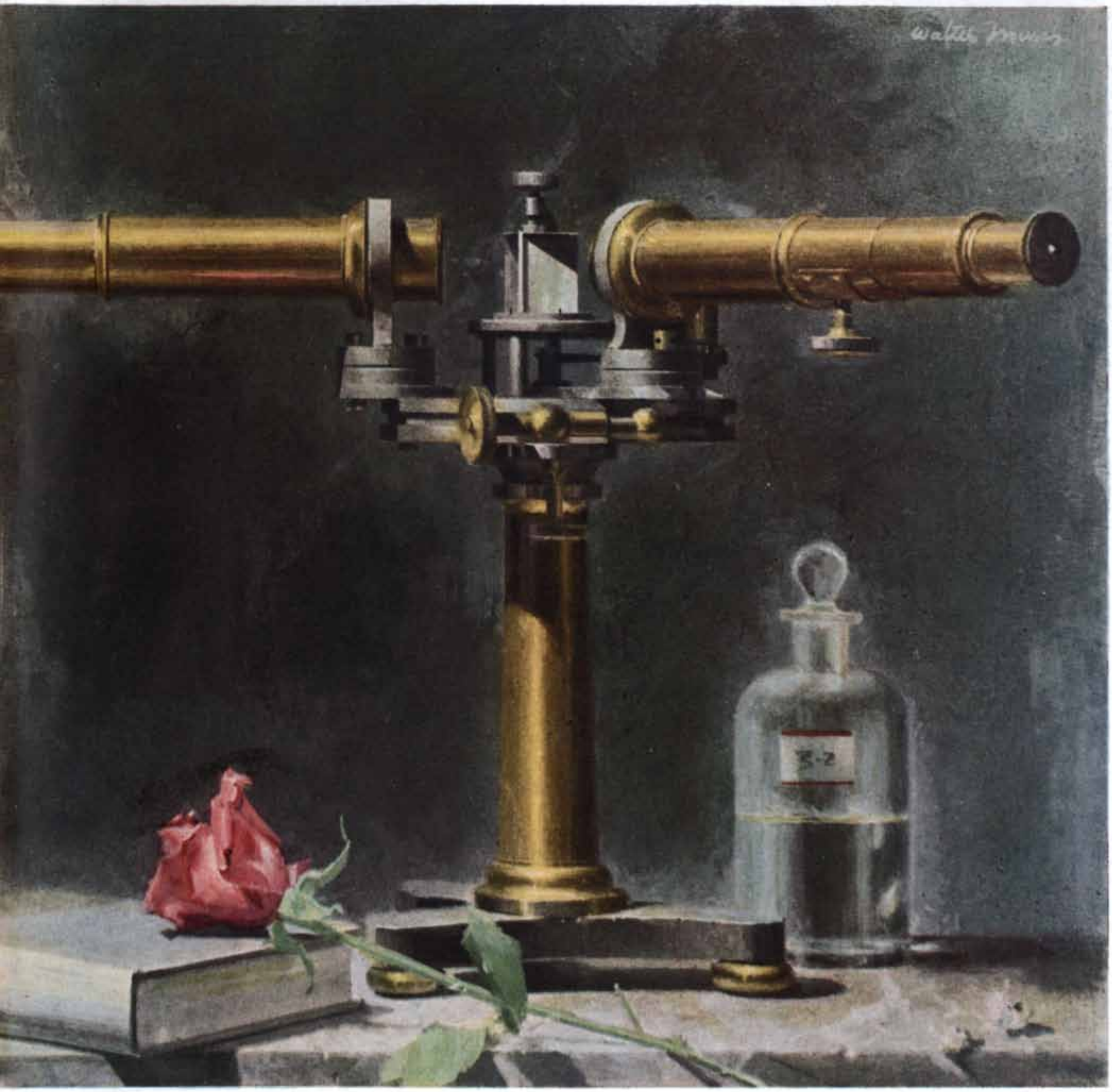
SCIENTIFIC AMERICAN



FUNDAMENTAL QUESTIONS IN SCIENCE

FIFTY CENTS

September 1953

Stokes is a Pioneer in High Vacuum

Stokes engineers are pioneers in the use of vacuum... first to develop commercial techniques for the preservation of blood plasma... first in vacuum research and application... designers and builders of the equipment by which vacuum cuts costs, improves products, creates new goods and new markets.

Stokes is the *only* manufacturer of *complete* vacuum systems. During fifty years of experience with vacuum and high vacuum, Stokes has built to customers' requirements, with a sure knowledge of what *is* and what *is not* practical.

Visit the Stokes plant and see for yourself what makes Stokes *first* in vacuum... first in the manufacture of complete vacuum processing systems.

F. J. STOKES MACHINE COMPANY, PHILADELPHIA 20, PA.

One of the first real signs of hope in the fight against paralytic poliomyelitis is gamma globulin, an extracted component from human blood, containing antibodies, which serve as a partial immunizing agent. Because it is destroyed at heat above body temperature, it cannot be dried by ordinary methods. Yet it *must* be dried to make it available for use when needed. The solution is to freeze the product rapidly, then apply mild heat under high vacuum conditions. Stokes Vacuum Freeze-Dryers are used for this purpose; also, for preserving blood plasma, hog cholera serum and many other substances which are sensitive to heat. Brochures, entitled "Freeze-Drying in Industry" and "Laboratory Freeze-Drying" are now available.

This isn't before and after the battle; it's before and after a toy tank has been metallized under vacuum. These tanks are injection-molded of *scrap* plastic; then placed by the dozens in the chamber of a Stokes Vacuum Metallizer. After 10 or 12 minutes, the pressure in the chamber is reduced to less than one micron. Aluminum staples are heated to the vaporizing point, assume molecular freedom, and instantly are deposited as a thin metal film over the dozens of toy tanks. Stokes Vacuum Metallizers are also used for finishing great quantities of costume jewelry at low production cost, and for many industrial purposes. We shall be glad to send a brochure, "Vacuum Metallizing Today".

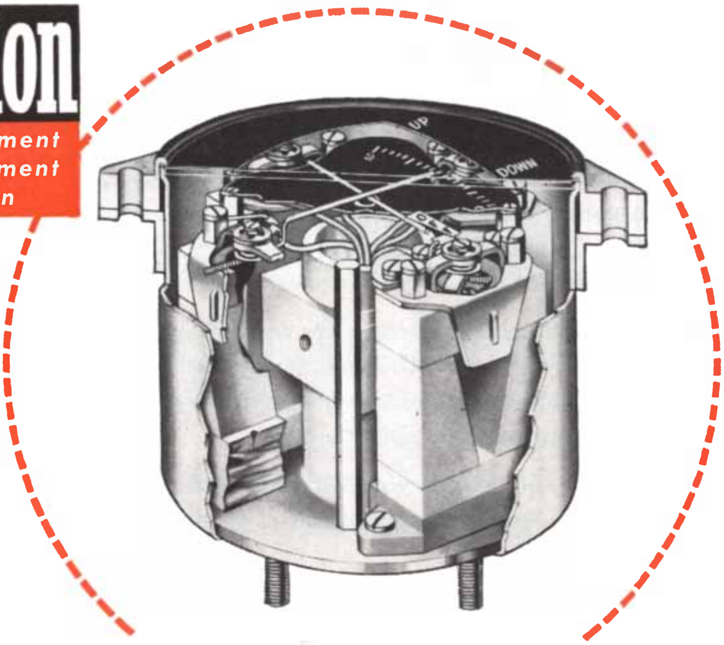
Among the little gadgets that make TV sets so efficient today are capacitors. These are what used to be known as condensers; for TV purposes, they are made of a paper and metal assembly which has been impregnated with a liquid possessing a high dielectric strength. This prevents electrical leakage even under high humidity. Stokes Vacuum Impregnators are used to impregnate thousands of these capacitors at a time. Once the air is exhausted from every fold and fiber of the paper, oil is introduced from an adjacent chamber and instantly fills every tiny, empty pore. Send for the new 24-page brochure on "Vacuum Impregnation."

Many airplanes of the future will take advantage of the high strength-weight ratio of titanium. It is a plentiful metal, spurns most corrosives which affect other metals, and endures extraordinary heat. Unfortunately, during some stages of production titanium has an incorrigible affinity for other elements . . . it wants to be anything but pure titanium. Part of the processing of ore to metal must therefore be carried out in vacuum. Stokes Vacuum Furnaces are designed for this purpose. Zirconium and hafnium are other metals long known to science as laboratory curiosities but of little practical value because they could not be smelted or refined to practical purity. Now they become useful as they are processed under high vacuum conditions. Write for the bulletin on Stokes Vacuum Furnaces.

STOKES

STOKES MAKES: High Vacuum Equipment, Vacuum Pumps and Gages / Industrial Tabletting, Powder Metal and Plastics Molding Presses / Pharmaceutical Equipment marion

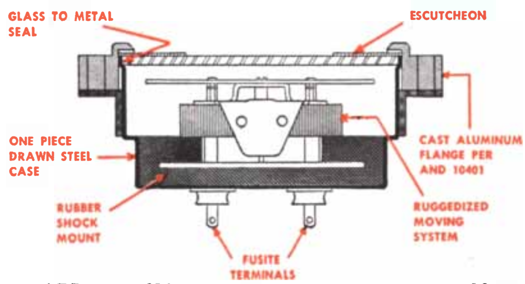
advancement in instrument design



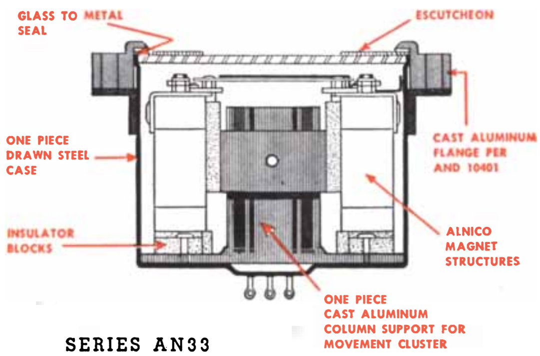
SETTING NEW DESIGN STANDARDS FOR AIRCRAFT INSTRUMENTS

Marion Electrical Instrument Company now makes available a line of aircraft instruments embodying proven Marion instrument features and incorporating new Marion developments. The result is single and multiple element aircraft types of greater durability and accuracy, incorporating a new single seal construction which isolates the glass-to-metal seal from mounting stresses and reduces thermal shock stresses. These instruments meet Army-Navy Aeronautical Design Standard AND 10401 requirements for 2¾″ dial instruments. Applications of the new Marion AN Series include ammeters, voltmeters, radio navigational types (such as omni-range and ILS) and temperature indicators.

The single element Marion Model AN3 is completely ruggedized (per MIL–M–10304) including internal shock mount.



SERIES AN3



SERIES AN33

Marion AN33 Series provides for instruments incorporating two, three or four Marion ruggedized movements. An unique one piece base and column support provides greater rigidity and more precise alignment of the elements. All wiring passes directly through the center of this column to terminal connections. Accessories such as multiplier resistors and bridge networks where required are contained in an extension cap which is attached to the base of the instrument. The series consists of two element (Model AN32E), three element (Model AN33E), and four element (Model AN34E) types.

In both the Marion AN3 and AN33 Series the one piece drawn steel case is single-seal (glass-to-metal) hermetically sealed to the glass window, making the instruments impervious to the most severe of environmental hazards. A cast aluminum flange retains the escutcheon and provides for panel mounting (per AND 10401).

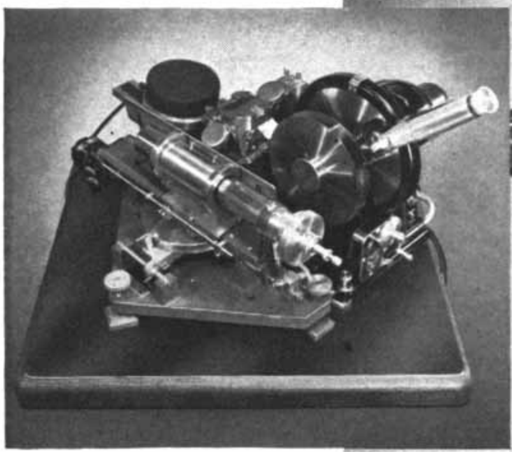
These Marion aircraft instruments represent another application of "Advancement In Instrument Design" to a critical instrument requirement.

Marion Electrical Instrument Company, 416 Canal Street, Manchester, New Hampshire.

Reg. U. S. Pat. Off

marion meters

MANUFACTURERS OF RUGGEDIZED AND "REGULAR" METERS AND RELATED PRODUCTS



STEP AHEAD TO NEW INVESTIGATIVE SPEED

WITH

FOUR-WINDOW X-RAY TUBE FLEXIBILITY

★ The effective line focus of the NORELCO basic X-ray Diffraction Unit is 0.06 x 10 mm. This unique line focus X-ray tube provides an effective slit source of intense radiation affording maximum resolution in shorter exposure times for diffractometry.

Radiation output from four windows provides opportunity to extend the utility of the basic X-ray Diffraction Unit—to operate two goniometers from the two slit sources and a choice of cameras from two simultaneously available spot sources. This single feature increases operational speed and overall efficiency over other designs with fewer X-ray windows. An *exclusive* NORELCO feature.

A Norelco PRODUCT NORTH AMERICAN

Serving Science and Industry

PHILIPS COMPANY, INC.

Dept. IH-9 • 750 South Fulton Avenue, Mount Vernon, N. Y.

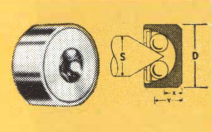
In Canada: Rogers Majestic Electronics Ltd., 11-19 Brentcliffe Road, Leaside, Toronto 17, Ontario

MPB miniature ball bearings offer a ready solution to many difficult miniaturization projects involving space, weight and friction.

RADIAL SERIES

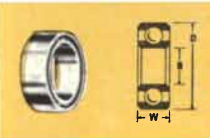
BEARING NUMBER	O.D.	BORE	WIDTH
100	.1000″	.0250″	.0312″
2	.1250″	.0400″	.0469″
2½	.15625″	.0469″	.0625″
3	.1875″	.0550″	.0781″
▼4	.2500″	.0781″	.0938″
▼5	.3125″	.09375″	.1094″

PIVOT SERIES



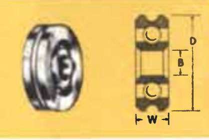
BEARING NUMBER	O.D.	BORE	WIDTH
1½ P	.0590″	.020″†	.0472″
3 P	.1181″	.030″†	.0709″
4 P	.1575″	.040″†	.0945″
▼5 P	.1968″	.050″†	.1181″
▼7½ P	.2953″	.075″†	.1772″
▼10 P	.3937″	.100″†	.2362″

SUPER-LIGHT RADIAL SERIES



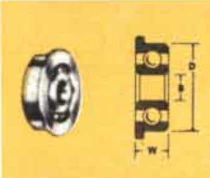
BEARING NUMBER	O.D.	BORE	WIDTH
418	.2500″	.1250″	.0938″
▼518	.3125″	.1250″	.1094″
5532	.3125″	.15625″	.1094″
5632	.3125″	.1875″	.1094″
5732	.3125″	.21875″	.1094″
614	.3750″	.2500″	.1250″

GROOVED RADIAL SERIES *(Full Race or Retainer Type)*



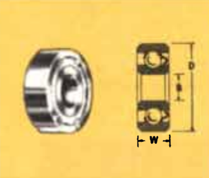
BEARING NUMBER		O.D.	BORE	WIDTH
3 G	3 GC	.2188″	.0550″	.0781″
4 G	4 GC	.2812″	.0781″	.0938″
5 G	5 GC	.3438″	.09375″	.1094″
518 G	518 GC	.3438″	.1250″	.1094″
5532 G	5532 GC	.3438″	.15625″	.1094″
5632 G	5632 GC	.3438″	.1875″	.1094″

FLANGED RADIAL SERIES *(Full Race or Retainer Type)*



BEARING NUMBER		O.D.	BORE	WIDTH
2½ F	2½ FC	.15625″	.0469″	.0625″
3 F	3 FC	.1875″	.0550″	.0781″
4 F	4 FC	.2500″	.0781″	.0938″
5 F	5 FC	.3125″	.09375″	.1094″
418 F	418 FC	.2500″	.1250″	.0938″
518 F	518 FC	.3125″	.1250″	.1094″
5532 F	5532 FC	.3125″	.15625″	.1094″
5632 F	5632 FC	.3125″	.1875″	.1094″

RADIAL RETAINER SERIES

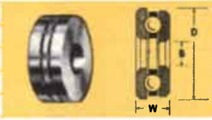


BEARING NUMBER	O.D.	BORE	WIDTH
2½ C	.15625″	.0469″	.0625″
3 C	.1875″	.0550″	.0781″
4 C	.2500″	.0781″	.0938″
5 C	.3125″	.09375″	.1094″
418 C	.2500″	.1250″	.0938″
518 C	.3125″	.1250″	.1094″
5532 C	.3125″	.15625″	.1094″
5632 C	.3125″	.1875″	.1094″

ANGULAR CONTACT SERIES

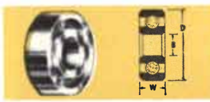
BEARING NUMBER	O.D.	BORE	WIDTH
2 A	.1250″	.042†	.0469″
3 A	.1875″	.062†	.0700″
▼4 A	.2500″	.085†	.0938″
▼6 A	.3750″	.124†	.1406″
6 A7B	.3750″	.150†	.1406″

THRUST SERIES



BEARING NUMBER	O.D.	BORE	WIDTH
2 T	.1250″‡	.0400″§	.0625″
4 T	.2500″‡	.0938″§	.0938″
5 T	.3125″‡	.1250″§	.1250″
6 T	.3750″‡	.1875″§	.1500″
7 T	.4375″‡	.1250″§	.1875″

SPRING SEPARATOR SERIES



BEARING NUMBER	O.D.	BORE	WIDTH
5 S	.3125″	.09375″	.1094″
518 S	.3125″	.1250″	.1094″
5532 S	.3125″	.15625″	.1094″
5632 S	.3125″	.1875″	.1094″

SEPARABLE SERIES

BEARING NUMBER	O.D.	BORE	WIDTH
3 M	.1875″	.0550″	.0781″
4 M	.2500″	.0781″	.0938″
5 M	.3125″	.09375″	.1094″
518 M	.3125″	.1250″	.1094″

Prefixes indicate material: Standard is chrome bearing steel (SAE 52100): use no prefix. All bearings also available in 440 stainless, except #100 and #1½P. Use prefix "SS" in ordering stainless. ▼Indicates also available in 25 beryllium. Order with prefix "NM". Suffixes indicate type of bearing: F—flange, G—groove, M—separable, C—radial retainer, S—spring separator, T—thrust, P—pivot, A—angular contact, FC—flanged with retainer, GC—grooved with retainer. Complete load ratings are given in catalog. †Shaft (S) min.; ‡ O.D. clearance of opposite race .002"; §Bore clearance of opposite race .002".

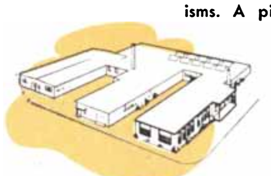
MPB ball bearings

are available in ten design series and in more than 140 different types and sizes which normally can be supplied from stock for prompt installation.

Instrument manufacturers and users of small precision mechanisms can now utilize all the well known extra advantages of anti-friction bearings (accurate alignment, long wear, freedom from attention) universally accepted in larger quality equipment.

For more than 20 years **MPB** ball bearings have contributed to the successful operation of precision mechanisms. A pioneer in designs and dimensions now being internationally standardized, **MPB** has also originated many precision manufacturing techniques. All **MPB** ball bearings are ground, lapped, honed and/or burnished in accordance with highest quality practice for optimum operating characteristics. Inspection limit tolerances are equal to ABEC 5 or better.

The most extensive engineering knowledge in miniature bearing applications is available to you. More than a million **MPB** ball bearings have been installed in precision mechanisms. Catalog 53 giving complete specifications, and additional data sheets mailed to you on request.



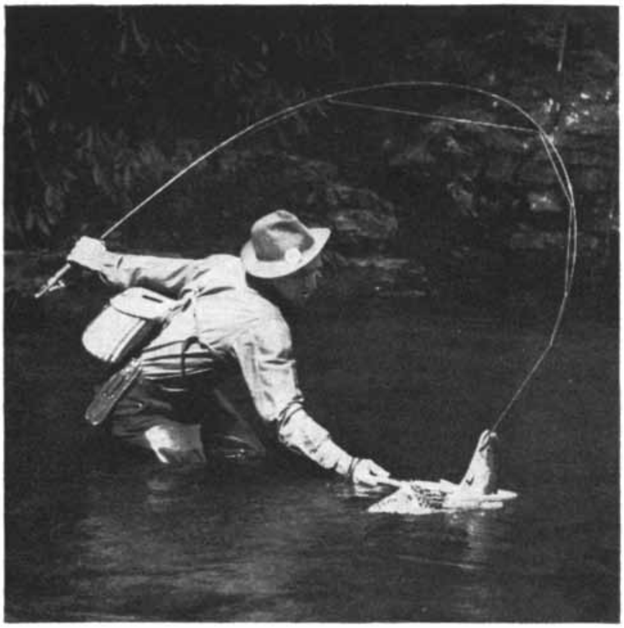
Miniature Precision Bearings

Incorporated — Keene, New Hampshire

"Pioneer Precisionists to the World's Foremost Instrument Manufacturers"

save space weight friction

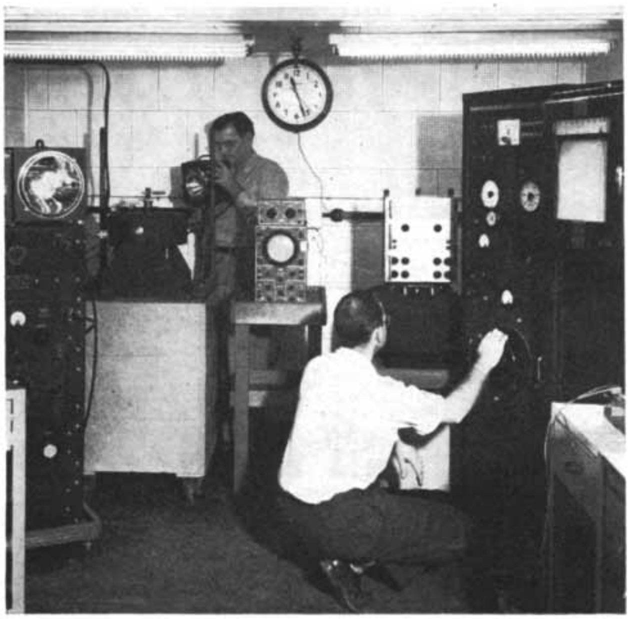
What do YOU want to protect?



1. S-T-R-E-T-C-H NYLON FIRST . . . over high heat, to make nylon fish line that won't shrink or stretch in use. Complicated temperature control equipment for stretching was quoted to one manufacturer at $18,000. Instead he's protecting his product and pocketbook by stretching the line under a heated die, temperature-controlled by a Fenwal THERMOSWITCH®. Saving $17,775.

2. MILITARY FIRE-FIGHTERS need pumps that are easily portable, quick and dependable in operation. Latest development in this field is the portable gas turbine, now proving itself as a versatile power source. Fenwal Over-Heat Detectors, developed for the aircraft field, are the thermostatic units used to protect the new gas turbine against overheating.

3. IN BLOOD BANKS, refrigeration and lighting systems must be kept functioning, regardless of main power failure. Emergency generators built for these and similar applications include two Fenwal THERMOSWITCH thermostats — maintaining the proper operating temperature in generator's water jacket . . . for immediate starting and trouble-free operation in any emergency.

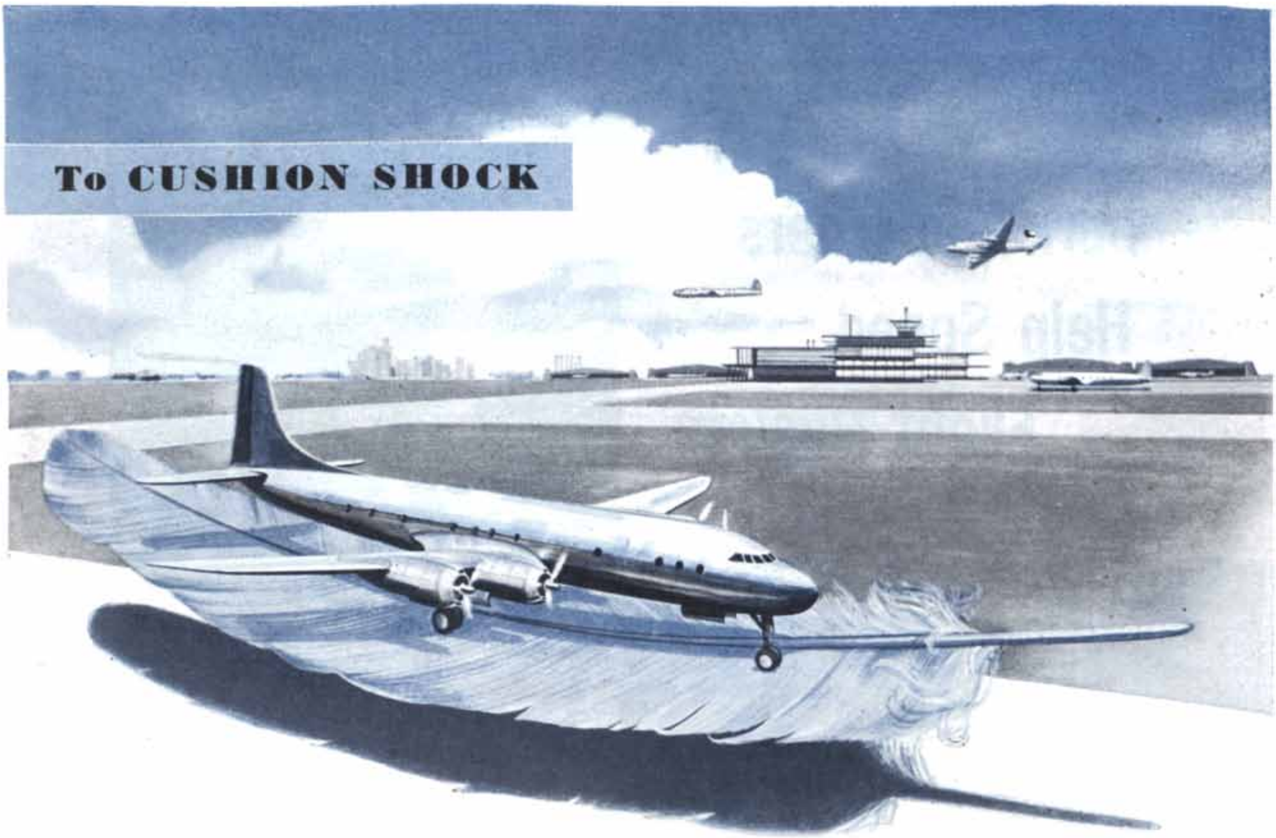


4. VIBRATION TEST EQUIPMENT, reproducing vibration conditions encountered in actual use, is typical of the modern engineering facilities at Fenwal. Fenwal engineers are constantly developing and improving temperature control and detection devices to help you protect products, processes, property and people. Perhaps they can help *you* solve a protection problem. Why not write us? **Fenwal Incorporated, 309 Pleasant Street, Ashland, Mass.**

Fenwal

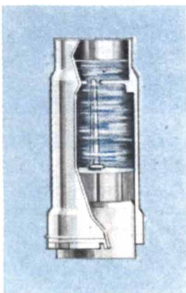
ELECTRIC TEMPERATURE CONTROL AND DETECTION DEVICES

PROTECTING PRODUCTS AND PROCESSES . . . PROPERTY AND PEOPLE



Easing tons down like a feather

has taught us how to solve your impact-cushioning problems



"I dozed off over Altoona and never even woke up when we landed..."

