." Explosion of 75 hydrogen bombs over the whole world in the course of the next 30 years, he said, would double the level of radiation.

The Federation of American Scientists proposed that to settle the question a United Nations commission be set up to assess the potential dangers from fission and thermonuclear bomb tests.

Boycott

The University of Washington, which turned down J. Robert Oppenheimer as a guest lecturer, is having trouble attracting other scientific guests. Last month the University's medical school called off a conference on enzyme chemistry because eight of the biochemists scheduled to lead the discussions refused to come. A letter signed by seven of them informed Henry Schmitz, president of the University, that his ban on Op-

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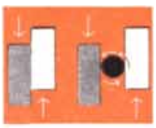

Let's start with the familiar principle that there's far less friction in *rolling* than in *sliding*. The average coefficient of friction of the sliding spline is .2—while that of the ball/bearing spline is only .005.

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STEERING GEAR DIVISION • GENERAL MOTORS CORPORATION • Saginaw, Michigan penheimer "clearly placed the University of Washington outside the community of scholars." The signers were Robert A. Alberty, David E. Green and Henry A. Lardy of the University of Wisconsin, Konrad Bloch and Bert L. Vallee of Harvard University, Arthur Kornberg of Washington University in St. Louis and William H. Stein of the Rockefeller Institute for Medical Research.

Earlier three other university professors had refused to lecture at Washington. They were Alex Inkeles and Perry Miller of Harvard and Victor A. Weisskopf of the Massachusetts Institute of Technology.

Solar Magnetism

A detailed picture of the sun's magnetic field was recently reported in *Nature* by astronomers at the Mount Wilson and Palomar Observatories. Horace W. and Harold D. Babcock have been scanning the solar disk for the past two years with their magnetograph, an instrument which can detect fields as weak as three tenths of a gauss.

They have found "consistent evidence" that the sun has a weak general field like that of the earth but of opposite polarity. It can be detected only at high latitudes, and at its strongest, near the poles, its intensity is about one gauss. (The earth's field near the poles is .7 gauss.) The sun's general field is not tilted with respect to the axis of rotation. It shows "remarkable random fluctuations" in intensity and extent.

In lower latitudes pairs of regions of opposite polarity appear sporadically. The authors conjecture that they are the trace on the surface of ring-shaped magnetic fields which come up from the sun's interior. Occasionally single-poled regions can be found. These may be remnants of disintegrating bipolar regions.

A strong unipolar region lasted for nine months during 1953. Each time the region came around to the side of the sun facing the earth, a magnetic storm followed in three days. The Babcocks "suggest tentatively" that their unipolar magnetic areas may be the sources of the streams of corpuscles that cause the periodic magnetic storms on the earth (see "Corpuscles from the Sun," by Walter Orr Roberts; SCIENTIFIC AMERICAN, February, 1955).

Unpopular Science

Physics has steadily been losing favor in public high schools for more than half a century. In 1895 about 23 per

If you package
liquids or
free-flowing solids,
even in opaque containers,

HYTAFILL
x-ray monitor

belongs in your .... production picture

Photo courtesy Carling Brewing Co.

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MANY leading brewers, beverage producers and food processors are now using General Electric HYTAFILL in their production. They have found that this modern x-ray method for checking container fill makes a big contribution to plant efficiency as well as quality control.

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cent of all high-school students were studying physics, and more than 95 per cent of that year's graduates had taken the course. In 1952 only 4.3 per cent were taking physics and only 21 per cent of the graduates had ever studied it. These figures were listed by W. C. Kelly, a University of Pittsburgh physicist, in a recent issue of *Physics Today*.

Other sciences have held their own or grown more popular. Chemistry has attracted about 7 per cent of high-school students each year since the turn of the century. Biology has risen from a 7 to a 20 per cent enrollment since 1910. General science, introduced more recently, has always attracted about 20 per cent.

The falling off in physics, Kelly points out, is due in part to changes in the social structure and in high-school curricula. In 1890 only 3.8 per cent of the eligible youngsters attended high school; in 1952, 65 per cent. Physics was one of nine available courses 65 years ago; now it is one of 274. Today only about half the public high schools offer physics, and a quarter of these have no laboratory facilities. Some schools are experimenting with a one-year course in physical science, which includes smatterings of physics, chemistry, astronomy, geology and meteorology.

Other factors which Kelly lists as contributing to the decline of physics include: its reputation as an "impossibly tough" course; its unwieldy agglomeration of subject matter, which should be pruned; lack of equipment and time for classroom demonstration and laboratory work; lack of competent and enthusiastic teachers; failure to offer a type of course suitable for students not planning to major in science.

Smoking Habits

The University of Michigan's Survey Research Center recently surveyed the effects of lung-cancer reports on people's use of tobacco. Some of the results:

In Ann Arbor, Mich., 8 per cent of the smokers quit entirely. Another 40 per cent changed their smoking habits: some cut down, others switched to filter-tip cigarettes or pipes. Of the smokers who continued smoking, 70 per cent said they thought the connection with lung cancer had not been conclusively established; of those who quit, only 38 per cent were doubters.

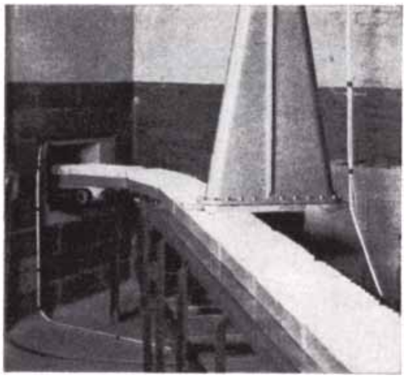
According to *Business Week*, the national consumption of cigarettes, of cigars and of pipe tobacco decreased last year. In the second half of the year, however, pipe tobacco sales rose sharply.

Advances in Applied Radiation

DEVELOPMENTS in the FIELD OF APPLIED RADIATION ENERGY, its APPLICATIONS and the APPARATUS USED TO PRODUCE IT

Van de Graaff Accelerator Sterilizes Plastic Containers —

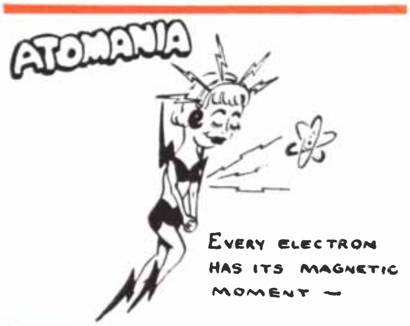
The first high voltage electron accelerator for use in the commercial sterilization of plastic containers has been installed and is now operating at Maynard, Mass., plant of the Bradley Container Corporation.



The machine, a 2-million-volt Van de Graaff accelerator built by HIGH VOLTAGE, generates a powerful beam of electrons capable of killing all bacteria within the polyethylene tubes and squeeze bottles being produced by the Bradley concern. Because there is virtually no heat involved in electron sterilization, the plastic material is not damaged by the process. The sterile containers are packed in sealed bags and sent to the user who fills them under aseptic conditions.

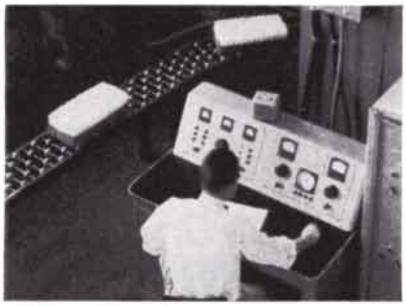
The unit also can sterilize small filled packages, such as tubes containing pharmaceuticals.

A patented extrusion-fabrication process developed in Europe is used by Bradley in the manufacture of its containers. Production is now topping half a million units a week, a figure which the company expects to quadruple before the end of the year. Electron sterilization, of course, is required for only a small proportion of this output at present, but demand for sterile packages, both unsealed and filled, is growing as new applications are developed.



Bradley Container's Van de Graaff is similar to the 2-million-volt electron machine installed in HIGH VOLTAGE's own radiation facility at its plant in Cambridge, Mass. The facility is completely equipped with radiation room, conveyor system, control room and product preparation room. This facility is available to industry on an hourly rental basis and has already been used by more than 80 companies for their exploratory work in electron sterilization, polymerization, cross-linking and other radiation processing applications.

The accelerator at the Bradley plant is the first high voltage electron beam sterilizer to be used in commercial packaging — an industry in which the Van de Graaff accelerator is expected to find wide future application.



Radiation-Sterilized Plastic Tubing Introduced —

The first electron-sterilized plastic tubing available commercially was offered for sale last month by the Clay-Adams Company, Inc., New York manufacturer of medical and surgical equipment and supplies. The new product is marketed under the Clay-Adams registered tradename of "Intramedic" Polyethylene Tubing. Available in convenient lengths, the tubing is packaged in sterile sealed plastic envelopes. The whole package is irradiated in one operation by passing it through a beam of electrons emitted by HIGH VOLTAGE's 2-million-electron-volt Van de Graaff accelerator. Complete sterility within the envelope is achieved within a few seconds. HIGH VOLTAGE performed the experimental testing irradiations for Clay-Adams in its 2-million-volt radiation facility at its plant in Cambridge. The sterile tubing is available in diameters of from .038″ to .075″. It is expected to be used primarily for the administration of caudal and spinal anesthesia and for the intravenous injection of blood plasma and other fluids.

The irradiation of this plastic tubing by HIGH VOLTAGE further establishes that complete sterilization can be accomplished economically using a Van de Graaff as a radiation source.

Radiation processing also is being utilized by the chemical and petroleum industries. For example, the use of electrons for the cross-linking and polymerization of plastics and other chemical products is a growing field. At HIGH VOLTAGE's Cambridge plant, products to be irradiated are loaded on a conveyor belt and are carried under the scanner of the Van de Graaff, permitting a continuous production-line type of operation. As a result, HIGH VOLTAGE can process small production lots at rates up to 400 lbs. per hour per megarep on a continuous basis. Details will be supplied upon request.

Another Van de Graaff For Britain —

The United Kingdom Atomic Energy Authority has ordered a 6-million-volt Van de Graaff particle accelerator from HIGH VOLTAGE. It will be installed at the Authority's Atomic Weapons Research Establishment at Aldermaston, Berkshire, England, and used for basic research by the Nuclear Physics Branch.

The huge machine stands more than 22 feet high and completely assembled with pressure tank weighs over 30 tons. Its cost, with all accessories and equipment, is $402,700.

HIGH VOLTAGE has manufactured similar accelerators for Oak Ridge National Laboratory, Rice University, and another for Columbia University which is now undergoing factory tests in Cambridge. The company also is making all of the technical and operating components of a 6-million-volt Van de Graaff for the Imperial College in London. The pressure tank and other heavy structural components for this machine are being obtained in England.

HIGH VOLTAGE ENGINEERING CORPORATION

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90,000 tons yearly production of Enjay Butyl, now available from its originators, will go into varied industrial products

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The low price and high-level performance of Enjay Butyl allow it to replace natural and other rubbers now used in industry. Enjay Butyl is the rubber that combines high resistance to aging . . . abrasion . . . tear . . . chipping or cracking . . . ozone or corona . . . chemicals and gases . . . heat . . . cold . . . sunlight . . . and moisture.

The new Enjay Laboratories, located at Linden, New Jersey, are equipped to provide expert technical assistance in compounding and adapting Enjay Butyl to individual uses and requirements.

Distinctive properties and low price give Enjay Butyl wide industrial application

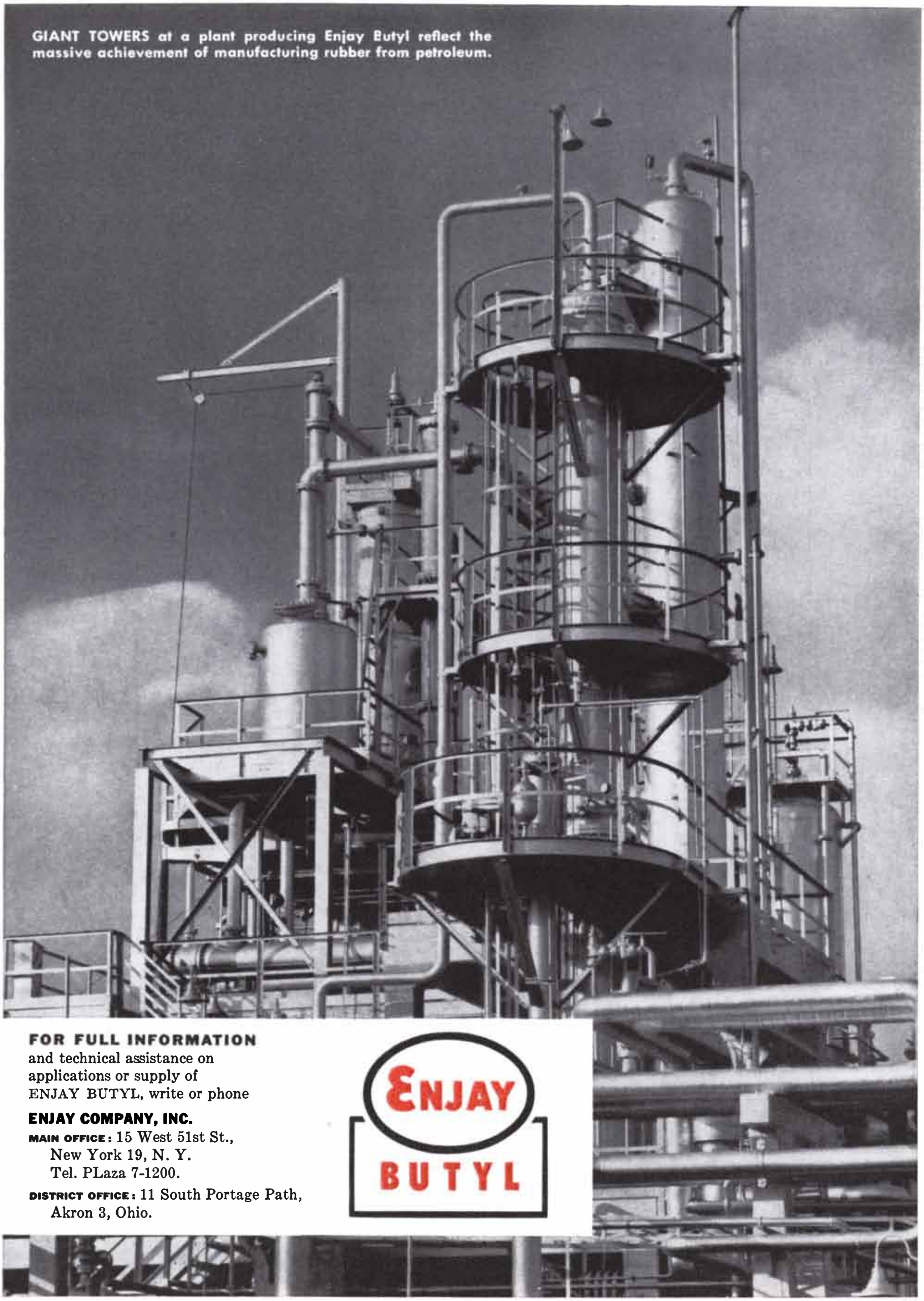
Inner tubes are made of BUTYL because BUTYL holds air ten times better than natural rubber. Its impermeability to gases promises many uses.

1955 cars use Butyl for dozens of rubber parts, because BUTYL has super-durable resistance to aging or deterioration on exposure to heat, cold, sun, weather, and chemicals.

High voltage electrical cables are made with BUTYL because BUTYL offers superior corona and ozone resistance, combined with excellent heat, cold, and abrasion resistance.

Tractor tires are made with BUTYL because BUTYL gives low tread wear and high resistance to weather, cracking, cutting, and chipping.

Protective clothing, tank linings, belt covers, hoses, and other equipment in contact with chemicals use BUTYL because of its exceptional resistance to chemicals.



GIANT TOWERS at a plant producing Enjay Butyl reflect the massive achievement of manufacturing rubber from petroleum.

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BUTYL

Haze hangs in a Maine forest

AIR POLLUTION

Although it is acute in some large cities, it is also found far from human habitations. An interesting example is the blue haze that sometimes hangs over forests and fields during the summer

by Frits W. Went

When we hear the expression "air pollution," we think of smoke billowing from factory chimneys, or of the Los Angeles smog. These are obvious cases, but air pollution is a much more general phenomenon. It seldom occurs to us that an autumn fog or a summer haze also is a form of air pollution. Nature, as well as man, pollutes the air in myriad ways which have to be considered in dealing with the pollution problem—a problem not confined to cities and world-wide in scope.

What is pure, unpolluted air? The answer is not at all simple. A chemist might say pure air consists of 20.82 per cent oxygen, 78.22 per cent nitrogen, .03 per cent carbon dioxide, .93 per cent argon and smaller amounts of neon, xenon, krypton and helium. But then there are also water vapor, which may vary from zero to 3 per cent, and the variable ozone, which increases after thunderstorms or at high altitudes in the stratosphere—to say nothing of the fact that the composition of the air has varied at different times in the earth's history. It is impossible to define the purity of air on a strictly chemical basis. A physicist would say that pure air should be completely transparent. In that sense the air of our atmosphere is never truly pure, because there are always molecular aggregates and dust particles which scatter the sunlight; indeed, the blue color of the sky is due largely to scattering of short wavelengths by minute particles in the lower atmosphere. Finally, biologically speaking, pure air should be free of all plant spores and other organisms. No sufferer from hay fever will consider the air over a wheat field in early summer, laden with invisible pollen, to be unpolluted, however clear and invigorating it may seem to others, and no surgeon will operate unless the air in his operating room is filtered to remove bacteria and other pollutants.

How, then, can we measure air purity? As a practical everyday definition, the best we can do is to say that the air is reasonably pure when it is sufficiently free of particles and gases to be clear of haze; in other words, the signs of pure air are a deep-blue sky and unlimited visibility.

Before considering the more esoteric forms of air pollution, let us first look into man-made air pollutants. These are conveniently divided into smoke particles and gases. The distinction is important in devising protective measures. The solid particles are rather easily removed by filters or electrostatic precipitators, but the absorption of gases is more difficult. For instance, a smelter roasting metal sulfides produces enormous amounts of sulfur dioxide. In a concentration as small as one part in one million parts of air this gas will injure plants long subjected to it. To prevent damage to vegetation such a factory must either be located in a practically vegetationless area or adopt some device to dispose of the sulfur dioxide, such as absorption in scrubbers or dispersal in the air from very high smokestacks to dilute the gases before they reach the ground.

In cities like Pittsburgh and St. Louis the worst of the pollution was due to release of great amounts of sulfur dioxide and smoke from incomplete burning of poor grades of soft coal. It was largely corrected by changing to better grades of fuel and improved combustion. More recently hydrofluoric acid has become recognized as a highly toxic air pollutant. In the neighborhood of factories using fluorine-containing materials (*e.g.*, aluminum and superphosphate plants) damage to vegetation due to hydrofluoric acid has been observed as far as five miles downwind.

As our economy uses more and more organic chemicals, air pollution by volatile organic compounds becomes more and more of a problem. The newest case in point is the famous Los Angeles smog. The name smog is a misnomer, because it is neither smoke nor fog. But since we need a new name for this type of air pollution, we may as well accept the word already in such wide use. This smog has worsened in the last 15 years. Visibility in Los Angeles, which used to be good, has gradually decreased. On some days the air takes on an acrid odor and irritates people's eyes to the point where tears flow.

The Los Angeles Smog

At first it was thought that smoke, dust, sulfur dioxide and hydrofluoric acid were responsible for the smog, but soon it became clear that these known pollutants, in the concentrations measured on smoggy days, could not cause the physiological effects observed. Besides, the typical smog odor could not be reproduced with any mixture of known pollutants. It was then that A. J. Haagen-Smit, the California Institute of Technology biochemist, suggested that peroxides and ozonides of hydrocarbons were responsible for smog. Upon mixing gasoline vapor with ozone he obtained a reaction mixture which immediately took on the bluish cast of the Los Angeles smog, had the same acrid odor and had the same physiological effects on plants. Then it was shown that peroxides and ozonides of hydrocarbons actually occurred in the Los Angeles atmosphere on a smoggy day. The Los Angeles County Air Pollution Control District is now attempting to reduce the discharge of hydrocarbons into the air in the area.

One of the most interesting aspects of smog is that the hydrocarbons which escape into the atmosphere, such as gasoline vapors and incomplete combustion products from gasoline engines, are relatively nontoxic at their point of emission. However, under the influence of light and the catalytic action of nitrogen oxides in the atmosphere the hydrocarbons are partly oxidized to peroxides and ozonides. These compounds are the most toxic air pollutants known. They will cause damage to plants in concentrations of one part in 10 million parts of air. The discovery that a comparatively nontoxic waste may be transformed into a noxious poison after escape into the atmosphere is an important new lead for students of the sources of air pollution.

One of the greatest difficulties in dealing with the Los Angeles smog is that it has so many aspects. Do we have to consider primarily eye irritation, which is very hard to assess, or loss of visibility,

POLLUTANT	ALTITUDE	COLOR IN DIRECTION OF LIGHT	COLOR AGAINST LIGHT	EXTERNAL EVENNESS	INTERNAL STRUCTURE
DUSTS	0-6000	BROWN YELLOW	GRAY	IRREGULAR UPPER BOUNDARY	EVEN
SMOKES					
COAL BURNING AND METAL REDUCTION FURNACES	0-1000	YELLOW BROWN	GRAY	STREAKS AND MUSHROOMS USUALLY IN LAYERS	UNEVEN
CEMENT KILNS	0-200	WHITE	GRAY	STREAKS	UNEVEN
TITANIUM OXIDE	0-20	WHITE	GRAY	BILLOWS	UNEVEN
ORCHARD HEATERS AND OIL BURNERS	0-500	BLACK	BLACK	STREAKS OR LAYERS	UNEVEN
VOLCANIC ERUPTIONS		BROWN TO WHITE	GRAY	STREAKS	IRREGULAR
WATER VAPOR CONDENSATION					
CLOUDS	100-8000	WHITE	GRAY	BILLOWS	UNEVEN
MIST	0-500	WHITE	GRAY	UNEVEN	UNEVEN
FOG	0-10	WHITE	GRAY	EVEN	UNEVEN
SMOGS					
METROPOLITAN	0-3000	BLUE	YELLOW	SHARP UPPER BOUNDARY	VERY EVEN
NATURAL	0-3000	BLUE	YELLOW	SHARP UPPER BOUNDARY	VERY EVEN
SO_2					
VISIBLE ONLY AFTER OXIDATION TO SO_3	0-200	WHITE	GRAY	UNEVEN	UNEVEN
HF	0-200	INVISIBLE	INVISIBLE	INVISIBLE	INVISIBLE

CHARACTERISTICS OF AIR POLLUTANTS are listed in this chart. The altitudes given in the second columns are in meters above the ground. Sulfur dioxide (SO_2) is visible only after it has been oxidized to sulfur trioxide. (SO_3). HF is hydrogen fluoride.

which is not necessarily linked with the physiological effects of the smog, or crop damage, which can easily be recognized and even evaluated in terms of monetary loss to vegetable growers (about $1 million per year)?

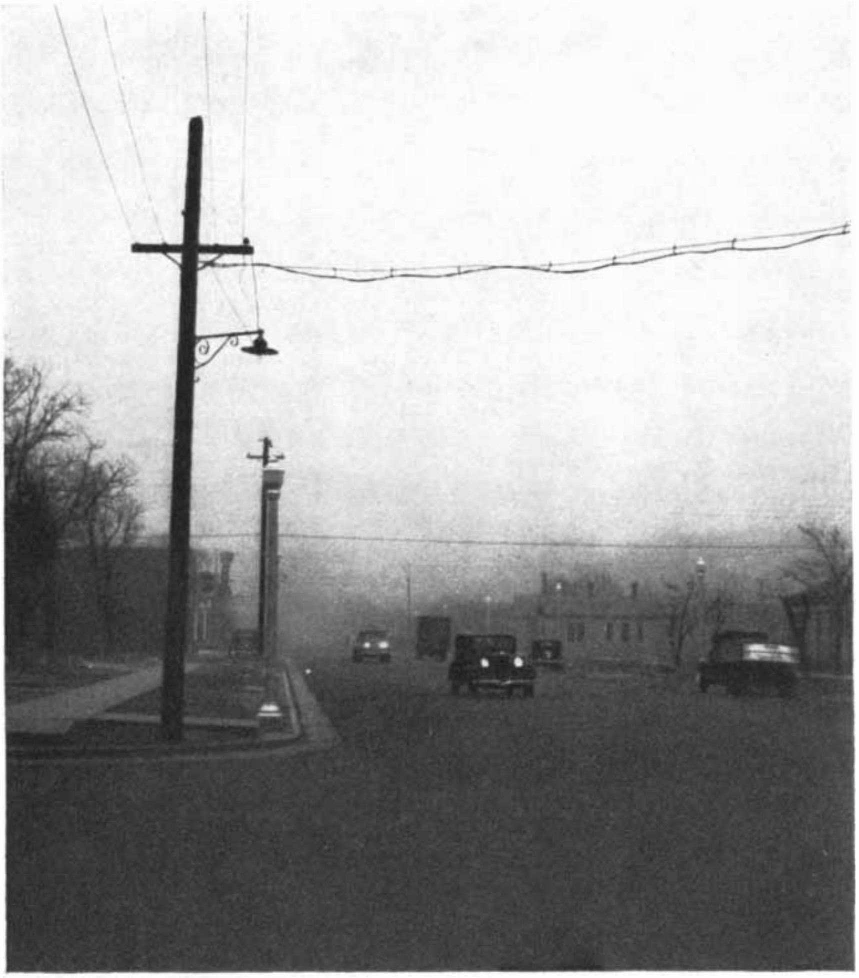
Plants are a convenient means of assessing the toxicity of smog. Leafy vegetables are very sensitive to smog and show typical damage on their leaves (silvering or browning of lower surfaces) one or two days after a smog attack. In this way it is easy to distinguish true smog from other pollutants. I have used the test to study smog in a number of large cities all over the world; the problem is not peculiar to Los Angeles.

Smog in Other Cities

Smog is a function not only of the hydrocarbons released into the air but also of geography and the pattern of air movement. The height of the inversion layer and the horizontal air movement over a city determine the volume of air in which the emitted air pollutants are contained, and consequently determine their ultimate concentration. In cities which have a low inversion ceiling on many days of the year and in which there usually is little wind, the smog problem is most serious. This condition exists typically in Los Angeles, San Francisco, São Paulo and Rio de Janeiro. All these cities are located near the sea in areas with stable air masses and are closed in by mountains which prevent lateral air drainage.

In São Paulo I observed the typical smog damage on leaves of tobacco plants grown in a greenhouse in the center of the city. During my visit there in March, 1954, the smog was so heavy that the airport had to be closed for several hours practically every morning because of poor visibility. São Paulo's smog closely resembled that of Los Angeles. It was definitely not fog or a product of the smoky factories around São Paulo, which burn soft coal and wood; such smoke is much darker than the bluish-gray smog. Unless São Paulo takes corrective steps, its smog will seriously interfere with the city's activities within a few years. At the moment the economic losses due to the daily closing of the airport must be considerable. Soon extensive plant damage can be expected.

In Rio de Janeiro a rather dense smog develops in the morning, moves eastward in the afternoon and is blown back toward the city in the evening. During the middle of the day the smog was fairly severe in the center of the city. I did not

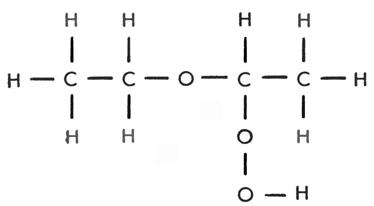


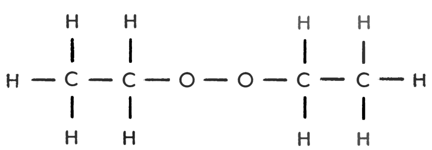
Drivers turn on their lights during a dust storm in Amarillo, Tex.

A farmer rakes ash from his roof during the eruption of the Mexican volcano Paricutin have an opportunity to test its damage to sensitive plants.

The San Francisco Bay area occasionally has smog just as severe as in Los Angeles, but it seems to come less frequently. Elsewhere in the U. S. I observed typical smog damage to plants in Baltimore, Philadelphia and New York, even though those cities have better lateral air drainage than the cities on the West Coast. New York sometimes has a heavy smog which reduces visibility enormously. In Chicago I found much damage to plants, but the damage was unlike that caused by smog; perhaps the smog effect was masked by damage from industrial gases. Among the large U. S. cities I have visited in recent years, only St. Louis and Houston seemed to be free of any smog damage to plants. Houston seems to have escaped in spite of the proximity of the Texas City oil refineries.

The cities of Bogota and Medellin in Colombia apparently had smog conditions, though in Medellin the culprit may have been smoke. Medellin, a town of 355,000, is located in a rather narrow valley surrounded by high mountains; consequently smoke or smog generated by its factories lies in the valley. On many days the airport was closed all morning. In Bogota a smog wave hovers over the city in early morning and late afternoon, at times hiding the neighboring mountains from view. In this city I observed definite smog damage on lettuce leaves and Swiss chard.





In Europe also the smog situation is becoming alarming. A month before London had its catastrophic smog week in December, 1952, when 4,000 people died, I had visited the city and found clear-cut smog damage on plants. Commercially significant smog damage was observed as far away from London as the Rothamsted Experimental Station in Harpenden and the National Institute of Agricultural Engineering station at Wrest Park. The damage had occurred on days when a slow wind blew air from London toward those places. No obvious sulfur dioxide damage was observed during my visits to London and surroundings, and it seems a logical conclusion that the deaths in London were due to actual smog rather than any other industrial chemicals. The city of Manchester also showed typical plant damage from smog.

I found no smog damage in the Netherlands during three visits there, but in 1952 Copenhagen showed evidence of true smog, and so did the nearby town of Lund in Sweden. Stockholm, however, seemed to be free of it. Liége in Belgium had clear-cut plant damage, but apparently it was due to hydrofluoric acid, and it seems likely that the wave of deaths in the Meuse valley near Liége in 1931 were caused by this chemical.

Except for Cologne, German cities I visited, as well as Rome and Madrid, showed no sign of smog. But Paris in the summer of 1954 had clear evidence of smog damage, though I had seen none there two years earlier. Gardeners in Paris corroborated my observation that the smog type of leaf damage was new to the city. If we assume that there has been no major change in meteorological conditions in Paris, we must conclude that since 1952 air pollution in Paris has reached the threshold value for plant damage. During the past two years the number of automobiles in Paris has increased and the consumption of high-octane gasoline has doubled. Haagen-Smit has observed that high-octane gasolines, containing unsaturated carbon bonds, produce highly toxic pollutants.

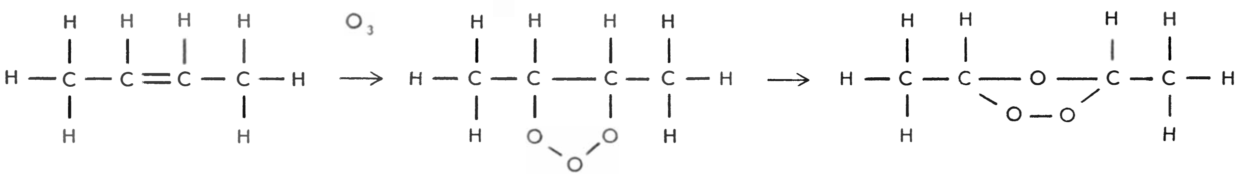
The plant test is so reliable a measure of dangerous air pollution that I wish to make a plea for periodic surveys with it of air pollution in all large communities. As long as the public and the responsible authorities assume that the hazes which hang over their cities are merely natural "fogs," no measures against them will be taken. But we may well heed the example of London, where several thousand people were killed by a "fog" in a single week.

Signs of Pollution

Even when smog is below the threshold concentration that causes visible damage to plants, it gives certain evidences of its presence. For one thing, it seems to stunt plant growth. In the Los Angeles suburb of Pasadena and in other cities the growth rate of seedlings was reduced to half long before any one took notice of the smog phenomenon; recently it has been found that air pollutants were responsible for this. For a long time it has been known that lichens no longer grow on the bark of trees in large cities; they can be found only on trees some distance away. It is likely that pollution in all the larger cities has already risen to such a level that no plant can grow normally in them.

Perhaps the simplest measure of air pollution is decrease in visibility. The appearance of the air, though far from a specific indicator, can give a general idea of the type of contamination. The table on page 64 lists some optical properties of various pollutants. The different types can be distinguished by their color, distribution in space, evenness and density. When the particle size is larger than the wavelength of light, the pollutant will tend to reflect its own color, which is black in the case of soot, brown or yellow for iron oxide or dust, white for calcium carbonate, and so on. When the particle size is less than the wavelength of light, the particles largely refract the short wavelengths, imparting a bluish color to the air when it is illuminated by strong light.

Dust clouds in the atmosphere may



TOXIC PEROXIDES AND OZONIDES occur when hydrocarbons are partly oxidized. At the top is the formula of ethyl ether peroxide. Second from the top is the formula of diethyl peroxide. At the bottom is the reaction that converts butene into butene ozonide.

originate from a great volcanic eruption such as that of Krakatoa, but this is rare; much more common are the dust storms blown up from bare soil or deserts by high winds. They may occur frequently in deserts with few mountains, such as the Sahara, or on the dry, endless plains of western Kansas, Oklahoma and Texas. Deserts bordered by high mountain ranges (*e.g.*, in Peru, Chile, Southern California) have less wind and, consequently, little dust. Whether we are dealing with dust generated by harrowing a dry field or with a sandstorm 18,000 feet high over the Arizona desert, the upper boundary of the dust cloud is always very uneven, because of the turbulence produced by the wind.

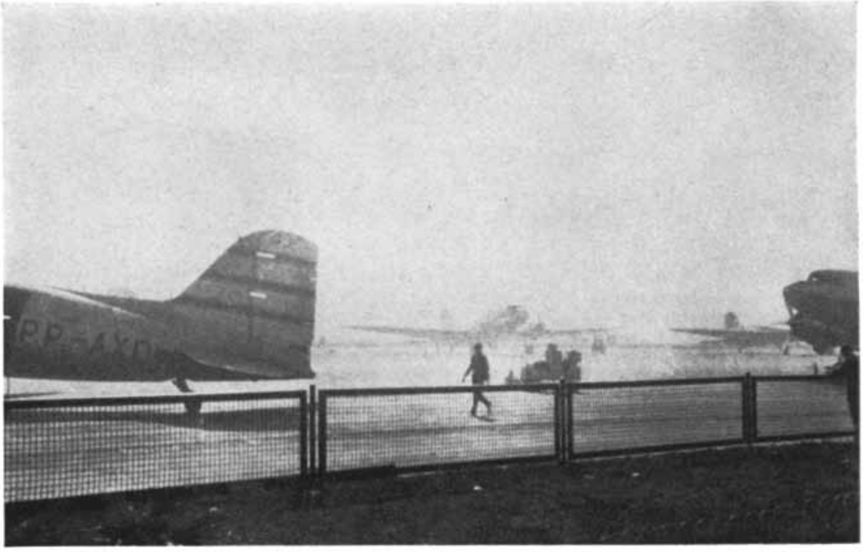
Smoke tends to settle in streaks or layers, because the smoke does not mix evenly with the surrounding air. Therefore, if the haze over a city is spread uniformly, it cannot be due to smoke. Smokes are usually yellow, brown or black, occasionally white, never blue.

The water droplets in mist or clouds deflect all wavelengths evenly, and therefore always look white in incident light. The smallest stable droplets in fog are five microns in diameter; in mist they may be 25 microns, and in drizzles or rain they are 200 microns or more in diameter. The smaller the particles and the greater the supersaturation of the air, the denser will be the cloud. Newly condensed steam reduces visibility to less than three feet. A fog whose droplets are five microns in diameter will allow no more than 15 to 30 feet visibility; in mist the maximum visibility is 300 feet; in drizzle or rain visibility may be half a mile or more. Any haze which allows visibility of more than half a mile cannot possibly be due to fog droplets.

The preceding considerations make it quite clear that the idea that smog or haze consists partly of water-vapor condensation on smog particles is fallacious. When water condenses on nuclei in the air, the droplets formed will quickly disappear unless they grow to at least five microns in diameter. This can happen only when the air is supersaturated. In ordinary, unsaturated air, water vapor cannot condense no matter what we add to the air. Furthermore, when any water vapor condenses, no matter how little, the cloud is white; it never has the bluish cast of smog.

Haze at Night

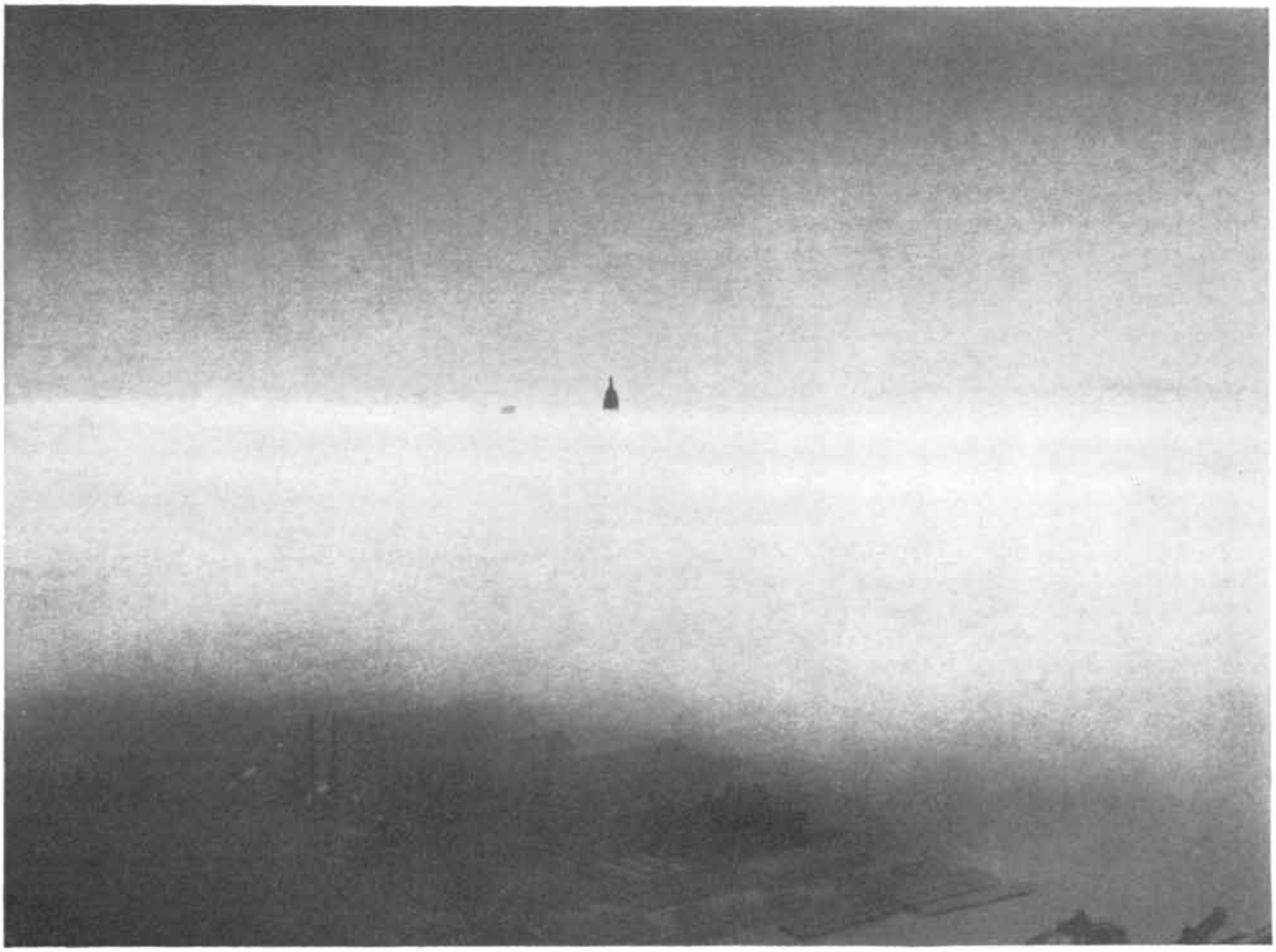
Thus smog and haze belong in a very special category. They differ from all other known overcasts in color, particle



Smog in São Paulo, Brazil

Sunset haze in Panama City, Panama

Autumn haze in Midhurst, England



Smog over Manhattan

size and relationship to winds. Whereas fogs, water clouds, smokes and dusts are all uneven, either in their internal structure or at their boundaries, both smog and haze are remarkably uniform in their internal structure and even in their external outline. The smog layer over Los Angeles is topped by an inversion layer with a very even ceiling, and the same thing is true for all kinds of hazes. When flying at high altitudes over the countryside, one can see that hazes have a definite upper boundary. Very often cumulus clouds form at this upper boundary, showing that the boundary coincides with an inversion layer.

It is a remarkable fact that no clear-cut distinction can be made between smog and haze. Typical smog occurs only in metropolitan areas and is obviously connected with human activities, but as far as appearance goes, smog shades indistinguishably into summer or "heat" haze. Such hazes are most easily recognized at night, when they obscure the fainter stars and decrease the jet blackness of the sky between stars. It is well known that the sky is clearest and the stars most brilliant (1) in the middle of the ocean, far from land or people; (2) during winter; (3) in the desert; (4) high in the mountains, and (5) immediately after a heavy storm, when all the haze particles have been precipitated or the sky has been swept by an incoming mass of pure air. Over a large city or an industrial area one can seldom see more than a few stars at night. The city lights are not the prime reason, for in a region clear of haze even the full moon will not dim the Milky Way. Over a large city there is so much smoke, dust and smog that faint starlight cannot penetrate it. The only city in which I remember having seen a velvet-black sky studded with millions of stars night after night even in summer is Jerusalem. That city has no industry, burns little fuel, lies high up in the Judean hills and is surrounded by desert.

The visibility of stars under standardized conditions might afford a good quantitative method for measuring air pollution. A daytime scale also might be developed on the basis of the visibility of landmarks, such as mountains, towers or trees, at known distances. But we would like to have a method independent of the human eye—a method by which the visibility component of air pollution could be measured automatically and could be expressed in numbers (with lots of decimals) neatly plotted in tables or graphs.

A very sensitive measure of haze might be obtained from observations of the light on the horizon just before sunset or after sunrise. The color of the sunset can tell us how much and what type of pollution is in the air. When the sun sets a brilliant white, the air is exceptionally clear. A red sunset means the atmosphere is smoggy or hazy. A bleak yellow sunset means that the air has lots of smoke and dust. To measure the amount of haze we might compare the atmospheric absorption of sunlight at midday with that at sunset, when the light passes through five times more air. From this we could draw good conclusions as to the nature of the haze, espe-

Smog over Los Angeles

cially if we made the measurements both in the blue and the red ends of the visible spectrum.

Flying over a large city at night, you may have been struck by the preponderance of red advertising signs. This is an optical illusion: the smog cuts off the blue lights and passes mainly the red. You may also have wondered about the brilliant green street lights you see from the air—a color you have never seen while driving through the city. These are mercury vapor lamps; they emit blue and green, but at a distance the blue is filtered out by the smog. Similarly, when you look at a Christmas tree from a distance, you will see the red lights but not the blue.

Summer Haze

Summer heat haze is a mysterious special phenomenon. It covers large areas of the world which are free from dust, fires or human habitation. A more or less dense haze hangs the year around over such areas as the Amazon basin, the vast jungles of northern Colombia and the highlands of southeastern Mexico. During the summer the heat haze covers most of the U. S. except the deserts of the Southwest. It is so dense that in summer the open country is almost as hazy as our cities. The heat haze has nothing to do with dust, smoke or even moisture, for it is just as dense near the ground, where the relative humidity may be 40 per cent, as near the inversion layer 10,000 feet up, where the humidity may be 100 per cent.

This blue summer haze looks so much like the man-made smog of Los Angeles and other cities that I propose to call it natural smog. What is its source? For an explanation of such a blue haze in the air we can turn to the famous discovery concerning the blueness of the sky that was made in the 1860s by the well-known English physicist and lecturer John Tyndall. He demonstrated experimentally that when a strong beam of light was passed through air containing small amounts of organic vapors, a "blue cloud" formed. The air was completely transparent, but it had a bluish tinge, which Tyndall surmised was due to the formation of submicroscopic particles from the organic molecules. He concluded that most of the sky's blue color had to be attributed to the reflection of sunlight by minute particles in the sky.

When we combine our observations with Tyndall's experiments, we can draw the conclusion that summer haze, or natural smog, is caused by organic emanations from plants. They release vast quantities of material into the air. Most of the aromatic substances emitted by flowers are hydrocarbons or slightly oxidized hydrocarbons belonging to the general group of essential oils. Many plants contain terpenes, which after evaporation into the air produce the pungent odors of the deserts, the chaparrals, the dunes or the pine forests. There is hardly any type of vegetation which does not emit volatile organic compounds. Haagen-Smit has estimated that the sagebrush vegetation of the Southwest releases approximately 570 pounds per square mile per day. When released, these organic substances are invisible gaseous molecules. But the terpenes from plants, like the hydrocarbons from gasoline, could easily form ozonides and peroxides in the air. It is very likely that these oxidation products, like those of gasoline vapors, are toxic, but we do not know yet whether they ever reach harmful concentrations in the air. I would guess that they are rarely present in sufficient amounts to show physiological effects on plants.

Apparently, then, natural smog is the same thing that Tyndall called the "blue cloud." Organic vapors arising from vegetation are immediately oxidized to the blue cloud. If you look closely when you drive through the country on a cloudless and windless day, you will see that the blue haze which blurs all distant objects is densest near the surface of the ground, where it evidently is generated. Presumably this smog can be blown by air currents and winds over fairly large distances, but through a process of self-cleaning of the air it gradually disappears, and thus the upper atmosphere and the air above the oceans are clean.

The hypothesis that the summer heat haze is a natural smog derived from vegetation accounts for all the observations of heat haze. It is particularly pronounced in summer, when the vegetation is most active, and it occurs mainly in areas densely covered with vegetation. Where vegetation is sparse or absent, as over deserts or oceans, there is little or no heat haze. The natural smog explains why a jungle such as the Amazon basin is so hazy that it is hard to see the ground from a plane 15,000 feet up; why fiery red sunsets are so common in the lush tropics; why the atmosphere absorbs more of the sun's light in summer than in winter, and why the night sky is so much clearer in winter.

A Petroleum Cycle?

How does the air clear itself of this natural pollution? We might consider the theory that the organic emanations from plants are ultimately oxidized to carbon dioxide and water, but the particles responsible for the bluish haze are hardly likely to disappear in that manner: they are large, complex molecules and presumably almost inert chemically. They must leave the air by settling. In the course of time the haze particles coalesce and grow in size. When they exceed one micron in diameter, they become heavy enough to settle very slowly to the surface of the ground, especially

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In a chemical analysis of snow residue it was found that even in remote country areas about 5 per cent of the residue was organic and of a black tarlike consistency. I suggest that this tar actually is the residue of natural smog, whose growing particles gradually change in color via whitish blue and yellow to brown and finally black. I also suggest that this inert material, consisting largely of hydrocarbons, might be a parent material for petroleum. The amounts of terpenes given off by plants are certainly sufficient to account for all the petroleum formed in previous geological periods.

Thus the discovery and study of man-made smog in the Los Angeles area in the last few years may have led us to discovery of a new carbon cycle in nature whereby volatile hydrocarbons from plants produce natural smog and in the long run may be distilled into oil deposits. When the oil is brought back to the surface and burned in our factories and automobiles, its volatilization takes the hydrocarbons through a second cycle which once again turns them into smog—this time man-made. If this very tentative hypothesis is correct, it would tend to indicate that there really is nothing new under the sun. But it must be admitted that the hypothesis fails so far to explain many geological facts concerning the formation of petroleum.

It is tempting to speculate similarly on other phenomena. For instance, consider the autumn haze, so common in countries with deciduous forests and with much dying vegetation. Who does not remember the typical smell of autumn woods and of decaying leaves? This smell must be due to volatile organic substances arising from the dying material. In decaying leaves we find considerable amounts of terpenes, in the form of the yellow pigments, or carotenoids. They eventually disappear in some unknown way. It is tempting to assume that such terpenes are volatilized and produce the autumn haze. Often water vapor condenses on such haze particles, giving rise to the familiar dense autumn fogs. Even more familiar are those beautiful days in late autumn when the sun filters weakly through a bluish haze which bathes the fields, forests and hills.

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The Physiology of Fear and Anger

Man exhibits two kinds of anger: anger directed outward and anger directed inward. Recent work suggests that each kind is associated with a different secretion of the adrenal glands

by Daniel H. Funkenstein

When the late Walter B. Cannon, by his historic experiments nearly half a century ago, showed a connection between emotions and certain physiological changes in the body, he opened a new frontier for psychology and medicine. His work, coupled with that of Sigmund Freud, led to psychosomatic medicine. It also made the emotions accessible to laboratory measurement and analysis. Within the last few years there has been a keen revival of interest in this research, because of some important new discoveries which have sharpened our understanding of specific emotions and their bodily expressions. It has been learned, for instance, that anger and fear produce different physiological reactions and can be distinguished from each other. The findings have given us a fresh outlook from which to study mental illnesses.

The best way to begin the account of this recent work is to start with Cannon's own summary of what he learned. Cannon found that when an animal was confronted with a situation which evoked pain, rage or fear, it responded with a set of physiological reactions which prepared it to meet the threat with "fight" or "flight." These reactions, said Cannon, were mobilized by the secretion of adrenalin: when the cortex of the brain perceived the threat, it sent a stimulus down the sympathetic branch of the autonomic nervous system to the adrenal glands and they secreted the hormone. Cannon graphically described the results as follows:

"Respiration deepens; the heart beats more rapidly; the arterial pressure rises; the blood is shifted away from the stomach and intestines to the heart and central nervous system and the muscles; the processes in the alimentary canal cease; sugar is freed from the reserves in the liver; the spleen contracts and discharges its content of concentrated corpuscles, and adrenin is secreted from the adrenal medulla. The key to these marvelous transformations in the body is found in relating them to the natural accompaniments of fear and rage—running away in order to escape from danger, and attacking in order to be dominant. Whichever the action, a life-or-death struggle may ensue.

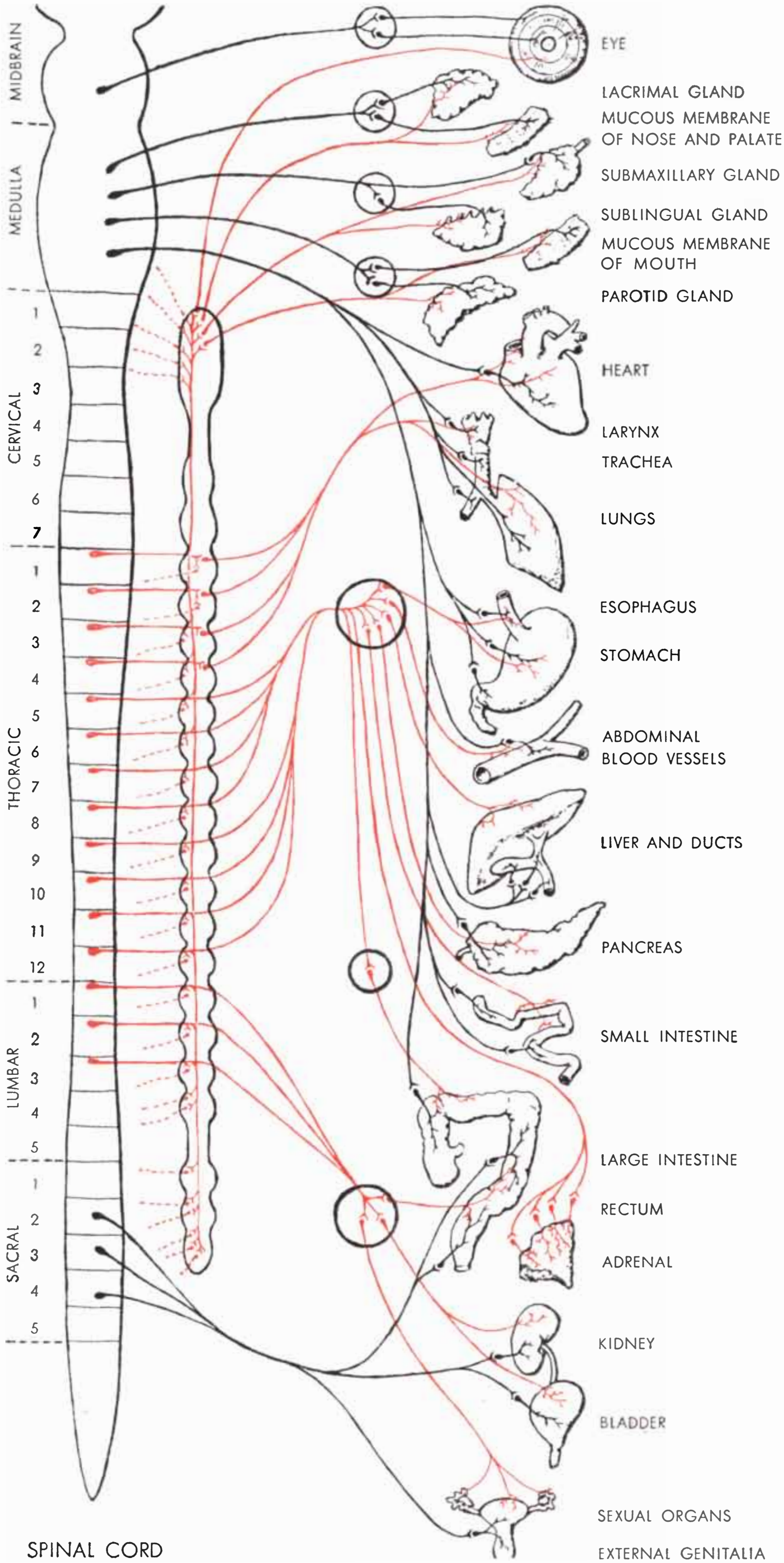
"The emotional responses just listed may reasonably be regarded as preparatory for struggle. They are adjustments which, so far as possible, put the organism in readiness for meeting the demands which will be made upon it. The secreted adrenin cooperates with sympathetic nerve impulses in calling forth stored glycogen from the liver, thus flooding the blood with sugar for the use of laboring muscles; it helps in distributing the blood in abundance to the heart, the brain, and the limbs (*i.e.*, to the parts essential for intense physical effort) while taking it away from the inhibited organs in the abdomen; it quickly abolishes the effects of muscular fatigue so that the organism which can muster adrenin in the blood can restore to its tired muscles the same readiness to act which they had when fresh; and it renders the blood more rapidly coagulable. The increased respiration, the redistributed blood running at high pressure, and the more numerous red corpuscles set free from the spleen provide for essential oxygen and for riddance of acid waste, and make a setting for instantaneous and supreme action. In short, all these changes are directly serviceable in rendering the organism more effective in the violent display of energy which fear or rage may involve."