The same hydraulic and pneumatic principles that let you sleep right through the landing of a 70-passenger transport are being used in industry and transportation to sop-up costly jolts and bolt-cracking shake.

We can engineer absorbers only inches long... to control mere inch-pounds of vibration... or yards long to handle many foot-tons of impact. As the world's largest producers and designers of aircraft landing gears, we have learned how to serve *all* industries—in many ways.

The machines you build, the precision equipment you ship, could probably work better, travel safer, if they were cushioned by Cleveland Pneumatic absorbers using air-and-oil or oil alone.

You are invited to write for information about our facilities and some typical shock-absorbing problems we have solved. Write for Booklet B-9.

Cleveland Pneumatic
Tool Company CLEVELAND 5, OHIO
Department D-9
BALL-SCREW ACTUATORS • AUTOMOTIVE SHOP EQUIPMENT
AIR-OIL IMPACT ABSORBERS
World's Largest Manufacturer of Aircraft Landing Gears

To MOVE with less EFFORT

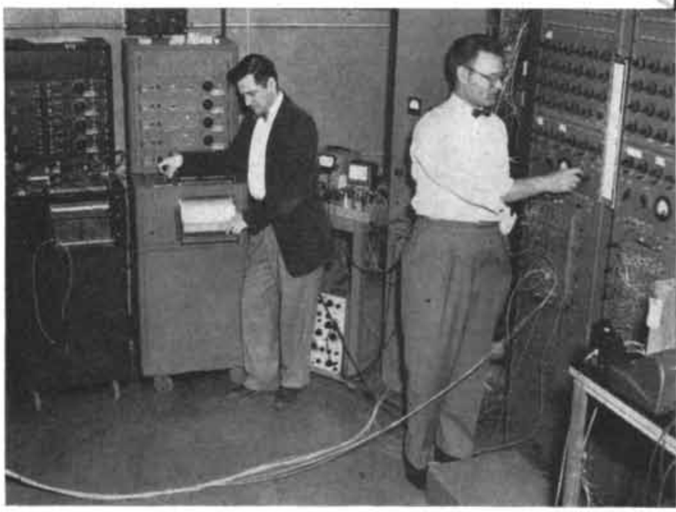
Combining the screw with balls enables Cleveland Pneumatic's patented ball-screw actuator to drive with as little as 10% friction . . . compared to as much as 50% for ordinary screw drives. You can cut the weight of a drive system, reduce its space, lessen its cumbersomeness, increase its control accuracy, and provide pin-point positioning. Let our engineers work out your ideas for using our ball-screw actuators.

SANBORN OSCILLOGRAPH RECORDING SYSTEMS HAVE MANY APPLICATIONS

Sanborn Recorders Help Speed Flight Design

SPERRY GYROSCOPE COMPANY uses a two-channel Sanborn Recording System for basic research on their Zero Reader* Flight Director, a device which simplifies the manual control of aircraft. The Sanborn System shown above is recording the output of a flight simulator that solves Zero Reader equations.

*T. M. REG. U. S. PAT. OFF.



At McDONNELL AIRCRAFT CORPORATION the movements of a guided missile are simulated by high-precision analog computers which in turn send *eight* different resultant electric signals into two Sanborn four-channel Recording Systems (left) for the graphic recording of the hypothetical results of the guided missile problem.

FOUR CHANNEL

TWO CHANNEL

ONE CHANNEL

At DOUGLAS AIRCRAFT COMPANY'S Flight Test Section, a Sanborn two-channel Recording System (shown removed from case for field operation) is used in conjunction with a telemeter radio link to record surface motion vibration in a flying aircraft while it is performing tests requiring continual monitoring. Recorded tracings provide the necessary permanent visual time history for comparison of the two events recorded and a study of their individual characteristics.

How can Sanborn help you?

Sanborn one-, two-, and four-channel Recording Systems can provide an accurate and permanent graphic registration of almost any electrical phenomena whose frequency spectrum falls within the range of zero to 100 cycles per second. The availability and ready *interchangeability* of amplifiers and preamplifiers offer a wide range of use.

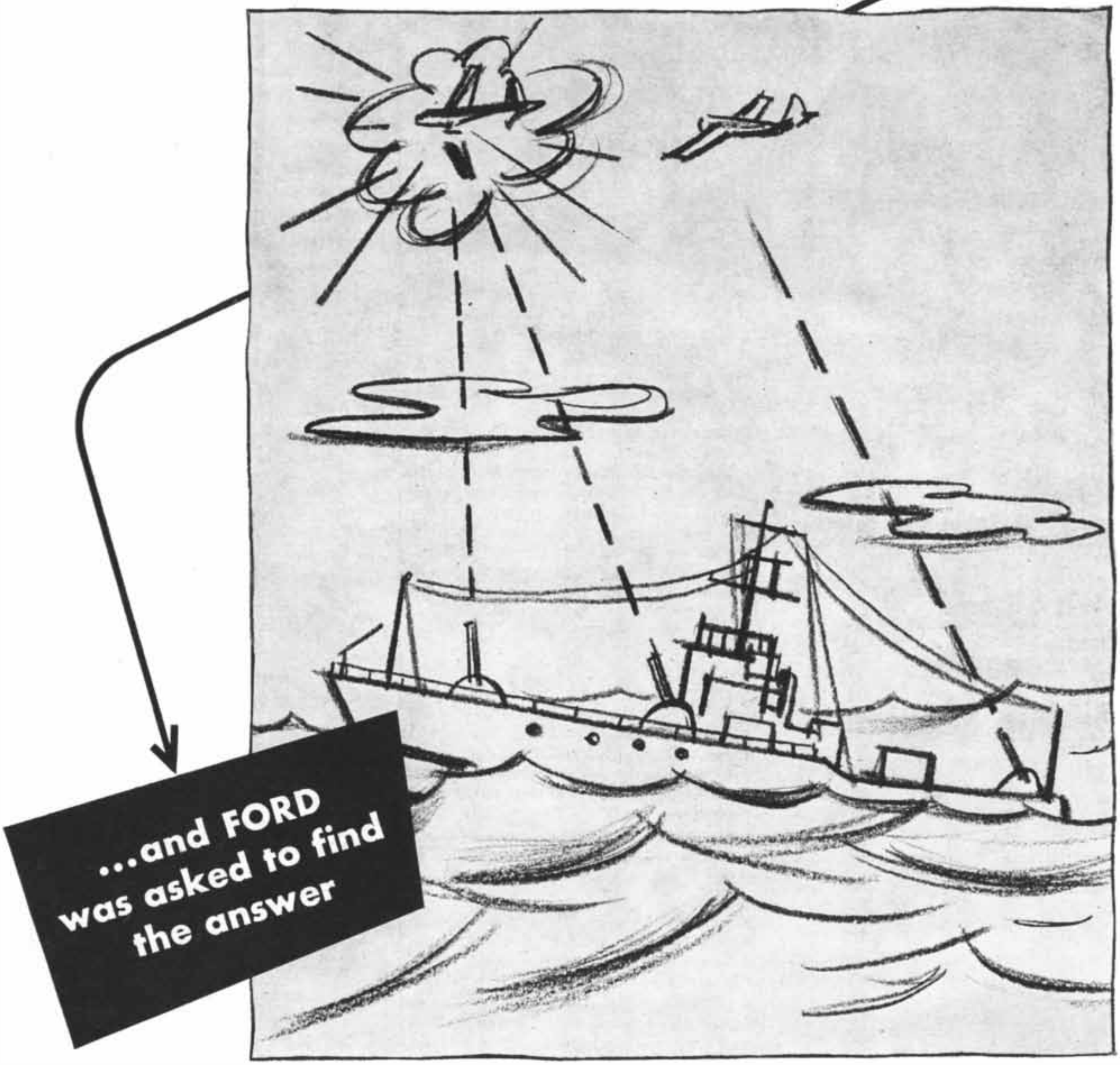
Records are traced by heated stylus on plastic coated strip-chart paper, and are in true rectangular coordinates. Other Sanborn advantages include: a high torque movement (200,000 dyne cms per cm deflection); built-in code and time markers; and a wide choice of paper speeds and channels.

Sanborn engineers will be pleased to make recommendations as to what type of equipment will best solve your recording problem. When writing, include the lower and upper limits and the frequency range of the phenomena to be recorded, and the type of transducer.

Ask for a copy of our "Applicability Folder" which presents a table of uses, complete performance data and specifications, brief descriptions of Sanborn Recording Systems and explanations of how their amplifiers may be readily interchanged.

SANBORN CO. INDUSTRIAL DIVISION
CAMBRIDGE 39, MASSACHUSETTS

TO HIT TARGET
from unstable decks of ship ?



A rolling, pitching ship . . . under attack from speedy, diving aircraft . . . counts on its anti-aircraft guns for protection . . . these guns must be able to stay on the target regardless of sea conditions. That's why the Ford Instrument Company was called on to design and build a control system that tracks and holds the target range with deadly accuracy.

This is typical of the problems that Ford has solved since 1915. For from the vast engineering and production facilities of the Ford Instrument Company, come the mechanical, hydraulic, electro-mechanical, magnetic and electronic instruments that bring us our "tomorrows" today. Control problems of both Industry and the Military are Ford specialties.

You can see why a job with Ford Instrument offers young engineers a challenge. If you can qualify, there may be a spot for you in automatic control development at Ford. Write for brochure about products or job opportunities. State your preference.

FORD

4

FORD INSTRUMENT COMPANY

DIVISION OF THE SPERRY CORPORATION

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

LETTERS

Sirs:

The article concerning Leonhard Euler and the Koenigsberg bridges [SCIENTIFIC AMERICAN, July] contains a statement in the introduction which I do not believe to be true. It is stated that a prodigious mathematical feat so overtaxed Euler's eyesight that he lost the sight of one eye and eventually became totally blind. In other words, he became blind from visual overwork.

The consensus among opthalmologists is that visual overwork causes no permanent ocular damage. It is probable that Euler's misfortune resulted from an intraocular inflammation or degeneration such as retinitis, uveitis, optic neuritis, retinal degeneration or even cataract, although at the time he was rather young for this affliction. Other possibilities are glaucoma, for which he was also rather young, and corneal disease. In any event the relationship between visual overwork and blindness was probably more coincidental than causal.

This misconception of the cause and effect relationship of visual overwork and permanent ocular damage is widespread. Unfortunately it has led to the rather common belief that even small refractive errors should be corrected by spectacles and that more than ample lighting is necessary for visual work lest the eyes be irreparably damaged. This viewpoint is in error, although of course visual overwork, poor lighting or a mod-

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Editorial correspondence should be addressed to The Editors, SCIENTIFIC AMERICAN, 2 West 45th Street, New York 36, N. Y. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

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You can't see SYNTHANE but it's in the picture

There are important factors about picture-making you never see in the print—the photographer, the lights, the darkroom, the chemicals. One of many materials essential to photography is Synthane—a laminated plastic.

Synthane is corrosion-resistant . . . Synthane spools carry film from early stages of emulsion coating through developing. Synthane is opaque to infrared rays which accounts for its use as slides for film packs. Synthane is an electrical insulator; you'll find it hidden in flash guns, lighting equipment and projectors. Synthane is wear-resistant and vibration-absorbing, fine for quiet gears in movie cameras.

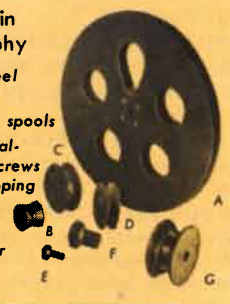
The photographic industry is only one part of the American industrial picture, and the properties for which Synthane is valued in it are only a few of the many Synthane has. Others are good tensile, compressive, flexural, and impact strengths, dimensional stability, light weight, high dielectric strength, ease of machining. Synthane has all these properties—and more—in combination. And the combination may be valuable to you.

To get the complete picture of Synthane and its possible place in your product, write today for the 24-page **Synthane** Catalog. Synthane Corporation, 2 **River** Road, Oaks, Penna.

Here you see the three basic forms of Synthane laminated plastics—sheets, tubes and rods. All three are made by applying heat and high pressure to resin-coated laminations of paper, fabric, glass cloth or mat. Synthane is thermo-setting, has many much-sought properties in combination.

Synthane in Photography

A—16mm Reel
B,C,D—Film processing spools
E,F—Chemical-resistant screws for developing equipment
G—35mm film carrier



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erate uncorrected refractive error can lead to fatigue and decrease one's efficiency.

EARL G. PADFIELD, M. D.

Medical Department
Administrative Command
Naval Training Center
San Diego, Calif.

Sirs:

Few people need defenders less than the articulate and ingenious pair of Cambridge theorists who invented the steady-state cosmology, H. Bondi and T. Gold. But they are rather far away. As a local would-be cosmologist I cannot let pass the wisecrack of Herbert Dingle, quoted by Loren Eiseley in his July piece on intelligent beings in space, which scoffs at the hypothesis of continuous creation by saying that it replaces the "single initial miracle" of a first creation by "a continuous series of miracles." I cannot speak as a theologian, but I feel certain that the choice between a unique apocalyptic explosion in the unrecoverable past, and a random atomic creation, going on everywhere and at every time, perfectly accessible at least in principle to detailed scientific study, is easy for anyone who seeks to limit science by reliance upon miracle. Indeed, His Holiness Pius XII, perhaps the most influential of theologians, has already strongly commended the theories of the explosion of the "monobloc" on religious grounds.

I am quite certain that the universe works independently of the philosophical satisfaction we may or may not take from its operation. Bondi and Gold, or George Gamow and Georges Lemaître, may be right; more likely no one is yet close to the full answer. Observation and reasoned consequences of theory must decide. But it is surely wrong to decry the Bondi-Gold hypothesis on the inverted grounds that it, and not all other present theories, implies the greater belief in miracle.

P. MORRISON

Cornell University
Ithaca, N. Y.

Sirs:

Your July issue contained an article by William McD. Hammon entitled "Gamma Globulin and Polio." Your department "The Authors" went into quite a bit of biographical detail about Bill Hammon. You did not mention, however, that

he obtained his bachelor's degree at Allegheny College in 1932.

In times when independent liberal arts colleges face criticism and crises, I think it is only proper that the contributions made to society by the graduates of these institutions should be given particular notice.

Allegheny is proud of Bill Hammon!

JOHN R. McFARLAND, JR.

Executive Secretary
Allegheny College
Meadville, Pa.

Sirs:

The article by Harold C. Reynolds entitled "The Opossum" [SCIENTIFIC AMERICAN, June] is an extremely valuable addition to the too-scant literature on this engaging animal. There is no doubt in my mind that Dr. Reynolds is one of the foremost authorities on this marsupial in the world. I wonder, though, if you are not in error in saying, in your department "The Authors," that "he was the first biologist ever to observe the birth of a litter of opossums."

In a handsome volume issued last year by the University of Texas Press, Carl G. Hartman writes an eye-witness account of the birth of an opossum which he and his wife observed in 1920. Dr. Hartman also credits Middleton Michel with observing an opossum birth in 1847, but he says that Dr. Michel "missed the migration of the young" into the pouch. Only a short time after Dr. Hartman had witnessed the birth and migration to the pouch, Edward McCrady, working at the Wistar Institute of Anatomy and Biology in Philadelphia, saw and recorded the same exciting event. Dr. Hartman continues: "L. M. Dickerson, who had taken a female that was in labor when removed from a trap . . . saw the young crawl as we have described the act." Dickerson's account was published in *Science* for August 3, 1928.

ROY BEDICHEK

Austin, Texas

Sirs:

I am interested in Roy Bedichek's point, but I must emphasize that Harold Reynolds was the first man to observe *a whole litter* of opossum young born. My wife and I saw only one of a litter. The essential point of marsupial birth, however, was settled before Reynolds was born. The essentials of opossum reproduction may be found in over a score of

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to oxidation				x		x		x	x
to temperature				x		x		x	
to organic solvents	x	x		x		x	x	x	x
Physical stability	x	x	x	x	x	x	x	x	x
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For removal of strong acids					x	x	x		
For high regeneration efficiency			x	x	x	x			x
For high capacity		x		x	x		x		x
For low initial exchanger cost	x	x	x		x		x		
pH range (operating)	6.2-8.7	6.9-7.9	0-11	0-13	0-12	0-13.9	0-13.9	0-13.9	0-13.9
For high porosity		x	x		x				
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x = generally recommended

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monographs and papers which I published between 1915 and 1929. Two principles learned from a study of opossum reproduction (short survival of germ cells and rapid, passive transport of sperms in the female genital tract) have revolutionized thought and practice in gynecology and animal husbandry.

I might add that Reynolds' failure to mention my book in his reference for further reading (a useful feature of SCIENTIFIC AMERICAN) was due to the fact that he had not yet seen it. A copy is now waiting for him in Australia, where he is soon to arrive from Japan after two years in U. S. Government service.

CARL G. HARTMAN

Ortho Research Foundation
Raritan, N. J.

Sirs:

No doubt you have received and will receive letters from some of your lawyer subscribers with reference to Webster Peterson's letter in the June issue.

The legal problem created by *renvoi* as he discusses it should in reality never arise, though through an inadequate grounding in conflict of laws some courts have perpetuated an amusing error. As pictured by Mr. Peterson, the problem becomes one of interstate table-tennis, and it has been so referred to by many legal scholars.

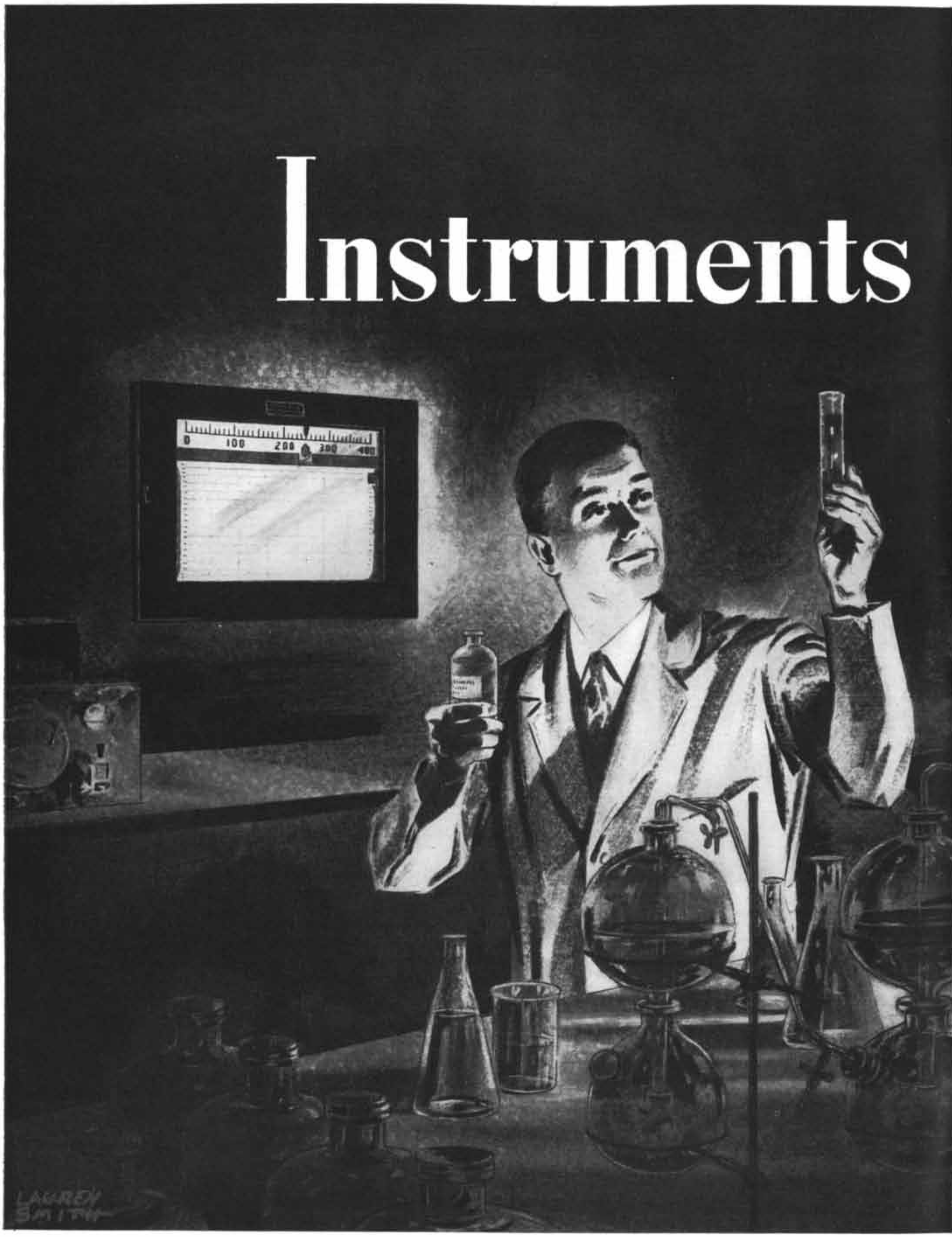
Actually, he has facetiously skirted the issue. True, where the action is brought in State A on a contract entered into in State B, to be performed in State A, elements of the law of both states are necessarily involved.

If the conflict of laws rule of State A requires that the law of the place of performance govern, there can of course be no *renvoi*, since the courts of State A will apply the domestic law of contracts. But if the conflict of laws rule of State A looks to the law of the place of contracting, *renvoi* comes into play. Regardless of State B's conflict of laws rule, which may apply the law of the place of performance, the contract is to be interpreted in accordance with the domestic law of contracts of State B.

So long as it is clearly borne in mind that the reference to the law of State B is a reference to its *domestic* law, and not to its conflict of laws rule, the paradox need never trouble us.

JOSEPH B. RUSSELL

New York, N. Y.


Instruments
0 100 200 300 400
LAUREN SMITH

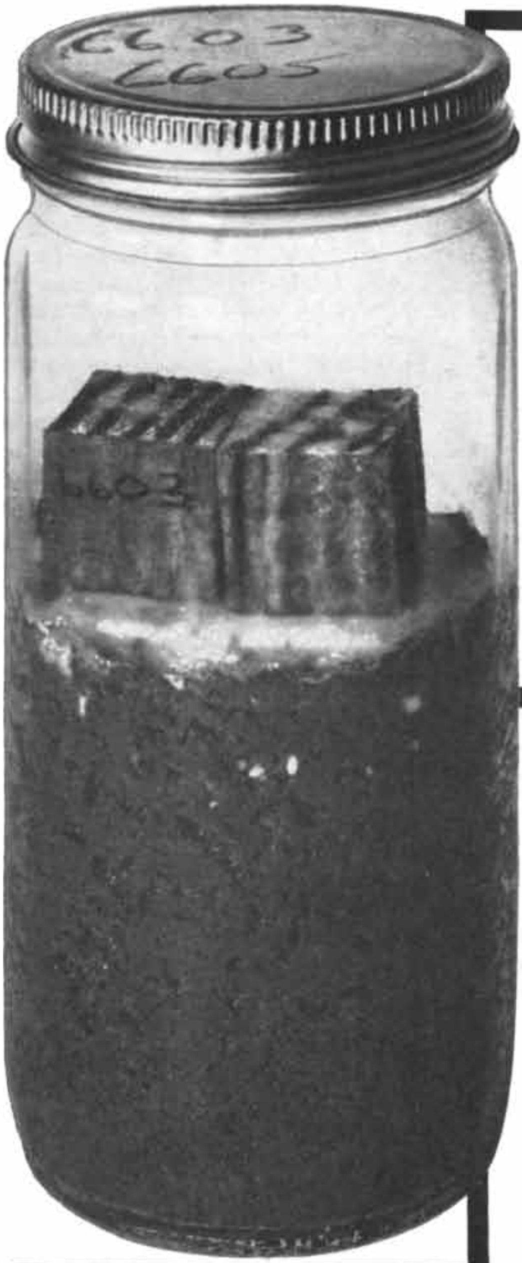
50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

SEPTEMBER, 1903: "Cable reports show that in Vienna radium has been used with excellent effect on a number of patients suffering from the most intractable forms of malignant disease. Of course it can be readily understood that these reports are only preliminary. Until at least three years have passed there must remain a question in the minds of serious physicians of any radical cure of cancer. The relief afforded by radium, however, seems to be exactly of the kind which is produced by the X-rays, only the radioactive metal has the advantage of producing more intense and rapid effects and seems also to be more generally applicable than the X-rays have proved to be."

"The claim to perfect secrecy of wireless messages suffered another shock last week during the yacht races, when the Marconi and the De Forest wireless messages were interfered with by some scientific 'Hooligan.' The scientific world is still chuckling over the clever work of Mr. Neville Maskelyn in upsetting Prof. Fleming's claim that tuned messages could not be intercepted or interfered with, and the trick was justified on account of Mr. Maskelyn's motive and the fact that he did not maliciously interfere with Prof. Fleming's lecture. Mr. Maskelyn's unknown imitator in this country, however, went to a spiteful extreme in entirely interrupting with floods of profanity and obscenity the news for which the public was eagerly waiting. The fact that tuning of systems has failed to accomplish all that was required of it is confirmed by the statement of the De Forest Company, that prior to the races an understanding was entered into with the Marconi Company whereby their respective systems should not be worked simultaneously to interfere with each other."

"Jules Verne once wrote a story in which he described the adventures of a certain Mr. Phileas Fogg who, after many harrowing incidents, succeeded in traveling around the world in 80 days.



THIS BOTTLE TURNS SEVEN YEARS INTO SEVEN MONTHS

Test blocks of pole wood are fed to destructive fungi in bottles like this at Bell Laboratories. Wood rests on soil which controls moisture conditions and promotes fungus growth. Test speeds search for better preservatives.

This year the Bell System is putting 800,000 new telephone poles into service. How effectively are they preserved against fungus attack and decay?

Once the only way to check a preservative was to plant treated wood specimens outdoors, then wait and see—for seven years at least. Now, with a new test devised in Bell Telephone Laboratories most of the answer can be obtained in seven months.

Cubes of wood are treated with preservatives, then enclosed in bottles with fungus of the most destructive kind, under temperature and humidity conditions that accelerate fungus activity. Success—or failure—of fungus attack on cubes soon reveals the best ways to preserve poles.

The new test has helped show how poles can be economically preserved for many years. It is another example of how Bell Telephone Laboratories works to keep down the cost of your telephone service.

A boring is taken from a pole section to see how far preservative has penetrated. For poles to last, it must penetrate deeply and be retained for a long time.

BELL TELEPHONE LABORATORIES

Improving telephone service for America provides careers for creative men in scientific and technical fields

On July 2 of this year Henry Frederick left New York on the steamer *Deutschland.* He returned at midnight August 26, after having completely encircled the earth in 54 days, seven hours and 20 minutes. Eighteen days were passed on the train from Paris to Dalny, China; two more were occupied in crossing the Yellow Sea. Japan was traversed in another two days. At Yokohama Mr. Frederick missed a steamer by 10 hours. That cost him seven days, for he was compelled to take a slow boat two days later, which spent 16 days in crossing the Pacific. Landing at Victoria, he made the trip across North America in somewhat more than four days. In all that time the traveler slept in but one hotel, and that was in Yokohama."

"*The Anglo-Indian Review* summarizes an interesting account of the possible future applications of radium. In its industrial application we are somewhat restricted by the extremely limited supply of radium available, but it is stated that a small fraction of an ounce, properly employed, would probably provide a good light sufficient for several rooms and would not require renewal during the present century. It has been calculated that the energy stored up in 1 gram of radium is sufficient to raise 500 tons weight a mile high. An ounce would, therefore, suffice to drive a 50-horse-power motor car at the rate of 30 miles an hour round the world."

"Until recently there has been great uncertainty as to the cause of hay fever, which has been variously attributed to the heat of early summer, exhalations from grass and new-mown hay, mechanical irritation by pollen from grasses and other plants and, recently, to bacteria. Prof. Dunbar of Hamburg, who has been studying the subject for seven years, now publishes, in the *Deutsche Medizinische Wochenschrift*, experiments which seem to show that the disease is caused by the pollen of grasses, but not by mechanical irritation. He has extracted from the pollen a poison or toxin which when dropped into the eye or nose at once produces the characteristic symptoms of hay fever. Dr. Dunbar set to work to produce a curative serum by inoculating animals with pollen toxin. For several months these animals yielded a blood serum which aggravated instead of relieved the sufferings of hay-fever patients, but in time counter-poisons were formed in the blood of the inoculated animals and a serum was obtained which, when dropped into the eye or nose together with pollen toxin,

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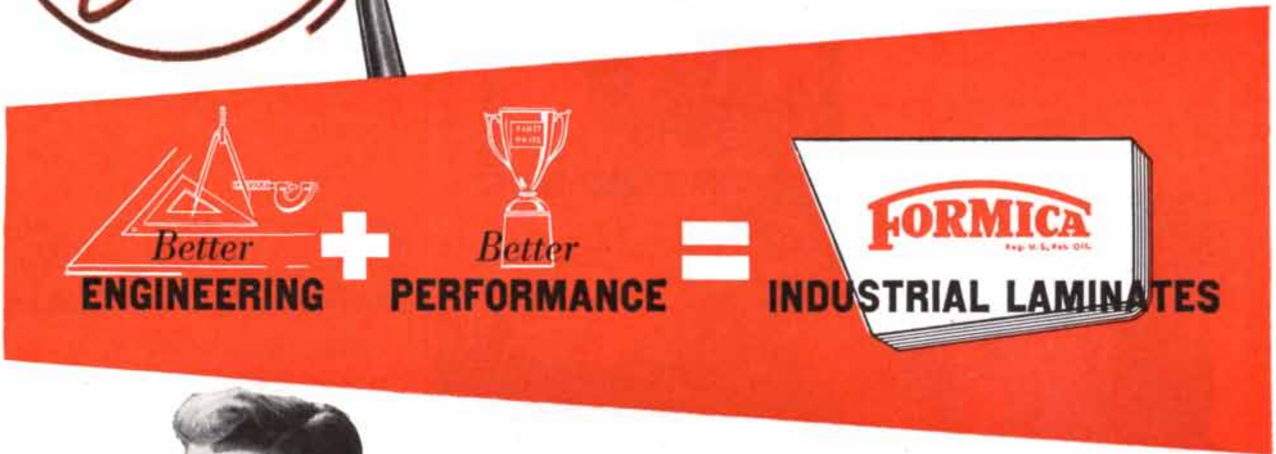

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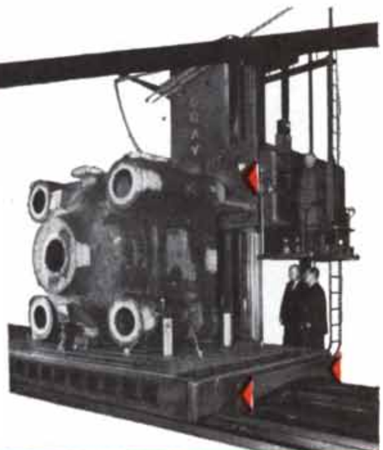

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completely prevented the attack which the latter alone would have caused."

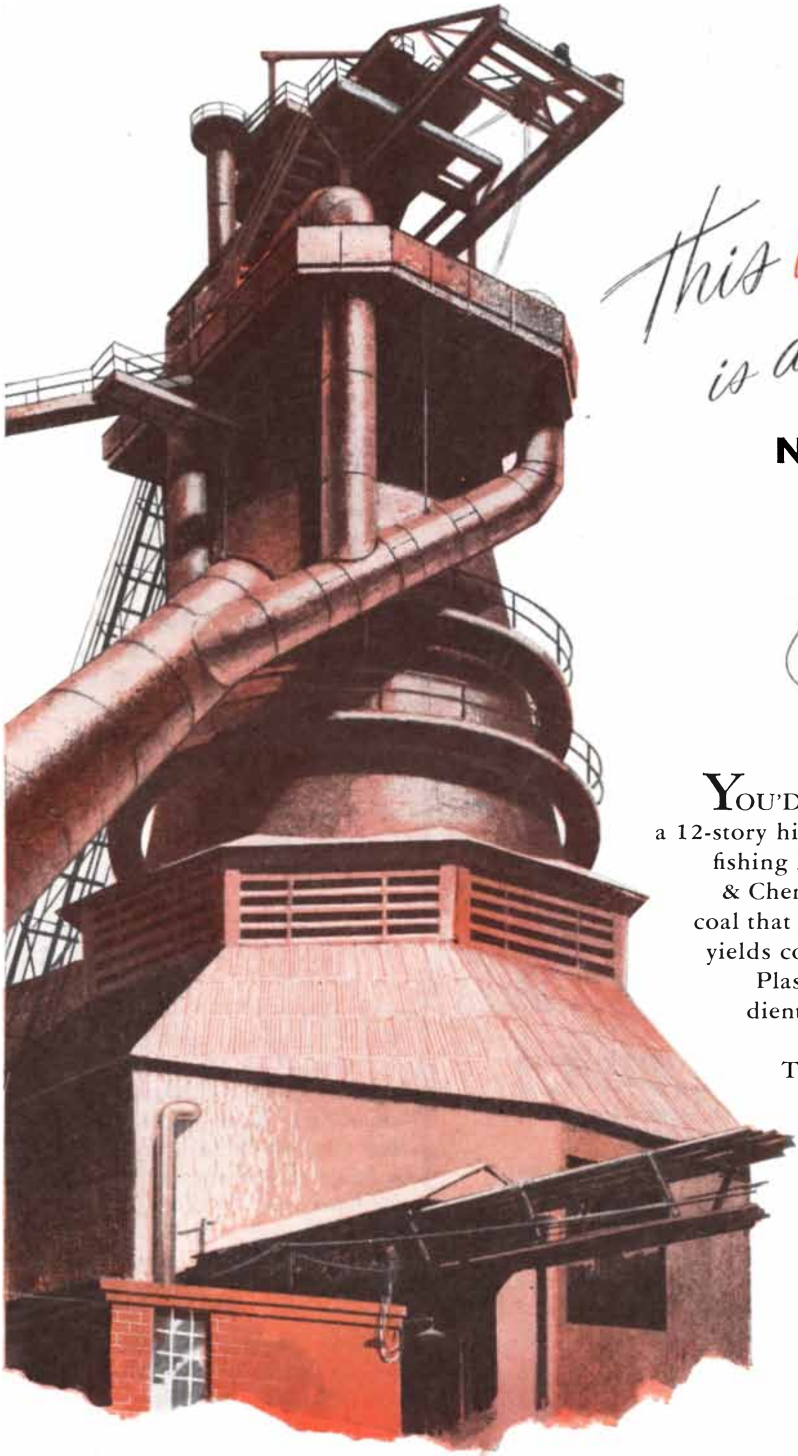
"The investigations concerning the longitude difference between Greenwich and Paris have now been completed. Altogether the English and French observers have carried out 230 observations, equivalent to 80 nights' work each. The observations were made at Greenwich and Paris simultaneously, and, in order to obtain absolutely similar results, the instruments were frequently interchanged. The results of these observations have proved both the Greenwich and Paris existent meridians to be erroneous, the calculations finally working out just between the two. The discrepancy that has been discovered, however, is very minute, being only a small fraction of a second."

"The bicycle police of Washington, D.C., have recently had Jones speedometers placed on the front forks of their wheels, and have been instructed to arrest no automobilists for excessive speeding unless, when following them, the speedometer shows that the legal limit is being surpassed."

SCIENTIFIC AMERICAN

SEPTEMBER, 1853: "In Lloyd's Rooms, at London, there is a curious weather gauge. It is an index turned by the vane on the roof, constantly showing by the vane below the direction of the wind, while a pencil is attached to a chart, and moved by the same power, so as to mark the precise course in which the wind has been blowing for days; making a record as distinct as the penciled course of a ship on the master's chart at sea. Studying this map of the winds, an insurer may make some calculation upon the progress of a vessel, and shape his business accordingly."

"To prevent the noise and din of omnibuses and other carriages on their way through the streets has long been a great desideratum. This, we learn, may now be accomplished in the most simple and effective manner. All that is necessary is merely to cover the rims with India rubber tires, of from an inch to an inch and a half in thickness, according to circumstances. At first it was thought that the India rubber would lack strength and durability; but, being expressly prepared for the purpose, it



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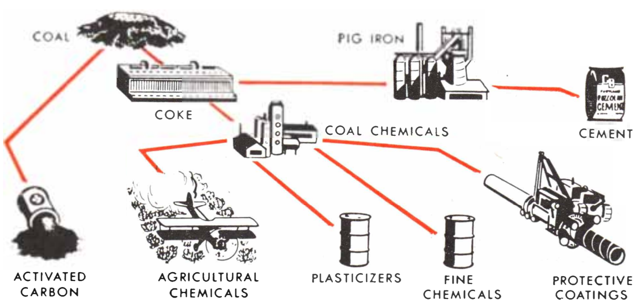

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is asserted that it is capable of enduring a long time."

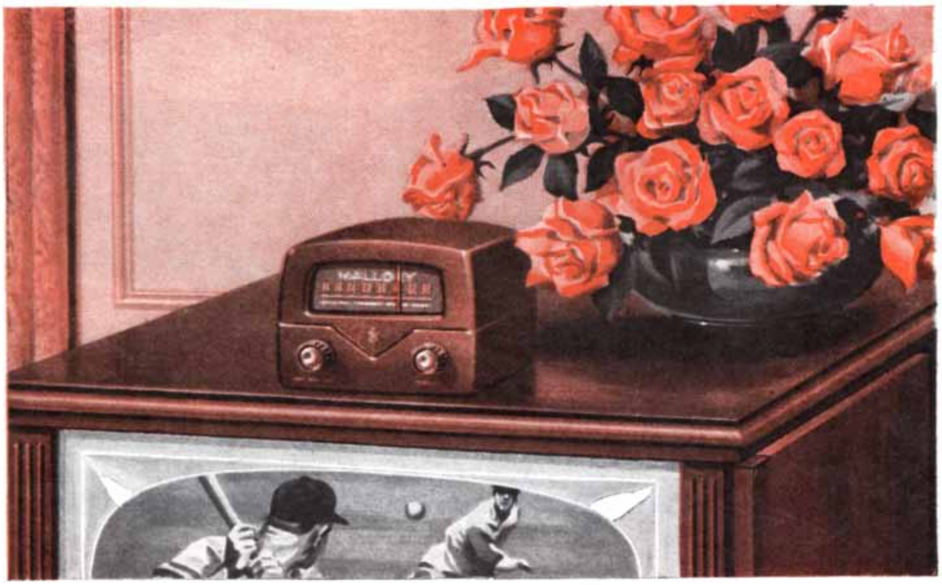
"A measure true to the hundredth part of an inch is rare, and the space of a thousandth of an inch could not be accurately measured by any device hitherto in use. But Mr. Whitworth exhibits, in the English Department of the Crystal Palace Exposition, a very modest looking little apparatus which can determine easily the one millionth of an inch. Two steel bars are placed in a cast-iron block, and are made to approach or recede from each other by means of screws moving accurately in their axes. The screw which moves one of the bars (the other being supposed stationary for the simplicity of the explanation) has 20 threads to the inch. On the head of this screw is a wheel with 200 teeth. Hence a motion of one space on the wheel would advance the bar 1/4,000 of an inch. An endless screw, which moves the wheel, has upon it a circle graduated with 250 divisions. One division of the graduated circle will therefore correspond with 1/250 of one of the wheel divisions, or to an advance of the bar consisting of one millionth (1/250 × 1/4,000) of an inch."

"Mr. Adams communicated to the Royal Society, at the closing meeting of their session in London, that he had discovered that the principle of Laplace's calculation of the secular motion of the moon is positively erroneous. This is a discovery which affects the whole range of lunar astronomy, seeing that all the calculations made on the assumption that the moon really was in the place assigned to her are wrong. A staff of computers will therefore have to be set at work to recompute the lunar observations, avoiding the error, which amounts to about seven seconds."

"Judge Mason, the Commissioner of Patents, has refused to grant an extension of Colt's patent for his repeating firearms. Reason, 'the inventor has been sufficiently remunerated.'"

"In 1846 we believe there was not a single garment in our country sewed by machinery; in that year the first American patent on a sewing machine was issued. At the present moment thousands are wearing clothes which have been stitched by iron fingers with a delicacy rivaling the work of a Cashmere maiden. Let no one of our readers who visits the Crystal Palace Exposition fail to pay particular attention to the operations of the sewing machines."

Not One . . . *But All*



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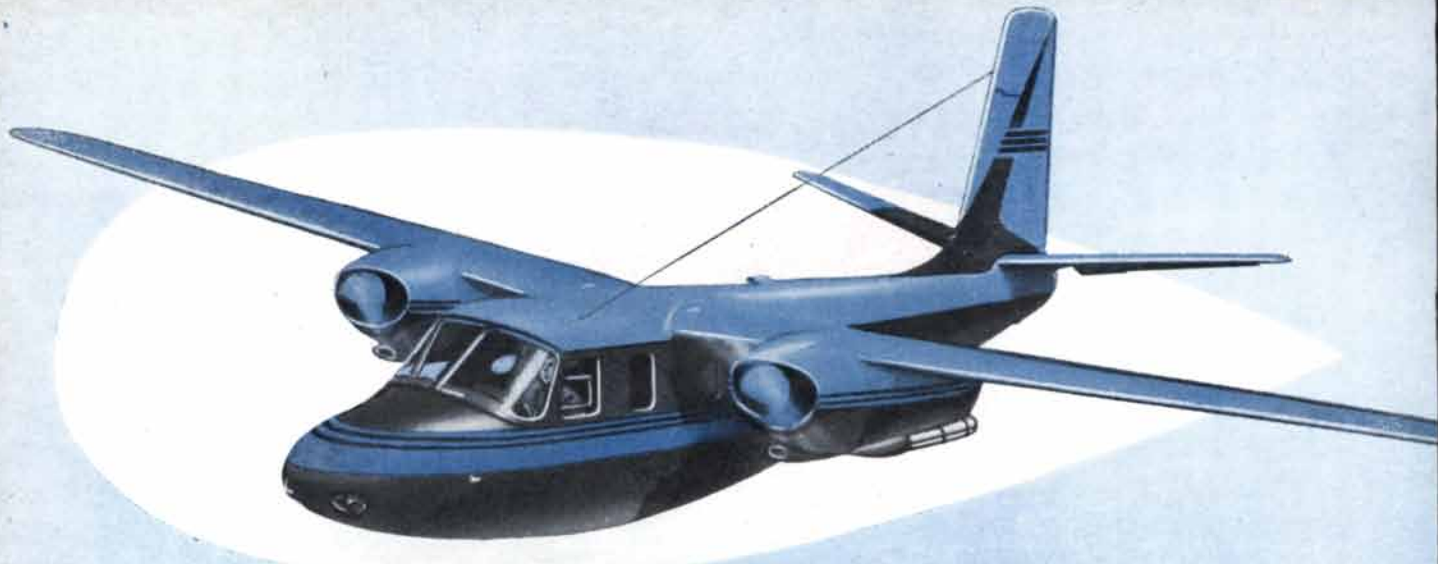

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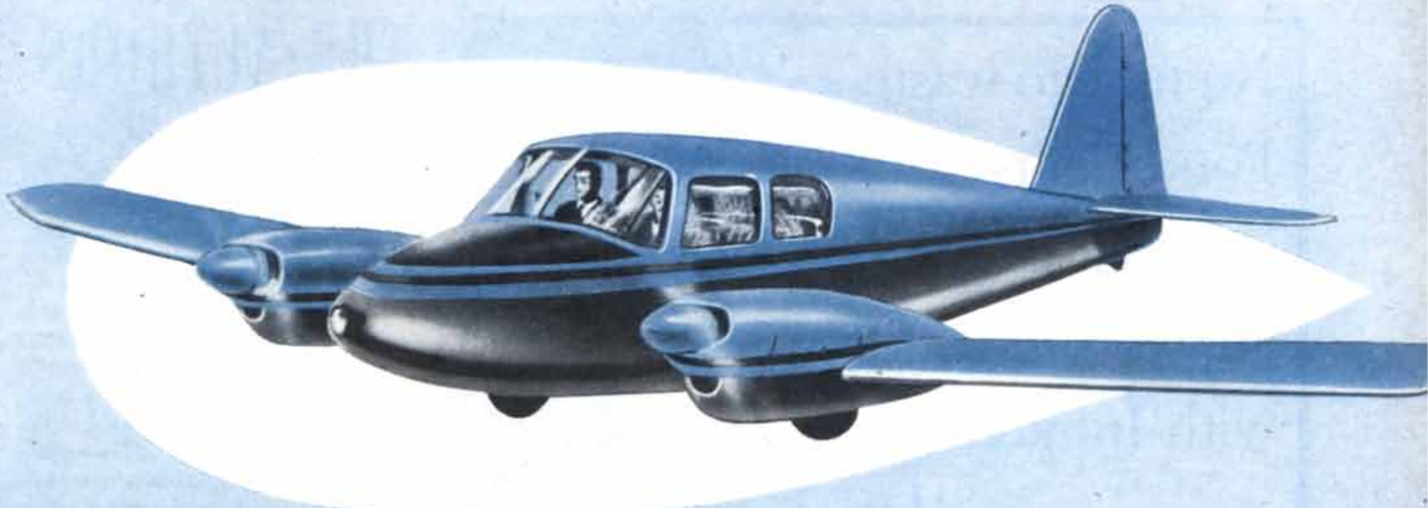

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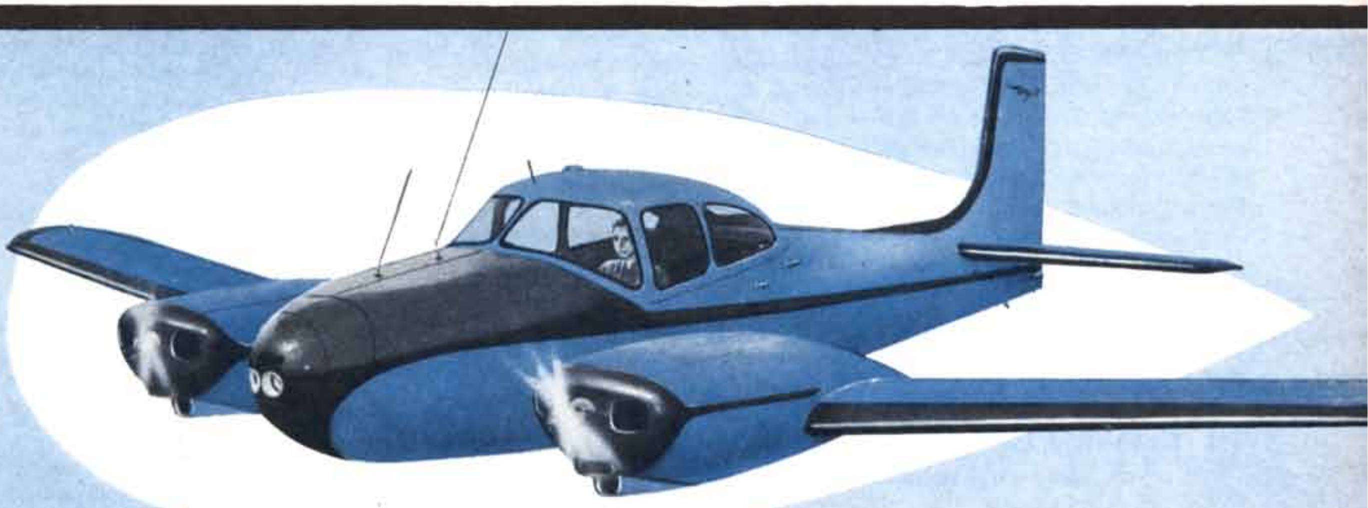

Riley Twin Navion Conversion. 4-place executive plane powered by two 150-h.p. air-cooled Lycoming engines.

THE AUTHORS

WARREN WEAVER ("Fundamental Questions in Science") is director of the Division of Natural Sciences and Agriculture in the Rockefeller Foundation and president-elect of the American Association for the Advancement of Science. He was trained as a mathematical physicist, but his career has also brought him into close contact with many other branches of science. He has worked for a "breaking down of old orthodox compartments" so that specialists can work together on broad, fundamental problems. Weaver was born in Wisconsin in 1894 and educated at the University of Wisconsin, receiving his undergraduate degree in 1916 and his Ph.D. in 1921. In 1932 he left the chairmanship of the mathematics department at Wisconsin to join the Rockefeller Foundation. During World War II he was chairman of the Fire Control Division of the National Defense Research Committee and later chief of the Committee's Applied Mathematics Panel. He received the Medal of Merit, the highest U.S. award for civilians, for having "revolutionized" antiaircraft fire control. Weaver's present chief scientific interest is in the mathematical theory of probability and communication theory. He has contributed three articles in these fields to SCIENTIFIC AMERICAN. Weaver's hobby is collecting the works of Lewis Carroll, of which he has one of the world's most complete collections.

ERWIN SCHRÖDINGER ("What is Matter?") is one of the founders of modern physics. For developing the theory of wave mechanics he shared the Nobel prize in 1933 with the British physicist P. A. M. Dirac. Schrödinger, born in Vienna in 1887, comes from the distinguished Austrian school of physics which produced Ernst Mach and Ludwig Boltzmann. He succeeded Max Planck in the chair of theoretical physics at the University of Berlin in 1927. Upon Hitler's rise to power he went to Dublin to join the Institute for Advanced Study, where he is now. In recent years he has been trying to combine the field theories of physics into a unified structure. He has also been interested in more general unifications of science, and perhaps his most famous book is *What Is Life?*

HANS A. BETHE ("What Holds the Nucleus Together?") is a professor of physics at Cornell University. He was

BUSINESS IN MOTION

To our Colleagues in American Business . . .

A national enterprise of long experience, such as Revere, inevitably accumulates a great deal of information, not only about its own products, but about other companies, their products, facilities and skills. Some of this data naturally is confidential, and is respected as such, but often it can be made available, with mutual advantage. Here are some examples.

• A Revere customer asked for advice about expanding copper tube. We recommended a change in size, and referred the company to a firm we knew had both the necessary equipment, and the know-how. Result: business for the three of us.

• A manufacturer had on his drawing boards a new product, a milk cooler. Having benefited by our collaboration in the past, he brought us into the picture, so that we were able to work closely with his engineers. Our knowledge of baffling led to a suggestion that increased efficiency by 30%, used no more material, and also eliminated soldering.

• When a product is in a highly competitive field, cost reduction can have a vital influence on sales and profits. The maker of a baby stroller asked Revere what could be done to cut costs of aluminum tube without affecting quality of the stroller. Changes in alloy and gauge were recommended, and proved effective in every way. Revere now sells this manufacturer less aluminum per stroller, but has gained the respect and orders of a growing company.

• Tuning condensers for radios usually have aluminum plates, stamped from strip that has to be held to close standards as to gauge and flatness. A condenser firm thought well enough of Revere to place a trial 500-pound order. Both the Sales Department and the Technical Advisory Service followed through, ascertaining the individual requirements of the company, and interpreting them in the light of mill techniques and previous experience in this field. The trial shipment was so satisfactory that a large production order was placed.

• A most competent manufacturer told Revere he had been working for two years on an aluminum brazing problem. It wasn't an easy problem to solve, as we found out when we dug into it, but we licked it in three weeks. After all, Revere began making aluminum mill products in 1922, and through all the years since has been adding to its knowledge of the metal.

• A fabricator took a contract to make soap dishes, a new kind of work to him. He had been told by his customer that each dish should be annealed twice. The Technical Advisory Service worked closely with him, set up specifications for temper and gauge, and stimulated new thinking on tool design. On two dishes, annealing was eliminated; on another, only one anneal is required.

These are but a few cases from the Revere files. Many other suppliers of materials of all kinds can match them. You may not buy metals, but such things as wood, paint, felt, chemicals, cement; no matter. Whatever you purchase, it will pay you well to take advantage of the special knowledge and skill of the firms with which your purchasing department is in contact.

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born in Strasbourg in 1906. His mother and grandmother were daughters of university professors, and his father was an eminent physiologist. Bethe was educated at the Universities of Frankfurt and Munich, receiving his Ph.D. from the latter institution in 1928. For two years he worked under Ernest Rutherford at Cambridge University and Enrico Fermi in Rome on a fellowship from the Rockefeller International Education Board. Like Schrödinger, he left Germany for the British Isles when the Nazis came to power. After two years in England he came to the U.S. to join the Cornell faculty in 1935. In 1938 he attended a conference in theoretical physics at which the problem of the source of the sun's energy was discussed. Six weeks later he had worked out the famous carbon cycle of thermonuclear reactions, which is his best known work. During the war Bethe served first on the staff of the Radiation Laboratory at the Massachusetts Institute of Technology and then as chief of the theoretical physics division of the atomic bomb project at Los Alamos.

BRUNO ROSSI ("Where Do Cosmic Rays Come From?") became "fascinated by the mystery of this extraordinary phenomenon" through reading an article about it in 1930. He at once began building his first Geiger-Müller counter, and has been building them ever since. Rossi was born in Venice in 1905 and was educated at the Universities of Padua and Bologna. He received his Ph.D. in physics in 1937. He taught at Florence and then at Padua until he was forced out by the Fascist government in 1938. He then spent a year in Denmark and England and came to the U.S. in 1939 at the invitation of Arthur H. Compton of the University of Chicago. Rossi was an associate professor of physics at Cornell University from 1940 to 1946, with three years out for work at Los Alamos. Since 1946 he has been professor of physics at the Massachusetts Institute of Technology.

CECILIA H. PAYNE-GAPOSCHKIN ("Why Do Galaxies Have a Spiral Form?") is Phillips Astronomer at Harvard University, a position she has held since 1938. She was born in England in 1900 and took her undergraduate education at Cambridge University. In 1923 she came to the U.S. and entered Radcliffe College, where she received her doctorate in 1925. She became a National Research Fellow at Harvard University in the same year and an astronomer at the Harvard Observatory in 1927.