Cannon recognized that among all these physiological changes there were a few which could not be ascribed directly to the action of adrenalin. He therefore postulated that the hormone was supplemented by two additional substances from the sympathetic nerves. An active agent, distinguishable from adrenalin, was eventually identified in 1948, when B. F. Tullar and M. L. Tainter at length succeeded in preparing the optically active form of the substance. It proved to be a second hormone secreted by the adrenal medulla. Called nor-adrenalin, it differs markedly from adrenalin in its physiological effects. Whereas adrenalin elicits profound physiological changes in almost every system in the body, nor-adrenalin apparently has only one important primary effect: namely, it stimulates the contraction of small blood vessels and increases the resistance to the flow of blood.

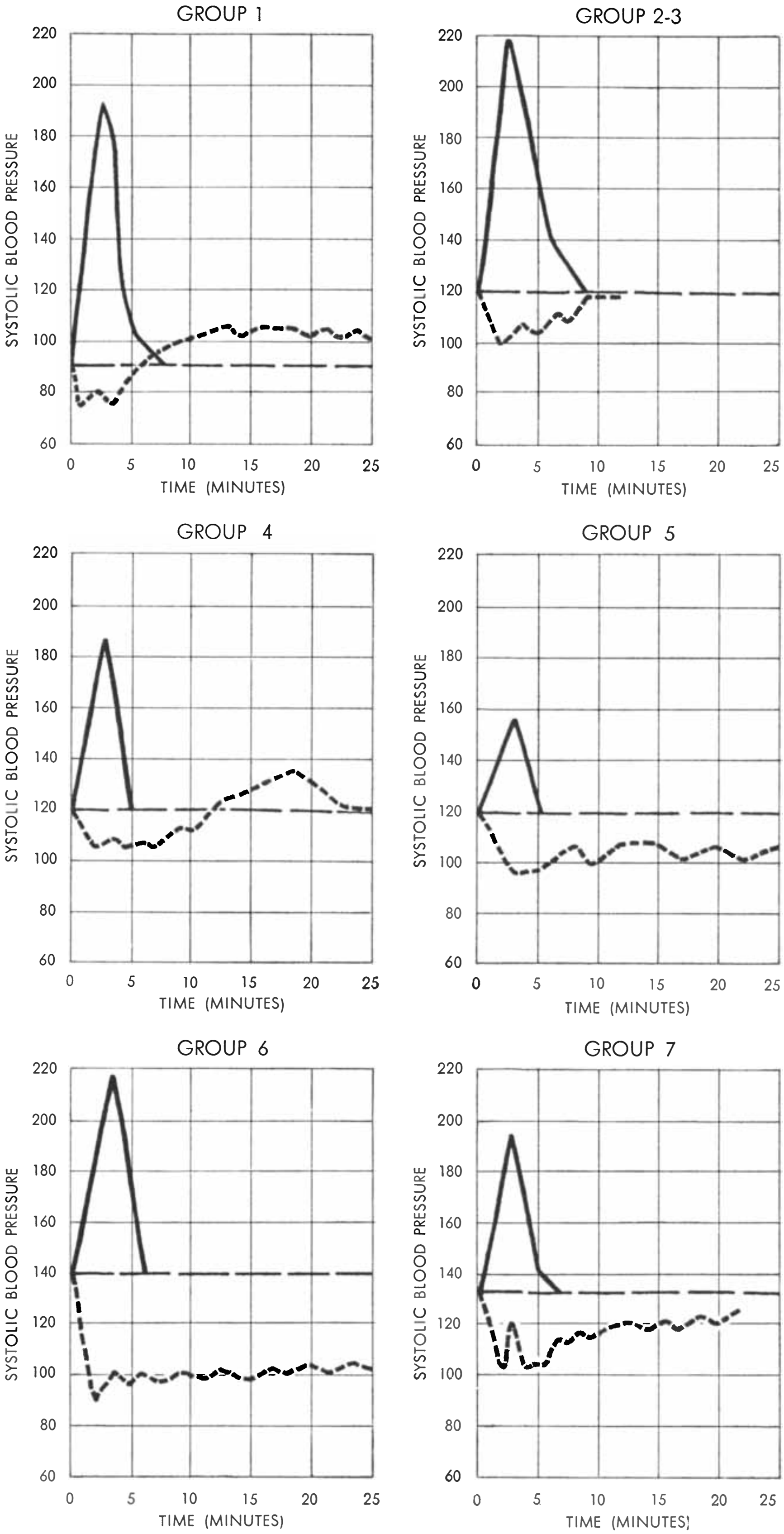
An animal exhibits only two major emotions in response to a threatening situation: namely, rage and fear. A man, however, may experience three: anger directed outward (the counterpart of rage), anger directed toward himself (depression) and anxiety, or fear. In studies of physiological changes accompanying various emotional states among patients at the New York Hospital, H. G. Wolff and his co-workers noticed that anger produced effects quite different from those of depression or fear. For example, when a subject was angry, the stomach lining became red and there was an increase in its rhythmic contractions and in the secretion of hydrochloric acid. When the same subject was depressed or frightened, the stomach lining was pale in color and there was a decrease in peristaltic movements and in the hydrochloric acid secretion.

The experiments of Wolff, the evidence that the adrenal medulla secreted two substances rather than one and certain clinical observations led our group at the Harvard Medical School to investigate whether adrenalin and nor-adrenalin might be specific indicators which distinguished one emotion from another. The clinical observations had to do with the effects of a drug, mecholyl, on psychotic patients. We had been studying their blood-pressure responses to injections of adrenalin, which acts on the sympathetic nervous system, and mecholyl, which stimulates the parasympathetic system. On the basis of their blood-pressure reactions, psychotic patients could be classified into seven groups [*see charts on next page*]. This test had proved of value in predicting patients' responses to psychiatric treatments, such as electric shock and insulin: certain groups responded better to the treatments than others. But more interesting was the fact that psychotic patients with high blood pressure reacted to the injection of mecholyl in two distinctly different ways. In one group there was only a small drop in the blood pressure after the injection, and the pressure returned to the usually high level within three to eight minutes. In the other group the blood pressure dropped markedly after the injection and remained below the pre-injection level even after 25 minutes. Not only were the physiological reactions quite different, but the two groups of patients also differed in personality and in response to treatment. Thirty-nine of 42 patients whose blood pressure was sharply lowered by mecholyl improved with electric shock treatment, whereas only three of 21 in the other group improved with the same treatment. Further, the two groups showed distinctly different results in projective psychological tests such as the Rorschach.

All this suggested that the two groups of patients might be differentiated on the basis of emotions. Most psychotic patients in emotional turmoil express the same emotion constantly over a period of days, weeks or months. Psychiatrists determined the predominant emotion expressed by each of 63 patients who had been tested with mecholyl, without knowing in which physiological group they had been classified. When the subjects' emotional and physiological ratings were compared, it turned out that almost all of the patients who were generally angry at other people fell in Group N (a small, temporary reduction of blood pressure by mecholyl), while almost all those who were usually depressed or frightened were in Group E (sharp re-



THE AUTONOMIC NERVOUS SYSTEM is represented by this diagram. The parasympathetic branches, arising from the brain and sacral vertebrae, are indicated in black; the sympathetic branches, arising from the thoracic and lumbar vertebrae, are in color.



SEVEN GROUPS of psychotic patients were distinguished on the basis of their blood pressure after injection with adrenalin or mecholyl. In these six charts the basal systolic blood pressure of the patients is indicated by the broken horizontal line. The solid curve shows their response to adrenalin; the broken curve, their response to mecholyl. Groups 2 and 3 are combined because the difference between them is too slight to show in the graph. The mecholyl response for Group 7 is incomplete because of experimental difficulties.

sponse to mecholyl). In other words, the physiological reactions were significantly related to the emotional content of the patients' psychoses.

The next step was to find out whether the same test could distinguish emotions in normal, healthy people, using medical students as subjects. They were studied at a time when they were under stress—while they were awaiting the decisions of hospitals on their applications for internships. As the competition among the students for the hospitals of their choice is keen, the period just prior to such announcements is a time of emotional turmoil for the men. A group of students who responded to this situation with elevated blood pressure was given the standard dose of mecholyl. The results were the same as for the psychotic patients: students who were angry at others for the situation in which they found themselves had a Type N physiological reaction; those who felt depressed (angry at themselves) or anxious showed a Type E physiological reaction. The reaction was related only to their temporary emotional state; after the internships were settled and their blood pressures had returned to pre-stress levels, all the students reacted the same way to the injection of mecholyl.

It was at this point that we undertook to investigate the comparative effects of adrenalin and nor-adrenalin. A group of workers at the Presbyterian Hospital in New York had shown that injections of nor-adrenalin and adrenalin produced two different types of rise in blood pressure, one due to contraction of blood vessels and the other to faster pumping by the heart. Upon learning of this work, we designed experiments to test the hypothesis that the two types of elevated blood pressure, differentiated by us on the basis of mecholyl tests, indicated in one instance excessive secretion of nor-adrenalin and in the other excessive secretion of adrenalin. Healthy college students were first given a series of intravenous injections of salt water to accustom them to the procedure so that it would not disturb them. Then each subject was tested in the following way. He was given an injection of nor-adrenalin sufficient to raise his blood pressure by 25 per cent. Then, while his blood pressure was elevated, he received the standard dose of mecholyl, and its effects on the blood pressure were noted. The next day the subject was put through the same procedure except that adrenalin was given instead of nor-adrenalin to raise the blood pressure.

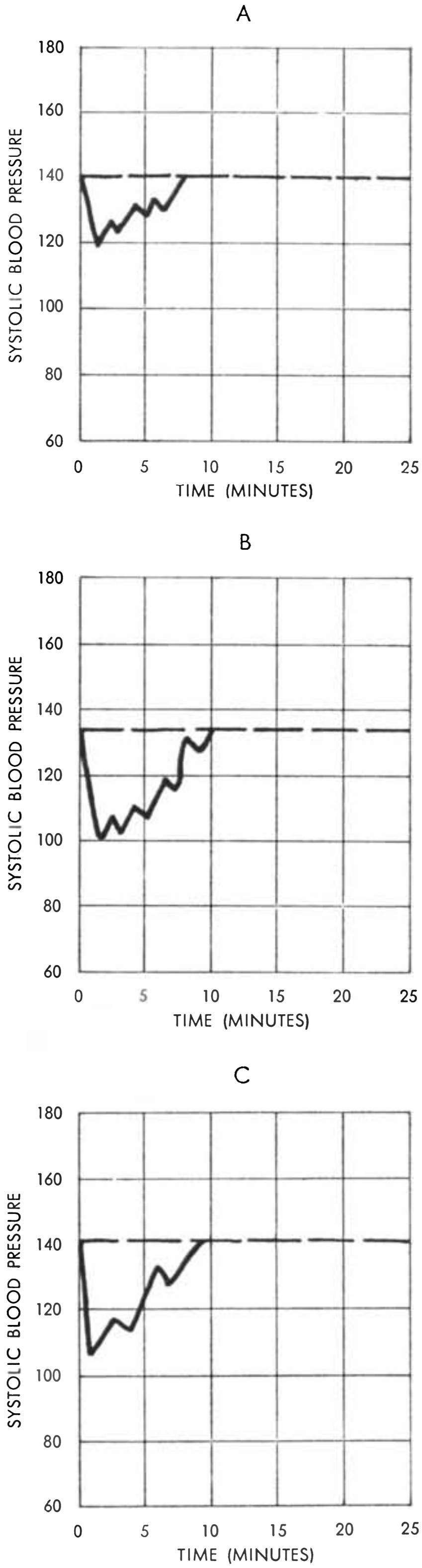
Ten students were studied in this way, and in every instance the effect of nor-adrenalin was different from that of adrenalin [*see charts on page 80*]. When the blood pressure was elevated by nor-adrenalin, mecholyl produced only a small drop in pressure, with a return to the previous level in seven to 10 minutes. This reaction was similar to the Type N response in psychotic patients and healthy students under stress. In contrast, when the blood pressure was elevated by adrenalin, mecholyl produced the Type E response: the pressure dropped markedly and did not return to the previous level during the 25-minute observation period.

These results suggested, in the light of the earlier experiments, that anger directed outward was associated with secretion of nor-adrenalin, while depression and anxiety were associated with secretion of adrenalin. To check this hypothesis, another series of experiments was carried out.

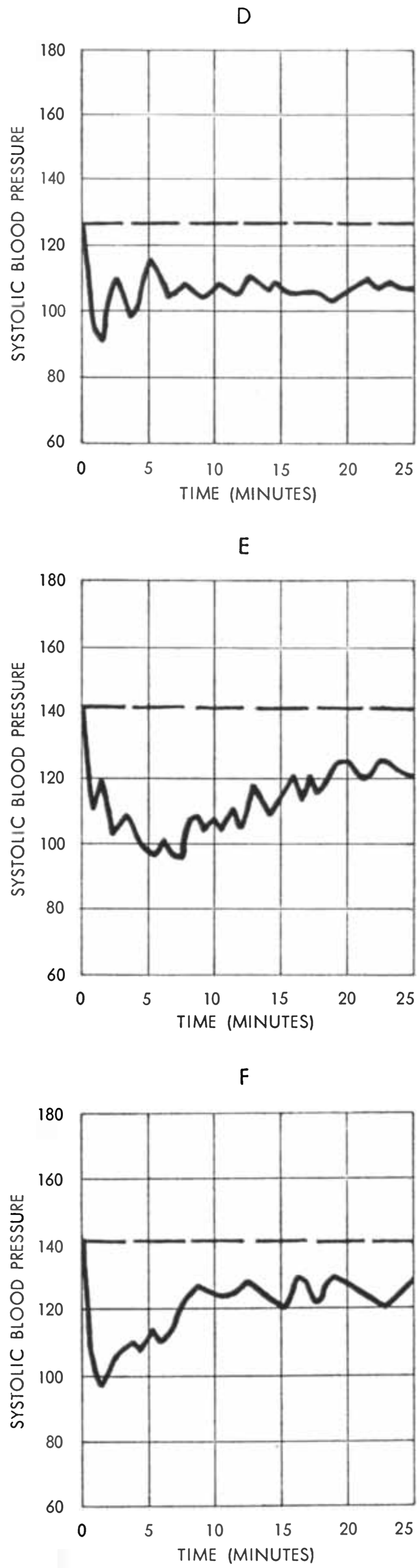
A group of 125 college students were subjected to stress-inducing situations in the laboratory. The situations, involving frustration, were contrived to bring out each student's habitual reaction to stresses in real life; that the reactions actually were characteristic of the subjects' usual responses was confirmed by interviews with their college roommates. While the subjects were under stress, observers recorded their emotional reactions and certain physiological changes—in the blood pressure, the pulse and the so-called IJ waves stemming from the action of the heart. This test showed that students who responded to the stress with anger directed outward had physiological reactions similar to those produced by injection of nor-adrenalin, while students who responded with depression or anxiety had physiological reactions like those to adrenalin.

There remained the question: Does the same individual secrete unusual amounts of nor-adrenalin when angry and of adrenalin when frightened? Albert F. Ax, working in another laboratory in our hospital, designed experiments to study this question. He contrived laboratory stressful situations which were successful in producing on one occasion anger and on another occasion fear in the same subjects. His results showed that when a subject was angry at others, the physiological reactions were like those induced by the injection of nor-adrenalin; when the same subject was frightened, the reactions were like those to adrenalin. This indicated that the physiology was specific for the emotion rather than for the person.

In all these experiments the evidence



TYPE N RESPONSE to the injection of mecholyl is traced by the heavy line. The broken line represents the basal blood pressure. The response is shown for three kinds of subject: (A) healthy individuals under stress who respond with anger toward others, (B) healthy individuals whose blood pressure has been elevated with nor-adrenalin and (C) psychotic individuals with elevated blood pressure and anger toward others.



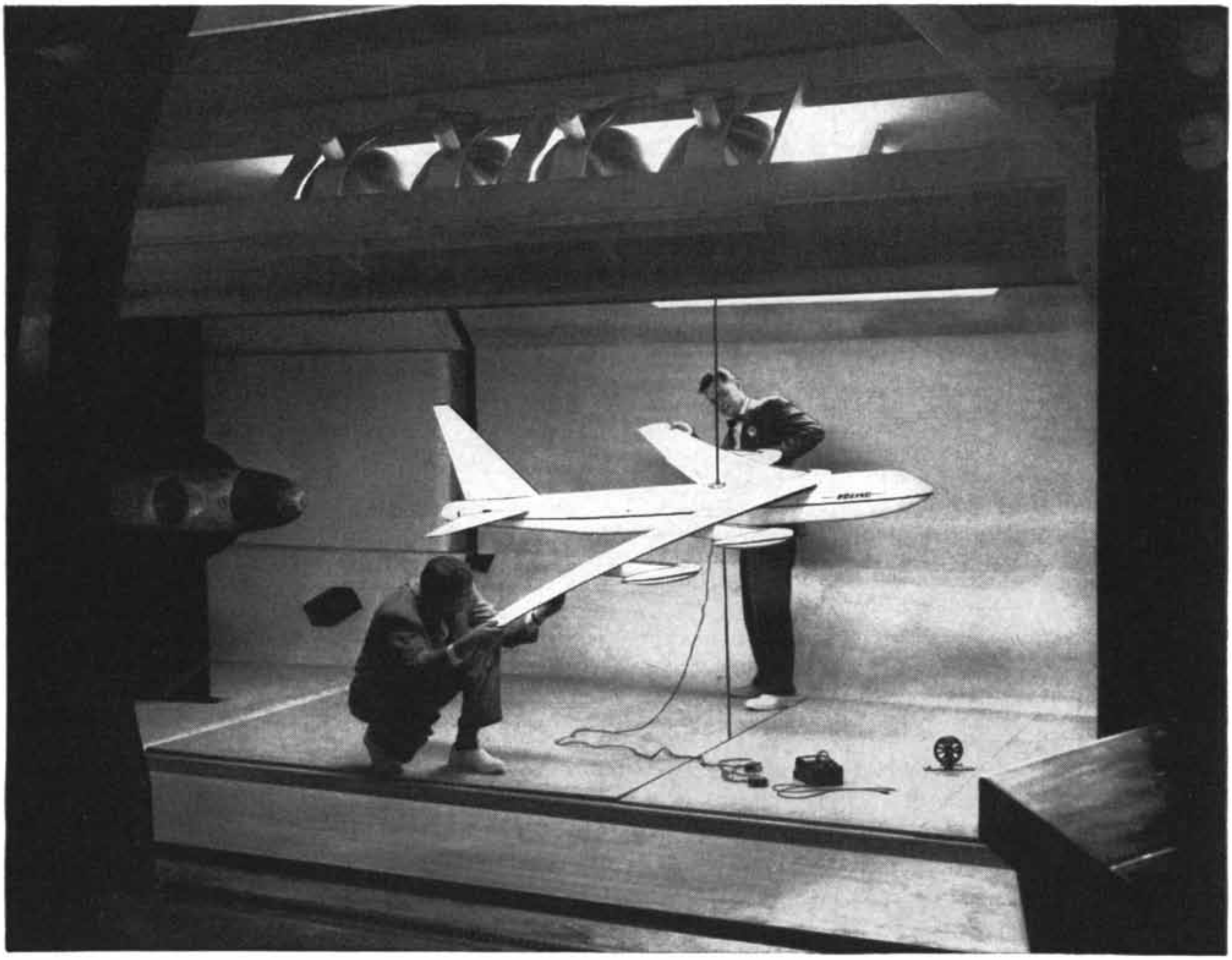
TYPE E RESPONSE to the injection of mecholyl is similarly traced by the heavy line. In these charts the response is shown for three different kinds of subject: (D) healthy individuals under stress who respond with anger directed inward, or depression, (E) healthy individuals whose blood pressure has been elevated with adrenalin and (C) psychotic individuals with elevated blood pressure and depression.

for excessive secretion of nor-adrenalin and adrenalin was based on the physiological changes being similar to those which can be produced by the intravenous injection of nor-adrenalin and adrenalin. Since the substances involved have not been identified chemically, and the evidence is entirely physiological, at the present time we prefer to limit ourselves to the statement that the reactions are *like* those to the two hormones. However, nothing in our experiments would contradict the hypothesis that these substances are actually adrenalin and nor-adrenalin.

What is the neurophysiological mechanism whereby different emotions evoke different adrenal secretions? Although no conclusive work in this area is yet available, some recent investigations suggest a possible answer. U. S. von Euler in Sweden found that stimulation of certain areas of the hypothalamus caused the adrenal gland to secrete nor-adrenalin, whereas stimulation of other areas caused it to secrete adrenalin. These areas may correspond to those which the Nobel prize winner W. R. Hess of Zurich stimulated to produce aggressive behavior and flight, respectively, in animals. The experiments suggest that anger and fear may activate different areas in the hypothalamus, leading to production of nor-adrenalin in the first case and adrenalin in the second. Until more experiments are made, these possibilities must remain suppositions.

Some of the most intriguing work in this field was recently reported by von Euler. He compared adrenal secretions found in a number of different animals. The research material was supplied by a friend who flew to Africa to obtain the adrenal medullae of wild animals. Interpreting his findings, J. Ruesch pointed out that aggressive animals such as the lion had a relatively high amount of nor-adrenalin, while in animals such as the rabbit, which depend for survival primarily on flight, adrenalin predominated. Domestic animals, and wild animals that live very social lives (*e.g.*, the baboon), also have a high ratio of adrenalin to nor-adrenalin.

These provocative findings suggest the theory that man is born with the capacity to react with a variety of emotions (has within him the lion and the rabbit), and that his early childhood experiences largely determine in which of these ways he will react under stress. Stated in another way, the evolutional process of man's emotional development is completed in the bosom of the family. We have found in other studies that in-



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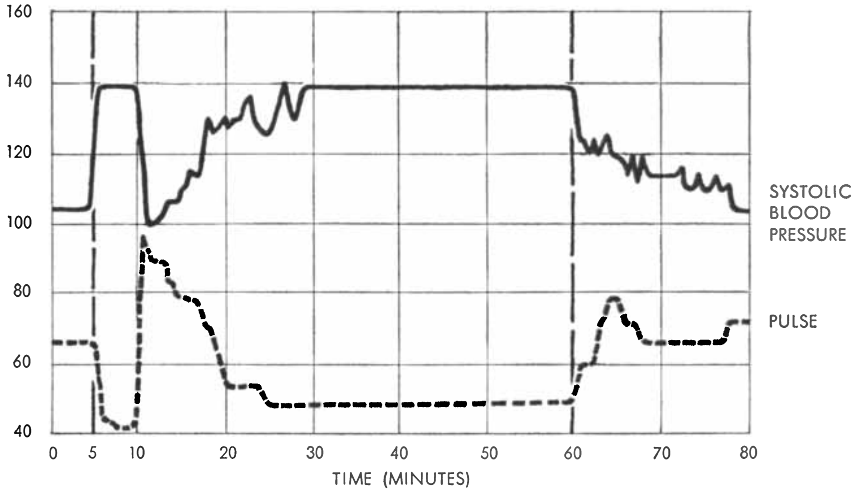
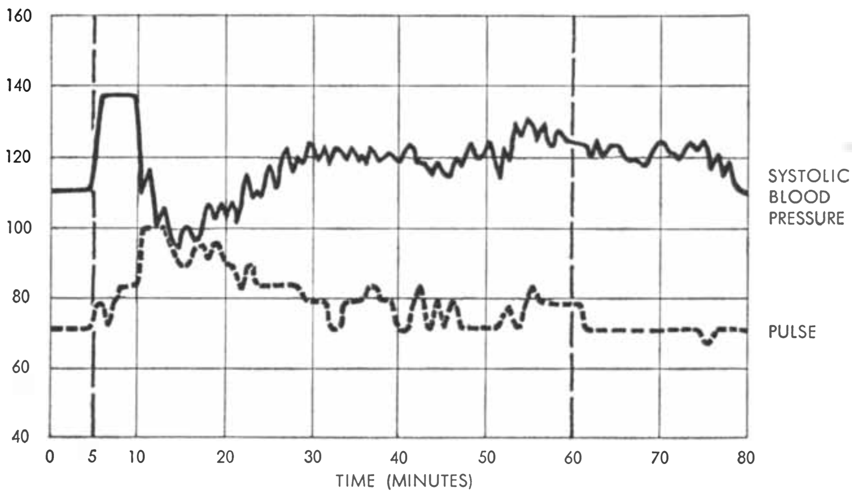


EFFECT OF NOR-ADRENALIN was observed by administering an infusion of the hormone for 60 minutes. After 5 minutes the blood pressure of the subject rose. After 10 minutes mecholyl was injected and the blood pressure fell. Then it rose in a Type N response.



EFFECT OF ADRENALIN was observed by the same procedure. After the injection of mecholyl the systolic blood pressure of the subject remained depressed in a Type E response.

dividuals' habitual emotional reactions have a high correlation with their perceptions of psychological factors in their families.

This entire series of experiments yielded data which can be understood in the frame of reference of psychoanalytical observations. According to theory, anger directed outward is characteristic of an earlier stage of childhood than is anger directed toward the self or anxiety (conflicts over hostility). The latter two emotions are the result of the acculturation of the child. If the physiological development of the child parallels its psychological development, then we should expect to find that the ratio of nor-adrenalin to adrenalin is higher in infants than in older children. Bernt Hokfelt and G. B. West established that this is indeed the case: at an early age the adrenal medulla has more nor-adrenalin, but later adrenalin becomes dominant.

Paranoid patients show a greater degree of regression to infantile behavior than do patients with depression or anxiety neurosis. And it will be recalled that in our tests paranoid patients showed signs of excessive secretion of nor-adrenalin, while depressed and anxious patients exhibited symptoms of adrenalin secretion.

These parallels between psychological and physiological development suggest further studies and some theories for testing. Standing on the shoulders of Cannon and Freud, we have extended our view of human behavior and discovered fertile new fields for exploration.