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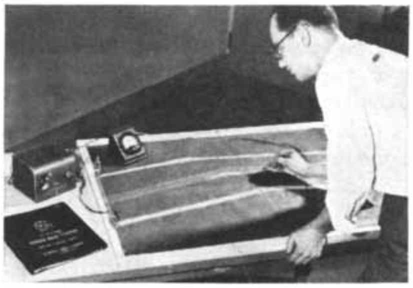

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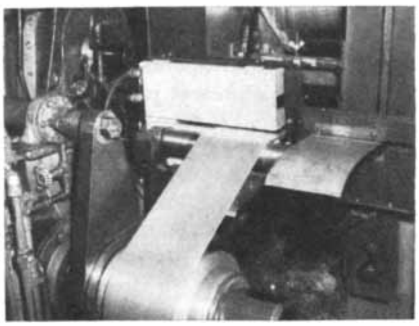

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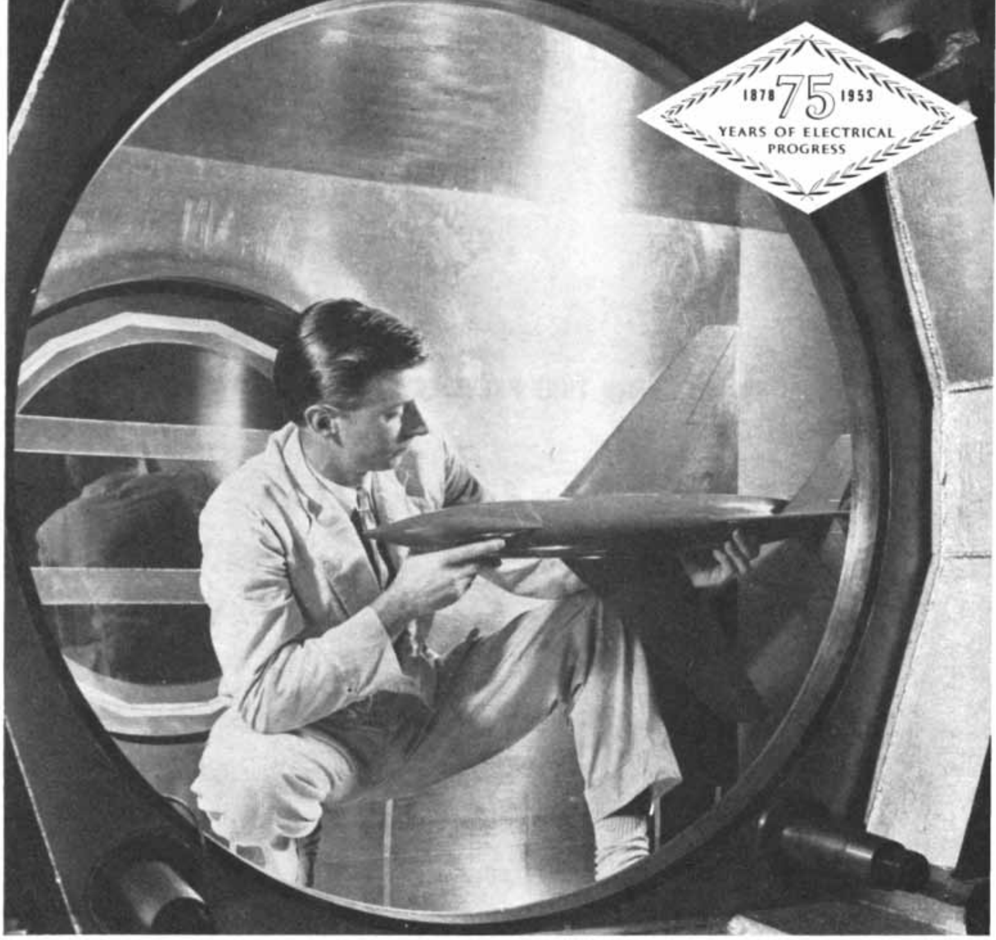

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She married Sergei I. Gaposchkin, a colleague at the Observatory, in 1934. They have three children. Mrs. Payne-Gaposchkin's work has been chiefly in stellar spectroscopy and photometry and in the study of variable stars.

KAJ ULRIK LINDERSTROM-LANG ("How Is a Protein Made?") is professor of biochemistry and head of the chemical department at the Carlsberg Laboratories in Copenhagen, Denmark. He was born in Copenhagen in 1896 and took his undergraduate work in chemical engineering at the Technical High School there. He has been at the Carlsberg Laboratories since 1919, working on protein chemistry during all of his scientific life. His earliest studies had to do with the fractionation of proteins; then he turned to research on the enzymes that attack proteins; most recently he has been studying the disintegration of proteins when they are attacked by purified enzymes. In 1931 he visited the U.S. as a Rockefeller Fellow at the California Institute of Technology.

C. H. WADDINGTON ("How Do Cells Differentiate?"), professor of animal genetics at the University of Edinburgh, Scotland, was a geologist before going into biology. Geology led him to an interest in evolution, he says, "and that led to genetics and that again to the mode of operation of genes in development and thus finally to embryology." Waddington was born in India in 1905 and spent the first few years of his life there. He was educated at Cambridge University, receiving a B.A. in geology in 1926 and a Sc.D. in biology in 1938. He taught at Cambridge until 1945, then took his present position at Edinburgh. During World War II he was in charge of the Operational Research Section of the Coastal Command of the Royal Air Force. In 1947 he was named a Fellow of the Royal Society. In addition to his technical books, Waddington has written *The Scientific Attitude* and *Science and Ethics*. His recreation is painting in oil. He confesses to a taste for "modern" but says his own productions "always turn out to be incompetent attempts at straight realism."

RALPH W. GERARD ("What Is Memory?") is director of the Neuropsychiatric Institute at the University of Illinois College of Medicine. He was born in Harvey, Ill., in 1900. He studied at the University of Chicago, taking his Ph.D. in 1921, and then got an M.D. at the Rush Medical College in 1925.

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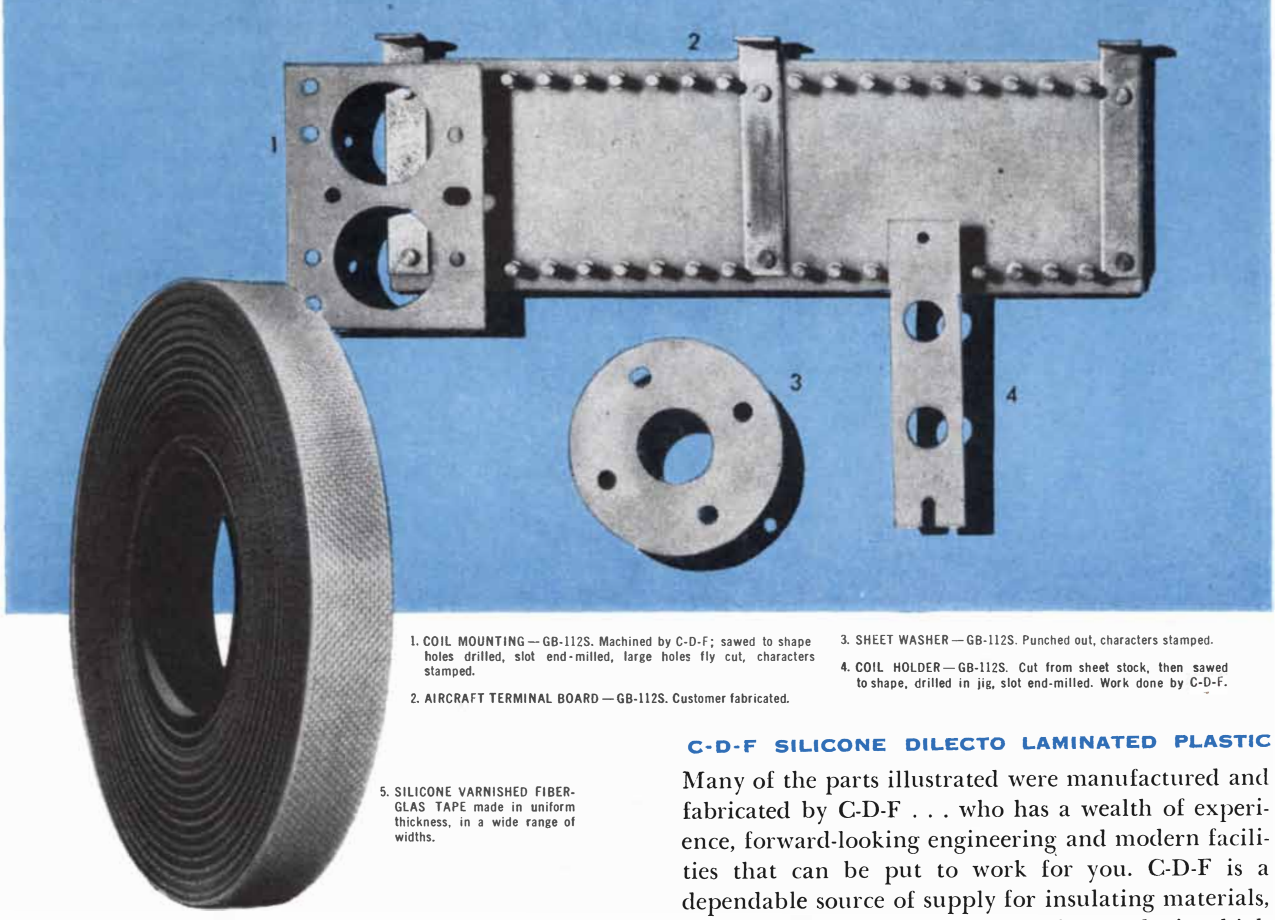

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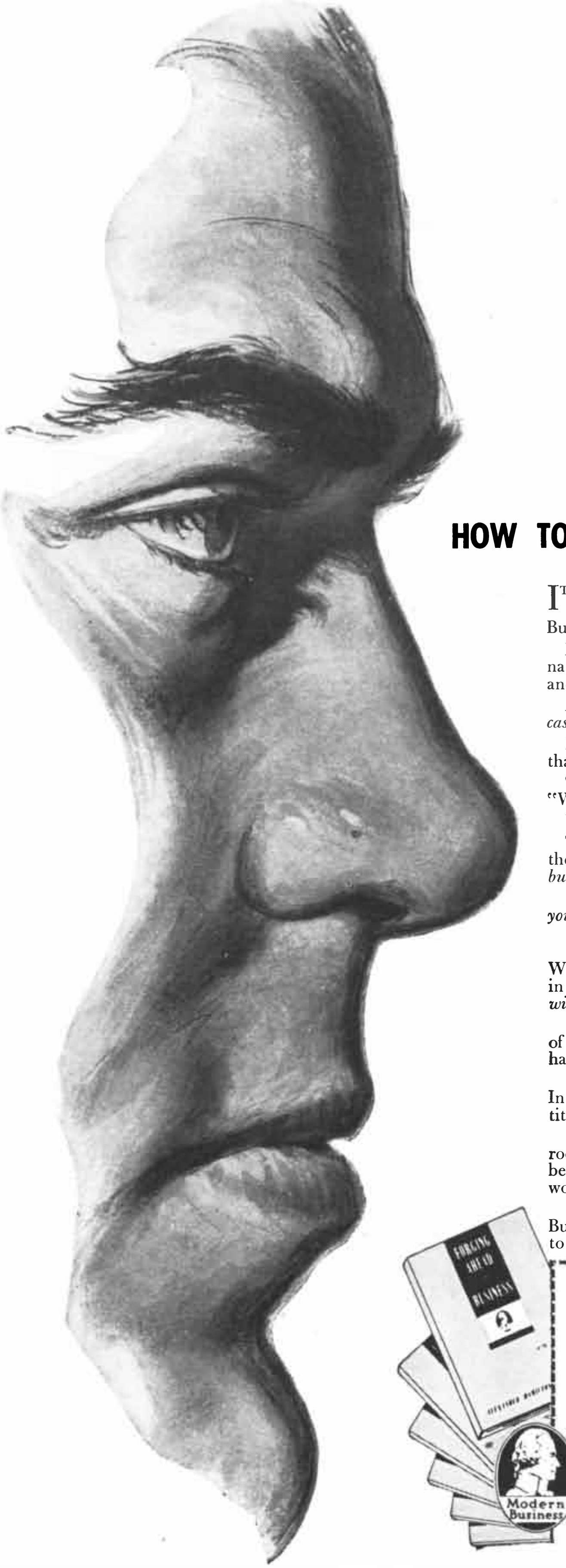
After his internship he spent two years in London and Berlin as a National Research Fellow, returning in 1928 to the University of Chicago, where he later became professor of physiology. Gerard has worked chiefly in the field of neurophysiology, investigating the chemical and electrical characteristics of the nerves and brain during activity, growth and injury. During the war he was director of the physiological section at Edgewood Arsenal, where he did research on the effects of phosgene.

RUDOLF CARNAP ("What Is Probability?") is professor of philosophy at the University of Chicago. He was born in Germany in 1891 and educated at the University of Jena, receiving his Ph.D. there in 1921. Carnap taught at the University of Vienna and at the German University of Prague until 1935, when he came to the U.S. to accept his post at Chicago. He received an honorary doctorate of science from Harvard in 1936. A leader of the logical empiricist school of philosophy, he has pioneered in applying semantics and the methods of symbolic logic to the theory of knowledge and reasoning. He is now on leave from the University of Chicago at the Institute for Advanced Studies in Princeton, where he is completing the second volume of an extended treatise on probability.

J. BRONOWSKI, who reviews R. B. Braithwaite's book *Scientific Explanation* in this issue, is director of the Central Research Establishment of the National Coal Board in England. Born in Poland in 1908, he spent his early years in Germany and moved to England at the age of 12. Bronowski studied mathematics at Cambridge University, taking a doctorate in 1933. Until 1942 he taught at University College in Hull and did original work in topology and mathematical statistics. He then entered government service, working on bomb damage assessment and pioneering in the new field of operational research. Later he was a member of the Joint Target Group in Washington and of the Chiefs of Staff Mission to Japan, where he wrote a classic report on the effects of the atomic bomb. After the war he stayed in government work. A versatile man, Bronowski has cultivated *belles lettres* as well as science. He is the author of *The Poet's Defense* and *William Blake: A Man Without a Mask*. His *The Face of Violence* won the Italia prize for the best radio play in Europe in 1950 and 1951. His most recent book is *The Common Sense of Science*.



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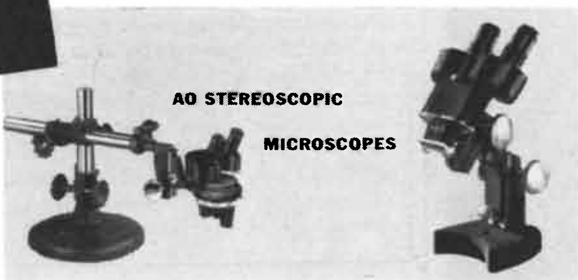

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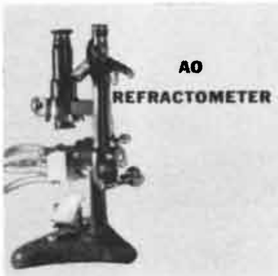

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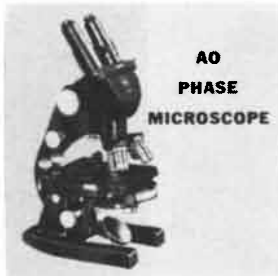

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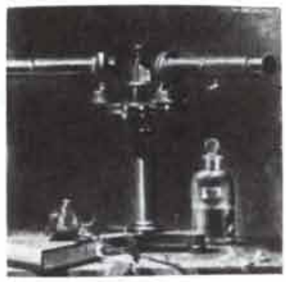

THE COVER

The painting on the cover is a poetical still life symbolizing the single theme of this issue of SCIENTIFIC AMERICAN: fundamental questions in science. It is unlikely that the objects in the painting would be found in any laboratory today; they are nonetheless characteristic of fundamental investigation. The instrument in the center is an ancient Bunsen spectroscope; its prism is mounted atop the central brass post. Surrounding the spectroscope are a laboratory bottle, a book and a rose.

THE ILLUSTRATIONS

Cover painting by Walter Murch

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DESIGNING WITH ALUMINUM

This is one of a series of information sheets which discuss the properties of aluminum and its alloys with relation to design. Extra or missing copies of the series will be supplied on request. Address: Advertising Department, Kaiser Aluminum & Chemical Sales, Inc., 1924 Broadway, Oakland 12, California.

NO. 4

CORROSION RESISTANCE

ALUMINUM ALLOYS RESIST ATTACK BY WIDE RANGE OF ENVIRONMENTS, MANY CHEMICAL COMPOUNDS

RESISTANCE to corrosion is a relative matter because it depends on the environment to which a metal is exposed. Aluminum and aluminum alloys have generally excellent corrosion resistance. They withstand corrosive attack by most types of environment, including many which adversely affect the performance of other commonly used metals.

Conditions which cause the corrosion of aluminum are the exception, not the rule. Normally, aluminum lasts indefinitely—bare and unprotected. This fortunate situation occasionally leads to over-enthusiastic use. The user may expect and demand a much higher level of performance from aluminum than he ever has or would from another metal, with resulting improper application or failure to follow good installation practice.

Reason for the good corrosion resistance of aluminum is that the practically transparent oxide coating that forms on surfaces exposed to air is tough, adherent and non-flaking. So, once formed, it is non-progressive and non-destructive, in contrast to oxidation which results in flaking that constantly exposes new metal to attack and so proceeds inevitably towards the total destruction of the metal.

Under most conditions the oxide coating of aluminum thickens within a relatively short time to a point where no further measurable oxidation occurs. It is also self-renewing. Whenever the oxide film is broken, it immediately reforms on exposure to air and again assumes its protective role.

It follows then that the conditions which promote the corrosion of aluminum usually involve the presence of a compound which dissolves or otherwise penetrates this coating, and the absence or exclusion of the oxygen required to rebuild it.

One of the useful properties connected with aluminum is that the electrolytic process known as anodizing thickens and strengthens the oxide coating artificially. Anodizing thus increases resistance to destructive atmospheres and also tends to reduce the possibility of galvanic corrosion. Anodizing is regular commercial practice in many applications and products of aluminum. A coincidental benefit resulting from this process is that brilliant color can be incorporated to obtain highly decorative effects, and frequently it is used for this purpose only. Building up the oxide coating also increases resistance to abrasion.

High purity aluminum is rated as having the best corrosion resistance to chemicals, but this is not always the case with other forms of attack. For instance, in marine atmospheres 52S is superior to high purity aluminum. Most aluminum alloys will generally outlast other metals except under special conditions.

ATMOSPHERIC CORROSION

In general service metals may be exposed to three types of atmosphere—normal (rural, uncontaminated), industrial (urban, contaminated) and marine (moist, salty).

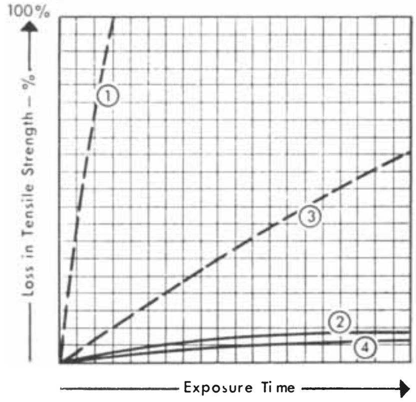
Tests of several aluminum alloys sponsored by the American Society for Testing Materials (Table 1), using the percent change in tensile strength as a measure of corrosion resistance, showed that all the alloys exposed were practically unaffected by normal atmospheres. In industrial and marine atmospheres corrosion was so slight as to be of no significance in practice. This was true even for 24S-T3, copper-bearing heat-treatable alloy. The clad form of this alloy suffered no loss in tensile strength, indicating the effective protection given to the high-strength alloy core by the cladding of higher-purity aluminum.

Table 1—EFFECT OF VARIOUS NATURAL ENVIRONMENTS ON ALUMINUM ALLOYS
(% Change in Tensile Strength Resulting from Ten Year Corrosion Tests Conducted by American Society for Testing Materials)

Alloy Type	MARINE			INDUSTRIAL		RURAL	
	La Jolla, California	Key West, Florida	Sandy Hook, New Jersey	New York, New York	Altoona, Pennsylvania	Phoenix, Arizona	State College, Pennsylvania
2S-H14	−5	−2	−3	−7	−5	−1	−4
3S-H14	−3	0	0	−4	−6	0	−1
24S-T3	−18	0	−3	−9	−6	−1	−4
Clad 24S-T3	+2	+1	+2	+2	0	+2	+1

NOTE: The gains in strength resulting in some cases arises from the fact that the tensile strength of heat-treatable alloys increases with natural aging.

Fig. 1—RELATIVE LOSS OF TENSILE STRENGTH IN INDUSTRIAL, MARINE ATMOSPHERES



1 Steel in Marine Atmosphere
2 Aluminum in Marine Atmosphere
3 Steel in Industrial Atmosphere
4 Aluminum in Industrial Atmosphere

Numerous other tests of aluminum alloys, both wrought and cast, have shown similar results, while steel simultaneously exposed has been virtually destroyed by industrial and marine atmospheres over a period of time. Typical relative loss in tensile strength of aluminum alloys and steel under exposure to marine and industrial atmospheres is illustrated in Figure 1. These test results are verified by the long actual service given by aluminum in buildings and equipment under severe conditions where other materials have required steady maintenance or replacement. A guide to the resistance of a number of aluminum alloys to atmospheric and sea water attack is given in Table 2.

Of importance as well is the fact that aluminum stands up well in contact with most other common building materials. Such attack as may occur is usually limited to superficial etching and minor pitting where dirt accumulates between faying surfaces. Although it has been considered good practice to protect the surface of aluminum where it is in contact with concrete or mortar, protection is really not necessary. Most if not all of any attack, even upon unprotected aluminum, takes place early during the setting period and is so minor as to be

PLEASE TURN TO NEXT PAGE ➡

of no consequence. Maximum penetration of the metal under such conditions probably would not be much over two mils. Where aluminum is in contact with masonry or wood which is continuously or repeatedly wet, it should be protected with a bitumen or similar coating on the contacting surface.

Table 2

RELATIVE CORROSION RESISTANCE OF ALUMINUM ALLOYS

Alloy	Non-Industrial Atmosphere	Industrial Atmosphere	Marine Atmosphere or Sea Water Service
2S	A	B	B
3S	A	B	B
4S	B	B	C
50S	A	A	A
52S	A	B	A
Clad 56S	A	B	B
61S	A	A	B
63S	A	A	B
24S	B	C	D
Clad 24S	A	B	C
75S	B	C	D
Clad 75S	B	B	C
43, 214, 356, 360	A	B	B
195	B	C	D

NOTE: Relative resistance — A, best; B, good; C, fair; D, not usually recommended without additional surface treatment. This table is useful only as a general guide.

After prolonged exposure to normal air, aluminum surfaces weather, with some loss of the original polish and smoothness. This is seldom more than a superficial condition that can be remedied by simple cleaning.

AQUEOUS CORROSION

Most of the non-heat-treatable aluminum alloys and clad forms of the heat-treatable alloys offer a high order of resistance to corrosion by alternate immersion in sea and harbor waters, where unprotected steel deteriorates rapidly.

Magnesium-bearing alloys such as 50S and 52S are especially resistant to all forms of aqueous corrosion. 52S, strongest non-heat-treatable sheet and plate alloy in commercial use which is noted for its ruggedness, is used extensively in marine applications.

The copper and zinc-bearing heat-treatable alloys such as 14S, 24S and 75S are generally less resistant to aqueous attack, but their performance under salt water conditions is substantially improved by cladding. 61S has better resistance than the other heat-treatable alloys, and is therefore used widely in the bare condition.

CHEMICAL CORROSION

The chemical process industries are large users of aluminum because it resists attack by many chemical compounds. Aluminum in some instances offers the further advantage that the salts of aluminum are colorless, tasteless and non-toxic so that any corrosive products will not adversely affect manufactured products.

An example is the use of aluminum for the manufacture, storage and transportation of glacial acetic acid. There is no contamination, other impairment or coloring of the product by any products which might be introduced through superficial attack.

Table 3

PARTIAL GENERAL GUIDE TO RESISTANCE OF ALUMINUM TO VARIOUS COMPOUNDS

COMPOUND	GRADE
Acetic Acid, Dilute	B
Acetic Acid, Glacial	A
Alcohol, Methyl & Ethyl	B
Ammonia (dry)	A
Ammonium Hydroxide	C
Benzene	A
Boric Acid	A
Bromine	D
Carbonic Acid (dilute)	A
Chloride of Lime (calcium hypochlorite)	C
Chlorine (v.c. with water)	D
Creosote	B
Dichlorodifluoromethane (Freon F-12)	A
Dichloromonofluoromethane (Freon F-21)	B
Dichlorotetrafluoroethane (Freon F-114)	A
Ethylene Glycol	B
Fluorine	D
Freon 11	B
Freon 22	A
Freon 113	B
Gasoline (anhydrous)	A
Hydrochloric Acid	D
Hydrogen Peroxide (30% and higher)	A
Lacquers	A
Lime	B
Nitric Acid (above 80%)	A
Nitroglycerine	A
Olive Oil	A
Oxalic Acid	C
Oxygen	A
Perchlorethylene (dry)	A
Phosphoric Acid	D
Potassium Bicarbonate	A
Potassium Carbonate	C
Potassium Chromate	A
Resins	A
Sewage	A
Sodium Carbonate	C
Sodium Nitrate	A
Sodium Sulfate	B
Steam, Low Pressure	A
Sulfur Dioxide (dry)	A
Toluene	A
Trisodium Phosphate	C
Urea	A
Varnish Solvents	A
Water, Distilled	A
Water, Industrial	B
Water, Rain	A
Water, Sea	C
Water, Tap	C
Zinc Acetate (up to 10% conc.)	A
Zinc Chloride	D

NOTE: Resistance — A, excellent; B, good; C, fair; D, poor.

Aluminum provides excellent corrosion resistance to organic compounds and such chemicals as ammonia, hydrogen sulfide, hydrogen peroxide (30% and higher) and concentrated nitric acid. Solutions of strong alkalis, sulphuric acid, hydrochloric acid, carbonates and fluorides tend to attack aluminum because they can dissolve or penetrate the protective oxide coating. However, the extent of corrosion varies with concentration and temperature and may often be minimized or eliminated through the use of inhibitors. Table 3 provides a guide to the relative chemical resistance of aluminum to a few widely used compounds.

GALVANIC CORROSION

Direct contact with dissimilar metals in the presence of a liquid which might become an electrolyte should be avoided to prevent corrosion of the anodic metal. Metals such as zinc and magnesium are usually anodic to aluminum. It is not always true that aluminum is anodic to steel. For example, in some tap water conditions, particularly where higher temperatures are involved, steel may be attacked in preference to aluminum.

The danger of galvanic corrosion is frequently overrated. Its extent depends on the amount of current flow between dissimilar metals. In turn this depends on the electrical resistance of the space by which the metals are separated as well as the difference in potential.

In most cases galvanic corrosion can be entirely eliminated or reduced to negligible proportions by simple, practical methods. There can be no galvanic corrosion if moisture is excluded or if insulating material increases electrical resistance. The problem is minimized when the anodic area is large in comparison with the cathodic area such as a large area of aluminum and a small area of steel or copper. Innumerable composite steel and aluminum structures have given long life.

CORROSION PREVENTION

There are numerous ways of protecting aluminum where it is used under circumstances where conditions may be conducive to corrosion. They include painting, artificial thickening of the oxide film through anodizing, formation of other insoluble films, plating or cladding. Where used with aluminum, steel bolts and other fittings should be galvanized or plated with cadmium. Design should avoid corners and crevices where moisture can lodge.

The assistance of Kaiser Aluminum engineers with information on the corrosion resistance of aluminum or on specific corrosion problems or other phases of aluminum application may be obtained by calling any Kaiser Aluminum sales office in the principal cities or by writing Kaiser Aluminum & Chemical Sales, Inc., 1924 Broadway, Oakland, California.

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What's Happening at CRUCIBLE

about hollow tool steel

Crucible is now making its high quality tool steel available in hollow form. Bars of Crucible Hollow Tool Steel can now be obtained with machine finished inside and outside diameters and faces — in three famous grades: Ketos, Airdi 150 and Sanderson. Already its use has effected substantial savings for makers of tool steel parts with cutout centers.

typical applications

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availability

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CRUCIBLE HOLLOW TOOL STEEL

	GRADES		
Sizes (inches)	Sanderson	Ketos	Airdi 150
2 O.D. x 1 I.D.	x	x	
2½ O.D. x 1½ I.D.		x	
3 O.D. x 1½ I.D.		x	
3¼ O.D. x 1¼ I.D.	x	x	x
3¼ O.D. x 1½ I.D.		x	
3½ O.D. x 1½ I.D.	x		
3½ O.D. x 2 I.D.	x	x	x
4 O.D. x 1½ I.D.			x
4 O.D. x 2 I.D.		x	x
4¼ O.D. x 1¾ I.D.			x
4½ O.D. x 2 I.D.	x		x
5 O.D. x 2 I.D.	x	x	x
5 O.D. x 2½ I.D.		x	x
5 O.D. x 3 I.D.	x	x	
5½ O.D. x 1¾ I.D.			x
5½ O.D. x 2 I.D.		x	
5½ O.D. x 2½ I.D.	x		x
6 O.D. x 1¾ I.D.			x
6 O.D. x 2 I.D.		x	
6 O.D. x 3 I.D.	x	x	x
6½ O.D. x 3¼ I.D.			x
6½ O.D. x 3½ I.D.		x	
6½ O.D. x 4 I.D.			x
7 O.D. x 2¼ I.D.			x
7 O.D. x 3 I.D.	x	x	
7 O.D. x 3½ I.D.			x
7 O.D. x 4 I.D.	x	x	
7½ O.D. x 3 I.D.	x	x	
7½ O.D. x 3½ I.D.	x	x	
7½ O.D. x 4 I.D.			x
8 O.D. x 3½ I.D.	x	x	
8 O.D. x 5 I.D.	x	x	x
8¼ O.D. x 3½ I.D.			x
8½ O.D. x 5¼ I.D.	x	x	x
9 O.D. x 4 I.D.	x	x	
9 O.D. x 5 I.D.		x	x
9 O.D. x 6 I.D.	x		
10 O.D. x 4 I.D.		x	
10 O.D. x 5 I.D.	x	x	
10 O.D. x 6 I.D.	x	x	x
11 O.D. x 4 I.D.	x	x	
11 O.D. x 6 O.D.	x	x	
11 O.D. x 7 I.D.		x	x
12 O.D. x 5 I.D.	x	x	x
12 O.D. x 6 I.D.	x	x	
12 O.D. x 7 I.D.	x	x	
12 O.D. x 8 I.D.		x	
13 O.D. x 6 I.D.		x	x
13 O.D. x 7 I.D.	x	x	
13 O.D. x 8 I.D.			x
13 O.D. x 9 I.D.		x	
14 O.D. x 7 I.D.	x	x	x
14 O.D. x 10 I.D.		x	
15 O.D. x 9 I.D.		x	x
15 O.D. x 10 I.D.		x	
16 O.D. x 10 I.D.	x	x	x
16 O.D. x 12 I.D.	x	x	

technical service

If you make tools with machined-out centers and wish additional information on Crucible Hollow Tool Steel, or technical assistance in solving an application problem, call in a Crucible representative. Our experienced staff of tool steel specialists is always available.

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SCIENTIFIC AMERICAN

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FUNDAMENTAL QUESTIONS IN SCIENCE

An issue devoted to science in its strict sense: the interrogation of nature. This introduction raises the question: Does our society confuse science with applied science, and thus neglect the former?

by Warren Weaver

It has become a custom for SCIENTIFIC AMERICAN to devote its September issue to a unified topic. The first of these special issues, three years ago, presented a review of the progress of science over the first half of the present century. Two years ago the subject was the human resources of the U. S., with special emphasis on scientific manpower. Last year it was automatic-control mechanisms. Under the title of "Fundamental Questions in Science," the present issue takes up another topic of wide public interest.

The unity of this issue has nothing to do with the subject matter of the various articles. Their authors deal with many fields of science—mathematics, astronomy, physics, biology, chemistry, psychology. They range over the heavens and the earth, the cell and the atom, man's mind and his ways of thinking. But these articles are nevertheless built around one central theme. It has to do with the motivation of the scientist, and with the true nature of free science.

Each of these articles is the reply of a first-rate and active scientist to one common query: "What question in your special field seems to you to be, at this moment in the development of science, a germinal question? What really interests you? What seems important to you? What do you like to think about?"

Do not be misled into brushing these questions aside as trivial. To the question "What is science?" the realistic answer, it has been said, is that science is what scientists do. And in the present scene, when a dangerous anti-intellectualism seems to be invading our society, and when pleasant temptations and unpleasant pressures divert scientists to "practical" researches, it would be still more meaningful to declare: What science *ought to be* is what the ablest scientists *really want to do*.

This may seem, at first thought, a shallow, hedonistic attitude, as though one were arguing that science should be merely a private entertainment for scientists. Actually free science, the free following of curiosity, has never been trivial, selfish or purposeless. The sober record of experience shows that the trained human mind, if you give it free play and a congenial climate, turns to deep and significant enterprises. The rational approach to life is a successful and productive approach. The most imaginative and powerful movements in the history of science have arisen not from plan, not from compulsion, but from the spontaneous enthusiasm and curiosity of capable individuals who had the freedom to think about the things they considered interesting.

The articles assembled here offer splendid confirmation of these claims. Their eight authors are concerned with great pivotal questions which go to the heart of our understanding of the structure of the physical universe, the processes of life and the nature of the human mind.

The first two articles are concerned with the way the physical universe is put together. What goes on within that tiniest of all mysteries, the nucleus of an atom? What has happened to the relatively tidy picture which we all had, not too many years ago, of a physical world built from only a couple of elementary particles? What sort of *reductio ad absurdum* are we headed for, when the number of elementary particles now stands at perhaps 20 and still tends to increase? Is it possible that these elementary particles have become neither elementary nor particles?

The next two articles go rocketing off to the other dimensional extreme of the universe, into questions about cosmic rays and galactic universes. For their explorations the authors use mental devices which have already penetrated farther into outer space than physical rockets can ever hope to go.

It is not uncharacteristic of modern trends in science that chemistry, in this series of articles, appears as the close companion of biology. A large fraction of present-day pure research in chemistry is either essentially indistinguishable from physics, or is intimately involved in the biological sciences. Thus we find chemistry here turned upon a truly central and universal question of the life sciences: How do living things build the characteristic material out of which they are so largely constructed?

Moving still further toward the life sciences in the nowadays continuous spectrum of science, we find an article on one of the great central mysteries of biology—the problem of differentiation. A man's body starts as a single fertilized cell. Somewhere along the way it is arranged that certain of the cells arising from this common ancestor cell develop specialized characteristics and become nerve cells; certain others become liver cells, while still others develop into the cells of fingernails, hair, muscle, connective tissue, and so on. How does this specialization take place? Here, surely, is a deep problem which is at the very core of biological science.

The last two articles take up questions in the realm of the mind itself. One deals with the nature and mechanism of memory. The other is concerned with the foundations of the mind's logical processes and its judgments. The author analyzes two concepts of probability—the statistical and the inductive—and shows how we find the former useful *in* statements about concrete physical situations, while we seek, in the latter, a method for making judgments *about* such statements.

Viewing these articles all together, what do they teach us about the character of pure science? As responsible citizens of a country which still desires intellectual freedom, still respects originality and variety, still treasures curiosity and still profits from dissent—and we must believe this in spite of the narrow, selfish, stupid, angry little men who try today to frighten us into a contrary position—as responsible citizens who believe in the conquering power of the mind, what lessons do these articles have for us?

Note first what these papers have to say concerning the character of the really interesting and important questions

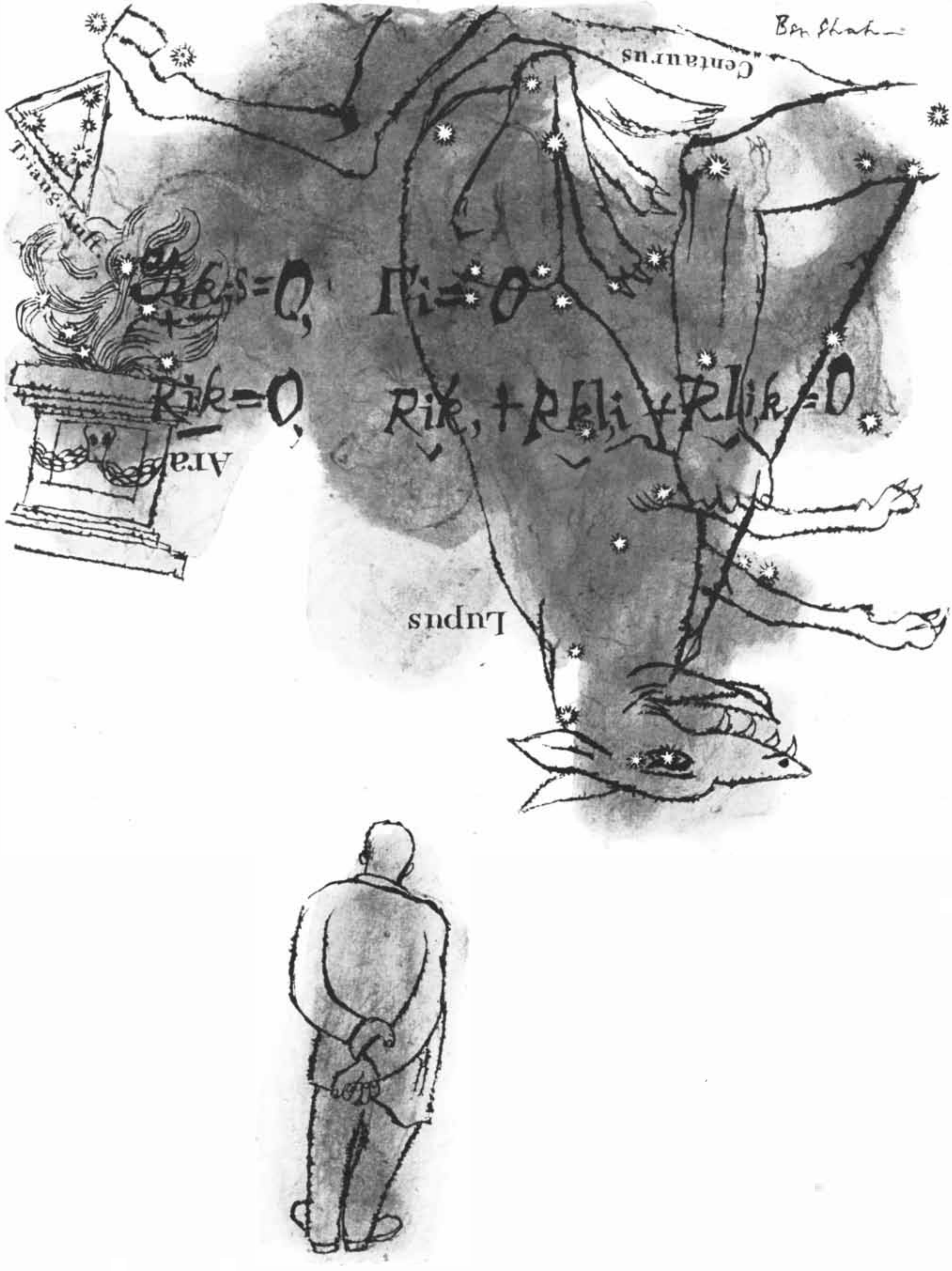
The Greeks of the Pythagorean school asked the question: What which are investigated by pure science. From certain "practical" points of view, these questions must seem esoteric and utterly remote. The interior of the nucleus! The distant galaxies of the cosmos! How can an investigating committee ever visit these places and check up? The chemical happenings within a cell, the inner workings of man's mind, the cosmic rays of outer space! In the play of what market place are their attributes assessed? What do such researches cure, whom do they feed, how much money will they make, how many will they kill?

There are, I think, two main observations to be made. The first is that the questions are important in the first instance because they have depth and sweep, because they are esthetically attractive, because they are instances of man's mind seeking to meet the challenge of the universe. The second observation is that pure science is also intensely practical. The whole of man's experience has demonstrated that the practical results required for tomorrow depend essentially on the "impractical" free curiosity of today.

This latter point is one to which we in the U. S. have learned to pay a certain amount of lip service. But we have not yet really come to believe it in any operational sense. It is a truism that we are most ingenious, here in America, in instrumenting and exploiting ideas. But we are not so good as we should be in producing fundamental ideas. And we are still immature in the sense that we are impatient, that we demand quick "results." We do not furnish for science enough of the sustained and flexible support which would provide great minds with the leisure and the calm to think. We know that this is, in fact, the way to make important progress, but we lack the courage and the foresight to act on that knowledge.

This is a particularly relevant and timely consideration, now that the public is underwriting so much of the cost

ure the relations of the sides and the angles of a triangle?



Modern man, reflecting on the heavens and Einstein's unified field equations, asks: What are the relations of the forces of nature?

of scientific research. Major financing for science today is coming from the great national drives for funds for research on various disorders and, to a much larger extent, from various agencies of the government. There are, within all of these agencies for the public support of science, some wise and discerning persons who understand what kind of support science needs. They do not believe that the crowning triumph of civilization is a one-year grant of money carefully restricted to work on some rigidly specified problem; they know that really imaginative science does not come in the form of tightly scheduled reports, turned out in multiple copies, wrapped in cellophane and tied up with red tape. But there are too few such persons, and they receive far too little informed public support.

There are signs that our National Science Foundation is at last on its way to obtaining funds which will give it a chance to grow and develop. It has an appropriation of $8 million for the coming year, compared to $4.8 million last year. The ridiculous statutory ceiling of $15 million on its annual budget has been removed by Congress. It is to be hoped that the National Science Foundation will have the imagination, skill and courage to lead public opinion to a higher concept of what basic science is. Everyone knows that our free democratic society requires science for its defense, for the maintenance of its standards of living and for the health and comfort of its people. In a still deeper sense, however, our society requires science for its own intellectual and artistic worth. This must be more widely comprehended if we are to develop the climate of opinion and the techniques of support which will assure that science in America can be free and imaginative.

Basic science has aspects which make it at once attractive and forbidding to popular interest and understanding. The articles in this issue suggest to me certain pregnant words: *explanation*, *control*, *precision*, *enthusiasm*, *humility*, *mystery*. It will not be surprising if some readers consider this a queer group of words and a contradictory association of ideas. But science, as this set of articles well illustrates, has more of an artistic structure than some would have us believe, and it accommodates within itself a wide and actually contrasting set of ideas. "The great scientist," as the Australian medical researcher W. I. B. Beveridge has said, "must be regarded as a creative artist, and it is quite false to think of the scientist as a man who merely follows rules of logic and experiment."

What, then, is a truly scientific explanation? At the level of sophomore science, and almost universally at the level of general public discourse, one explains something by describing and analyzing it in terms of more familiar experience. This normally provides the illusion desired, for we seldom stop to think that the more familiar terms themselves require explanation. When one is talking at a fundamental level, however, explanation is a very different process. Familiarity ceases to be so useful, and the main requirements of an explanation, at this basic level, are compactness and generality. If you have a very compact (and hence often mathematical) way of stating relationships among a wide range of things and events, then you may say that you have explained them. The explanation need not be, and in fact almost surely is not, understandable in any ordinary sense. On the contrary, we must adjust ourselves to the notion that understandability, in this basic sense, is actually synonymous with compactness and generality and that we cannot ask for more.

Compactness and generality may offer less reassurance than the cozy explanation most of us originally look for. Esthetically and logically, however, they yield much deeper satisfactions. If we persist nonetheless in hankering for reassurance, perhaps this is to be found in another aspect of the scientific kind of explanation. Such explanations not only relate present data but make possible the prediction of future data. When a prediction is realized in actuality, then no end of comfort is available in the assurance that the theory works, that things are under control. It is this same control over nature that we carry over into the practical applications of science in technology.

The control which science gives us depends essentially upon the third aspect of science which I want to discuss. This is the precision of science, which is here most convincingly illustrated by the article on the forces that bind the atomic nucleus. Think, for just one sobering moment, of the incredible smallness which is involved. Roughly ten million atoms are required to stretch across the head of a pin. Yet if an atom were enlarged until it were as large as a house, its nucleus would then itself be about the size of the head of a pin. Science weighs this mite within a mite with an accuracy of one part in a million. Here is penetrating precision which is almost unbelievably exquisite. Yet, abstract as it is, it establishes a vast new industry, so powerful that we are not even permitted to know its size.

And lastly, what about those three words enthusiasm, humility and mystery? Enthusiasm we find everywhere in science; here, in these articles, we read such phrases as: ". . . so rich in form and function"; ". . . one of the great questions"; ". . . on the challenging frontier." Humility we should find everywhere, as we do here: ". . . we cannot be sure"; ". . . especially hard to understand"; ". . . in deep water." But this virtue seems more characteristic of the great researchers in pure science than of those concerned with more applied and superficial problems. And mystery, although science continuously crowds it back, stubbornly and beautifully remains at the core. Necessarily, it confronts writers on fundamental questions at every turn: ". . . still remains the secret of the cell"; ". . . I am almost as little prepared to answer [this question] as to tell where Sancho Panza's second donkey came from." Science has not become so lost in specialization but that the central mysteries of nature continue to be its first concern, and there are hundreds of scientists investigating them today with the sweep and penetration exemplified in these articles.

The idea that science is coldly logical and faultlessly relentless in its forward march is contradicted by all that we read here. Science, as we find it in these articles, is no juggernaut, crushing all before it. Science here reveals itself as it truly is—a natural and integral part of man's whole life, an activity which, at base, is a blend of logic, intuition, art and belief. It has been refined into an instrument of great beauty and precision by the few, but this science of the few is merely the distillation of the experience of the many. As a natural social activity of man, science belongs to all men.

It is well for us that this is true. For it tells us that science need not be regarded as the possession of some select inner priesthood, but that its essential nature can be understood by all literate persons. This is the proposition on which SCIENTIFIC AMERICAN is based. This is the proposition which assures that the citizens of a free democracy, understanding and prizing the work of science, will provide the support and the terms of support that will cause science to prosper and bring its benefits, power and beauty to the service of the people.

What Is Matter?

The wave-particle dualism afflicting modern physics is best resolved in favor of waves, believes the author, but there is no clear picture of matter on which physicists can agree

by Erwin Schrödinger

Fifty years ago science seemed on the road to a clear-cut answer to the ancient question which is the title of this article. It looked as if matter would be reduced at last to its ultimate building blocks—to certain submicroscopic but nevertheless tangible and measurable particles. But it proved to be less simple than that. Today a physicist no longer can distinguish significantly between matter and something else. We no longer contrast matter with forces or fields of force as different entities; we know now that these concepts must be merged. It is true that we speak of "empty" space (*i.e.*, space free of matter), but space is never really empty, because even in the remotest voids of the universe there is always starlight—and *that* is matter. Besides, space is filled with gravitational fields, and according to Einstein gravity and inertia cannot very well be separated.

Thus the subject of this article is in fact the total picture of space-time reality as envisaged by physics. We have to admit that our conception of material reality today is more wavering and uncertain than it has been for a long time. We know a great many interesting details, learn new ones every week. But to construct a clear, easily comprehensible picture on which all physicists would agree—that is simply impossible. Physics stands at a grave crisis of ideas. In the face of this crisis, many maintain that no objective picture of reality is possible. However, the optimists among us (of whom I consider myself one) look upon this view as a philosophical extravagance born of despair. We hope that the present fluctuations of thinking are only indications of an upheaval of old beliefs which in the end will lead to something better than the mess of formulas which today surrounds our subject.

Since the picture of matter that I am supposed to draw does not yet exist, since only fragments of it are visible, some parts of this narrative may be inconsistent with others. Like Cervantes' tale of Sancho Panza, who loses his donkey in one chapter but a few chapters later, thanks to the forgetfulness of the author, is riding the dear little animal again, our story has contradictions. We must start with the well-established concept that matter is composed of corpuscles or atoms, whose existence has been quite "tangibly" demonstrated by many beautiful experiments, and with Max Planck's discovery that energy also comes in indivisible units, called quanta, which are supposed to be transferred abruptly from one carrier to another.

But then Sancho Panza's donkey will return. For I shall have to ask you to believe neither in corpuscles as permanent individuals nor in the suddenness of the transfer of an energy quantum. Discreteness is present, but not in the traditional sense of discrete single particles, let alone in the sense of abrupt processes. Discreteness arises merely as a structure from the laws governing the phenomena. These laws are by no means fully understood; a probably correct analogue from the physics of palpable bodies is the way various partial tones of a bell derive from its shape and from the laws of elasticity to which, of themselves, nothing discontinuous adheres.

EDITOR'S NOTE

This article is condensed from a lecture entitled "Our Conception of Matter," given by Professor Schrödinger in 1952 at a conference in Geneva organized by Rencontres Internationales de Genève. The condensation is based on a translation by Sonja Bargmann, and it is published here with the kind permission of Editions de la Baconnière of Neuchâtel, Switzerland, who are publishing the full lecture in a volume called *L'homme devant la science*, presenting the proceedings of the conference.

The idea that matter is made up of ultimate particles was advanced as early as the fifth century B.C. by Leucippus and Democritus, who called these particles atoms. The corpuscular theory of matter was lifted to physical reality in the theory of gases developed during the 19th century by James Clerk Maxwell and Ludwig Boltzmann. The concept of atoms and molecules in violent motion, colliding and rebounding again and again, led to full comprehension of all the properties of gases: their elastic and thermal properties, their viscosity, heat conductivity and diffusion. At the same time it led to a firm foundation of the mechanical theory of heat, namely, that heat is the motion of these ultimate particles, which becomes increasingly violent with rising temperature.

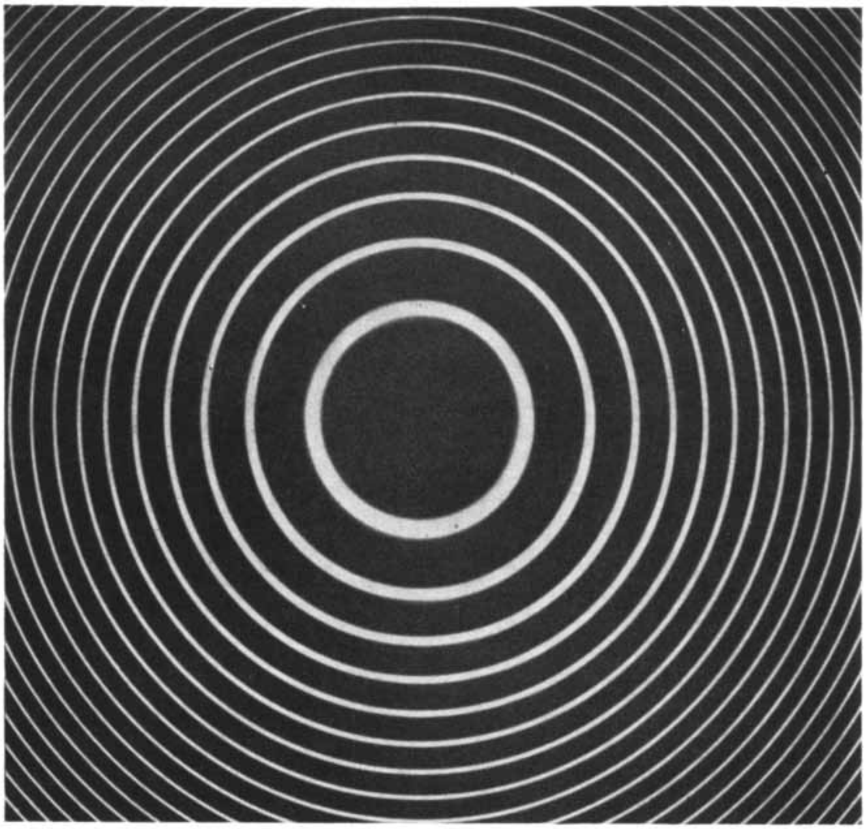
Within one tremendously fertile decade at the turn of the century came the discoveries of X-rays, of electrons, of the emission of streams of particles and other forms of energy from the atomic nucleus by radioactive decay, of the electric charges on the various particles. The masses of these particles, and of the atoms themselves, were later measured very precisely, and from this was discovered the mass defect of the atomic nucleus as a whole. The mass of a nucleus is less than the sum of the masses of its component particles; the lost mass becomes the binding energy holding the nucleus firmly together. This is called the packing effect. The nuclear forces of course are not electrical forces—those are repellent—but are much stronger and act only within very short distances, about 10^{-13} centimeter [*see Hans Bethe's article on page 58*].

Here I am already caught in a contradiction. Didn't I say at the beginning that we no longer assume the existence of force fields apart from matter? I could easily talk myself out of it by saying: Well, the force field of a particle is simply considered a part of it. But that is not the fact. The established view today is rather that everything is at the same time both particle and field. Everything has the continuous structure with which we are familiar in fields, as well as the discrete structure with which we are equally familiar in particles. This concept is supported by innumerable experimental facts and is accepted in general, though opinions differ on details, as we shall see.

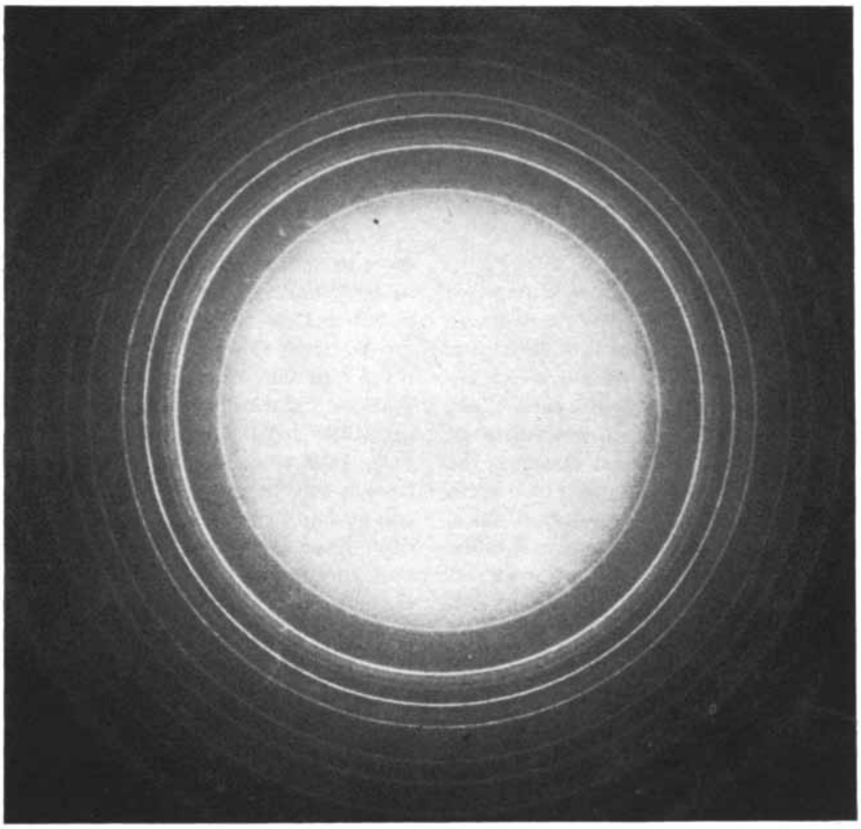
In the particular case of the field of nuclear forces, the particle structure is more or less known. Most likely the continuous force field is represented by the so-called pi mesons. On the other hand, the protons and neutrons, which we think of as discrete particles, indisputably also have a continuous wave structure, as is shown by the interference patterns they form when diffracted by a crystal. The difficulty of combining these two so very different character traits in one mental picture is the main stumbling-block that causes our conception of matter to be so uncertain.