THE DEATH OF A CIVILIZATION

Toward the end of their history the Maya built Mayapan, a pale reflection of earlier glories. In its ruins archaeologists now reconstruct the forces that destroyed this remarkable culture

by Tatiana Proskouriakoff

At the darkest time in European history, when the Vandals and Huns were destroying the last vestiges of the Greco-Roman civilization, two younger civilizations on the opposite side of the world were enjoying an era of extraordinary prosperity. One of these was the colorful culture of the Andes and the west coast of South America, which later was to be incorporated in the empire of the Incas. The other was the Middle American civilization whose best-known expression is the Maya culture. Here, in the subtropical jungle, was the birthplace of literacy in America. We do not know whether the Maya people originated this writing, the first in aboriginal America, but it was they who developed it most fully and who led the subsequent intellectual advance. What we have deciphered of their complex hieroglyphics shows that they had a wondrously intricate calendar, based on concurrent cycles merging into greater cycles as their multiples coincided in time. Some Maya calendrical computations span millions of years, and this grandiose concept of the vast dimension of time is all the more impressive if we recall how recently in Europe the creation of the world was placed at 4004 B.C.

The earliest flowering of the Maya culture was in a rainy forest region of northern Guatemala, now virtually uninhabited. Ecologists have repeatedly claimed that a tropical jungle could not give rise to a high civilization, and indeed the Maya region must have offered formidable obstacles to cultivation by a people who knew nothing of metals, who had no draft animals and whose experience of mechanics did not include even the simple device of the wheel. Nevertheless, with only primitive stone-age tools the Maya built large stone temples and erected beautifully carved monuments on which they inscribed a record of celestial and mundane events. They constructed many centers of artistic and intellectual activity, of which the greatest, and probably the oldest, was the city of Tikal [*see map on page 84*].

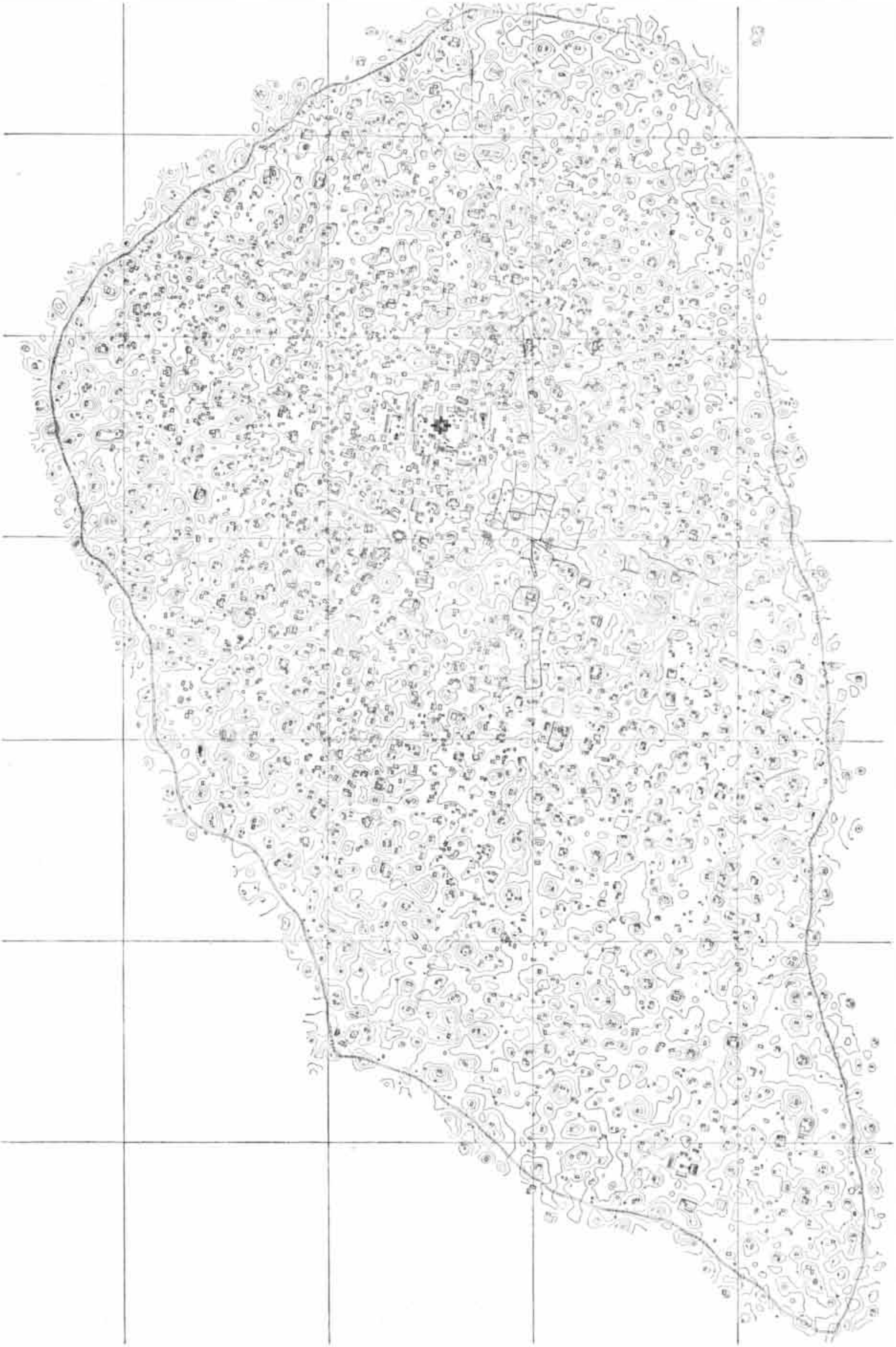
Surrounded by other civilized peoples who, like themselves, had more interest in trade than in war, the lowland Maya were in a good position to develop their arts and sciences. Yet their great early cities did not last. Why they were abandoned, and what happened to their inhabitants, remains a mystery. Little by little, however, the general pattern of the Maya's history is becoming apparent, and it presents a curious parallel to the fate of the Greco-Roman civilization in Europe about a thousand years earlier. The rise of intellectualism among the lowland Maya can be compared to the similar but more advanced rise of rationalism in ancient Greece; later the civilization of Middle America passed through phases that correspond to the ascendancy of the Roman Empire and the final fall of Rome to barbarian invaders. In Middle America the "Romans" were the Toltec people of Mexico, and their barbaric conquerors were the Aztec people, who created an empire with a capital at Tenochtitlan.

The Toltec capital, Tollan, which stood near the present town of Tula, north of Mexico City, never actually formed an empire or exercised such strict control over its colonies as did Rome, but like Rome it generated a proud tradition that survived even barbaric conquest. To be a Toltec in Mexico was to be an exponent of civilization. The Toltec tribe, a militant people who had drifted down from the north after the fall of the city of Teotihuacan, absorbed the older culture of the Valley of Mexico and eventually claimed for themselves the credit for all its intellectual accomplishments. Toltec warriors seized the provincial Maya city of Chichen Itza in northern Yucatan and for a time made it the center of Maya culture. They learned Maya techniques of building and even improved on them, making their buildings larger and more spacious. The columns of their temples were carved in the form of the feathered serpent, their principal deity, but most of their art was devoted to the portrayal of warriors and their exploits; it gives us a vivid picture of battles and processions and of the dramatic rite of human sacrifice. It was an art less intricate and less refined than the art of the Maya, striving for monumental effect rather than for precision of form.

In the year 1168 the Toltec capital at Tula fell to other warrior tribes. The subjugated Maya inhabitants of Chichen Itza seized the opportunity to rise against their Toltec masters. Tradition tells us that they killed the Toltec lords for their bad conduct, and that a time of troubles followed.

While the Toltec rule was being broken by successive waves of invasion by tribes from the north, culminating in the supremacy of the Aztec, there arose in Yucatan a Maya hero by the name of Kukulcan. (The name was the Maya version of Quetzalcoatl, the title of the

COMPLETE MAP of Mayapan was made in two seasons by Morris Jones of the U. S. Geological Survey. The city had from 10,000 to 20,000 inhabitants and some 3,500 houses. It was surrounded by a wall. The large building above the center is the principal temple of the city. Grid lines are 500 meters apart.



chief Toltec deity; derived from the name of the colorful quetzal bird and the word for serpent, it means "feathered serpent.") Whatever his lineage or his pretension, this Kukulcan unified the Maya once more and founded a new capital at Mayapan [*see map below*], about 25 miles south of the modern city of Merida. Here he brought together the native lords of the various provinces (centered in Chichen Itza, Uxmal and Mayapan), who henceforth ruled their lands from the capital, appointing governors to look after their interests at home.

If tradition is to be believed, the hegemony of Mayapan lasted for almost two centuries. However, the Maya could not resurrect their formerly brilliant culture. The government proved unable to cope with internal conflicts between the rival lords, though it hired Mexican troops to suppress them.

When the Spaniards conquered Yucatan early in the 16th century, they were so intent on religious conversion of the people that they felt impelled to destroy the local written records as subversive documents. Later some of the more curious friars attempted to learn something about Yucatan's past, but by then the memories of the natives had dimmed, and those who might have served as informants were none too eager to display their knowledge. So we are left today only with scraps of contradictory, inadequate accounts of the Maya, some gathered by the friars from conversations with the natives, others compiled by 17th- and 18-century scribes from fragmentary and corrupt older texts. The result is a history that is at the mercy of its interpreters, who seldom seem to agree on even its outlines.

It is a challenge to archaeology to try to straighten out the conflicting versions of Maya history. With this purpose, in part, the Carnegie Institution of Washington in 1951 undertook to excavate and explore ancient Mayapan. The site had been visited by archaeologists before. What they had seen did not encourage us to expect sensational finds. Mayapan is not the place to see the richness of the Maya culture in full flower, but it offered an important, and neglected, phenomenon for study—the death of a civilization, paralleling in a small way the decline and fall of Rome.

The first step in the archaeological project was to obtain a detailed and accurate map of the site. This was not easy, for Mayapan was matted over by an incredibly thick tangle of vicious thorns and brambles. Morris Jones, a young engineer of the U. S. Geological Survey, undertook to cut through that impenetrable bush to map the ruins. Fortunately he had the enthusiastic help of the local people, who are accustomed to chopping their way through the jungle with machetes. They liked the young American, who cheerfully shared their noon "posole," an unsavory porridge of ground corn mixed with water which is a staple of their diet. Jones spent two seasons at the hot, humid site, and he

CITIES of Maya times are located on this map of part of Mexico and of Central America. Mayapan is at upper right in what is now the Mexican state of Yucatan. Tula is a modern town near the site of Tollan, capital of the Toltecs. Tenochtitlan was the Aztec capital.

produced a map of unusual accuracy and completeness. At a glance it showed us more about the city plan of Mayapan than we know about any other Maya site.

Mayapan had been known as a collection of ruins of shoddily built temples and colonnaded halls, surrounded by a thick masonry wall. The impression had developed that the Maya town was little more than a ceremonial center and perhaps a market in which people assembled from the countryside on special occasions. Jones's map showed for the first time that Mayapan was actually a residential metropolis of considerable size, covering about two and a half square miles and housing from 10,000 to 20,000 inhabitants. It had some 3,500 houses and a water supply consisting of a number of natural wells in the limestone rock. The houses were in closely packed groups, each surrounded by a rough masonry wall. The walls formed a maze of winding, irregular alleys.

How did the people live, and what were their chief activities and preoccupations? The Carnegie Institution staff began intensive excavation of the city in 1952 under the direction of H. E. D. Pollock. A. Ledyard Smith and Karl Ruppert were assigned to study the houses and the burials, which in Mayapan were usually placed in buildings, because the soil of Yucatan is too shallow for cemeteries. Robert E. Smith explored the refuse heaps and sinkholes in the rock for pottery, with the object of establishing sequences and dating the excavated remains. Edwin M. Shook investigated the pottery styles, the formal architecture of Mayapan and the ritual and commercial activities of the center of the town. Gustav Strömsvik had charge of restoring (in part) some of the typical buildings for the benefit of interested visitors; he also built us comfortable working and living quarters in a village near the site. My own task was to study all small artifacts other than pottery and to map the construction of the ceremonial center in detail.

Three seasons' work has amassed a huge body of data that awaits study and publication. Already we can discern a few clues that help to clarify the story of Mayapan. Our excavations confirm the legend which says that Kukulcan founded Mayapan "after the death of the lords," probably somewhere between A.D. 1263 and 1283. The construction of Mayapan's ceremonial plaza was started at a time when Chichen Itza had fallen into decay. The builders of Mayapan began their city on the same plan as that of the older capital: its principal temple is very nearly a replica of the great Castillo at Chichen Itza. Another structure, with serpent columns and a deep shaft filled with the bones of sacrificed victims, is very like a Chichen Itza building known as the "High Priest's Grave," and a massive round structure is comparable to the Caracol, which some believe to be an astronomical observatory. Both cities had long colonnaded halls, probably used as training quarters for warriors and priests. All the structures at Mayapan, however, were more shoddily built than those of Chichen Itza: they used plaster instead of skillfully worked stone, wooden roofs instead of masonry vaults and grotesque motifs instead of the classic serpent.

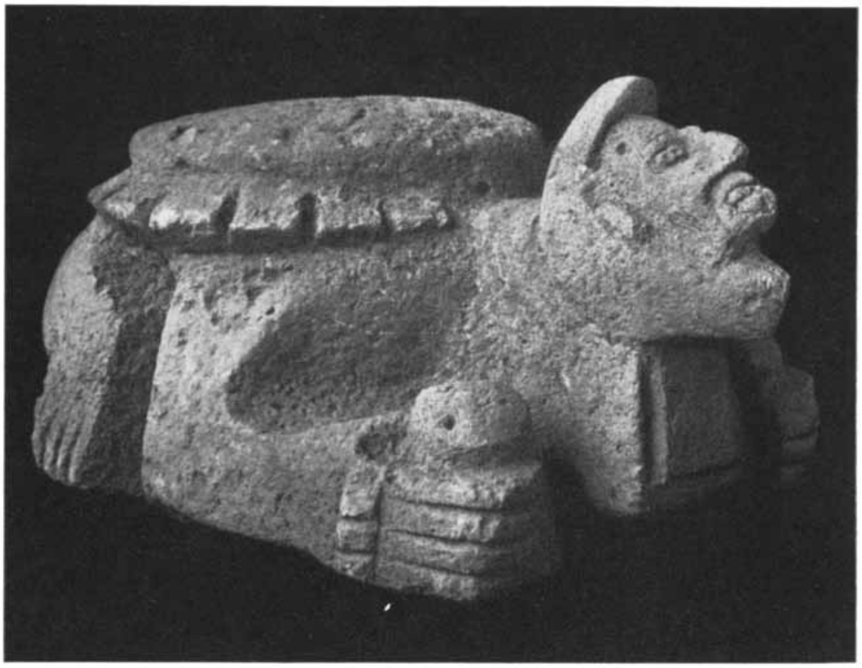
Late in the history of Mayapan new religious practices were introduced. They are reflected in the building of numerous small shrines that crowd the courts of the ceremonial center, and in the use of gaudily painted pottery censers made in the images of gods. The blackened interiors of these censers show that they were used for the burning of copal, an aromatic resin still used in religious rites by some Middle American Indians. From the censer images we get a clear impression of the credulous, inartistic and militant character of this age, which contrasts sharply with the scope and serenity of earlier Maya traditions. During the "classic" period

QUETZALCOATL found at Mayapan has the wide face, straight nose and narrow lips of Mexicans who were foreign to the Maya.

(about A.D. 300 to 900) the Maya had made symbolic sculptures which suggest a highly organized, mystic mythology in which a sky serpent bearing celestial symbols played the central role. In the Chichen Itza period, the Toltec portrayed a feathered serpent as the dominant god. Mayapan, in contrast, had numerous gods. Some appear to be derived from Maya mythology; others can be linked with the gods of the valley of Mexico; still others probably were patrons of vocations and private ancestral gods.

Figures of some of the gods, excavated at Mayapan, appear below and on the next page. The man with the conchshell on his breast is almost certainly Quetzalcoatl. He has the headdress of an animal, probably the jaguar, representing one of the Toltec military orders. He holds in his hand a ball of copal. The wide face, straight nose and narrow lips of Quetzalcoatl and some other gods identify them as Mexican—foreigners in the Maya country. More native in aspect is Chac, the Maya rain-god, with a pendulous nose. He wears a headdress representing the sky serpent, and his body is painted half red, half blue, possibly symbolizing the dry and the rainy seasons. An old man with a big Roman nose and a toothless mouth is thought to be the sky-god Itzamna. Very curious and unexpected at Mayapan are numerous representations of turtles. Some are of stone, others of pottery in the form

CHAC was the rain-god of the Maya. His face, with its drooping Roman nose, is more characteristic of the inhabitants of Mayapan.



ITZAMNA, the sky-god of the Maya, is represented as a toothless old man with his head emerging from the mouth of a turtle. Such turtles were an unexpected find at Mayapan.

of a bowl. Usually the turtle holds the head of a god in its beak, but in one amusing piece a man or god with two immense front teeth is riding on the turtle's carapace.

With the proliferation of cults came a tendency to worship privately without the intercession of priests. In Mayapan every private house had some sort of shrine. Yet it is clear that the Maya descendants were not merely making excuses when they told Spanish priests that their ancestors had not been idol-worshipers before Kukulcan came. Certainly the hierarchic religion of the Maya in classic times had been very different from that in the time of Mayapan. Probably many of the new features were brought in by Mexican soldiers.

The same soldiers, said to have been stationed as a garrison in Mayapan, may have introduced the bow and arrow, for in no earlier Yucatan site have we found the tiny flint and obsidian arrowheads that turn up here. Previously warfare had been carried on with spears. The Mayapan walled fortification also was an innovation. With military progress there came a toughening of sensibilities, as evidenced at Mayapan by a barbarous flaying ceremony and by wholesale human sacrifices.

Yet somehow through all this a tenuous thread of the classic tradition survived. We hear a murky echo of its deep and powerful poetry and its grandiose scheme of time in a Maya script, written long after the fall of Mayapan, mourning the death of the city: "This is the pronouncement of 8 Ahau. This it was when occurred the depopulation of Mayapan. Evil is the pronouncement of the Katun in its great power. Thus it shall always come to pass, its pronouncement in Lord 8 Ahau. Then it shall return again to where our writing began according to the prophecy of the Great Priest Chilam Balam when he painted the aspect of the Katun in 8 Ahau, when he painted the glyph of the face of Katun 8 Ahau."

An ahau was a period on the Maya calendar, amounting to 7,200 days (about 20 years). There were 13 such periods, and 8 Ahau ran from A.D. 1441 to 1460. It was about this time that Mayapan was destroyed by an internal conspiracy of its lords. The records mention "fighting with stones in the fortress" and the breaking down of the city wall. The Maya country thereafter suffered recurrent local wars and disasters until its final subjugation by the Spaniards.

In the light of historical perspective, the fall of Mayapan appears as a dramatic culmination of a long process of cultural decay. The causes of the decline of the brilliant Maya culture remain obscure, but to those who perceive the danger signals of esthetic decline and rising militarism in our own civilization, the story of Mayapan should have a vital and timely interest.

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The Monte Carlo Method

It is used to predict the outcome of a series of events, each of which has its own probability. Here it is outlined in terms of neutrons, needles, roulette wheels and furniture factories

by Daniel D. McCracken

During World War II physicists at the Los Alamos Scientific Laboratory came to a knotty problem on the behavior of neutrons. How far would neutrons travel through various materials? The question had a vital bearing on shielding and other practical considerations. But it was an extremely complicated one to answer. To explore it by experimental trial and error would have been expensive, time-consuming and hazardous. On the other hand, the problem seemed beyond the reach of theoretical calculations. The physicists had most of the necessary basic data: they knew the average distance a neutron of a given speed would travel in a given substance before it collided with an atomic nucleus, what the probabilities were that the neutron would bounce off instead of being absorbed by the nucleus, how much energy the neutron was likely to lose after a given collision, and so on. However, to sum all this up in a practicable formula for predicting the outcome of a whole sequence of such events was impossible.

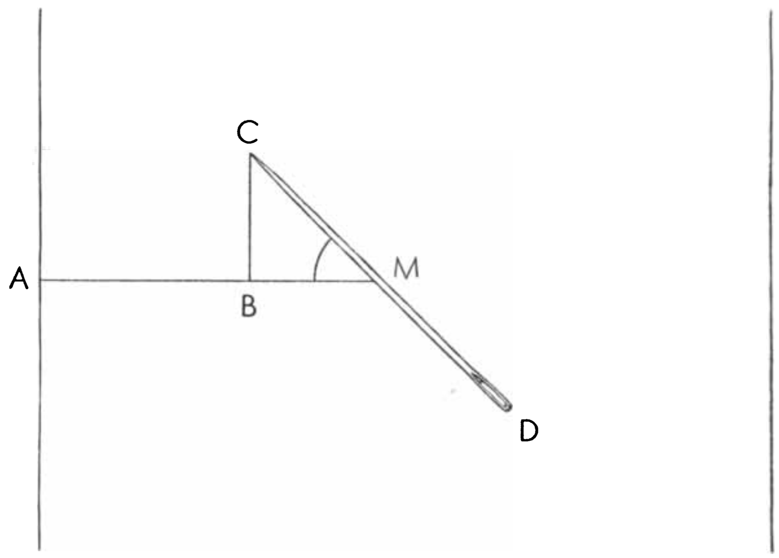
At this crisis the mathematicians John von Neumann and Stanislas Ulam cut the Gordian knot with a remarkably simple stroke. They suggested a solution which in effect amounts to submitting the problem to a roulette wheel. Step by step the probabilities of the separate events are merged into a composite picture which gives an approximate but workable answer to the problem.

The mathematical technique von Neumann and Ulam applied had been known for many years. When it was revived for the secret work at Los Alamos, von Neumann gave it the code name "Monte Carlo." The Monte Carlo method was so successful on neutron diffusion problems that its popularity later spread. It is now being used in various fields, notably in operations research.

To illustrate the method let us start with the simple, classic Buffon needle problem. You get a short needle, draw on a sheet of paper several parallel lines spaced precisely twice the length of the needle apart, and then toss the needle onto the paper again and again in a random fashion. How often will the needle land on a line? The mathematicians say that the ratio of hits to trials should be 1 to 3.1416. That is, dividing the number of hits into the number of throws, you should come out with the number 3.1416 (pi) if you continue the trials long enough (and throw the needle truly at random, without trying either to hit or to miss the lines).

I tried the experiment, with the following results. In the first 10 throws, the needle landed on a line four times. In the language of the statistician, there were four "successes" in 10 trials. The quotient is 2.5, which one must admit is not very close to 3.1416. In 100 trials there were 28 hits for an estimate of 3.57, also not good, but better. After 1,000 trials there were 333 hits for an estimate of 3, and my arm was tired.

This was hardly good enough to quit on, but the improvement with increasing numbers was not rapid, so it did not seem practicable to go on by hand. The fact is that the accuracy of a Monte Carlo approximation improves only as the square of the number of trials: to double the expected accuracy of the an-

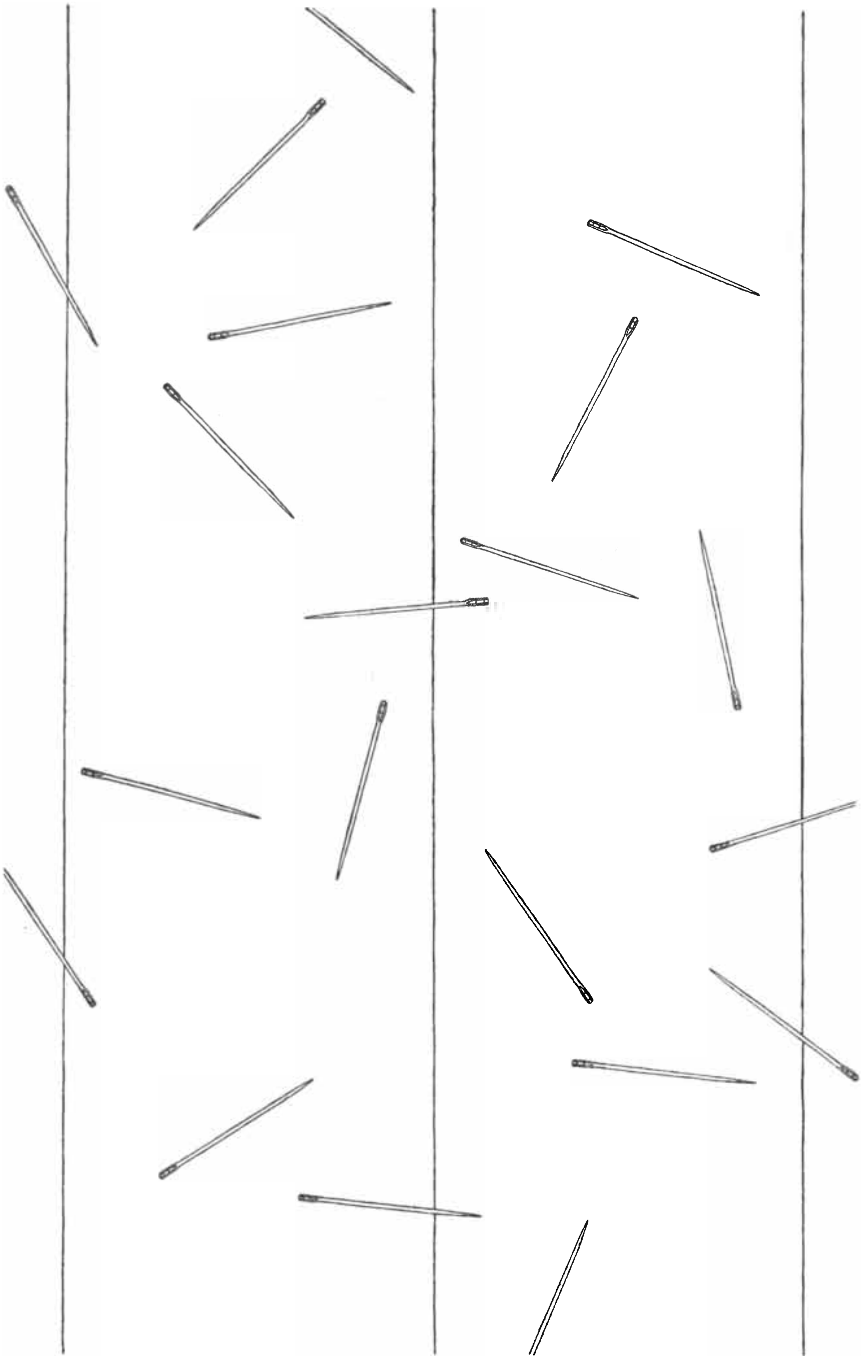


NEEDLE PROBLEM is illustrated by a needle lying on a piece of paper ruled with parallel lines. The length of the needle is two inches; the distance between the lines, four inches. If the needle is thrown on the paper at random, how often will it land on one of the lines?

swer, you must quadruple the number of trials. I decided to make a calculating machine do the work, and I translated the problem to a medium-sized electronic calculator.