Neither the particle concept nor the wave concept is hypothetical. The tracks in a photographic emulsion or in a Wilson cloud chamber leave no doubt of the behavior of particles as discrete units. The artificial production of nuclear particles is being attempted right now with terrific expenditure, defrayed in the main by the various state ministries of defense. It is true that one cannot kill anybody with one such racing particle, or else we should all be dead by now. But their study promises, indirectly, a hastened realization of the plan for the annihilation of mankind which is so close to all our hearts.

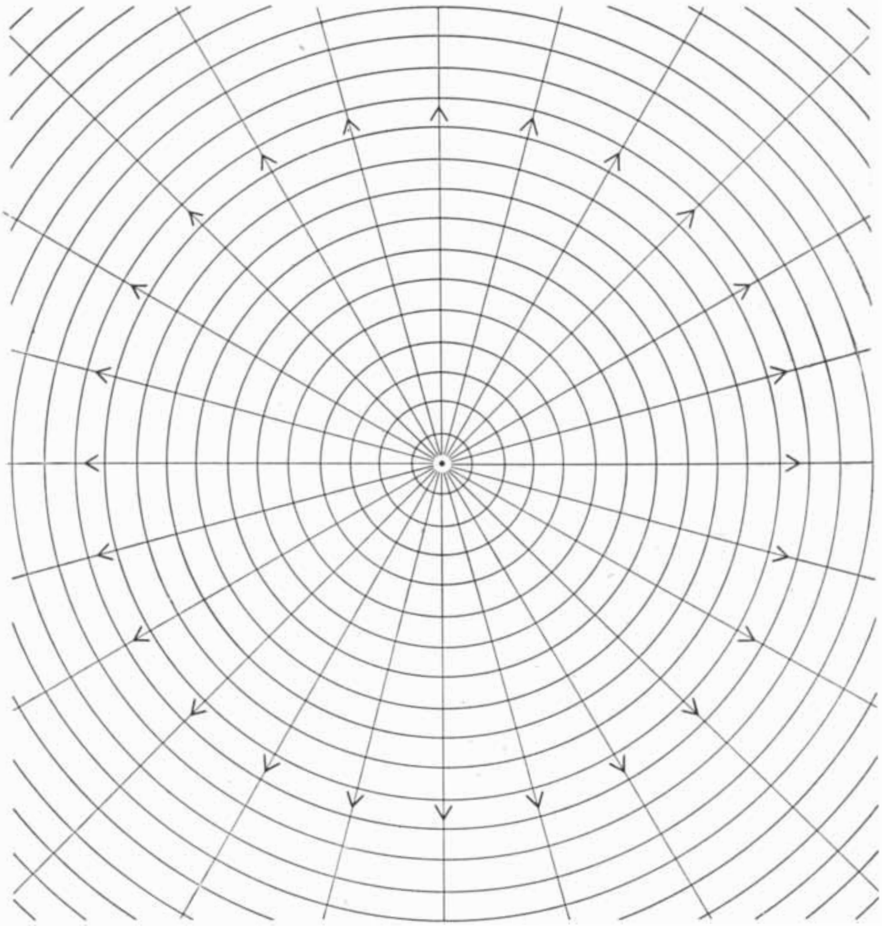
You can easily observe particles yourself by looking at a luminous numeral of your wrist watch in the dark with a magnifying glass. The luminosity surges and undulates, just as a lake sometimes twinkles in the sun. The light consists of sparklets, each produced by a so-called alpha particle (helium nucleus) expelled by a radioactive atom which in this process is transformed into a different atom. A specific device for detecting



LIGHT INTERFERENCE pattern, showing the wave nature of light, was produced at the National Bureau of Standards, using light from mercury vapor and an interferometer.



ELECTRON INTERFERENCE pattern from a crystal diffraction experiment at the Radio Corporation of America Laboratories gives convincing evidence that electrons are waves.



WAVE DIAGRAM in two dimensions shows wave fronts (*circles*) and wave "normals" or "rays" (*arrows*). In three dimensions the fronts would be surfaces like layers in an onion.

and recording single particles is the Geiger-Müller counter. In this short résumé I cannot possibly exhaust the many ways in which we can observe single particles.

Now to the continuous field or wave character of matter. Wave structure is studied mainly by means of diffraction and interference—phenomena which occur when wave trains cross each other. For the analysis and measurement of light waves the principal device is the ruled grating, which consists of a great many fine, parallel, equidistant lines, closely engraved on a specular metallic surface. Light impinging from one direction is scattered by them and collected in different directions depending on its wavelength. But even the finest ruled gratings we can produce are too coarse to scatter the very much shorter waves associated with matter. The fine lattices of crystals, however, which Max von Laue first used as gratings to analyze the very short X-rays, will do the same for "matter waves." Directed at the surface of a crystal, high-velocity streams of particles manifest their wave nature. With crystal gratings physicists have diffracted and measured the wavelengths of electrons, neutrons and protons.

What does Planck's quantum theory have to do with all this? Planck told us in 1900 that he could comprehend the radiation from red-hot iron, or from an incandescent star such as the sun, only if this radiation was produced in discrete portions and transferred in such discrete quantities from one carrier to another (*e.g.*, from atom to atom). This was extremely startling, because up to that time energy had been a highly abstract concept. Five years later Einstein told us that energy has mass and mass is energy; in other words, that they are one and the same. Now the scales begin to fall from our eyes: our dear old atoms, corpuscles, particles are Planck's energy quanta. *The carriers of those quanta are themselves quanta.* One gets dizzy. Something quite fundamental must lie at the bottom of this, but it is not surprising that the secret is not yet understood. After all, the scales did not fall suddenly. It took 20 or 30 years. And perhaps they still have not fallen completely.

The next step was not quite so far-reaching, but important enough. By an ingenious and appropriate generalization of Planck's hypothesis Niels Bohr taught us to understand the line spectra of atoms and molecules and how atoms were composed of heavy, positively charged nuclei with light, negatively charged electrons revolving around them. Each small system—atom or molecule—can harbor only definite discrete energy quantities, corresponding to its nature or its constitution. In transition from a higher to a lower "energy level" it emits the excess energy as a radiation quantum of definite wavelength, inversely proportional to the quantum given off. This means that a quantum of given magnitude manifests itself in a periodic process of definite frequency which is directly proportional to the quantum; the frequency equals the energy quantum divided by the famous Planck's constant, h.

According to Einstein a particle has the energy mc^2, m being the mass of the particle and c the velocity of light. In 1925 Louis de Broglie drew the inference, which rather suggests itself, that a particle might have associated with it a wave process of frequency mc^2 divided by h. The particle for which he postulated such a wave was the electron. Within two years the "electron waves" required by his theory were demonstrated by the famous electron diffraction experiment of C. J. Davisson and L. H. Germer. This was the starting point for the cognition that everything—anything at all—is simultaneously particle and wave field. Thus de Broglie's dissertation initiated our uncertainty about the nature of matter. Both the particle picture and the wave picture have truth value, and we cannot give up either one or the other. But we do not know how to combine them.

That the two pictures are connected is known in full generality with great precision and down to amazing details. But concerning the unification to a single, concrete, palpable picture opinions are so strongly divided that a great many deem it altogether impossible. I shall briefly sketch the connection. But do not expect that a uniform, concrete picture will emerge before you; and do not blame the lack of success either on my ineptness in exposition or your own denseness—nobody has yet succeeded.

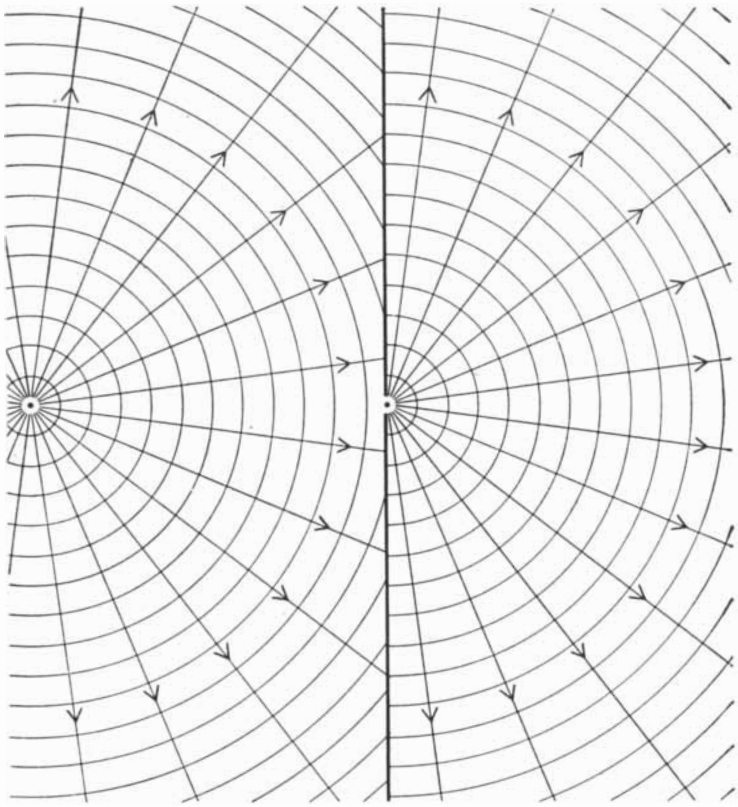
One distinguishes two things in a wave. First of all, a wave has a front, and a succession of wave fronts forms a system of surfaces like the layers of an onion. You are familiar with the two-dimensional analogue of the beautiful wave circles that form on the smooth surface of a pond when a stone is thrown in. The second characteristic of a wave, less intuitive, is the path along which it travels—a system of imagined lines perpendicular to the wave fronts. These lines are known as the wave "normals" or "rays."

We can make the provisional assertion that these rays correspond to the trajectories of particles. Indeed, if you cut a small piece out of a wave, approximately 10 or 20 wavelengths along the direction of propagation and about as much across, such a "wave packet" would actually move along a ray with exactly the same velocity and change of velocity as we might expect from a particle of this particular kind at this particular place, taking into account any force fields acting on the particle.

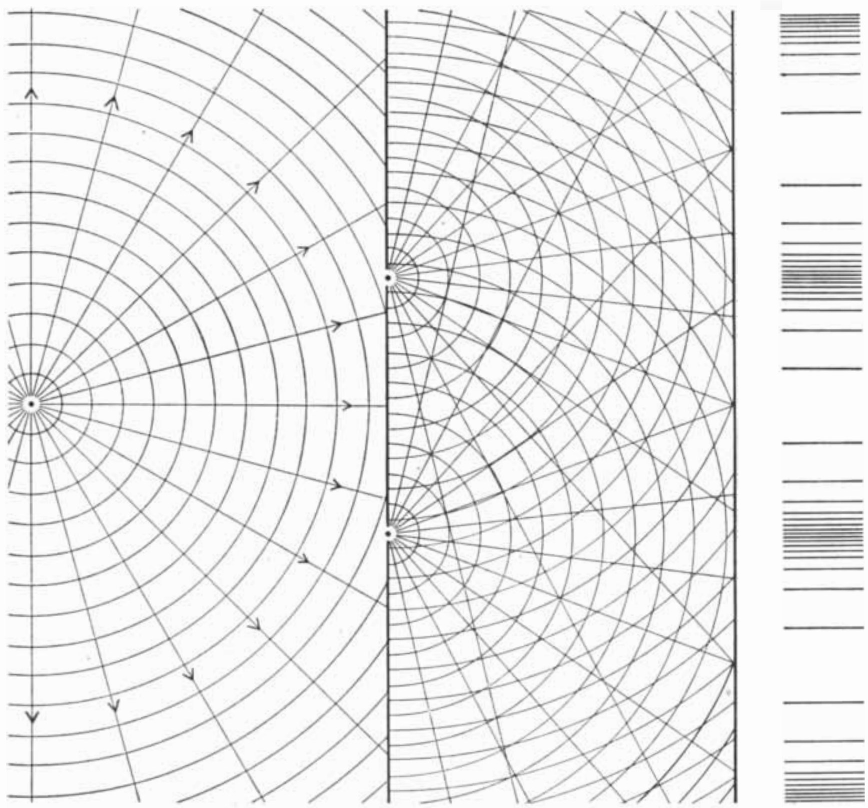
Here I falter. For what I must say now, though correct, almost contradicts this provisional assertion. Although the behavior of the wave packet gives us a more or less intuitive picture of a particle, which can be worked out in detail (*e.g.*, the momentum of a particle increases as the wavelength decreases; the two are inversely proportional), yet for many reasons we cannot take this intuitive picture quite seriously. For one thing, it is, after all, somewhat vague, the more so the greater the wavelength. For another, quite often we are dealing not with a small packet but with an extended wave. For still another, we must also deal with the important special case of very small "packelets" which form a kind of "standing wave" which can have no wave fronts or wave normals.

One interpretation of wave phenomena which is extensively supported by experiments is this: At each position of a uniformly propagating wave train there is a twofold structural connection of interactions, which may be distinguished as "longitudinal" and "transversal." The transversal structure is that of the wave fronts and manifests itself in diffraction and interference experiments; the longitudinal structure is that of the wave normals and manifests itself in the observation of single particles. However, these concepts of longitudinal and transversal structures are not sharply defined and absolute, since the concepts of wave front and wave normal are not, either.

The interpretation breaks down completely in the special case of the standing



DIFFRACTION is characteristic of waves. When a wave (*left*) comes to a barrier perforated with a small hole, it diffracts around the edges of the hole to form a new wave (*right*).



INTERFERENCE is also evidence of waves. Its characteristic pattern is formed when rays interact. For light waves the pattern shows up as bright and dark bands on a screen (*right*).

waves mentioned above. Here the whole wave phenomenon is reduced to a small region of the dimensions of a single or very few wavelengths. You can produce standing water waves of a similar nature in a small basin if you dabble with your finger rather uniformly in its center, or else just give it a little push so that the water surface undulates. In this situation we are not dealing with uniform wave propagation; what catches the interest are the normal frequencies of these standing waves. The water waves in the basin are an analogue of a wave phenomenon associated with electrons, which occurs in a region just about the size of the atom. The normal frequencies of the wave group washing around the atomic nucleus are universally found to be exactly equal to Bohr's atomic "energy levels" divided by Planck's constant h. Thus the ingenious yet somewhat artificial assumptions of Bohr's model of the atom, as well as of the older quantum theory in general, are superseded by the far more natural idea of de Broglie's wave phenomenon. The wave phenomenon forms the "body" proper of the atom. It takes the place of the individual pointlike electrons which in Bohr's model are supposed to swarm around the nucleus. Such pointlike single particles are completely out of the question within the atom, and if one still thinks of the nucleus itself in this way one does so quite consciously for reasons of expediency.

What seems to me particularly important about the discovery that "energy levels" are virtually nothing but the frequencies of normal modes of vibration is that now one can do without the assumption of sudden transitions, or quantum jumps, since two or more normal modes may very well be excited simultaneously. The discreteness of the normal frequencies fully suffices—so I believe—to support the considerations from which Planck started and many similar and just as important ones—I mean, in short, to support all of quantum thermodynamics.

The theory of quantum jumps is becoming more and more inacceptable, at least to me personally, as the years go on. Its abandonment has, however, far-reaching consequences. It means that one must give up entirely the idea of the exchange of energy in well-defined quanta and replace it with the concept of resonance between vibrational frequencies. Yet we have seen that because of the identity of mass and energy, we must consider the particles themselves as Planck's energy quanta. This is at first frightening. For the substituted theory implies that we can no longer consider the individual particle as a well-defined permanent entity.

That it is, in fact, no such thing can be reasoned in other ways. For one thing, there is Werner Heisenberg's famous uncertainty principle, according to which a particle cannot simultaneously have a well-defined position and a sharply defined velocity. This uncertainty implies that we cannot be sure that the same particle could ever be observed twice. Another conclusive reason for not attributing identifiable sameness to individual particles is that we must obliterate their individualities whenever we consider two or more interacting particles of the same kind, *e.g.*, the two electrons of a helium atom. Two situations which are distinguished only by the interchange of the two electrons must be counted as one and the same; if they are counted as *two* equal situations, nonsense obtains. This circumstance holds for any kind of particle in arbitrary numbers without exception.

Most theoreticians will probably accept the foregoing reasoning and admit that the individual particle is not a well-defined permanent entity of detectable identity or sameness. Nevertheless this inadmissible concept of the individual particle continues to play a large role in their ideas and discussions. Even deeper rooted is the belief in "quantum jumps," which is now surrounded with a highly abstruse terminology whose common-sense meaning is often difficult to grasp. For instance, an important word in the standing vocabulary of quantum theory is "probability," referring to transition from one level to another. But, after all, one can speak of the probability of an event only assuming that, occasionally, it actually occurs. If it does occur, the transition must indeed be sudden, since intermediate stages are disclaimed. Moreover, if it takes time, it might conceivably be interrupted halfway by an unforeseen disturbance. This possibility leaves one completely at sea.

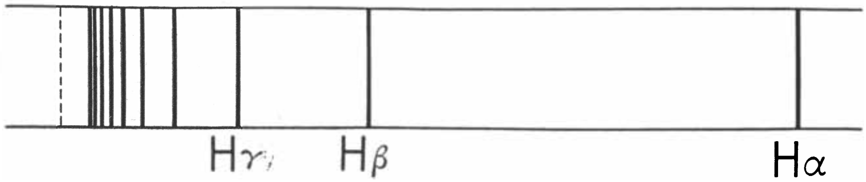
The wave *v.* corpuscle dilemma is supposed to be resolved by asserting that the wave field merely serves for the computation of the probability of finding a particle of given properties at a given position if one looks for it there. But once one deprives the waves of reality and assigns them only a kind of informative role, it becomes very difficult to understand the phenomena of interference and diffraction on the basis of the combined action of discrete single particles. It certainly seems easier to explain particle tracks in terms of waves than to explain the wave phenomenon in terms of corpuscles.

"Real existence" is, to be sure, an expression which has been virtually chased to death by many philosophical hounds. Its simple, naive meaning has almost become lost to us. Therefore I want to recall something else. I spoke of a corpuscle's not being an individual. Properly speaking, one never observes the same particle a second time—very much as Heraclitus says of the river. You cannot mark an electron, you cannot paint it red. Indeed, you must not even *think* of it as marked; if you do, your "counting" will be false and you will get wrong results at every step—for the structure of line spectra, in thermodynamics and elsewhere. A wave, on the other hand, can easily be imprinted with an individual structure by which it can be recognized beyond doubt. Think of the beacon fires that guide ships at sea. The light shines according to a definite code; for example: three seconds light, five seconds dark, one second light, another pause of five seconds, and again light for three seconds—the skipper knows that is San Sebastian. Or you talk by wireless telephone with a friend across the Atlantic; as soon as he says, "Hello there, Edward Meier speaking," you know that his voice has imprinted on the radio wave a structure which can be distinguished from any other. But one does not have to go that far. If your wife calls, "Francis!" from the garden, it is exactly the same thing, except that the structure is printed on sound waves and the trip is shorter (though it takes somewhat longer than the journey of radio waves across the Atlantic). All our verbal communication is based on imprinted individual wave structures. And, according to the same principle, what a wealth of details is transmitted to us in rapid succession by the movie or the television picture!

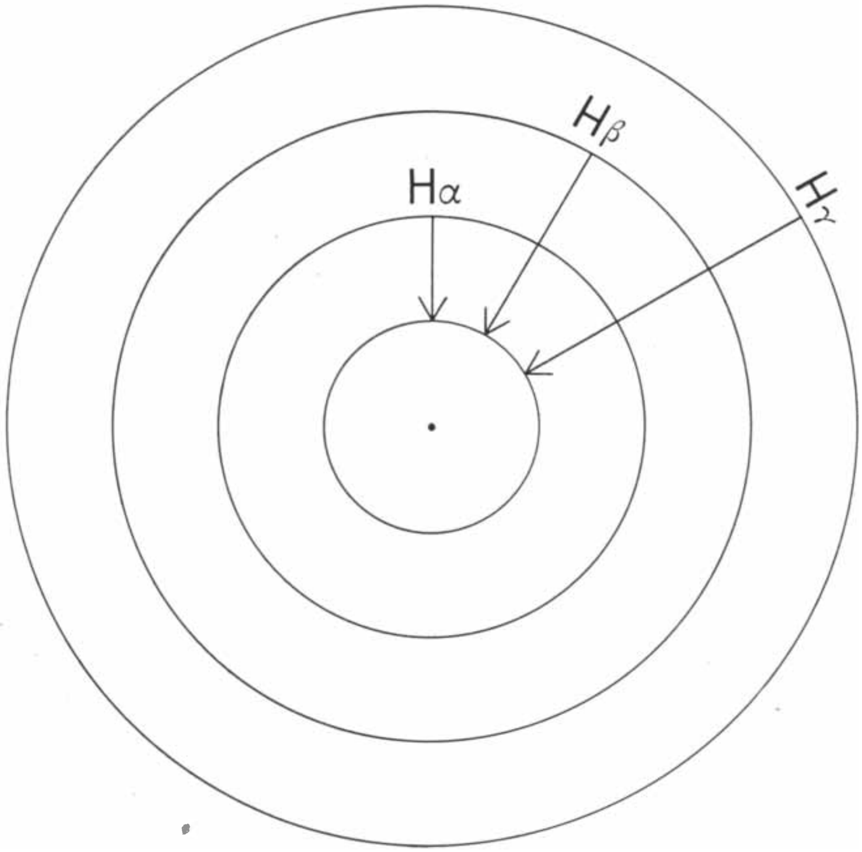
This characteristic, the individuality of the wave phenomenon, has already been found to a remarkable extent in the very much finer waves of particles. One example must suffice. A limited volume of gas, say helium, can be thought of either as a collection of many helium atoms or as a superposition of elementary wave trains of matter waves. Both views lead to the same theoretical results as to the behavior of the gas upon heating, compression, and so on. But when you attempt to apply certain somewhat involved enumerations to the gas, you must carry them out in different ways according to the mental picture with which you approach it. If you treat the gas as consisting of particles, then no individuality must be ascribed to them, as I said. If, however, you concentrate on the matter wave trains instead of on the particles, every one of the wave trains has a well-defined structure which is different from that of any other. It is true that there are many pairs of waves which are so similar to each other that they could change roles without any noticeable effect on the gas. But if you should count the very many similar states formed in this way as merely a single one, the result would be quite wrong.

In spite of everything we cannot completely banish the concepts of quantum jump and individual corpuscle from the vocabulary of physics. We still require them to describe many details of the structure of matter. How can one ever determine the weight of a carbon nucleus and of a hydrogen nucleus, each to the precision of several decimals, and detect that the former is somewhat lighter than the 12 hydrogen nuclei combined in it, without accepting for the time being the view that these particles are something quite concrete and real? This view is so much more convenient than the roundabout consideration of wave trains that we cannot do without it, just as the chemist does not discard his valence-bond formulas, although he fully realizes that they represent a drastic simplification of a rather involved wave-mechanical situation.

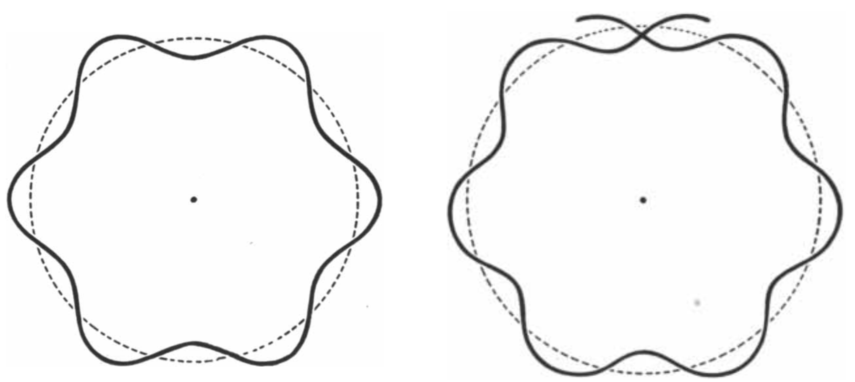
If you finally ask me: "Well, what *are* these corpuscles, really?" I ought to confess honestly that I am almost as little prepared to answer that as to tell where Sancho Panza's second donkey came from. At the most, it may be permissible to say that one can think of particles as more or less temporary entities within the wave field whose form and general behavior are nevertheless so clearly and sharply determined by the laws of waves that many processes take place *as if* these temporary entities were substantial permanent beings. The mass and the charge of particles, defined with such precision, must then be counted among the structural elements determined by the wave laws. The conservation of charge and mass in the large must be considered as a statistical effect, based on the "law of large numbers."



HYDROGEN SPECTRUM expresses the behavior of a fundamental constituent of matter, the electron. Shown above is a part of the Balmer series of spectral lines, which are in the visible light range. Each line is the result of a change in energy of the atom's electron.



BOHR THEORY explained spectral lines of hydrogen by postulating a pointlike electron revolving around the nucleus in any of a number of possible orbits. In falling from one to another, the electron emits light energy whose wavelength is that of one of the spectral lines.



WAVE MECHANICS sees the electron not as a point mass, but as a standing wave washing to and fro in the atom. Some modes of vibration are possible (*left*), while others are not (*right*). The possible modes correspond exactly to the Bohr theory's possible energy levels.

What Holds the Nucleus Together?

Electrical forces bind the electron to the atom, but they cause nuclear particles to fly apart. The powerful cohesion of protons and neutrons must be explained by a wholly different phenomenon

by Hans A. Bethe

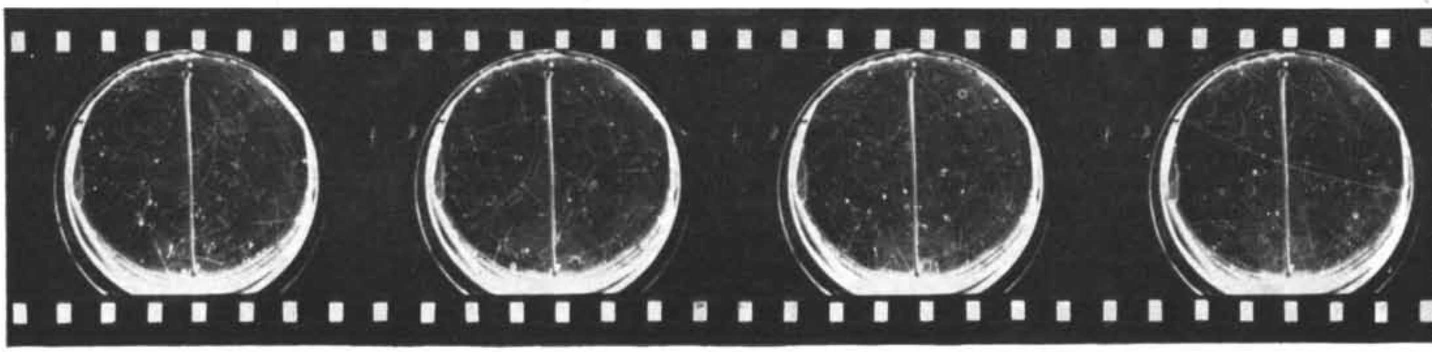
In the preceding article Erwin Schrödinger deals with the basic nature of matter (does it consist of particles or waves?) and touches on some of the questions about its construction. My assignment is to discuss what is by all odds the most mystifying of these questions: What holds the nucleus of the atom together? In the past quarter century physicists have devoted a huge amount of experimentation and mental labor to this problem—probably more man-hours than have been given to any other scientific question in the history of mankind. The problem is not only fundamental but alien to our experience. By all the laws of known forces, the particles in an atom's nucleus should flee from one another, instead of clinging together so strongly that we must build enormously energetic machines to pry them apart. The glue that holds the nucleus together must be a kind of force utterly different from any we yet know.

Let us first look briefly at the general features of the atom, which is much too small to be seen under the most powerful microscope but about which we nonetheless have a great deal of information. It is constructed of a heavy, positively charged nucleus surrounded by a "planetary system" of light, negatively charged electrons. The forces that govern the behavior of the electrons are thoroughly familiar: they are the forces of electric attraction and repulsion. To describe the motions of the electrons physicists had to invent a new mechanics known as quantum mechanics. Once this was worked out, it became possible to understand all the properties of atoms as a whole—their sizes, their chemical behavior, the light they emit, and so on—in terms of the motions of the electrons around the nucleus.

The nucleus itself is a very different problem. Its building blocks are the positively charged particles called protons and the electrically neutral particles known as neutrons. The nucleus, containing about 99.95 per cent of the total mass of the atom, is far more densely packed than the electrons in the atom's outer regions; if you were to imagine the atom as a whole to be as big as a house, the nucleus would be the size of a pinhead. Now detailed investigations of the nucleus early turned up a remarkable fact: whereas the density of the fluffy outer structure of atoms varies greatly from one kind of atom to another, all nuclei have a uniform density (about 100 trillion times that of water). Thus the total volume of an atom, insofar as its volume can be defined at all, is not necessarily proportional to its weight, a circumstance which makes some substances denser than others. But the volume of a nucleus is very nearly proportional to its weight, just as a piece of iron 10 times as heavy as another is also 10 times as large in volume.

This resemblance of nuclei to the matter of everyday experience suggested that the forces holding the nucleus together might be something like those that bind atoms together. We know that gross matter is held together by forces between neighboring atoms, and that there are no important interactions between atoms distant from one another. It is therefore assumed that the forces in the nucleus likewise act mainly between neighboring particles, rather than from one end of the nucleus to the other.

But what can these forces be? Clearly electric forces are out of the question.



Nuclear events caused by the cyclotron at the Nevis Laboratory of Columbia University are revealed by thin white tracks

In the first place, the electric force between two protons is repulsive, not attractive. And even if the sign were changed so that they attracted one another, the electric force of attraction would be too small by a factor of 40 to account for the binding energy with which protons are held together in the nucleus. Besides all this, what about the uncharged neutrons, which cannot exert any electric force, attractive or otherwise—how could the nucleus hold them?

As for gravitation, the other important force with which we are acquainted, that is completely hopeless. The gravitational force between two particles in a nucleus is too small to explain their attraction by a factor of 10^{37}!

We are confronted with a problem which is just the opposite of the one physicists had when they began to study the atom as a whole. They were completely familiar with the forces (electric) at play, but had to discover the laws (quantum mechanics) that governed the operation of these forces. In the case of the nucleus, we are fairly confident about the governing laws (again quantum mechanics), but must discover the force.

One might picture the situation in this way. You are walking in the park and come upon a group of men playing baseball. After watching for a few minutes you decide that it is a match between lunatics. The batters seem to run to any base that pleases them; the fielders throw the ball at random; the object of the game is utterly obscure, and the score, impossible to compute. But by long, intense observation you finally figure out the strange rules of the game. That is where atomic physics had arrived 20 years ago. We have now moved along to another place in the park and discovered a second game more insane than the first. The rules seem to be the same, but the players are playing without a ball! Something—we do not know just what—is passing back and forth among the players, and to understand the game we must find out what that something is. The invisible ball shuttling among the players corresponds to the force between particles in the nucleus.

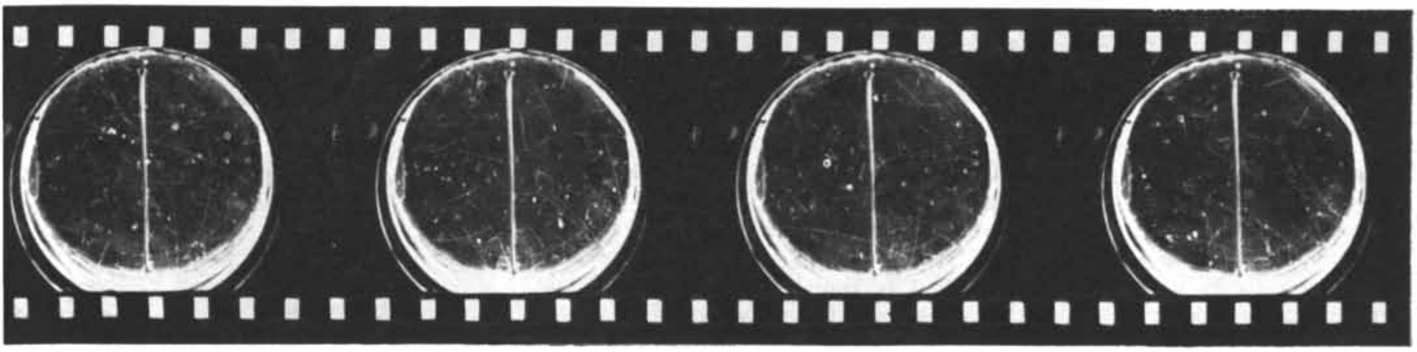
Our problem is twofold: (1) to measure the force and determine its other properties, and (2) to probe into the "cause" of the nuclear force, as it were, by studying its connections with other physical phenomena.

We can get an approximate measurement of the strength of the nuclear forces by determining the binding energy with which the nucleus is held together. This can be done in two ways: by measuring the energy set free or consumed in various nuclear reactions, or by using Einstein's relation $E = Mc^2$, which says that the binding energy is equal to the mass defect in the nucleus times the square of the velocity of light. The "mass defect," of course, refers to the fact that the mass of the nucleus is slightly smaller than the sum of the masses of the particles combined in it; the difference is the "defect."

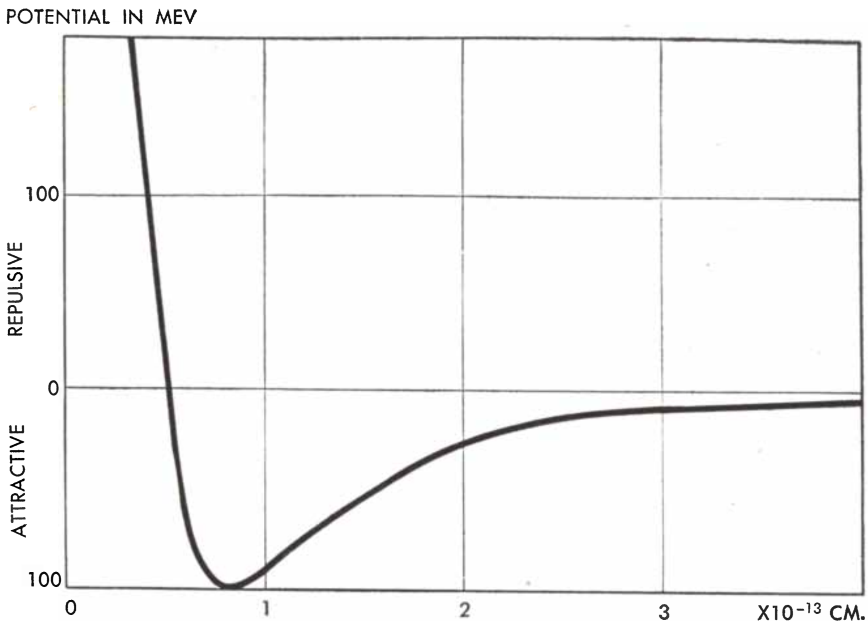
By these two methods it has been determined that the binding energy holding each particle in a heavy nucleus is between six and eight million electron volts (roughly a million times the energy that holds atoms together in a molecule). But this is still far from telling us much about the force between two individual particles—to say nothing of the complex set of interacting forces operating among the whole group of particles. We can try to use the measured energies with which particles are bound to the nucleus as a basis for calculating the nuclear force. If we tried this with any complex nucleus, however, we would be in very deep water; the mathematical problem of computing from the binding energy the forces among the 16 particles of the oxygen nucleus, for instance, is so formidable that no one would dream of attempting it. We are forced to concentrate, as the atomic physicists did in studying the atom, on the simplest possible system. The atomic physicists obtained most of their information about atoms from the two-particle hydrogen atom—one proton and one electron. As a subject for investigating nuclear forces, the simplest nucleus we can find is the deuteron (the nucleus of heavy hydrogen), which consists of one proton and one neutron.

Unfortunately the deuteron is far less helpful than the hydrogen atom was. The hydrogen atom's various energy states, normal and excited, all provide means of testing the laws governing the forces between its proton and electron. But the deuteron has no excited state. The only measurement it can give us is the binding energy in its fixed ground state, and this alone is not sufficient to determine with precision the force between its two particles and—what the nuclear physicist particularly wants to know—how that force varies with distance. We have therefore had to study the matter indirectly by investigating the interaction between free protons and free neutrons. A beam of neutrons is directed at a piece of matter containing hydrogen. Neutrons colliding with the protons in the hydrogen are scattered in various directions. By observing how many neutrons are scattered in each direction, and by using neutron beams of varying speeds, we are able to deduce the force between the proton and the neutron.

The most conspicuous feature of nuclear forces turns out to be their short range. At a distance of about 10^{-13} centimeter (which is a hundred-thousandth of the radius of an atom) the nuclear force of attraction between two protons is about 40 times as strong as the electric force of repulsion between them. At four times that distance the nuclear force has dropped off to the same strength as the electric force; at 25 times the distance the electric force is a million times stronger. On the other hand, there is some evidence that at extremely short distances (perhaps less than half of 10^{-13} cm.) the nuclear force changes from a



in a diffusion cloud chamber. A 35-millimeter camera automatically photographs the chamber once every 10 seconds



NUCLEAR FORCE (measured in millions of electron volts) is plotted against the distance between particles. When the distance is less than half of 10^{-13} centimeter, the nucleons repel one another. They most strongly attract one another at just under 10^{-13} cm.

strong attractive force to an even stronger force of repulsion.

The nuclear forces are far more complicated than electric or any other known forces. The force between two nuclear particles apparently depends not only on the distance but also on the particles' relative velocity and on the relative orientation of their spins. Moreover, there are forces which act among three, four or more particles simultaneously. Again, there is the remarkable fact that the force between particles is independent of the particles' charge. Proton and proton, neutron and neutron, proton and neutron—all have about the same attractive force toward each other. This finding is especially hard to explain because it is so contrary to the behavior of charged particles in common experience.

Another remarkable feature of the nuclear force is the kind of exchange that occurs between one particle and another. In the gross material world, and in the world of atoms, when two bodies of equal weight collide usually the faster moving body retains the greater speed or the two bodies share their energy about equally. But in the world of protons and neutrons something quite different commonly happens. When a very fast neutron hits a proton, very often the proton jumps forward with almost as much speed as the neutron had, while the neutron is stopped almost to a standstill. The simplest way to explain this is that the neutron snatches the positive charge from the proton and keeps on going, without transferring much of its momentum to the proton. In other words, the proton that suddenly jumps forward is really the original neutron transformed into a proton.

Having explored the properties of nuclear forces, we may now try to "explain" them. At this point it is appropriate to point out that for a physicist the word "explanation" has a rather different meaning from that in everyday usage. People generally explain something in terms of concepts more familiar than what they are explaining. But physicists very often "explain" a rather familiar phenomenon in terms of far less familiar concepts. For them an explanation consists in connecting different physical phenomena, building a logical structure and deriving the simplest possible mathematical formula to describe all the connected phenomena.

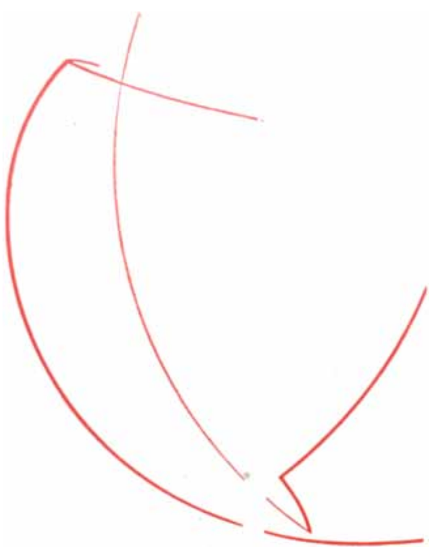
It must be clear from what has already been said that the nuclear forces cannot be explained in terms of forces with which physicists were familiar before 1930. Analogies with those forces can, however, be a starting point for a theory of the new force.

The force about which we know the most is electromagnetic force. We know that the interaction between electrically charged bodies moves with the speed of light. Further, this interaction can be described essentially by saying that quanta of light are emitted by one electric particle and absorbed by another. In the process, the light quanta transmit energy and momentum from the first to the second particle; in other words, they transmit an electric force, though they themselves have no electric charge.

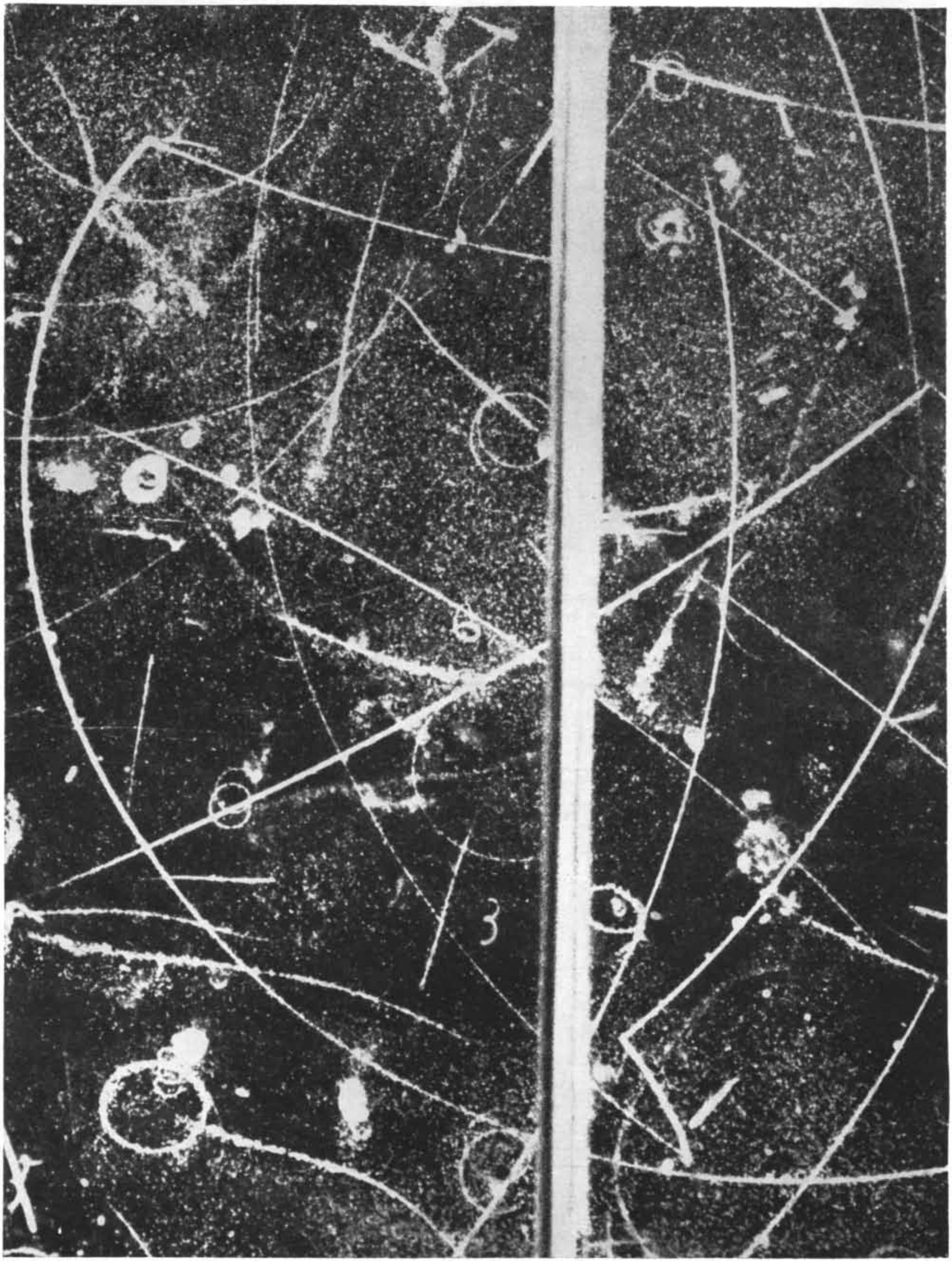
It was natural to assume that nuclear forces behave like electromagnetic ones, and this suggestion was made by the Japanese physicist Hideki Yukawa as early as 1935. In Yukawa's theory, in the nucleus the role of the light quantum is taken by a new particle, whose emission and absorption is supposed to transmit the nuclear forces. This particle, when Yukawa invented it, was of course purely hypothetical. Today it is known as the meson.

Yukawa next tried to figure out what properties his hypothetical particle should have. First of all, he noted that the short range of nuclear forces would be explained if the mesons were supposed to have a mass—in contrast to light quanta which have none. In fact, he worked out the range of the nuclear forces mathematically in terms of Planck's constant, the velocity of light and the mass of the meson. He estimated that the meson mass should be between 100 and 200 times the mass of the electron. (Today we know that 300 is a better figure.)

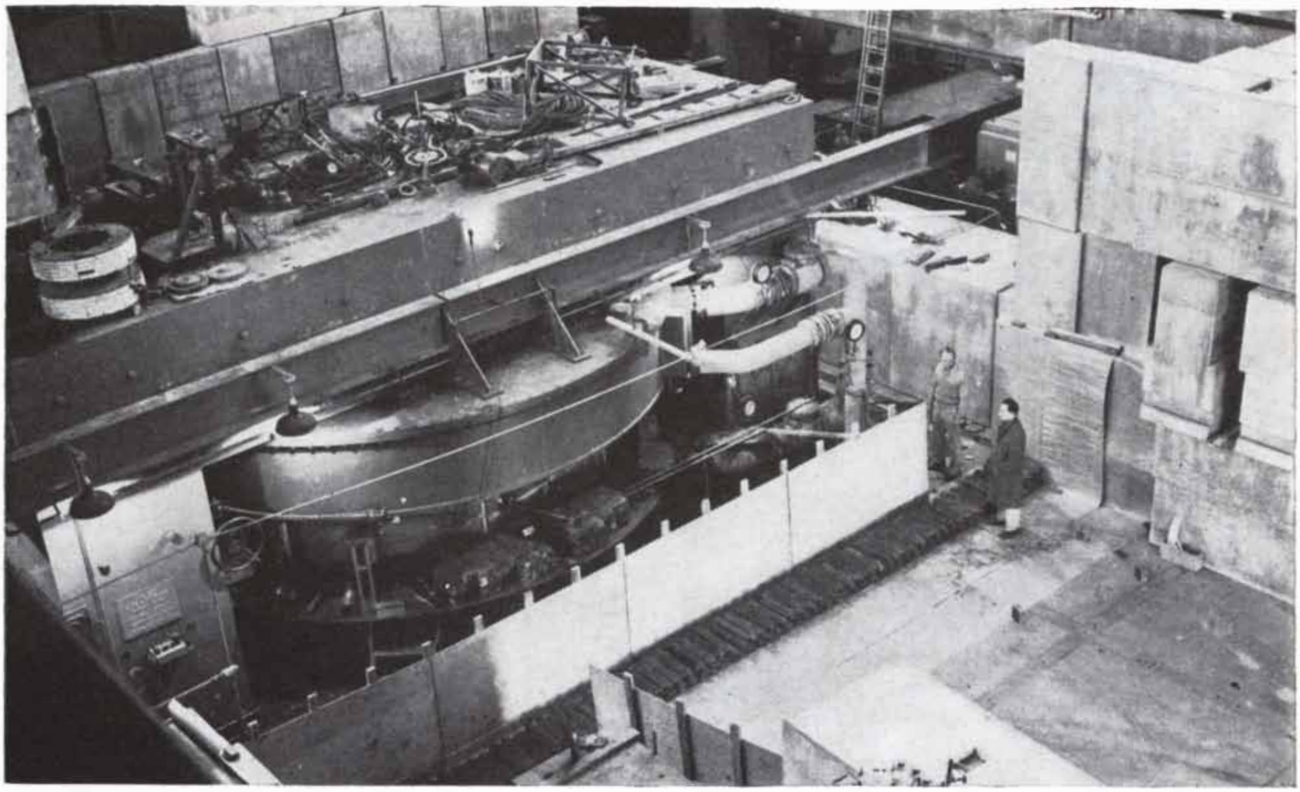
Secondly, Yukawa suggested that to explain exchange forces the mesons must be charged. When a proton and a neutron interact, he postulated, the proton may emit a positive meson which is absorbed by the neutron. In this process the



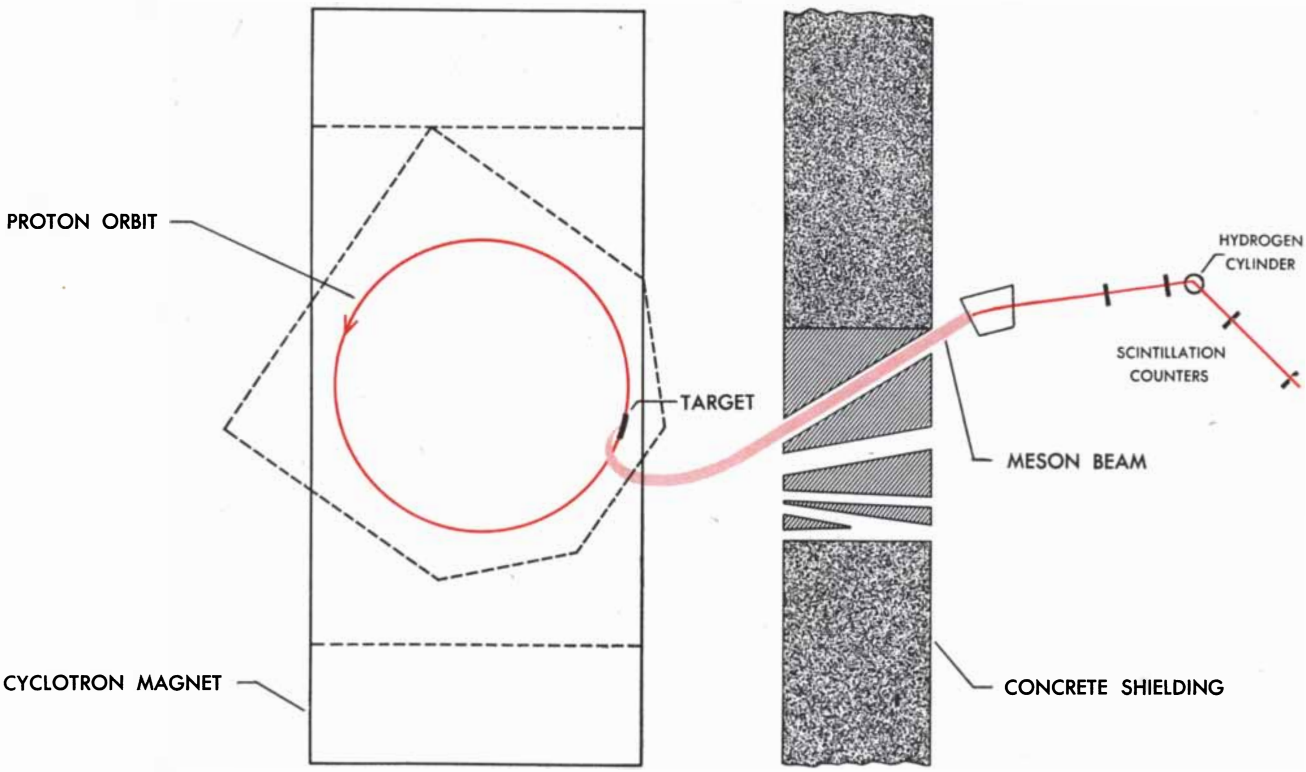
TWO MESON "EVENTS," which are diagrammed above, can be seen in a cloud chamber photograph from the Nevis Cyclo-



tron Laboratory of Columbia University. A negative pi meson entering at bottom right splits into a high-energy pair of electrons, positive and negative, at top left. Another negative pi meson entering at right center decays into a mu meson (first jog) and then into a high-speed electron (second jog). The object running from top to bottom of the picture is not in the path of the particles.



CYCLOTRON at Nevis Laboratory operates at 385 million electron volts and can produce mesons. In this picture the six-foot-thick concrete shielding blocks have been removed to the pile at right, exposing the circular magnetic pole pieces (*center*). Between the magnets can be seen the vacuum chamber, which connects with the pumping system through the system of pipes to the right.



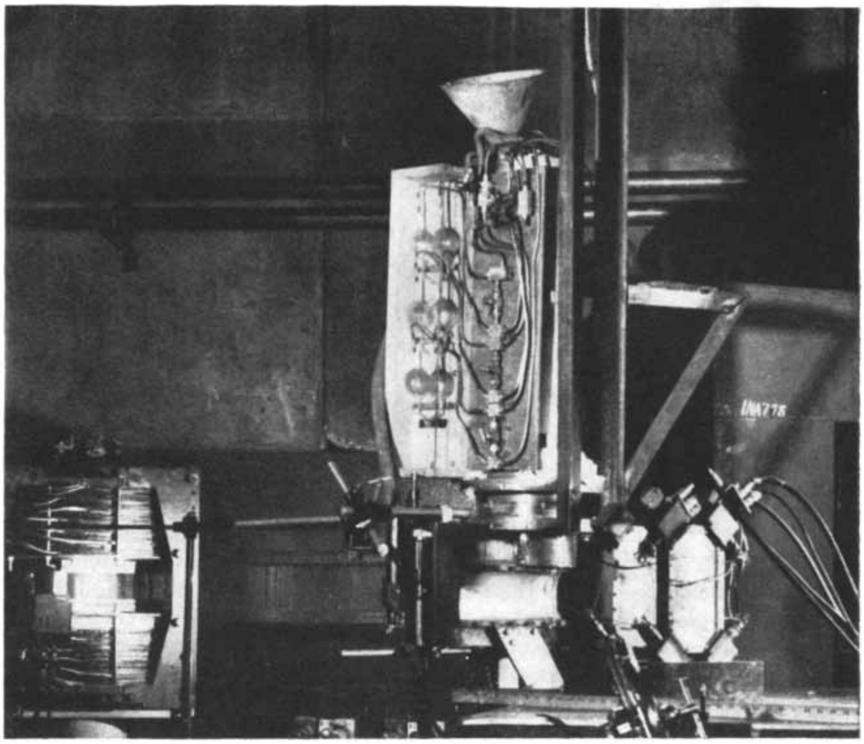
MESON SCATTERING experiment is shown in outline. Accelerated protons (*red circle*) hit metal target to form mesons (*red line*) which are deflected by magnet through a port in iron block (*cross-hatched*). Second magnet to right of port steers them to hydrogen sample which scatters them. Counters placed ahead of sample and behind it insure that only scattered mesons are detected.

proton loses its positive charge and becomes a neutron, while the neutron gains a unit of positive charge and turns into a proton. The same result is obtained, of course, if the neutron emits a negative meson which is absorbed by the proton. Yukawa suggested the existence of both positive and negative mesons, in conformity with a general principle of physics: that for every positively charged particle there is a negatively charged counterpart. The best known examples are the negative and positive electrons.