It is no difficult matter to make a calculating machine carry out operations which simulate the results of dropping a needle on ruled paper. Consider the diagram on the opposite page. To describe the situation to the machine we must decide on a way of specifying the position of the needle relative to the nearest line. It does not matter on which side of this line the needle lies; nothing is changed if we turn the paper around. We can see that the distance from the midpoint of the needle to the nearest line (MA) is specified by a number between zero and two inches. The only other information needed to specify the position of the needle completely is the angle it makes with the perpendicular (MA) to the line. The angle is somewhere between zero and 90 degrees (not 180 degrees, because we are concerned only with the closer end of the needle). Given these two quantities, the machine can easily decide whether the needle touches a line; all it needs to do is to compute the distance MB (the cosine of the angle) and note whether it is less or greater than the distance MA—in the machine's terms, whether the difference is positive or negative.

Now to find out by experiment in what proportion of the trials a needle dropped at random would touch the line, we would like to test all possible positions in which the needle might land. To do this we would have to consider all possible combinations of distances and angles—essentially the method of the integral calculus. Obviously we are not going to tackle this infinite task. But in place of attempting a systematic exploration of all positions, we can take a random sample of them, and this should give us a reasonably accurate approximation of the correct answer, as a sampling poll may do.



ACTUAL EXPERIMENT on the needle problem was tried by artist Eric Mose. Each needle represents a toss and shows the position in which the needle landed with respect to the lines. In a sufficiently large number of trials, the ratio of hits to trials will be 1 to 3.1416 or pi.

How shall we select the random sample? This is where the Monte Carlo method comes in. Suppose we built a roulette wheel with 20 compartments, representing 20 different distances from the line (up to two inches) for the needle midpoint. A spin of the wheel would select the distance for us in a random manner, and over many trials each of the 20 distances would be selected about the same number of times. With a similar wheel we would pick the angle each time in the same random fashion. Then a series of spins of the two wheels would give us a random set of positions, just as if we had actually dropped a needle at random on ruled paper.

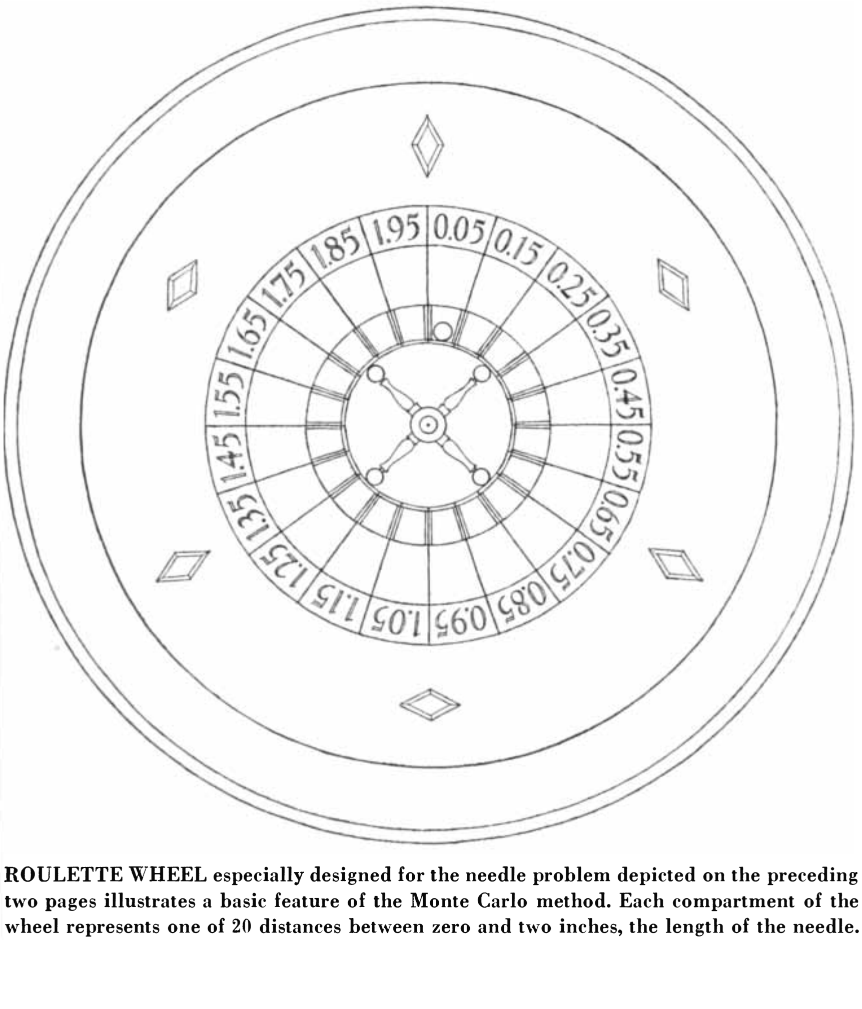
Of course the wheel-spinning method would be more cumbersome than dropping the needle, but there are ways of doing about the same thing with numbers and a calculating machine. First we get up two lists of numbers: one for distances in the range between zero and two inches, the other for angles in the range between zero and 90 degrees. The numbers are chosen at random to cover the whole range in each case without favoring any part of the range; we can take them from some list of numbers already checked for randomness or we can make our own list from, say, a table of logarithms, taking the numbers' last three digits. Then we put the calculator to work computing whether various combinations of the distance and angle numbers place the needle on a line or not (*i.e.*, whether the difference between MB and MA is positive or negative). Repeating the operation many, many times, we can get as close to precision as we like; statistical principles tell us the degree of precision we can expect from a given number of trials.

The moderately fast computer I had available when I made the experiment was able to perform 100 "trials" per minute. In about an hour the machine ran through 6,000 trials, and there were 1,925 "hits." In other words, the estimate of pi was 3.12, which is as good as can be expected for 6,000 trials.

Even this simple case required a rapid computer. Most applications of the Monte Carlo method of course are much more complex. However, the present high-speed computers make them feasible: there are machines which can perform 5,000 trials per minute on the Buffon needle problem.

Let us see now how the method works on a simple problem in neutron diffusion. Suppose we want to know what percentage of the neutrons in a given beam would get through a tank of water of a given size without being absorbed or losing most of their speed. No formula could describe precisely the fate of all the neutrons. The Monte Carlo approach consists in pretending to trace the "life histories" of a large sample of neutrons in the beam. We imagine the neutrons wandering about in the water and colliding occasionally with a hydrogen or oxygen nucleus—remember that to a neutron water looks like vast open spaces dotted here and there with tiny nuclei. We shall follow our neutrons one by one through their adventures.

We know how far a neutron travels, on the average, before it encounters a nucleus, the relative probability that this encounter will be with oxygen or with hydrogen, the relative chances that the neutron will be absorbed by the nucleus or bounce off, and certain other necessary information. Let us, then, take a specific neutron and follow its life history. It is a slow-moving neutron, and its first incident is a collision with a hydrogen nucleus. We know (from experiments) that the chances are 100 to one the neutron will bounce off from such a



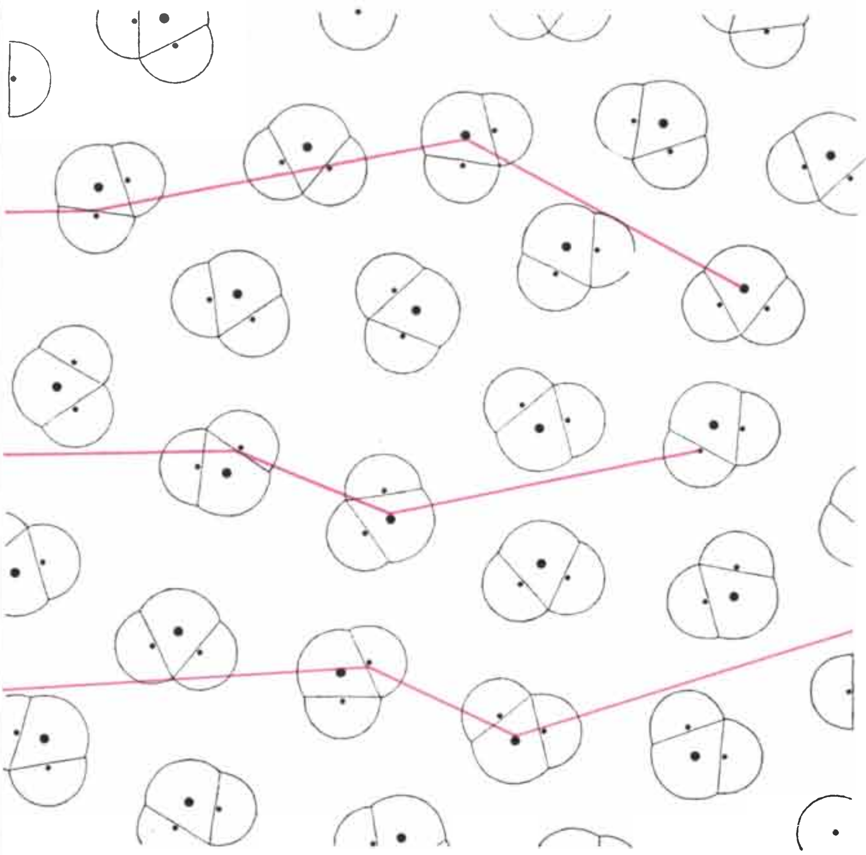
ROULETTE WHEEL especially designed for the needle problem depicted on the preceding two pages illustrates a basic feature of the Monte Carlo method. Each compartment of the wheel represents one of 20 distances between zero and two inches, the length of the needle.

collision. To decide what it will do in this instance, we figuratively spin a roulette wheel with 100 equal compartments marked "bounced off" and one marked "absorbed." If the wheel says "absorbed," that is the end of the neutron's history. If it says "bounced off," we perhaps spin another appropriately marked wheel to decide what the neutron's new direction is and how much energy it lost. Then we must spin another wheel to decide how far it travels to the next collision and whether that collision is with oxygen or hydrogen. Thus we follow the neutron until it is absorbed, loses so much energy that it is no longer of interest or gets out of the tank. We go on to accumulate a large number of such histories and obtain a more or less precise figure for the percentage of neutrons that would escape from the tank. The degree of precision depends on the number of trials.

In practice, of course, we do not use roulette wheels but random numbers, as in the previous example. I have omitted much of the detail of the calculation for the sake of simplicity and clarity. In one very simple problem on which I assisted, an electronic calculator labored for three hours to trace the life histories of 10,000 neutrons through 1.5 million collisions. I would have had to sit at a desk calculator for some years to accomplish the same results.

As a third illustration of the Monte Carlo method, let us take a simple problem in operations research. Imagine a woodworking shop consisting of a lathe, a drill press and a saw, with three men to operate the machines. The shop makes one model of chair and one model of table. The question is: How should the work of the shop be scheduled to yield the greatest production, considering a number of variable conditions affecting output?

Certain basic information must be gathered before any calculation can begin. How long does it take on each machine to do the necessary work on each piece of wood? How much does the time needed for each job fluctuate because of fatigue, boredom or other personal factors? How frequently do the machines break down? After the data are gathered, a way is devised to make the computer simulate the operation of the shop under specified conditions of scheduling. We will not go into the details here; perhaps enough has been presented in the other examples to give an indication of what has to be done. The computation is properly classified as Monte Carlo because it is necessary to spin a roulette



NEUTRONS wander through water in a series of events, each with a known probability. Here the microscopic structure of water is depicted in highly idealized form as consisting of simple molecules of H_2O. The larger sphere in each molecule is oxygen; the two smaller spheres are hydrogen. The neutrons (*colored lines*) may be absorbed by either an oxygen or a hydrogen nucleus or may bounce off from the collision. Some may escape from the water.

wheel, or the equivalent, to pick samples from the known distributions. For example, we may know that a certain job may take anywhere from 12 to 16 minutes, and we have noted the percentages of the cases in which it is performed in 12, 13, 14, 15 and 16 minutes respectively. Which time shall we use for a particular case as we follow the course of a day's work in the shop? The question must be decided by random sampling of the type I have described.

With the Monte Carlo method high-speed computers can answer such questions as these: How should the schedule be changed to accommodate a market change demanding twice as many chairs as tables? How much could the shop produce, and at what cost, if one man should be absent for two days? How much would the total output be increased if one man should increase his work rate 20 per cent? Under a given schedule of work flow, what percentage of the time are the men idle because the work is piled up behind a bottleneck machine? If money values can be assigned to idle time, loss of orders due to low production and so on, dollars-and-cents answers can be given to problems of this kind in business operation.

The Monte Carlo method, in general, is used to solve problems which depend in some important way upon probability—problems where physical experimentation is impracticable and the creation of an exact formula is impossible. Often the process we wish to study consists of a long sequence of steps, each of which involves probability, as for instance the travels of the neutron through matter. We can write mathematical formulas for the probabilities at each collision, but we are often not able to write anything useful for the probabilities for the entire sequence.

Essentially the Monte Carlo method goes back to probability theory, which was developed from studies of gambling games. But it takes the opposite approach. The mathematicians who originated the probability theory derived their equations from theoretical questions based on the phenomenon of chance; the Monte Carlo method tries

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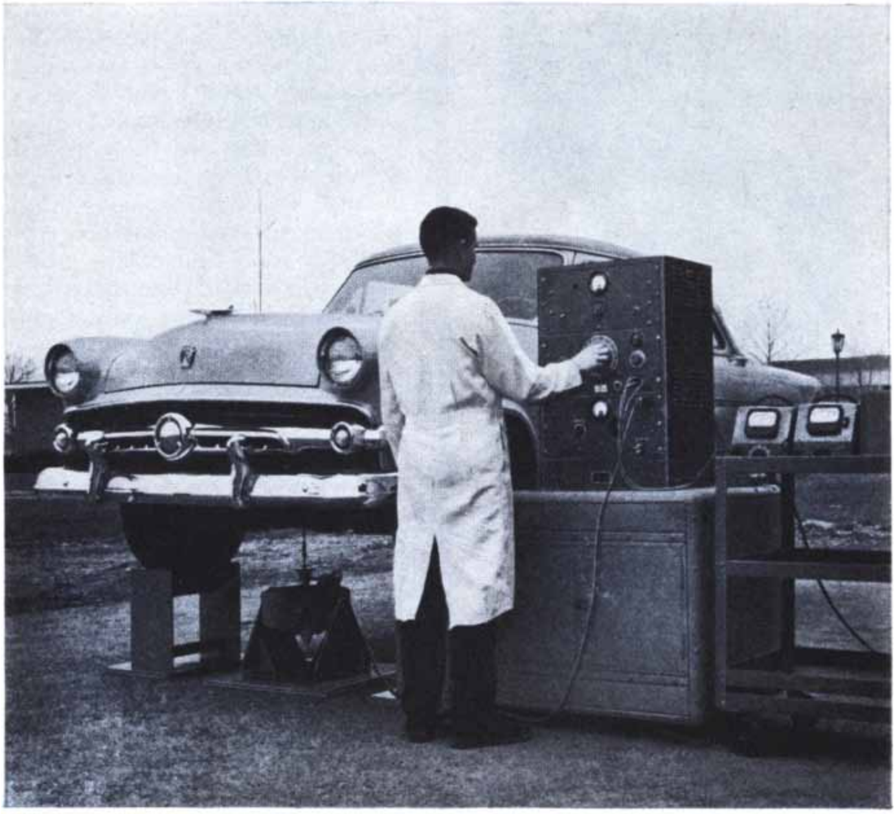

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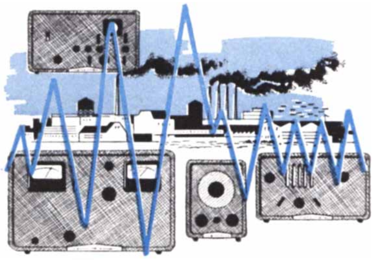

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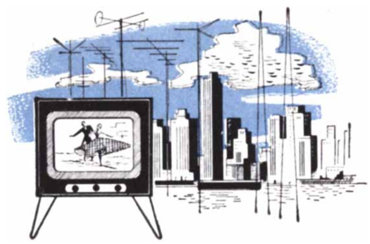

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to use probability to find an answer to a physical question often having no relation to probability.

In the neutron problem, for example, the investigator's thinking might have been along these lines: "I have a physical situation which I wish to study. I don't think I'll even try to find an equation representing the entire problem. Even if I could find one, which is very doubtful, I probably wouldn't be able to get much useful information out of it. I'll just see if I can't find a game of chance which will give an answer to my questions, without ever going through the step of deriving an equation." In some other situations the investigator would reason: "The physical situation I am interested in has resulted in an equation which is very difficult to solve. I cannot possibly solve it in any reasonable length of time by usual methods. I wonder if I could devise some statistical method which would approximate the answer to my problem."

Much work remains to be done on the method. One is always faced with the unhappy choice of either inaccurate results or very large amounts of calculation. A problem which demands 100 million trials of some "experiment" is still impracticable, even on the fastest present computers. Another difficulty is that it is seldom possible to extend the results of a Monte Carlo calculation to another set of conditions. For instance, after we have solved the problem of the passage of neutrons through ordinary water, we have to start all over again to find out how they will behave in heavy water. Nevertheless, in spite of its various limitations the Monte Carlo method is able to give at least approximate answers to many questions where other mathematical techniques fail.

Many mathematicians are working to improve the method, especially to reduce the computation required and to determine exactly how much reliability can be attributed to its results in various types of problems. Up to now the technique has been used mainly on problems of nuclear physics, such as the diffusion of neutrons, the absorption of gamma rays, atomic pile shielding and the like. In the author's opinion, one of the most promising applications of the method is in operations research. It could be useful not only on production problems such as the one described here but also in telephone operation, traffic control, department-store inventory control and so on. Some of these possibilities are already being investigated. It is safe to say that we shall hear more from Monte Carlo in the next few years.

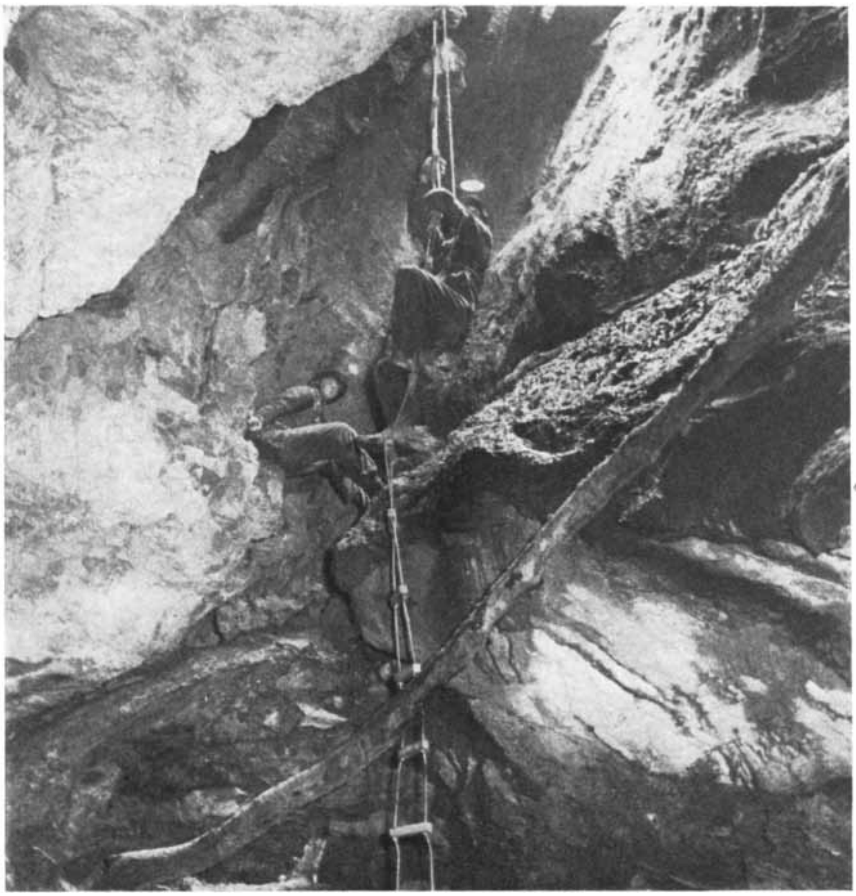
LIFE IN CAVES

In the dark, damp recesses immediately below the earth's surface live a multitude of interesting creatures. Their unique features provide a vivid lesson in the processes of biological adaptation

by Brother G. Nicholas, F. S. C.

The deep interior of a cave would seem, at first thought, an unlikely place for life. Its Stygian blackness prohibits plant life, which depends on sunlight, and it is hard to see how its bare, rocky depths could supply food for animals. But one of the striking facts of nature is the ability of living things to adapt themselves to practically any environment on earth. There is life in the perpetual darkness of the deepest oceans and in the barren ice of mountain tops. Caves are no exception: they harbor whole populations of living creatures, some of them with a longer history than forms of life which dwell in richer environments.

The study of cave life has two special attractions. First, it offers the unusual situation of organisms living in a constant environment: the temperature, humidity and other conditions are practically the same night and day, winter and summer. Second, a cave is an excellent natural laboratory for investigating evolution, since the extreme environment manifests its effects on living forms in a direct, dramatic way. To be sure, the difficulties of exploring cave life are at least as great as its rewards. One has to crawl through narrow passages, cross underground lakes, pick his way down sharp descents, slither up steep, muddy slopes—all with a pack of cameras, traps and other paraphernalia on one's back. The search for the inhabitants of the cave is itself a slow, painful task, as most of them are so small that they easily hide under rocks, in cracks and in crevices. And the scientific study also is full of pitfalls, because it is not always easy to distinguish permanent members of the cave population from accidental visitors washed in by streams. So it is understandable that the literature on studies of cave life is not large.



Cave explorers make their way down a cave near York, Pa.

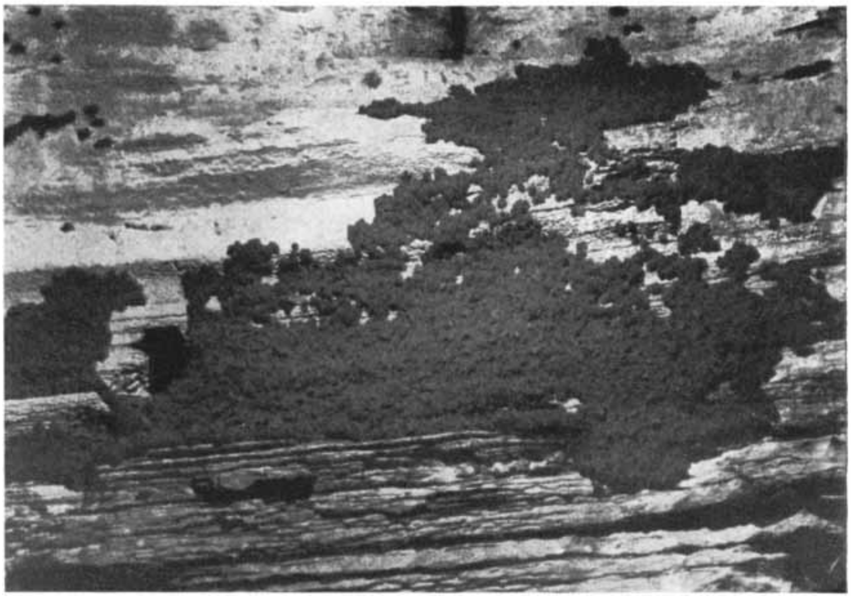
A cave has three zones: the open area just inside the entrance, a twilight region and the perpetually dark interior. Each offers a different environment, and each has its own population. The first two zones, of course, have housed all sorts of creatures from time immemorial, including man himself. Among wild inhabitants of this part of the cave, a typical example is the bear. Many occupants of the outer zones are cave dwellers only in the sense that they use it for shelter; they get their food and carry on most of their activities outside. However, in the twilight zone we begin to find the true troglodytes (from a Greek word meaning "one who crawls into holes") that prefer caves to any other habitation.

The twilight zone varies from a few feet to several hundred yards long, depending on the size of the cave opening and on how far twisting passages let the light penetrate. Here it is light enough for some plants to grow—lichens, moss, algae, ferns. Many of the animal dwellers in this zone forage outside, and the population is unstable. But by and large the twilight-zone inhabitants are apt to be born and raised and often to die in the cave; the remains of recent and fossil animals are frequently found there.

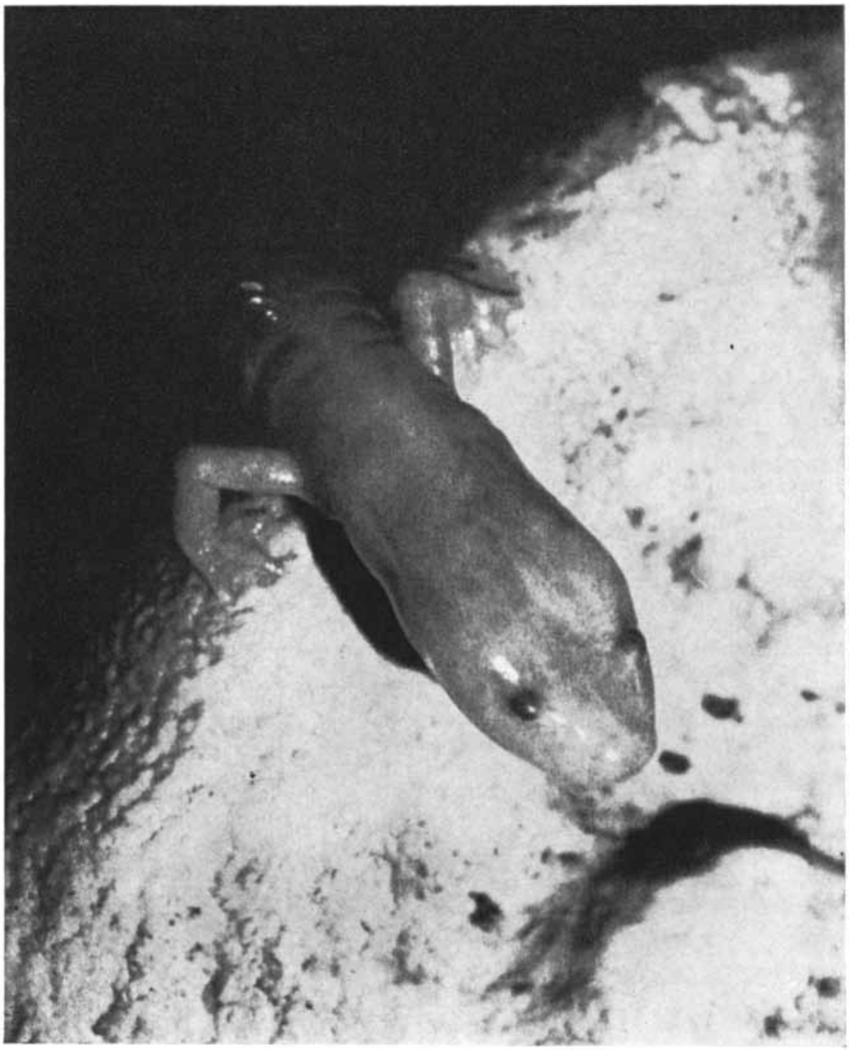
Among these animals are bats, small birds, insects, weasels, raccoons, cats and rodents. One of the rodents is the cave rat, or Allegheny wood rat, a noted pilferer and hoarder (bright objects, pieces of metal and even a wristwatch have been found in their cave nests). The cave rat is a friendly type; it has been known to feed tamely on tidbits from a person's hand. Of the birds found in caves, only a few nest there—owls, phoebes, occasionally jackdaws, and of course the guácharo (oil bird) of Venezuela, the only true avian cave dweller. Even the guácharo leaves the cave daily, flying out at twilight and returning before dawn. These huge birds, which have a wingspread of four feet, live in absolute darkness more than a thousand feet inside the cave. Like bats, they use an acoustic echo-location system to avoid obstacles [see "Bird Sonar," by Donald R. Griffin; SCIENTIFIC AMERICAN, March, 1954]. Since more than 5,000 of these birds inhabit a single cave, the noise is deafening when they make their daily flights in and out.

The best-known inhabitant of caves is the bat. Dozens of species of this flying mammal live in caves, using them either as regular dwellings or as retreats for hibernation. The bat has only rudimentary eyes, and it depends largely on supersonic echo-location for navigation. Bats mate in the fall of the year and then go into hibernation. The female's eggs are not fertilized by the spermatozoa until she releases the eggs in the spring; the sperm may remain alive in her body for four or five months after copulation. Bats do not have true wings; the appendage they use for flying is a membrane attached to the forelimbs. While resting or hibernating in the cave they hang head downwards, clinging firmly to tiny crevices in the rocks with their toes. Recent studies of bat migrations by means of banding have shown that they frequently return to the same cave year after year, sometimes over a period of 10 years or more.

Through the avenue of the twilight zone an astonishing amount of food material penetrates into the dark inner



Gray bats (Myotis grisescens) *cling together by thousands on the roof of a cave in Missouri*

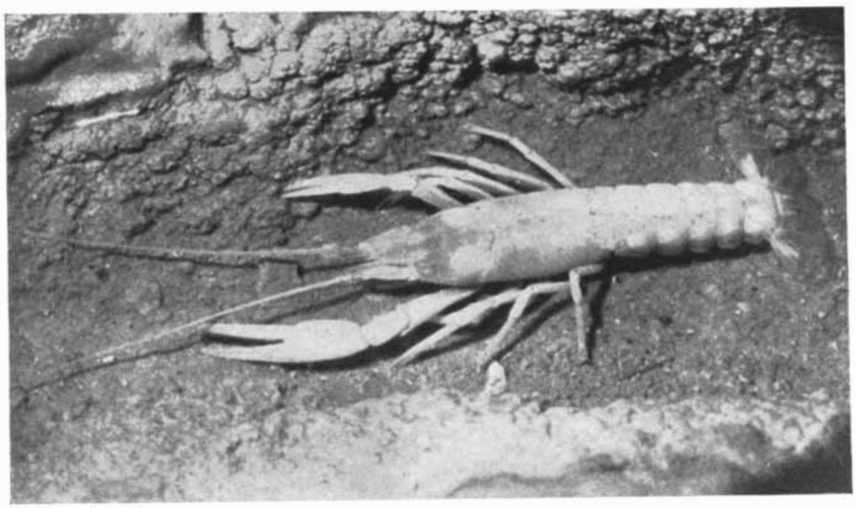


The eyes of the Ozark cave salamander Typhlotriton speleus *are covered with skin* zone to support life there. Streams and springs wash in particles of organic material from outdoor plants; rain freshets frequently carry in leaves, logs and humus; air drafts waft in fungus spores; the animal inhabitants of the twilight zone contribute their droppings and remains to the food supply. Bat guano is piled up several feet thick in some caves. Seeds carried in by animals sometimes sprout in the dark zone and send up pale, ghostly shoots, which grow for a few days on the nourishment stored in the seeds and then collapse and become organic food.

Thus the basis for a food cycle is established in the zone of darkness, and it breeds a varied population of land and water animals: worms, insects, small crustaceans, snails, fish, salamanders, frogs, fungi and bacteria. Naturally many of them are strange species unlike those in the outer world. Even before examining them one should be able to guess from the nature of the environment some of the physiological curiosities to be expected. Kenneth Dearolf, of the Public Museum and Art Gallery in Reading, Pa., has analyzed the situation from the standpoint of invertebrate life, and the writer has studied it with respect to vertebrates.

First, because the temperature is relatively constant, we should expect to find the animals lacking the usual coat or other mechanisms for protection against heat or cold. Most are cold-blooded, and the constant temperature of the environment controls their rate of metabolism. Secondly, because the humidity is unvaryingly high (approaching 100 per cent), the animals need no special body covering either to hold or repel moisture. Third, the complete absence of light makes eyes unnecessary. Having no eyes, or at least no use for them, the inner

Nonpigmented planarian worms (Sorocelis americana) *are found in Ozark caves*



The white crayfish **Oronectes pellucidus** ***is a true inner-cave dweller***

cave dwellers need exceptionally sensitive organs of touch or smell to locate food. Fourth, because the food supply is relatively uncertain, subject entirely to accidental imports from the outside world, a permanent cave dweller must be a scavenger or predator, with ability to survive on a meager diet.

In short, we should expect the animal species in the dark zone to be small and slender; to have a thin, unpigmented body covering; to be eyeless; to have long tactile organs and an acute sense of smell; to be able to exist on a limited diet; to have no daily cycle of activity, and to be either scavengers or predators. Upon actual inspection, the cave inhabitants fit this description perfectly.

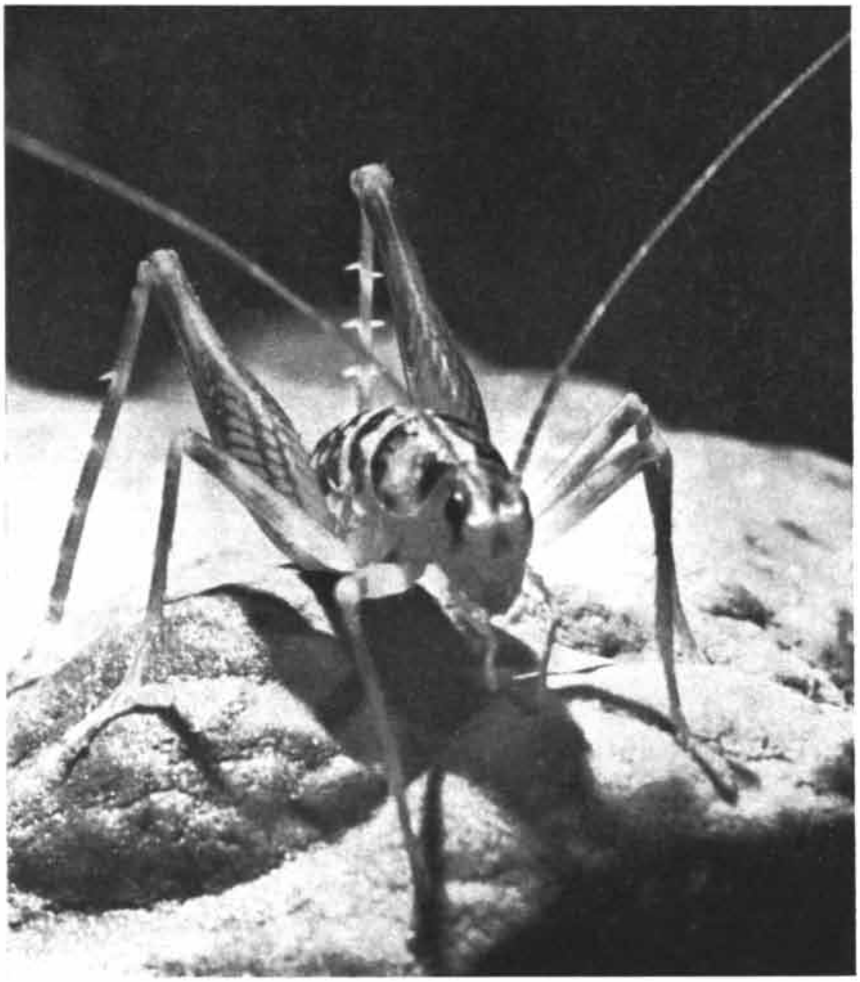
One large group are the flatworms, with white, flattened bodies which stretch into odd shapes as they twist and turn. They are carnivorous, feeding on insect larvae, small isopods and decaying organisms. The flatworms in turn serve as food for fish and crustaceans. Perhaps the most common aquatic creatures in caves are the isopods, or water lice, which feed on fungi and guano. They are usually white and eyeless and have flattened forms. Some of them grow fairly large—up to half an inch in length. Other aquatic animals include the amphipods, a smaller version of shrimps; water fleas (Daphnia), which are almost invisible but can be detected as white specks fluttering about when a light is shined upon the water; hydras and fresh-water sponges, and crayfish. The crayfish are one of the largest water creatures that have adapted to live in caves. They feed on insects, millepedes and organic remains. The cave crayfish are blind and have an acute tactile sense, aided by elongated antennae or feelers. The 19th-century naturalist A. S. Packard, who in 1870 studied the blind crayfish *Oronectes pellucidus* in Mammoth Cave in Kentucky, concluded that the species had acquired the hereditary tendency to become blind as a result of the effects of the environment on the adults. The eyes of these crayfish are better during their youth than after they mature, and it would seem that they can be considered examples of degenerative evolution.

Blind fish are not peculiar to caves: some blind species are found in crevices and holes along the California coast and in ocean depths. The kinds in caves are generally small—no more than two or three inches in length. A giant among them is the foot-long olm, found in certain European caves.

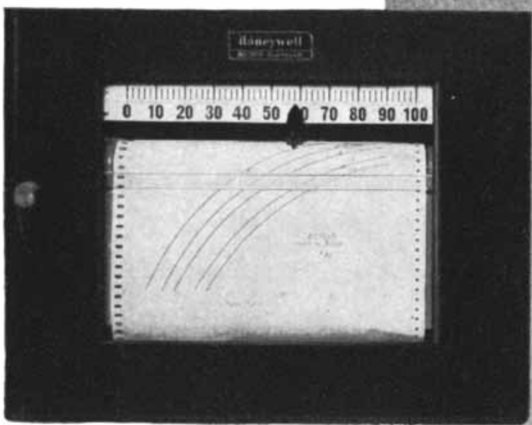
Of the cave amphibians, the outstanding group are the salamanders. More than a dozen known species either live permanently in caves or spend much of their time there. In caves of the Ozark Plateau and Texas there are two salamander species with degenerate eyes entirely or almost entirely covered by fused lids. The Texas cave salamander has never been found except in underground streams and deep wells. A single specimen of another type of blind salamander was once found in a well in Georgia. Not all cave salamanders are white; some forms are spotted. Even the colorless salamanders have a pinkish tint because of the network of blood vessels close to their skin, through which they breathe. The only known salamander completely without eyes is one found in certain caves in Austria. Frogs are another amphibian common in caves, but they are not permanent dwellers there: they are attracted from the outside by insects and other food or are washed in or occasionally spend the winter in caves where there is running water.

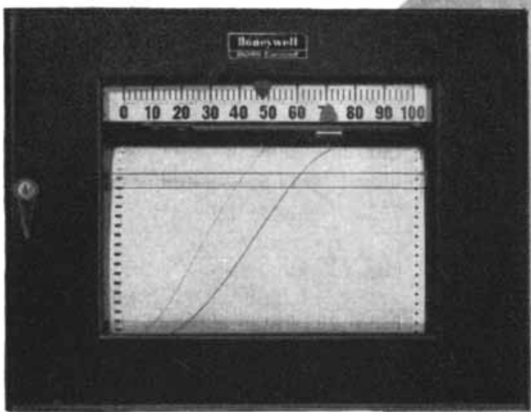
Most of the nonaquatic animals in caves are arthropods—centipedes, springtails, moths, beetles, spiders, harvestmen, mites, various kinds of flies, crickets, fleas. The author was once driven out of a cave into which he crawled in the middle of winter by swarms of mosquitoes. They were waiting out the cold weather in the cave. Actually there are few insects that dwell exclusively in caves; most of the types found there either leave the cave occasionally for food or will live in any dark place. For instance, one of the most common cave insects in the U. S., the so-called cave cricket (*Ceuthophilus gracilipes*), is not a true cave species, because it is also found in other dark habitats. The true cave insects have either nonfunctional eyes or no eyes at all. They are often light in color but never white. Their antennae are long, and occasionally the whole body is covered with hairs to supplement the feelers. Practically no caves in areas that were covered by the last glacier have true cave insects; the permanent cave dwellers must have been annihilated by flooding of the caves.

Mollusks found in caves include snails and slugs. Whether these animals can be considered true cave natives is de-



The most familiar cave cricket* Ceuthophilus *is also found in cellars





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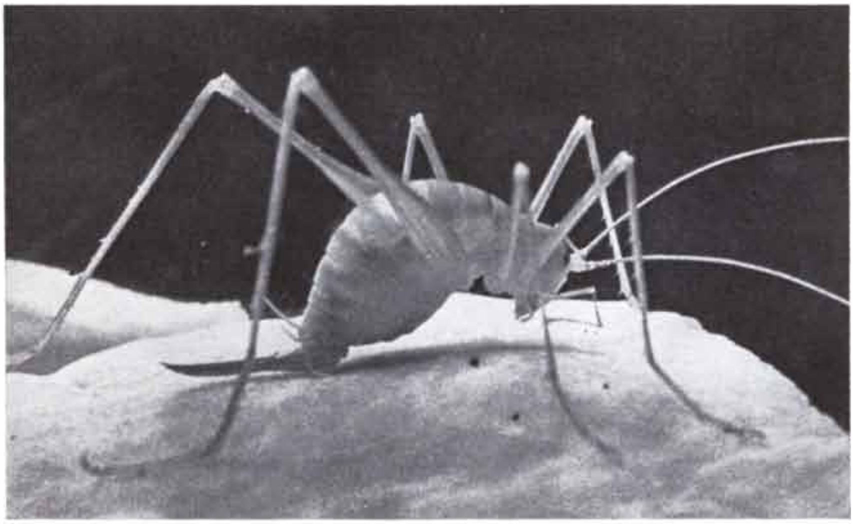


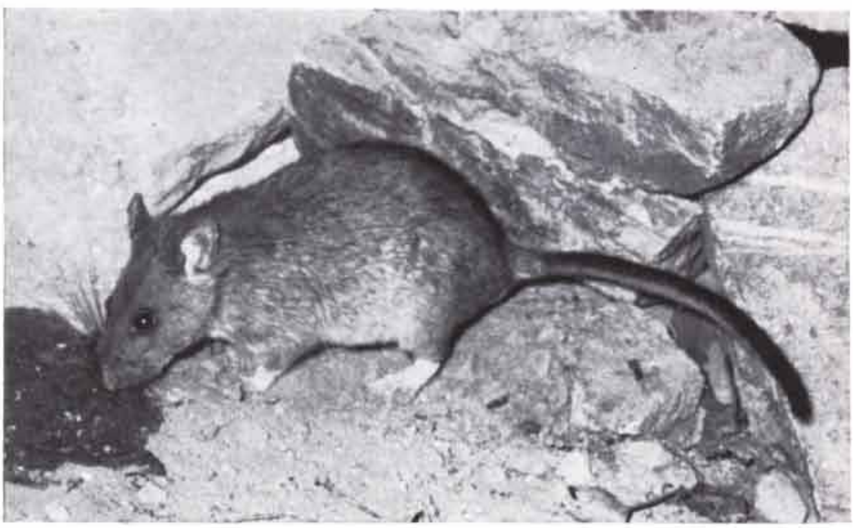
The rarer cave cricket Hadenoecus *is found in the dark regions of Kentucky caves*

batable, because the same species are found in many damp, dark places above ground. The mollusks in a cave play a part in its food chain, as they feed on decaying plant material and are preyed upon in turn by salamanders and perhaps frogs.

Normally no reptiles are found in caves, although snakes and lizards use the entrances as dens. The interior of a cave is too damp for them. In cases where snakes have been reported in caves it has always been shown that they either fell in or were carried in by some outside agency.

Like the deep sea, the dark environment of caverns has produced some phosphorescent animals, though only a few of them. There is a thread-shaped worm, *Bolitophila luminosa*, that lives in tightly packed colonies hanging from the ceiling of the caverns at Waitoma in New Zealand. These glowworms lose their luminosity when disturbed. In caves of the Great Smokies in Tennessee and North Carolina, there is a large fly, the fungus gnat (*Platyura fultoni*), which is luminous in its larval stage. This fly has the unusual habit (for a fly) of spinning a web to catch other insects and spiders. Caves also harbor several species of luminescent fungi, but they occur elsewhere as well.

Cave life is an important study for biology and evolution, but unfortunately the study is seriously threatened by a rise in popular interest in the subject. The increased exploration of caves within recent years has become a menace to the animals and plants dwelling in them. (This is the reason specific



The cave rat Neotoma magister *is found in U. S. caves*

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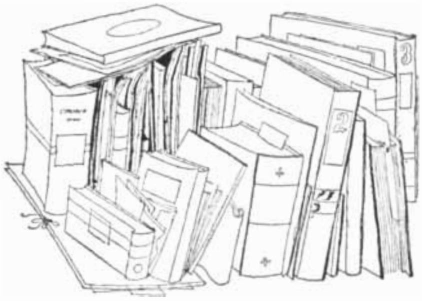
SUBSIDIARY

VITRO MINERALS CORPORATION, owned jointly with Rochester & Pittsburgh Coal Co., explores and mines uranium ores caves have not been named in this article.) As a result of indiscriminate collecting, some species of cave animals have become practically extinct. Moreover, sight-seeing tours have destroyed some cave life. The continual passage of people through a cave in wintertime disturbs the hibernation of bats and insects. The activated animals, not finding food, soon die. A rise in their temperature increases their metabolic rate and thus upsets the balance between the food they require and the food available.

Another threat to cave life is the practice of dumping used carbide in caves and pools where it contaminates the water supply. Calcium carbide, reacting with water, forms acetylene and calcium hydroxide. Aside from the solid pollution in the water, the calcium hydroxide can raise the alkalinity of the water to levels that will kill any organisms present. Carbide may also poison the organic material used as food by insects and amphibians. If carbide must be left in a cave, it should be placed in some dry, secluded spot where water cannot wash it to other parts of the cave.

Most people readily realize that it is important not to disturb cave rock formations, such as stalactites and stalagmites, because they take thousands of years to form. Yet they fail to appreciate that some species of cave life have taken millions of years to reach their present stage of development, and while a rock formation may eventually be replaced by water seeping through a cave, once a living species becomes extinct it is gone forever.

Paradoxically, the more difficult a species is to find, the greater is the danger that it will be destroyed. Certain colonies of rare salamanders have been decimated within the past few years by collectors who sought them as prize additions to their collections. Even when a cave population is abundant, far more can be learned about the little-known life cycles of the animals by not disturbing or collecting them than by capturing all the available specimens. As the cave investigator Charles Mohr has pointed out, living creatures have to be studied over a long period in their natural habitat to learn their habits. Courtship, egg-laying, the larval stage, the rate of growth, feeding habits and migrations all need study. Most cave populations are too small to justify any collecting at all. If the cave species are to be preserved for the advancement of science, we shall all have to come to realize that animals living underground are just as much a part of nature as those living above the ground.



BOOKS

An account of the first of five volumes about technology from prehistoric to modern times

by James R. Newman

A History of Technology, edited by Charles Singer, E. J. Holmyard and A. R. Hall. Oxford University Press ($23.55).

This cumbrous volume, about the size of a small picnic hamper, is a first-rate contribution to the study of the history of science. The book weighs five pounds and is scarcely manageable except on a lectern, but the discomfort of holding it is offset by the good things within. "The road to learning," as Menaechmus warned Alexander, "is not always easy."

Charles Singer is the foremost British historian of science. His monumental project when completed will comprise five volumes. This first volume contains 31 monographs by 28 specialists. It is a work which will appeal to anyone interested in the evolution of tools and techniques and the marvelous development of man's ability to manipulate nature. The period of the volume extends from the Lower Paleolithic, say half a million years ago, to the fall of ancient empires, about 1,000 years before the Christian Era. It opens with the "humblest beginnings," when languages were starting to take form and the crudest stone implements were coming into use; it ends with achievements of skill and artistry that have never been surpassed. As we look about us in the modern world we are apt to fall into a coma of self-veneration at what science and technology have accomplished; Singer's book restores a sense of proportion. We may continue to admire man's cleverness but we may no longer reserve the highest congratulations for ourselves. "Long before there was anything that we can recognize as self-conscious science, long before steel or even iron had come into general use, long before there existed any conception of an inhabited world as a whole, long before any fuel was available other than wood and charcoal or any roads but tracks, man had produced such masterpieces of dexterity as the Gebel-el-Arak knife of flint and ivory of about 3800 B.C., such triumphs of portraiture as that of Sargon I of about 2600 B.C., and a work of such unsurpassed technical skill as the inner coffin of Tutankhamen of about 1350 B.C."

The monographs deal with the social factors affecting technological advance, with man's early food collecting, firemaking, chemical and culinary arts and primitive building; with the domestication of animals and cultivation of plants; with metal, wood and ivory working, pottery making, and weaving; with water supply and irrigation, mining and metallurgy, land and water transport, writing, weights and measures, ancient mathematics and astronomy. The editors have been discriminating in their invitations. I have not encountered another cooperative work with so high a proportion of readable essays. The book for all its detail can be read straight through; indeed, a sense of what happened over the entire period is only to be gained by continuous reading, for no philosophical evaluation or summary has been included.

Benjamin Franklin aptly described man as a toolmaking animal. But as a tool user man is certainly not unique. Kenneth Oakley (who attracted attention for exposing the unfortunate Piltdown man) gives interesting examples of tool users among animals. The female burrowing wasp, entombing her caterpillar victim, not only uses stones to close the burrow but has been known to seize a tiny pebble in her jaws and use it as a hammer to pound down the spot and make it as hard as the surrounding surface. One of Darwin's finches, *Cactospiza*, uses a cactus spine held in its beak to poke out insects embedded in tree trunks. The greater spotted woodpecker of England cuts clefts in a tree trunk and uses them as vises to hold pine cones firm while it pulls out their seeds. And well known, of course, is the southern sea otter's practice of placing a shellfish on a slab of rock reposing on its chest and pounding it with a stone.

It is a characteristic of evolutionary advance that behavior becomes increasingly dependent on learning. Primates are unequaled in their ability to learn; thus they can also forget. A South African naturalist, Eugène Marais, took an otter pup from the water and a baby baboon from its troop and reared them on foods to which they were unaccustomed. On returning the animals to their native habitat he discovered that the otter dove right in and caught fish as if it had been doing it all its life, but the baboon would have nothing to do with grubs and scorpions, the usual diet of its species in the wild. Instead it started munching on poisonous berries which no normal adult baboon would touch.

Man owes his skill to his ability to coordinate sensory impressions, to the structure and musculature of his hands and arms and to his eyes. But he also owes some of it to the demands of the environment that tests and challenges him. We are more like monkeys than like apes. Our monkey-like ancestors swung around in trees, but when they got to grassland they learned to walk on two legs (when on all fours they supported themselves, as we do and modern apes do not, on their palms instead of their knuckles). In these circumstances their hands retained "primitive simplicity and prehensile power, but, freed from locomotive functions, became progressively more skilled as manipulative organs." Ability to rotate the thumb is an important faculty of the primates. So are their visual powers, though man alone has the capacity to give prolonged close attention to a task and to coordinate eye and hand. A chimpanzee can thread a needle, but fine embroidery is, I daresay, beyond it. Baboons use pebbles to kill scorpions, and sometimes when chased they clamber to a high place and dislodge stones and boulders to discourage their pursuers; chimpanzees learn to use sticks for various purposes. But it is important to observe in both cases that living on the ground is what evokes these skills.

It is conjectured that the early *Hominidae*, our forbears, occasionally used improvised tools. But it was not until man himself appeared that the use, not to say the making, of tools became a regular thing. From mere tool using to toolmaking is an enormous jump: it marks the birth of forethought. Only man can visualize, imagine, see forms in the unformed and turn them into reality. This faculty is embraced in Aristotle's definition of art, which "consists in the conception of the result to be produced before its realization in the material." Sultan, the famous chimpanzee of Tenerife, made history when he fitted a small bamboo pole into a larger one, thus creating a stick long enough to reach a bunch of bananas. He was obviously an exceptional ape; moreover, he had an immediate, visible reward as incentive. There is no indication, says Oakley, "that apes can conceive the usefulness of shaping an object for use in an imagined eventuality."

The capacity for foresight is said to reflect an improvement in cortical function. Our heads are not bigger but they are evidently better than our apelike ancestors'. The power of conceptual thought fed by remembered experience is closely linked to skilled behavior. Language of course has played an enormously important part in toolmaking; in fact it is sometimes regarded as itself the most fundamental of human tools, "more distinctive of man than toolmaking." It is the medium of education by an oral tradition—"in effect a new kind of inheritance." Moreover, as Oakley points out, it is almost impossible "to think effectively, to plan, or to invent, without the use of words or equivalent symbols." Speech therefore had to be invented before toolmaking became a normal practice.

By the time of the Lower Pleistocene, about a million years ago, the human level of cerebral development had been

TAMING OF FIRE was imagined by the first century B.C. Roman architect Vitruvius. This engraving is from a French edition of his works published in 1547. In the left background men and animals flee from the burning forest. In the foreground other men, who have overcome their fear, gather around and feed a portion of the fire they have isolated.

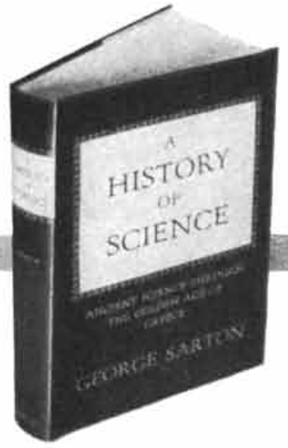
reached. Deposits of this period in Africa, Asia and Western Europe have yielded stone artifacts of "standardized types" showing that toolmaking now served permanent needs. Since men are largely carnivorous (though "dentally and from the alimentary point of view they should be vegetarians") the tools were needed to kill game, to remove skin and fur and to divide flesh. Broken bones served as implements; lumps of quartz were converted into crude choppers; large pebbles were flaked to give a cutting edge. Flaking is a kind of chipping or peeling, analogous to the whittling of wood. Various forms—pointed, tongue-like, sharp-edged—were produced. Two basic techniques were employed: a stone was trimmed to the required shape (core tool) or a flake was detached and itself used as the tool (flake tool). Flint hand axes were a standard tool; for a very long period they were unhafted, the shaped stone being simply held in the hand. Extraordinary skill in craftsmanship was attained; for example, hand axes of the Acheulean Period, more than 100,000 years ago, displayed "perfection which exceeds bare technical necessity." Scrapers, arrows, spears, knives, hand drills, chisels, burins were among the tools that primitive man brought to a high level of efficiency and beauty. The achievements of the Stone Age must be accepted, says L. S. B. Leakey, "as fully comparable in their place, time and circumstance to those of the greatest modern inventors and engineers."

Leakey calls attention to another interesting point: that "Stone Age" is a misnomer if it gives the impression that stone was the only or even the principal material worked throughout this period. Stone implements have survived because they are durable, but there is every reason to believe that wood, bone and ivory also played important parts in primitive technology. Repeatedly the authors of this book remind us how vast are the gaps in our knowledge of prehistoric and even historic times, and repeatedly one is forced to admire the brilliant reconstructions of the past accomplished with meager clues.

For at least 95 per cent of the whole life span of humanity, says V. Gordon Childe, men merely collected their food. They foraged, hunted and fished, and produced no regular or reliable surplus. Everyone had to contribute to the food supply; there was no true division of labor; no one could be a full-time specialist. The great Neolithic revolution of the post-Pleistocene period was initiated by the practice of food-raising. Men began to grow edible plants, to breed cattle, sheep, goats and pigs. Population increased and communities were formed. Farming became a full-time occupation. An accompanying development was the enslavement of prisoners; for as some prudent social innovator came to realize, one could get more out of men even by working them to death than by eating or torturing them. In any case it is safe to assume that what slaves raised tasted better than the slaves themselves.

Some members of the society could devote themselves to specialties: mining flint, quarrying rock, making pots, shaping tools, brewing intoxicants, concocting sedatives, manufacturing articles of adornment, constructing huts and, later, shrines and temples. Granaries and storehouses "to hold the freewill offerings of the pious cultivators" were attached to the temples. Taxes were levied to assure a steady flow of revenue to support the corporation of priests, and artisans were enlisted to provide the equipment for the temple. Records had to be kept, and this called for conventional symbols comprehensible to all who were engaged in the business of making offerings to the deities. The invention of writing took place in Mesopotamia around 3500 B.C.

Several monographs attempt to trace the progress in technology during the successive periods of savagery, barbarism and civilization. By the end of the Early Stone Age in Europe harpoon-headed spears were in common use, as were the bow and arrow and entangling weapons such as the noose and bola. Nets, traps and pounds were used in forest hunting; dip-nets, cast-nets, seines, lines, hooks and spears in fishing. Primitive men were skillful in making weirs and dams. The environment gave direction to the food-collecting technology. In central California, where acorns were an important food source, the early inhabitants invented special methods of cooking and storing them, and reached a high proficiency in weaving baskets. In the Arctic, where food had to be hunted over a wide area, the Eskimos were forced to invent boats and dog sleds to keep mobile. But the influence of environment on man's technology was qualified in two important ways. Since man is even less particular in his eating habits than a goat, he was not restricted in his search for food; thus there are no "pure gleaners, pure hunters, or pure fishers." And his technology was enriched by diffusion of knowledge from one locality to another. The Eskimos, for instance, "almost certainly" derived some of their equipment from the Old



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Editor's Note About This Month's LIBRARY OF SCIENCE selection

In all frankness, it is difficult to say whether HISTORY OF SCIENCE *through the Golden Age of Greece* is a history of science from the broad cultural point of view or a history of human culture from the scientific point of view.

Only the leading science historian of our time, George Sarton, could have written this panorama of ancient science from pre-historic times through The Great Age of Greece, whose physicians, engineers and philosophers were rivaled only by her sculptors and poets.

The importance of Professor Sarton's work may be seen in SCIENTIFIC AMERICAN's comment on it that "The study of the history of scientific thinking adds a new dimension to the mind of the scientist himself. It reveals the conditions and processes of scientific discovery, throws light on the genesis of hypotheses, shows the unconscious influence of contemporary patterns of thought and diagnoses the hidden factors that cause science to develop in a given direction. An intimate knowledge of the inner history of his field of study can enlarge a scientist's imaginative grasp and add to his flexibility of mind."

There is no doubt that Professor Sarton's history of science *"will be an essential part of the library of the scientist"* (Yale Journal of Biology and Medicine), and, I may add, of every thinking individual.

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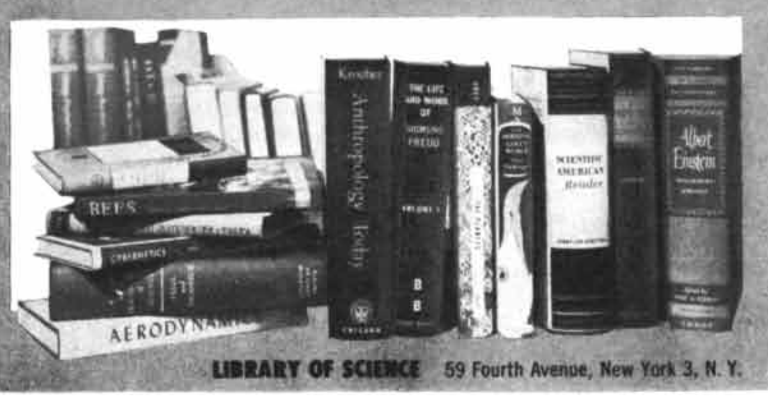

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World. In contrast, the isolated Tasmanians never learned to make a canoe or even to throw a spear.

Rotary motion, exemplified by the wheel, is a comparatively recent invention. In its sophisticated form it was the most decisive factor of the industrial revolution, says Childe. It can hardly have been less decisive when embodied in the spindle, perhaps 8,000 years ago, and in the potter's wheel and wheeled vehicles, some 6,000 years before that. Probably long before these triumphs of continuous rotation were created, tools were rotated to bore holes. Perforated stone objects survive from the Paleolithic age. There are reindeer antlers pierced by holes two centimeters in diameter, undoubtedly drilled with pointed flints. The Maya used hand-drills, and the Egyptians had bow drills which are thought to go back to Paleolithic times. Stone door-sockets were used in Neolithic houses in Central Europe and in the village of Hassuna in Assyria by 4500 B.C. Where stone was scarce, as in Mesopotamia, a tenant who rented a dwelling had to bring his own door socket as he would his couch.

The predecessor of the wheeled cart and wagon was the sledge, used not only over snow but over sand, steppes and even rocky tracts. There is a fine illustration in the book of the handsome sledge chariot of Queen Shub-Ad of Ur in Mesopotamia about 2500 B.C. The first cart-wheels were disks, probably made of wood. For spoked wheels metal saws were needed, and saws and spoked wheels begin to appear in the archaeological record of Mesopotamia after 2000 B.C.

By facilitating transport and allowing a larger population to be fed at a single center (the food transport pattern is itself singularly like a wheel, the center being at the hub) the wheel accelerated the urban revolution. But it was first pressed into service for less rational purposes: to improve chariots and engines of war and to support hearses as they conveyed royal corpses to their tombs. It is worth remarking that while the spoked wheel is generally believed to have evolved from the solid wheel by carving openings in the planks, there is no archaeological evidence to support this view. The transitional forms are lacking, and so the spoked wheel may quite possibly represent a true mutation.

In a comprehensive essay on pottery and weaving Sir Lindsay Scott points out that the development of pottery depended on the growth of urban civilization. As its manufacture became more complex it required specialists, and reduction of its cost required machinery. The weaving of textiles, on the other hand, is less dependent on group effort and seems to have been invented earlier. Basketry and textiles appear around 5000 B.C. in Egypt and Iran. The making of cord and rope is thought to have started still earlier: a pre-Neolithic cave painting in eastern Spain "depicts a person using what appear to be ropes to climb down the face of a cliff, in order to collect wild honey."

One of the most interesting monographs, by Seton Lloyd, director of the British Institute of Archaeology at Ankara, deals with building in brick and stone. He describes the problems of quarrying in Egypt, of moving colossal blocks of stone weighing as much as 1,250 tons for great distances with nothing better than rollers for transport, of putting the blocks in place without pulleys, and of cutting and fitting them smoothly into an edifice without the use of metal saws, chisels or drills. On this last point, however, the experts seem to disagree. Lloyd dismisses the suggestion that the Egyptians used steel or even hardened copper tools, but C. N. Bromhead, in discussing mining and quarrying, asserts that blocks could not have been cut from the stone without metal implements.

Man's need of water led him early to devise ingenious methods of irrigation and storage. Dams and runnels were constructed even by peoples of the early food-gathering cultures, and by the time of the great Near East civilizations canals and aqueducts were in wide use. Ancient texts record laws dealing with water-claims and obligations of "rivals." "That very word," M. S. Drower informs us, "in Roman law denoted those who shared the water of a *rivus*, or irrigation channel; it thus implies jealously guarded rights and frequent quarrels." Immense stone dikes were built to channel rivers and to prevent inundation. The Nile, known as the "most gentlemanly river," rises and falls with almost "calendrical precision." The Pharaohs harnessed its waters in elaborate systems for irrigation. Though gentlemanly, the Nile is capable of misbehaving. To this fact we may owe the birth of geometry. When the river is low, there is famine; when it is high, there is flood. The Egyptians developed efficient administrative machinery to deal with both contingencies. After the land had been irrigated, and corn had been planted and the ears had begun to ripen, tax inspectors came to measure the fields for assessment. It was very important to have clear boundaries, marked by stones. But when the

Nile overflowed, the boundaries were apt to disappear. Surveys employing geometric methods were needed to settle disputes.

S. H. Hooke presents a brief but brilliant account of the invention of writing. It appears, for instance, that the form of the Sumerian script was shaped by the fortuitous fact that Sumerian scribes wrote their signs on small tablets which could be held comfortably in the left palm. As a result their pictorial symbols were drawn slantwise, with each figure reclining and facing upward. The symbols were written at the same angle even after the Sumerians began to write on larger tablets, but by that time the signs had been conventionalized and had lost their pictorial character, so that they no longer looked unnatural lying on their backs.

Hooke describes an Egyptian slate tablet which illustrates one of the major turning points in the development of writing. The tablet celebrates the military achievements of an Egyptian king named Narmer. His name is given by two symbols, one representing a fish whose name is pronounced "nar," the other representing a chisel, pronounced "mer." The tablet, dating from 3100 B.C., is the first known instance of the use of a pictorial sign to represent a phonetic sound rather than an object.

This fascinating, richly illustrated book is not a great work of historical synthesis, but many of its monographs are excellent and it gathers into a single volume a vast range of hitherto scattered knowledge. Certain omissions are surprising. There is no essay on medicine or architecture; the treatment of ancient mathematics and astronomy is thin; the lack of philosophical evaluations is disappointing. The volume almost completely neglects the technology of India and the Far East, offering the unconvincing explanation that there are no authors with sufficient knowledge of the subject and that in any case "the more ancient civilizations in that area have had relatively little direct influence on Western cultures." Experts in various fields will undoubtedly have other bones to pick with the editors and contributors. But all will agree on the massive merits of the book and will look forward eagerly, as I do, to its successors.

Short Reviews

FROM AN ANTIQUE LAND, by Julian Huxley. Crown Publishers, Inc. ($6.00). In 1948, while director-general of UNESCO, Huxley toured the Middle East. He went to Beirut, Damascus and Palmyra, to Aleppo, Knossos, Baghdad, Ctesiphon, Petra, Istanbul, Cairo, Isfahan and many other places in a region of the world which he characterizes as "solid history." He saw with a fresh eye, interpreted and reflected with a cultivated mind; he was no less interested in tombs and mosques and fabulous antiques than in living men and women and problems of irrigation and education. This admirably written report is illustrated by Huxley's own photographs, some of which are in color; they are very good.

QATABAN AND SHEBA, by Wendell Phillips. Harcourt, Brace and Company ($5.00). Phillips is a frighteningly energetic young explorer and paleontologist who in 1947, when he was 26, organized and led the expensive Cairo-to-Capetown African expedition sponsored by the University of California. He is now president of the American Foundation for the Study of Man. In this volume he describes another motorized expedition which, following the "Biblical spice routes," explored several sites in Saudi Arabia and made valuable archaeological discoveries. But the book is less concerned with these than with the expedition's adventures in Yemen, where the Queen of Sheba's "moon temple of Awwam" was excavated. The party, fearing an attack by Arab tribesmen, fled the country, leaving behind a great store of expensive equipment. This is an occasionally entertaining book, but it would go down better were it not for the chronic palpitations of Phillips, who strikes the reader as a mixture of Captain Peachey and the late Wyatt Earp.

THE MATHEMATICAL PRACTITIONERS OF TUDOR AND STUART ENGLAND, by E. G. R. Taylor. Cambridge University Press ($9.50). Professor Taylor's book deals with the motley group of half-forgotten mathematical practitioners who armed England with improved techniques in navigation, gunnery, surveying and timekeeping in the centuries when she rose to become queen of the seas. They included such men as William Bourne, the innkeeper who wrote nautical almanacs; Richard Delamain, the joiner who devised a circular logarithmic scale; John Whiblin, the carpenter and "philomath" who was "ingenious at models"; Richard Sault, a "gentleman" who kept a mathematical boarding school; Richard Anderson, the silk weaver who wrote on stereometry and gunnery; John Twysden, the lawyer who was an astronomical observer and the author of many mathematical tracts; William Buckley,

Dr. Robert N. Hall, of the General Electric Research Laboratory, is shown examining a rate-grown germanium crystal. He received both his B.S. (1942) and his Ph. D. (1948) degrees from the California Institute of Technology. Though trained as a nuclear physicist, most of Dr. Hall's research work has been done in the field of solid-state physics.

Growing semiconductors

General Electric's Dr. R. N. Hall conducts basic studies leading to new methods for the production of transistors

In 1948, Dr. Robert N. Hall began his work at the General Electric Research Laboratory with a study of the preparation of high-purity germanium crystals. As an outgrowth of this work, he found that indium and germanium could be fused to make alloyed *p-n* junctions—the basic elements of power rectifiers and most transistors.

Later studies showed how desirable impurities are segregated during the growth of germanium crystals. This led to the *rate-growing process* for making crystals containing large numbers of *p-n* junctions—now generally regarded as the most suitable process known for the mass production of grown-junction transistors for high-frequency use. Dr. Hall is currently engaged in research on modifications of the *rate-growing process* which will make possible the preparation of units for amplification at still higher frequencies.

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who made a ring dial for Princess Elizabeth and imparted the elements of Euclid to the "Royal Henchmen" (the court pages); Humfrey Cole, the engraver and diesinker who was the most famous instrument maker of Elizabethan times; Robert Recorde, the mint employee whose textbooks taught generations of Englishmen the rudiments of algebra and geometry. One is not apt to find the names of most of these men in history books. But during a period in England when formal mathematical courses at the universities were almost nonexistent, when scholars would not permit themselves to be defiled by learning, much less teaching, what was practical, it was this higgledy-piggledy company that helped bring the sailor home from the sea, that promoted trade and exploration, that improved the arts of war and enabled ladies to be punctual in their appointments. Taylor's story is a delightful and a most important addition to the history of science.

American Men of Science: The Physical Sciences, edited by Jaques Cattell. R. R. Bowker Company ($20.00). The ninth edition of *American Men of Science* is to be published in three volumes, of which this is the first. In place of the former single volume covering all branches of science, it will divide scientists into the physical, biological and social science groups, and it will expand the list from 50,000 to 90,000 names. The book is clearly printed and adequately bound.

Walter Gropius, by S. Giedion. Reinhold Publishing Corporation ($10.00). This book by the noted author of *Space, Time and Architecture* pays tribute to a world-famous architect who was the first director and guiding spirit of the Weimar State School of Building, better known as the Bauhaus. Giedion discusses the contributions made by Gropius and his group to architecture, design and town planning. Much of the volume consists of illustrations of their work, ranging from furniture, sleeping cars, locomotives and door handles to Berlin housing projects, the Ukrainian State Theatre at Kharkov, the Harvard Graduate Center and the Hua Tung University of Shanghai.

Wartime Psychiatry, edited by Nolan D. C. Lewis and Bernice Engle. Oxford University Press ($15.00). This volume is a compilation of the U. S. and British literature on psychiatry during World War II. It abstracts articles, books and other publications. "Experience in both world wars," the editors write, "has shown that psychiatric disorders total more than half of all disabilities and are the single most important cause of manpower shortages."

STUDIES IN MATHEMATICS AND MECHANICS. Academic Press, Inc. ($9.00). This volume, intended as a *Festschrift* on the occasion of the 70th birthday of the distinguished mathematician and philosopher Richard von Mises, who died before its publication, consists of some 40 studies by various contributors on subjects of pure mathematics, theoretical and applied mechanics, probability and statistics. There is a brief introduction by Philipp Frank and a bibliography of von Mises' writings, but it is regrettable that no biographical essay was included on the work of this creative thinker, whose writings on the frequency theory of probability and on the philosophy of positivism are probably the best general appraisals of those subjects available.

ART AND INDUSTRY, by Herbert Read. Horizon Press ($6.00). A stimulating study of industrial design by an eminent British art critic. The text is full of penetrating insights into the relation of machine products to everyday living and the principles of intelligent design. It discusses the contemporary relapse into "sophisticated antiquarianism" and the "unashamed nostalgia for ornament and period style" resulting from the "justifiable dissatisfaction with the bleakness of a pioneering functionalism." Many apt illustrations.

Notes

SEISMICITY OF THE EARTH, by B. Gutenberg and C. F. Richter. Princeton University Press ($10.00). The second edition of an analysis which covers observations since 1899. It has new material on the structure of the earth's crust and the velocity distribution of seismic waves.

THE QUANTUM THEORY OF RADIATION, by W. Heitler. Oxford University Press ($7.20). In its third edition this book emphasizes advances in the electrodynamics of electrons and positrons.

TROPICAL METEOROLOGY, by Herbert Riehl. McGraw-Hill Book Company, Inc. ($8.50). Dr. Riehl of the University of Chicago has written a useful volume dealing with tropical storms, monsoons and other aspects of the weather in low latitudes.

THE AMATEUR SCIENTIST

How to make an aerodynamic smoke tunnel and more about the puzzle of the 12 balls

Some months ago we expressed the opinion that amateur aerodynamics enjoys the smallest following among all the scientific avocations. No one challenged the statement, and a number of professional aerodynamicists wrote that the lack of amateur interest in the study is all too apparent in this nation, where the airplane was invented and carried to its highest development.

"The reason," writes J. J. Cornish of the department of aerophysics at Mississippi State University, "may lie in the nature of aerodynamics and the invisibility of the air itself. Perhaps the solution to the problem lies in making the flow of air visible. The words 'I don't see' have become synonymous with 'I don't understand.' And surely with understanding comes interest.

"If so complicated a device as a cloud chamber, which renders cosmic-ray tracks visible, can be reduced to the simple apparatus shown in your April, 1953, issue, surely aerodynamics likewise can be simplified.

"The aerodynamic smoke tunnel has long been used to gain a better understanding of various flow phenomena. Alexander Lippisch has made extensive use of the smoke tunnel in designing delta-wing aircraft. The Forrestal Research Center at Princeton University has several smoke tunnels in operation. This aerodynamic tool, the smoke tunnel, is well suited for experiments by amateurs.

"I recently constructed a small smoke tunnel which was designed to make use of an ordinary tank-type vacuum cleaner for its source of power [*see drawing on page 120*]. The smoke for the tunnel is obtained from cigarettes.

"The tunnel itself is made of two-by-twos and Masonite. The pieces were assembled to form a duct approximately one foot high and two feet long. One end of the duct, the entrance, was flared out to a width of about six inches. The rest of the duct has a width of 1½ inches. One face was then covered with a pane of window glass. A 'screen door' made of fine screening (a couple of layers of window screen will do) was made to cover the entrance so as to smooth out the entering air. Toward the other end of the tunnel a hole was cut in the back wall to allow the air to be exhausted by the vacuum cleaner. The cover from a two-inch spool of adhesive tape makes the fitting to attach the vacuum cleaner tube.

"The smoke is introduced into the tunnel through a 'rake' made from several pieces of ⅛-inch copper tubing attached to a pipe about half an inch in diameter [*drawing on page 122*]. To this rake is attached, by means of rubber tubing, the smoke generator. The smoke generator is made of two narrow cans and some balsa plugs. I started off with a generator that 'smokes' a single cigarette but soon worked up to a 'three-holer' for a denser smoke. From the other side of the generator another rubber tube is led to the exhaust side of the vacuum cleaner

Editor's Note

Regular readers of "The Amateur Scientist" will observe that this month it does not begin with the words "Conducted by Albert G. Ingalls." At the age of 67 Ingalls has decided to retire. He will continue to contribute as often as he chooses, but from now on the burden of the department will be carried by other editors.

Ingalls has conducted "The Amateur Scientist" for 27 years. Actually the department has not always borne this title. When it was founded in May, 1928, it was called "The Backyard Astronomer." Later it became "The Amateur Astronomer," then "The Amateur Telescope Maker," then "Telescoptics," then "The Amateur Astronomer" again. During those years the department was obviously devoted to amateur telescope making. After the reorganization of Scientific American in 1948 the department was enlarged to include other amateur activities, and was given its present title. Despite these apparent metamorphoses the department has always had the same unique character reflecting the unique personality of Ingalls.

Ingalls' department has been only a part of his activity in amateur telescope making. As every amateur telescope maker knows, Ingalls has published three books: *Amateur Telescope Making, Amateur Telescope Making—Advanced* and *Amateur Telescope Making—Book Three*. These minor classics may be found not only in the homes of amateurs but also on the shelves of professionals interested in optics. During World War II Ingalls organized a program in which amateurs made 30,000 roof prisms for military range- and height-finders. Perhaps Ingalls' most characteristic activity has been his personal correspondence. This awesome flow of letters, postcards, letters on envelopes, letters written between the lines of other letters, letters written on the back of once-used mimeograph sheets, has done much to assemble the fraternity of amateur telescope makers. Ingalls says he has no intention of retiring from this enjoyable activity.

to produce the pressure differential necessary to burn the cigarettes.

"After sealing all joints and corners with plastic wood and smoothing the inside of the duct, I painted everything except the glass with flat black paint.

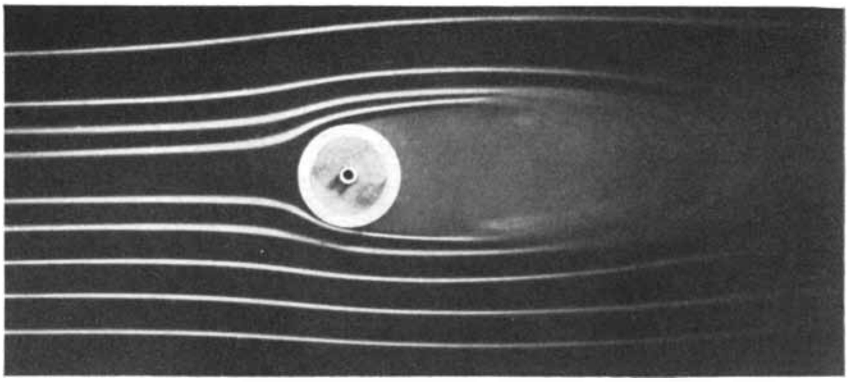
"Wonder of wonders, the thing worked on the first try. However, later I became dissatisfied with the smoke filaments and found that, as in mirror grinding, the product improves with attention to detail. I found that the smoke filaments were sharpest when the tubes of the rake were lined up accurately with the center line of the tunnel and when no air leaked in but all the flow came in by the front door. With only a little care sharp, crisp smoke lines were obtained.

"Models to be tested are mounted in the middle of the tunnel behind the glass face. With a knob projecting from the back of the tunnel I control the angle between the model and the flow. For best results the models should be big enough to span the 1½-inch tunnel and should be about three or four inches long.

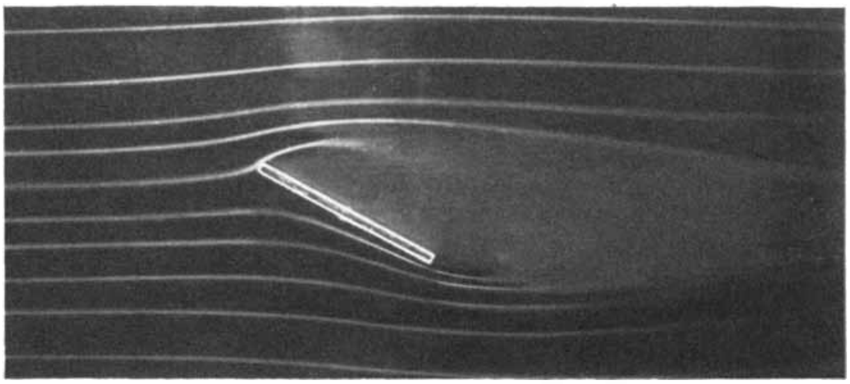
"It might be mentioned that the use of cigarettes as the smoke source has the advantage that the exhaust from the tunnel need not be conducted out-of-doors, as in the case of smokes from burning rotten wood or vaporized kerosene, often used in the larger tunnels. Even after a long evening of running, my kitchen is no worse off than after an evening with several cigarette-smoking guests. Supplying the tunnel with three cigarettes at a time has cut down on my own smoking, incidentally.

"Photographing the flow patterns obtained in the tunnel is one of the most interesting aspects of this hobby. When you have pictures of the flows, you can study the details at your leisure and compare different conditions. The black background and white smoke streams form contrasting patterns which are easily photographed. If you make pictures, you must pay some attention to lighting and reflectivity. The back wall of the tunnel must be almost absolutely flat black for the best results. Ordinary rough black paper such as is used in photograph albums is not quite black enough to get good contrast, as it reflects about 10 per cent of the incident light. Black velvet or velveteen reflects less than 1 per cent. [Roger Hayward, the illustrator of this department, points out that a sheet of glass painted black on the rear face and lighted from the front at a relatively low angle of incidence would give a much "blacker" black.]

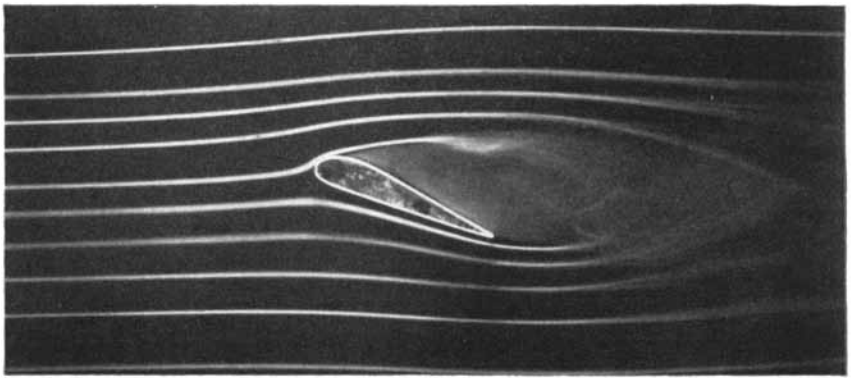
"The models should be painted so that



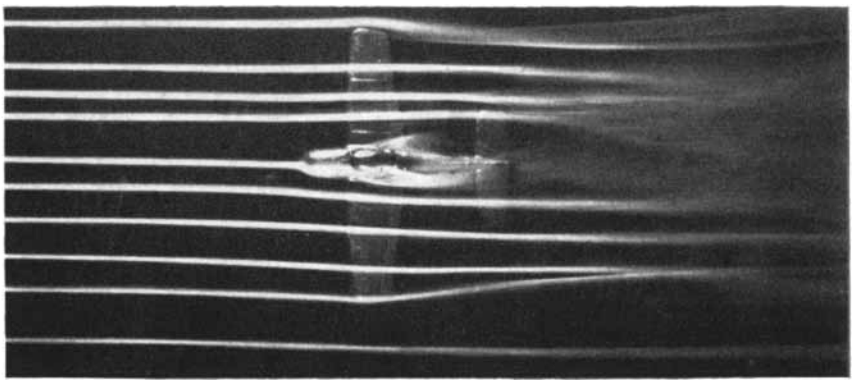
A cylinder in an aerodynamic smoke tunnel



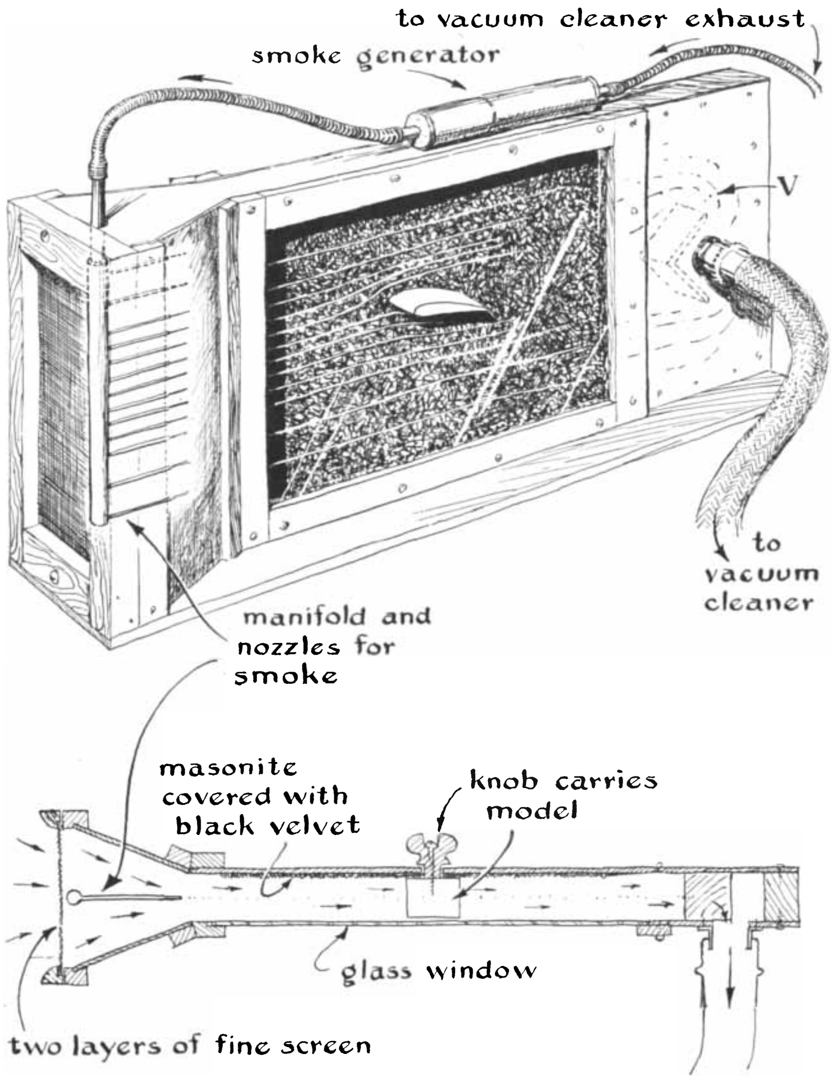
A flat plate



An airfoil



A model airplane



Details of the smoke tunnel

they show up in the pictures. At first I painted the models all white but this reflected too much light. Later I found that if the models were given a coat of white paint, then a coat of black paint, and then some of the black paint was scraped away around the edges, the white paint that showed through outlined the model very well.

"I used two 200-watt bulbs in reflectors placed at 45-degree angles to the glass to light the smoke lines. The camera was a pre-World War I Kodak, *circa* 1905. I used plus-X film and a setting of $f/8$ at one quarter second.

"The pictures on the preceding page show the effects on wind flow of an inclined flat plate, a cylinder and an airfoil section. The airplane model shows how the lift on the wings of an airplane causes the flow to curl up into wing-tip vortices as it streams past the wing. Of course many other experiments can be performed. I have done some preliminary work on boundary-layer control, both by suction and by blowing, in the tunnel. The problems of laminar separation and boundary-layer transition are readily studied.

"The speed of this tunnel is on the order of two to eight feet per second and may be regulated by choking off the flow out of the exhaust end of the vacuum cleaner. Incidentally, a V-shaped baffle should be installed in the exhaust end of the tunnel [*see above*] to prevent the flow pattern from necking down into the exhaust hole. The speed is best measured at the exhaust hole, and the speed in the test section is computed from the ratio of the area of the test section to that of the exhaust hole.

"Although not very fancy and certainly not expensive (less than $3, exclusive of the vacuum cleaner and camera) this aerodynamic smoke tunnel can afford many an hour of entertainment. Model airplane builders have used mine to test new airfoil sections. There are doubtless many other uses."

In the February issue this department published a puzzle suggested by Alvin von Auw. The problem was to find the odd ball among 12 by means of three weighings on a pan balance and to state whether it weighed more or less than the other 11. Readers were invited to forward a stamped, self-addressed envelope for the answer.

Letters like the following have filled our mail ever since. "Please inform Mr. von Auw," wrote Fred Lathrop of Portland, Ore., "that he has wrecked the serenity of our engineering department. His problem has cost three Ph.D.'s, five M.S.'s and a dozen lesser lights like myself a shameful amount of sleep—both on and off the job. Please let us know if the enclosed solution is correct. Incidentally, why not dig into the mathematical origin of this problem, if it has a literature, and publish the result? I am sure the majority of your readers would enjoy the story of this blister on the heel of progress!"

Digging into the background of a classic puzzle is something like trying to uncover the roots of a giant sequoia, and we did not feel up to the job. But J. S. Robertson, a researcher on radiation sickness at the Brookhaven National Laboratory, who makes a hobby of recreational mathematics, came to our aid. He wrote: "Although you referred to Mr. von Auw's 12-ball problem as a 'classic,' I wonder if you know that it is of relatively recent vintage and that there is a fair amount of literature on it? It is usually referred to as the '12-coin' problem. Your presentation did not clearly indicate that there are two distinct types of solutions to the problem. In one, which can be called the 'contingent' type, the procedure to be used for the second weighing depends upon the results of the first weighing, and the third on the second. In the 'predetermined' type, the balls (or coins) to be used in each weighing are selected at the beginning. Howard D. Grossman, a professional mathematician and lecturer on recreational mathematics, has shown that the balls can be so numbered that the results of the three weighings indicate the number of the odd ball directly. In a paper in *Scripta Mathematica* for March, 1950, I showed that all predetermined solutions can be derived from seven primitive solutions by such operations as renumbering, switching pans and changing the order of the weighings.

"Incidentally, Mr. von Auw's limitation on the capacity of the pans to five balls seems unnecessary, as none of the solutions uses more than four balls on a pan."

A check of references suggested by Robertson shows that the problem is indeed new. It appears to have been invented about 1945. Within six months of publication it had circled the globe and appeared in mathematical journals in all the major languages. No one cares to estimate how many millions of man-hours it has cost engineering departments. Most foreign authorities, particularly the British, agree that it was invented by an American. Grossman seems to have been the first American to publish it—in *Scripta Mathematica* of December, 1945. He writes, however: "I did not invent the 12-ball problem. I always had the impression that it started in England about 1945. May I give you a skeleton *gestalt* of the whole thing as I see it? The problem seems to be a happy composite of two diverse themes.

"The first is illustrated by Claude Gaspar Bachet's weight problem, probably the granddaddy of all weight problems, which appeared in his second edition of *Problèmes Plaisants et Délectables* in 1624. Bachet asked: With what five weights can you weigh any whole number of pounds from 1 to 31, placing the weights on only one side of a scale? Or, with what four weights can you weigh any number from 1 to 40 pounds, using the weights on both sides?

"The second theme involves concepts recently formalized by Claude Shannon's information theory, particularly that of the 'bit,' or binary digit. In the binary system of notation all numbers are based on powers of 2, and they are expressed in terms of the two digits 0 and 1. The system lends itself naturally to the description of situations involving 2^n choices.

"The version of Bachet's problem which specifies the use of five weights on only one side of the beam balance is based on the binary system—the weights being 2^0, 2^1, 2^2, 2^3 and 2^4, or 1, 2, 4, 8 and 16 pounds, respectively. The second version of his problem, which adds the choice of placing weights on the other side of the balance, is a three-choice situation that can be described by a 'ternary' number system. The four weights to be used are 3^0, 3^1, 3^2 and 3^3, or 1, 3, 9 and 27 pounds. All weighing problems involving triple choices—for example, 'up,' 'down' and 'balance'—owe their interesting properties to numbers based on the digit 3. Scores of such puzzles have been proposed.

"But rarely has a century produced one that aroused as much interest among amateur mathematicians as the 12-ball problem. The charm of the problem lies in the fact that it just does not seem to offer enough—nor even nearly enough—information for reaching a solution. Thus it resembles many of the 'easy to ask but hard to answer questions' found in nature. Solving the 12-ball problem demands something closely akin to the creative act—reasoning by elimination or induction rather than deduction. In this respect the 12-ball problem claims a feature in common with detective-story puzzles and even, on an elementary plane, with such profound problems as that posed by photosynthesis."

The earliest published account of an "odd-ball" problem that we could find in the literature was one proposed by E. D. Schell of Arlington, Va., in the August-September, 1945, issue of *American Mathematical Monthly*. Schell gives you eight coins and the traditional beam balance. One of the coins is counterfeit—underweight. You are asked to sort out the counterfeit in two weighings.

It was solved immediately by a number of readers of his article and was generalized for *m* coins and *n* weighings by Irving Kaplansky, G. H. Neugebauer and W. O. Pennell. They showed that for any set of *m* coins, where $3^{n-1} \leqq m < 3^n$, not more than *n* balancings are needed to sort out the counterfeit.

Grossman independently published a similar generalization of the eight-coin problem in his December, 1945, paper in *Scripta Mathematica*, and he introduced the more ingenious 12-coin version with three weighings, with the troublesome additional requirement that you tell whether the odd coin is lighter or heavier. Apparently his problem had access to air transportation, because in a matter of days R. L. Goodstein published it, along with a generalization, in the *Mathematical Gazette*, the British counterpart of *Scripta Mathematica*. The avalanche of papers touched off by these two ingenious author-mathematicians has not yet died out.

"Like the wood's colt," writes Grossman, "this problem encounters difficulty in tracing its sire. During the mid-1940s it was just 'in the air,' and many of those who make a hobby of recreational mathematics took a whack at refining it. Royal V. Heath, a New York stockbroker, amateur magician and amateur mathematician, passed it on to me. The fact that I published it first would seem incidental."

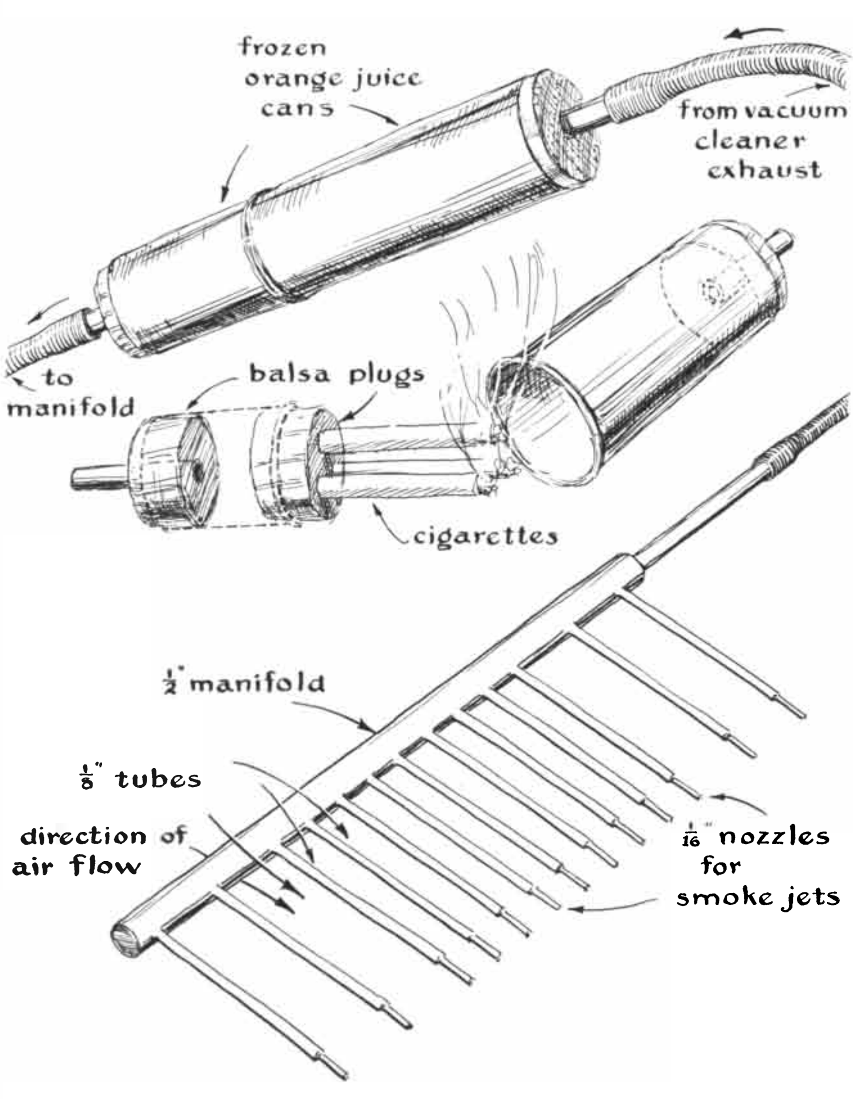
Among the intuitive generalizations of

the problem, one of the easiest for laymen to follow was presented by Karl Itkin in *Scripta Mathematica* for March, 1948. He demonstrated by experiment that two weighings are enough to identify and describe the odd ball from a set of three balls; three weighings suffice for 12 balls; four for 39, and five for 120. From these results he showed that if n weighings handle m balls, $n + 1$ weighings can cope with a set of $3(m + 1)$ balls. The ternary nature of the problem had been suggested by F. J. Dyson and C. A. B. Smith in the *Mathematical Gazette* of October, 1946, and February, 1947, and had been refined and simplified by Grossman. Hence Itkin recognized that his experimental results conformed to the ternary series: $3 = 3^1$, $12 = 3^1 + 3^2$, $39 = 3^1 + 3^2 + 3^3$, $120 = 3^1 + 3^2 + 3^3 + 3^4$, and so on. He expressed the generalized equation as: $m = (3^n - 3)/2$. The equation states, for example, that with only seven weighings you can identify and describe the odd ball among

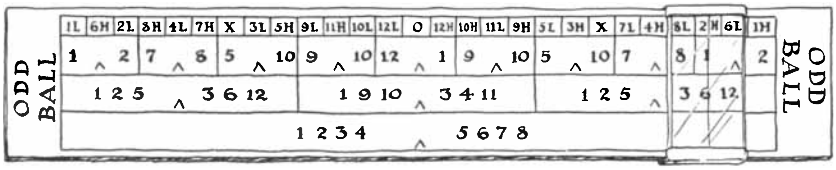
$$\frac{(3 \times 3 \times 3 \times 3 \times 3 \times 3 \times 3) - 3}{2}$$

or 1,092 balls!

Most amateurs who lose sufficient sleep over the problem manage to come up with one or more solutions of the contingent type. Through trial and error—and guided by the happy faculty for guessing right that characterizes a good research man—they simply weigh various combinations of balls until they hit the jackpot. Estimates of the total number of ways in which the problem can be solved run from a few score to several hundred thousand, depending on how you define a distinct solution. But until last year all of the contingent solutions were largely products of the cut-and-try method. Then Paul J. and Dorothy Kellogg, of the Laboratory of Nuclear Studies at Cornell University, hit upon a way of eliminating the guess-



Smoke-generating apparatus for the tunnel



A slide rule for the 12-ball problem

work by making an ingenious application of information theory. They told about it in a paper called "Entropy of Information and the Odd Ball Problem" in the *Journal of Applied Physics* for November, 1954. Shannon, author of the information theory, defined "information" in a rather special way. The amount of possible information depends on the range of choices afforded by the system of symbols. A one-letter alphabet, for example, would allow no freedom of choice, and the information you could transmit would approach zero. An alphabet of two letters would afford greater choice and hence make possible the transmission of more information. It turned out that the equations which Shannon developed for assessing the information potential of such systems were precisely the equations that define entropy in thermodynamic systems.

The Kelloggs analyzed the odd-ball problem by means of these equations and found that certain combinations of balls yield a greater change in entropy than others. Those combinations in which entropy change reaches maximum value lead to solutions.

Although entropy equations take the guesswork out of contingent solutions, you will find the computation complicated unless you happen to be a designer of jet engines or a specialist in some other branch of thermodynamics.

To make the job easy for the rest of us, J. J. Cornish, the designer of the aerodynamic smoke tunnel discussed above, invites you to construct the little computer shown above. Its operation resembles that of a slide rule. You first position the hairline of the slider over the caret between the first four balls (1, 2, 3, 4) and the second four (5, 6, 7, 8) in the bottom tier of this rule. This represents the first weighing. Let us suppose that in an actual weighing the left side goes down, showing that the combination of the first four balls is heavier than the second four. Now for the second weighing go to the second tier and move the slider toward the light side—that is, the right side in this case. (The slider must always be moved to the light side.) Set the hairline on the caret toward the right in this tier—the caret between the balls 1, 2, 5 and 3, 6, 12. Say the weighing shows the left side again is heavier and that side goes down. So you again move the slider to the right and go to the third tier for the final weighing. Now the caret on which the hairline falls is between balls 1 and 2. Suppose the right side goes down. To read the result of the third weighing move the slider to the light side, over ball 1, and read the answer above: 2 H. The odd ball is 2, and it is heavier than the others. In this manner the odd ball, whichever of the 12 it happens to be, can be identified quickly in three weighings.

In our opinion the contingent solutions are less elegant and entertaining than those of the predetermined type. Grossman is credited with presenting the first comprehensive treatment of a predetermined solution in 1948. His approach employed the ternary system.

The ternary system, as we have seen, uses the powers of 3: $3^0=1$, $3^1=3$, $3^2=9$, and so on. Any decimal number can be stated in terms of powers of 3 and their negative counterparts: -1, -3, -9 and so on. For instance, the number 5 can be written $-1-3+9$. With the first three powers of 3, and the negatives of the first two, we can construct a table from which all the numbers from 1 to 12 can be formed by such algebraic addition. Put down these powers as column headings and list in each column the numbers requiring the figure at the head in their ternary expression: for example, the number 5 is listed in the column under -1 and also under -3 and $+9$. The table is:

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

Such a table has remarkable properties. You can easily extend it to 100

numbers or more and astonish your friends with it. For instance, if a friend indicates in which columns his age is listed, you can immediately tell his age by adding the headings of those columns algebraically. A table of this kind can suggest card tricks and other puzzles that may be solved by means of ternary numbers.

Grossman made one that tells you how to weigh the balls in the 12-ball problem so that the column headings give you a solution of the predetermined type. His table has six columns—a pair for each of the three weighings. He rearranged the entries so that only four numbers appear in each column—corresponding to four balls for each pan during each weighing. He accomplished this by treating some of the numbers as though they were negative. The digit 5, for example, can be made negative simply by reversing the signs of its ternary components: + 1 + 3 — 9. Grossman observed that the columns would be equalized—that is, each would contain just four numbers—if he considered as negative all even numbers of the form $(3^n - 1)/2$ (*e.g.*, 4) and all odd numbers not of this form (*e.g.*, 3). Numbers remaining positive (up to 12) are, then: 1, 2, 6, 8, 10 and 12. Those considered negative are 3, 4, 5, 7, 9 and 11.

Here is Grossman's table:

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

Each of the 12 balls is identified by a number. To use the table, weigh the balls under +1 against those under —1, then those under +3 against those under —3 and finally those under +9 against those under —9. At each step note which pan is heavier, if either one is, and after the third weighing add up algebraically the numbers at the heads of the heavy columns. The sum will identify the odd ball, and if that number appears in the "heavy" columns, the odd ball is heavier than the others; if it appears in the "light" columns, it is lighter. For instance, suppose that 7 is the odd ball and it is light. On the first weighing the +1 pan will be heavier than —1; on the second, —3 will be heavier than +3; on the third, +9 will be heavier than —9. The sum is + 1 — 3 + 9 = 7. The number 7 appears in the light columns; therefore the ball is light.

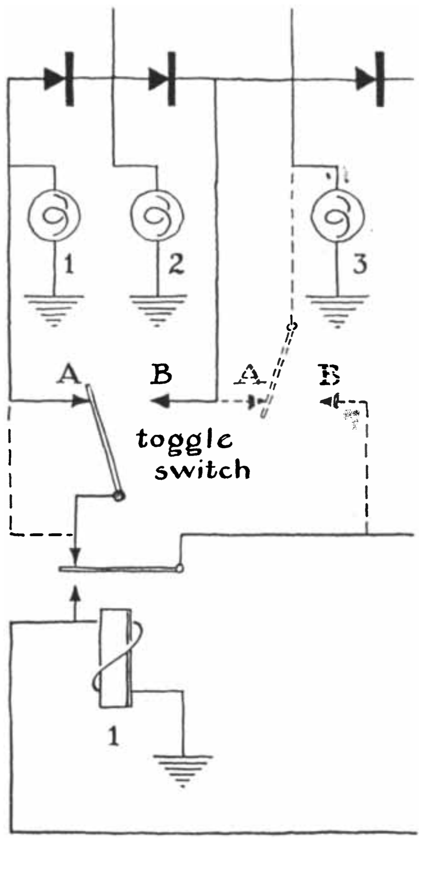
If there are insomnophiles who wish to venture further into this fascinating territory, Octave Levenspiel of Bucknell University offers more sophisticated problems:

"Can you find the odd ball among 13 in three weighings?

"Given 15 coins, one identified as genuine, can you find the single counterfeit among them in three weighings?

"Is it true that in n weighings (with n greater than 3) one can find two balls heavier than the others among m balls if $m=3^{\frac{n}{2}}$ when n is even, or $m=2[3^{\frac{n-1}{2}}]$ when n is odd?"

In the circuit diagram for Harry Rudloe's "battle of numbers" game, which appeared in this department in the March issue, the operation of the toggle switch did not conform to the description in the text. A corrected diagram is shown below: the dotted lines represent the part of the original diagram that was wrong. The wiring should follow the solid lines. When the toggle switch is at position A, as shown here, the machine's opponent makes the first move. When the game starts with the switch at position B, the machine has made the first move, which consists in extinguishing the first two lamps.



An error in the March issue

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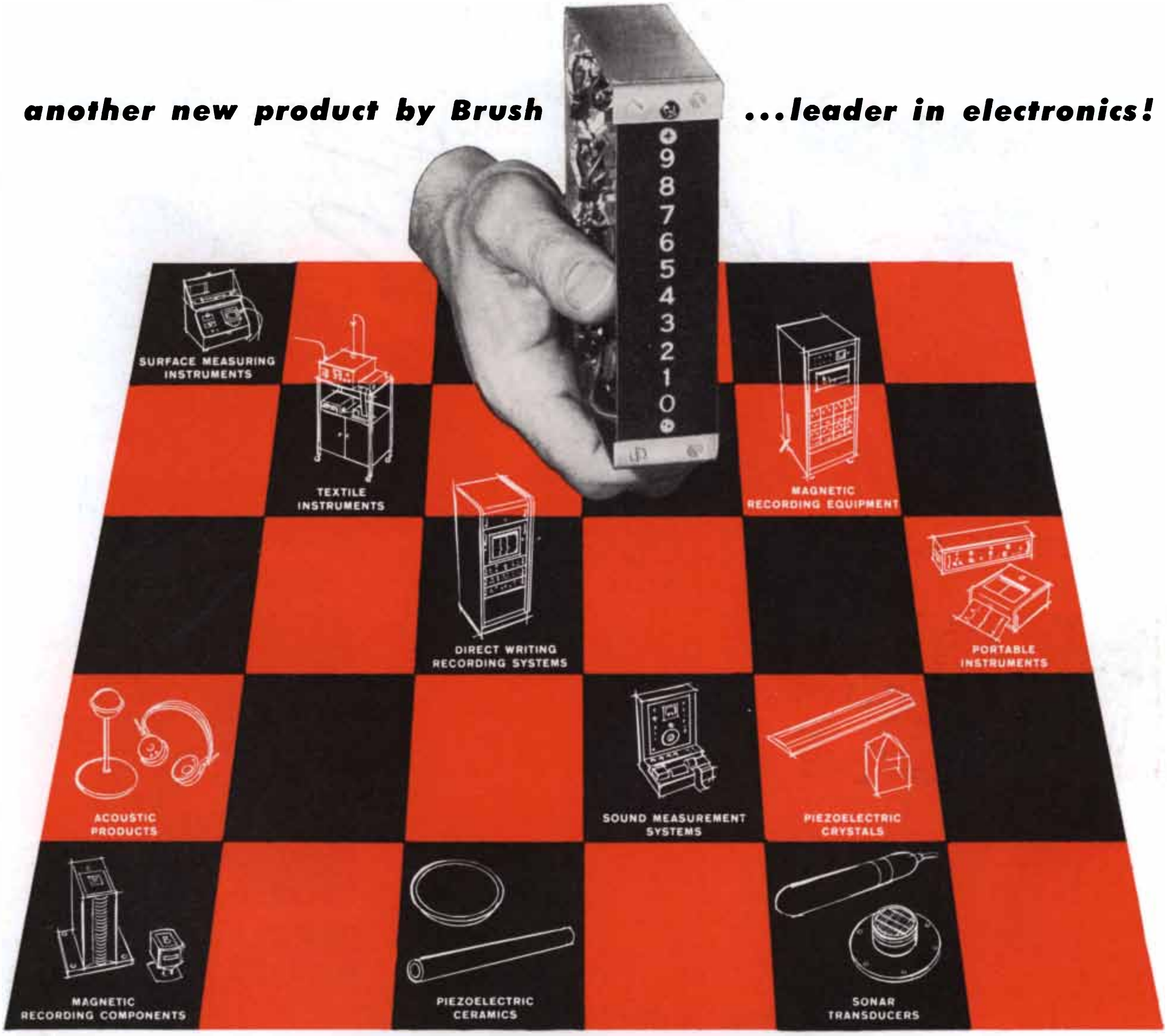

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