Three years after Yukawa proposed the meson, physicists found in cosmic radiation a particle which seemed to have just the properties he had predicted. It had a mass about 200 times that of the electron and was found in both positive and negative forms. But this particle turned out to be the wrong answer—it did not interact strongly with nucleons and therefore could not transmit nuclear forces. At length in 1947 C. F. Powell, G. P. S. Occhialini and C. M. G. Lattes—an Englishman, an Italian and a Brazilian working together—discovered another particle which *did* interact strongly with nucleons and had a mass of 276 electron masses. There is every indication that this is Yukawa's meson. It is known as the pi meson, or "pion." (If kept away from nucleons it will decay after a moderately short time into one of the earlier discovered mesons, now called mu mesons.) Since the discovery of the pion, heavier mesons have been found, but probably they are less important for nuclear forces.

The next step in the theory was taken by the English physicist N. Kemmer. He reasoned that there should be a neutral meson, in order to explain the interaction between proton and proton (or neutron and neutron). A proton cannot absorb a positive meson, for it cannot acquire a second positive charge. Therefore no single charged meson could transmit a force between protons (though the simultaneous exchange of two mesons of opposite charge might, it is true, do so). Kemmer consequently suggested that a neutral meson might carry the forces between proton and proton, or, for that matter, between unlike nucleons. His theory accounted for the nuclear forces' independence of charge.

Soon after the pions were discovered in cosmic radiation, it became possible to produce them artificially with large new cyclotrons. Physicists now could obtain mesons in large quantities and explore their properties and interactions with nucleons. They soon confirmed the



SCATTERING EXPERIMENT setup is photographed above. At left is port through which mesons emerge. Large apparatus topped by funnel supplies liquid hydrogen to aluminum chamber, where scattering occurs. The rectangular objects at right are two of the counters.

existence of Kemmer's neutral mesons. As for the interaction of mesons and nucleons, exact calculations will probably remain very difficult for a long time—incomparably more difficult than the calculation of electric and atomic phenomena. The main reason is that the interaction between a meson and a proton or neutron is exceedingly strong—about 1,000 times stronger than that between an electron and the electric field. The mathematical methods of quantum theory are all adapted to the weak interactions of electrodynamics.

Once the interaction between mesons and nucleons has been worked out, one can then try to derive that between two nucleons. As we have seen, the mass and charge of mesons are sufficient in themselves to explain the nuclear forces' short range, their exchange property and their independence of charge. Other aspects of meson theory can account for the dependence of nuclear forces on the direction of the spins of the nucleons and of the line joining their positions, for the strong repulsion between nucleons at extremely small distances and for the simultaneous interaction between more than two nucleons.

In short, the meson theory already accounts for all the qualitative features of nuclear forces. It looks as if we have found the ball with which the nuclear game is played. But we cannot be sure until we have figured out whether our theory can explain the behavior of the participants in quantitative terms, that is, whether the range of forces, the strength of interactions and other quantities derived from the theory by calculation are of the right magnitude.

A promising start has been made by the French physicist Maurice Lévy, working at the Institute for Advanced Study in Princeton. He has shown that calculations based on the observed mass of the meson do indeed yield the correct figure for the range of the nuclear forces. His work, in combination with the theoretical work of others, also shows that the strength of interaction between nucleon and meson required to explain nuclear forces is about the same as that required to explain the scattering of mesons by protons. *About* the same—actually, the two numbers differ by approximately 50 per cent, but probably this difference is simply a measure of our mathematical ineptness in dealing with large forces. Thus the indications are that physicists are on the right track in explaining nuclear forces by transfer of mesons. But it will be a long time before our mathematical tools are developed sufficiently to determine whether the meson theory *really* explains the forces in all details.

Where Do Cosmic Rays Come From?

This question involves another one: How do these particles attain their awesome energy? They have told us much about the nature of the nucleus, and they promise to tell more about the universe

by Bruno Rossi

The earth is under a ceaseless rain of particles from space. These cosmic rays, our only material contact with the vast universe outside our planetary system, have excited wonder and eager study ever since they were first discovered 41 years ago. They fall upon us with energies far beyond anything that can be produced on earth. They shatter the atoms of matter and make their nuclei explode into strange fragments. It is the investigation of cosmic rays that has been responsible for the discovery of so many new elementary particles in the past quarter-century: the positron, the various mesons, the V-particles and others which are being discovered even as these lines are written. Besides this, cosmic rays are of great interest in biology, for by producing mutations in genes they are said to have played, and continue to play, a large role in the evolution of life on the earth.

Thus the cosmic rays have been very useful to science. But the big question remains: Where do they come from, and how do they get their fantastic energy?

At six o'clock on the morning of August 7, 1912, a balloon took off from a field near the Austrian town of Aussig. It carried three men, one of them a young physicist named Victor Hess, and three sensitive ionization meters. Hess was out to learn something about the source of a certain mysterious radiation which physicists had been detecting for some time with laboratory instruments. His balloon rose to 16,000 feet, and he found the radiation much stronger there than at sea level. After analyzing his readings, he announced: "The results of my observations are best explained by the assumption that a radiation of very great penetrating power enters our atmosphere from above. . . ."

This was the first recognition of what the U. S. physicist Robert Millikan later named cosmic radiation. The fascinated investigation that ensued concerned itself first of all with finding out what the cosmic rays were.

Outside the earth's atmosphere cosmic radiation consists mainly of protons (nuclei of hydrogen), varying widely in energy. There are few, if any, protons of energy below one billion electron volts (Bev). Most of them are in the range of one to 100,000 Bev. Occasionally a cosmic-ray particle hits the atmosphere with much higher energy, up to 100 million Bev; it produces a gigantic shower containing millions of particles. For comparison, recall that the most powerful accelerator made by man, the Brookhaven Cosmotron, accelerates protons to an energy of a little more than two Bev.

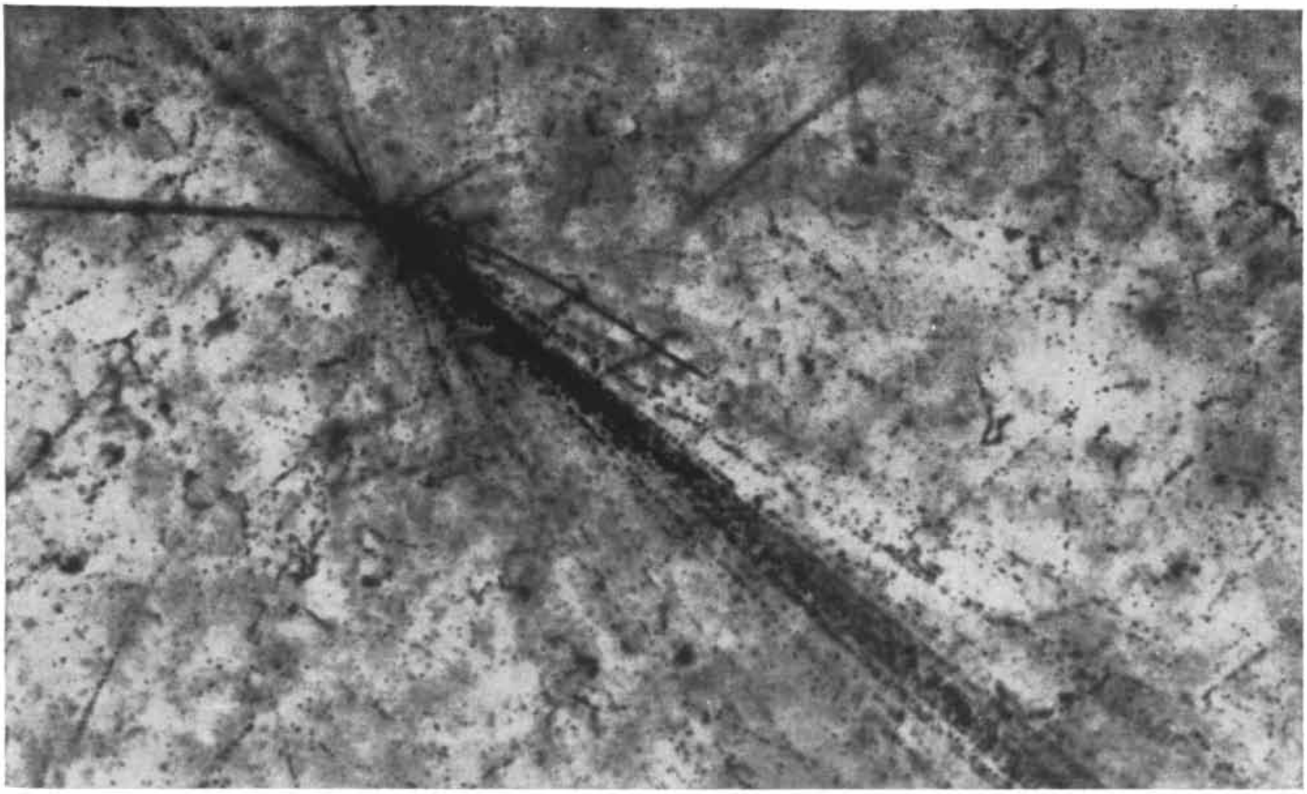
Cosmic rays also contain nuclei of helium and of heavier elements. According to our still incomplete information, the velocity range of all the types of nuclei is approximately the same. At any given velocity, we find approximately 85 helium nuclei and six heavier nuclei for every 1,000 protons. It is interesting to note that the relative abundance of the various nuclei in cosmic rays corresponds closely to the relative abundance of those elements in the universe. Long before striking our atmosphere and beginning the series of collisions by which their energy is eventually dissipated, cosmic-ray particles are deflected by the earth's magnetic field. Some of them are thrown back into space; others reach the earth from a direction which may differ considerably from their original path.

Suggestions as to where the cosmic rays may come from divide themselves into two general schools of thought. One school holds that the cosmic rays were created several billion years ago in a tremendous explosion that gave birth to the universe; since then they have been traveling through space along trajectories curved by the universe's general gravitational field. The trouble with this point of view is that it confines the entire problem to the realm of pure speculation. It therefore seems more profitable to explore the second hypothesis, which is at least theoretically verifiable. This point of view assumes that cosmic rays are produced continuously somewhere in the system of stars which forms our galaxy.

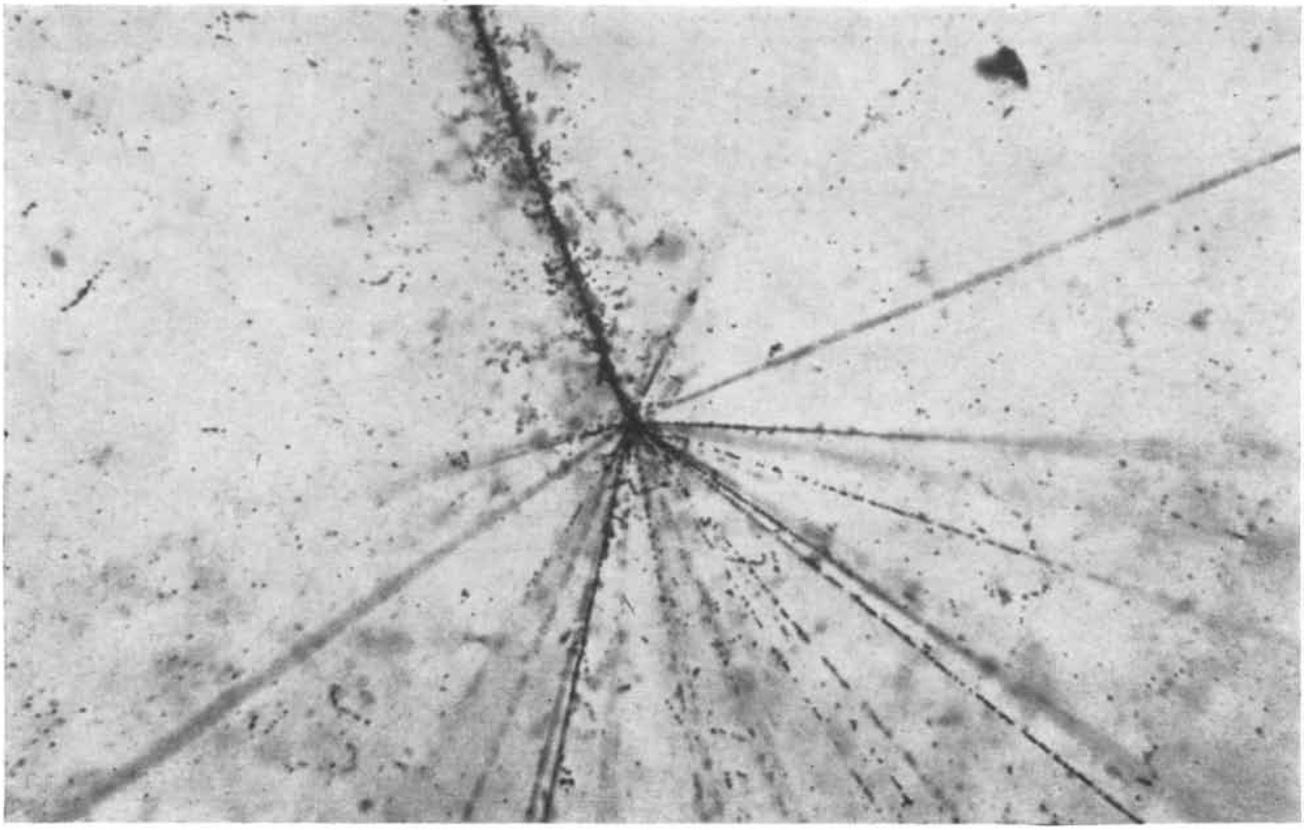
The most attractive theory is that they come from the nearest star, our sun, for the farther away we place the source, the harder it is to account for the relatively heavy intensity of the cosmic-ray fall on the earth. The energy of this fall is very small compared to the energy of the light and heat we get from the sun, but it is comparable to the light from the distant stars.

Correlations between the intensity of cosmic radiation and activity in the sun have, in fact, been observed. Shortly after the appearance of a large flare on the sun, there is sometimes a sudden burst of extra cosmic radiation at the earth. Three such events are on record. On November 19, 1949, cosmic-ray meters at widely separated stations registered abnormally high intensities about one hour after a solar flare had reached its maximum. A detector of cosmic-ray neutrons at Manchester, England, went off the scale. At Climax, Col., a detector of cosmic-ray mesons registered a 180 per cent increase.

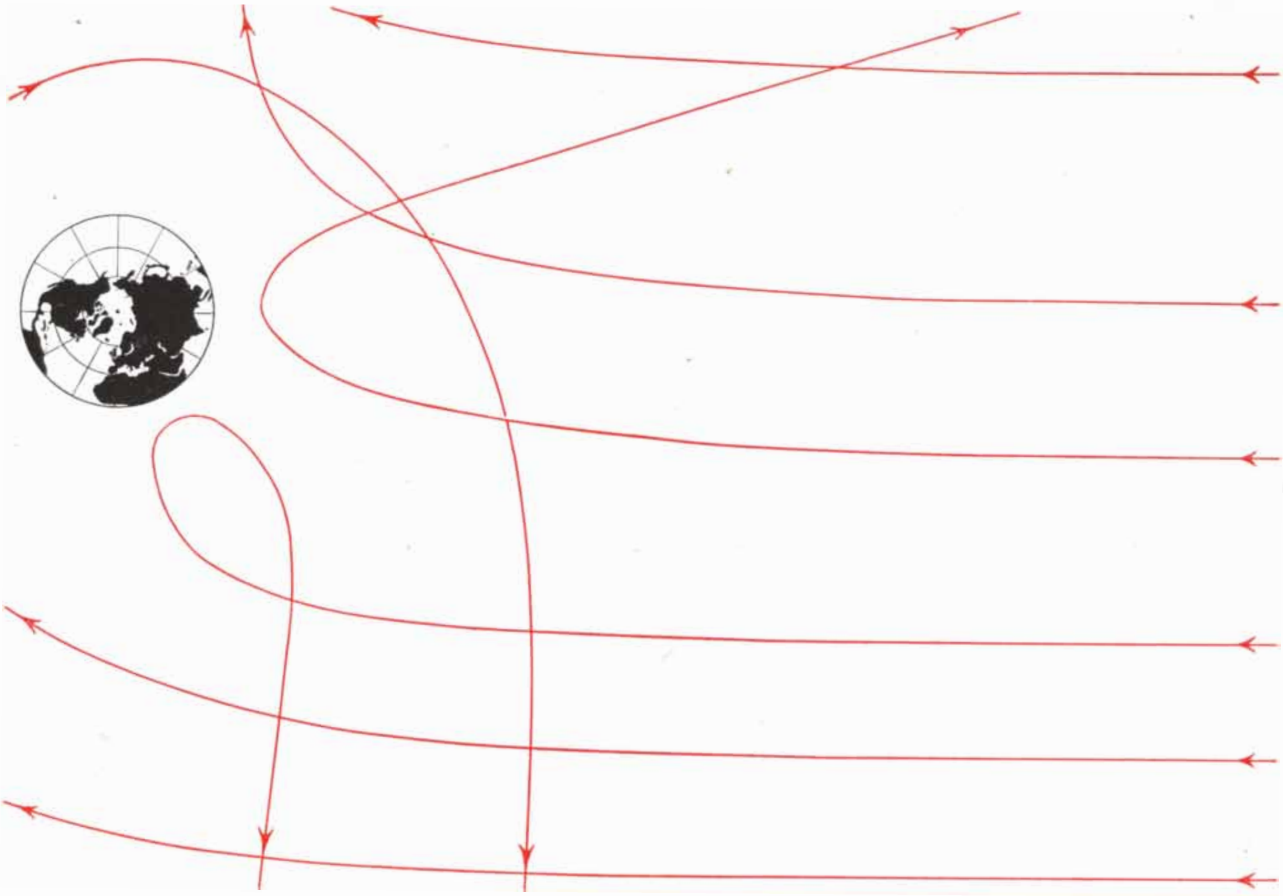
Solar flares are often followed by perturbations of the magnetic field around the earth (magnetic storms), which



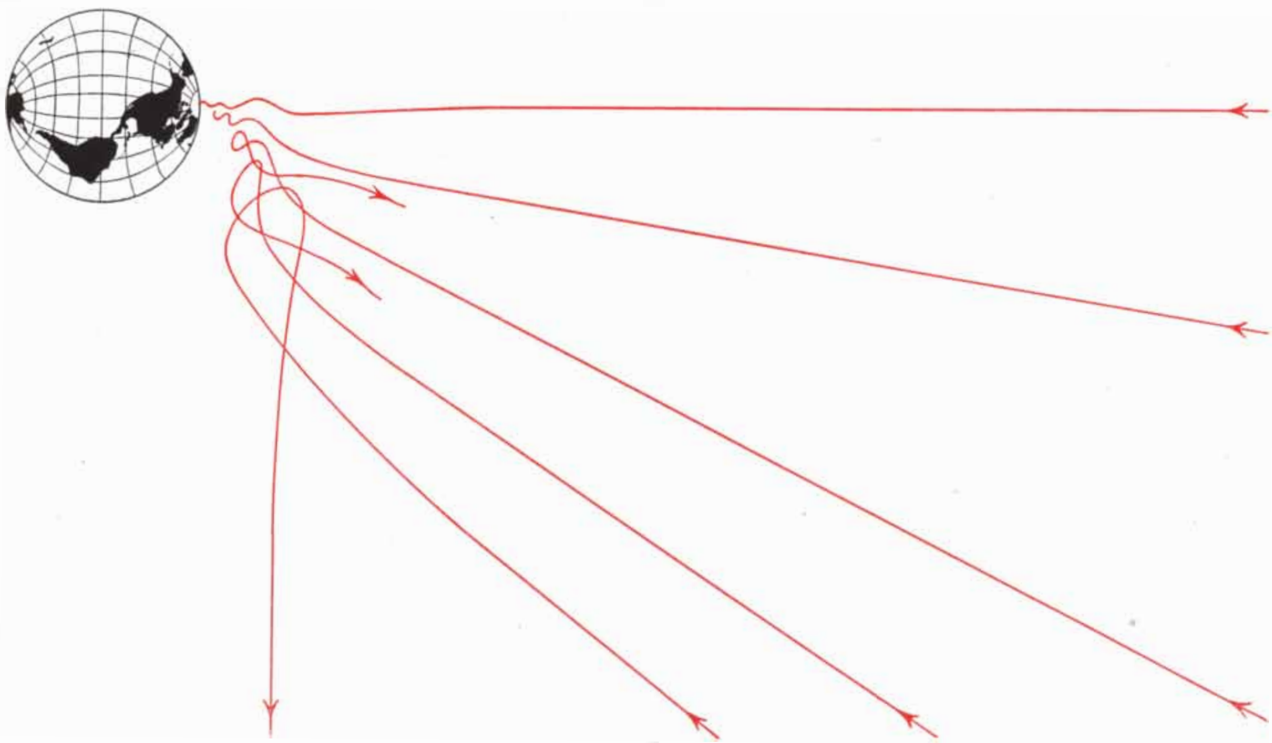
COSMIC PARTICLE caused this tiny explosion revealed by a photomicrograph of a photographic emulsion especially prepared to record nuclear events. An exceptionally energetic helium nucleus struck a heavier nucleus in the emulsion, giving rise to the jet of mesons going off to the lower right. These photographs were provided by Herman Yagoda of the National Institutes of Health.



PRIMARY COSMIC PARTICLE entered this emulsion from the upper left and shattered a nucleus into about 40 nucleons and mesons. Some of the particles went off at large angles to the plane of the emulsion, and hence are not visible. The nuclear charge of the primary was about 20, that of calcium. The event was recorded during the flight of an unmanned balloon from Pyote, Texas.



POLAR PROJECTION of the earth shows some typical trajectories (*red lines*) of charged particles such as the cosmic rays in the plane of the equator. The earth's magnetic field causes some of the particles to veer sharply, others to describe complex loops.



EQUATORIAL PROJECTION shows some typical trajectories of charged particles in the plane of the poles. Because the lines of force in the earth's magnetic field bend downward at the poles, more particles reach the earth's surface there than at the equator.

could conceivably modify the flux of cosmic rays reaching the earth even if they came from another source. But the rise just mentioned is much too large to be explained in this manner. It is difficult to escape the conclusion that on November 19, 1949 (and on two similar occasions) the earth was struck by a particularly intense burst of cosmic rays emitted directly from the sun.

This does not necessarily mean that the sun is the sole source of cosmic rays. If they came only from the sun, their intensity should vary markedly with the position of the sun in the sky. Experiments have shown, however, that the variation during the day's 24 hours is less than half of one per cent. Of course, the earth's magnetic field makes cosmic-ray particles of moderate energy describe very complicated trajectories and it thus produces a more or less random distribution in their direction of arrival. But the magnetic field has no appreciable effect on particles of higher energies, and yet they too appear to arrive with almost equal intensity from all parts of the sky.

To answer this objection, Edward Teller of the University of California has suggested that in the region of space surrounding the sun there may exist irregular magnetic fields of sufficient strength to prevent or greatly retard the escape of cosmic rays. This trapping field would scatter cosmic-ray particles back and forth for some time, destroying any original preferred direction of motion. Only on rare occasions would a cosmic-ray beam arrive at the earth directly, as, for example, following the appearance of solar flares.

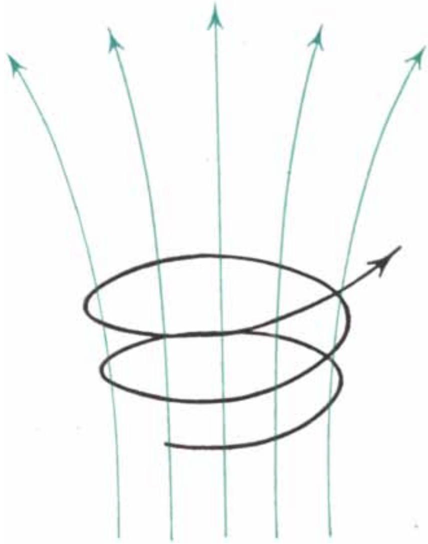
The Swedish astrophysicist Hannes Alfvén has proposed a possible mechanism to account for the magnetic fields postulated by Teller. It is well known that when a conductor moves in a magnetic field, electric currents are induced; these tend to slow down the motion and at the same time produce a supplementary magnetic field. Thus kinetic energy is exchanged for magnetic energy. Now it is known that the sun continuously ejects clouds of ionized and therefore highly conducting gas. The clouds move outward with tremendous velocities, sometimes approaching one per cent of the velocity of light. In passing through the sun's magnetic field a cloud transforms part of its kinetic energy into magnetic energy, and the magnetic field thus produced is carried along by the cloud in its motion away from the sun.

But even if some such mechanism accounts for the dispersed trajectories of particles coming from the sun, the question of how much that body actually contributes to the observed cosmic-ray flux is still open. Most physicists agree that the sun cannot produce any appreciable fraction of the more energetic particles. In the first place, the radiation observed on the occasion of solar flares contains only particles of moderate energy. This is proved by the fact that the intensity does not rise at the equator, where the energy necessary to penetrate the earth's magnetic field is highest (about 15 Bev for protons). Moreover, the trapping field could not be sufficiently strong to keep particles of the highest observed energies confined to the vicinity of the solar system. It is perfectly possible, however, that cosmic-ray particles of energies below 10 Bev come in part from the sun, and the next question to be considered is the way in which they may be produced.

Large-scale electromagnetic phenomena are a part of the sun's activity. One can imagine various situations in which such phenomena could accelerate any charged particles present in the solar atmosphere. A specific process, still regarded as a possible source of cosmic rays, was suggested by W. F. G. Swann 20 years ago.

The sun's surface is often marked by the disturbances called sunspots, which cover areas many thousands of miles in diameter. A sunspot, seen as a dark region on the sun's disk, is the seat of a magnetic field which increases gradually in strength as the spot develops and then decays as the spot fades. A changing magnetic field produces an electric field, according to the well-known laws of electromagnetic induction. That is the basic principle of operation of the betatron, a machine capable of accelerating electrons to energies of several hundred million electron volts. One may crudely describe a betatron as a transformer in which the secondary winding has been replaced by an evacuated tube shaped like a doughnut and containing a source of electrons. As the magnetic flux increases, the electrons are set in motion by the induced electric field, while the magnetic field itself obliges the electrons to follow a circular path inside the doughnut.

According to Swann's hypothesis, a sunspot operates like a gigantic natural betatron. (Note, however, that the betatron had not yet been developed when this hypothesis was first advanced.) Ions of hydrogen and of other elements in the sun's atmosphere are caught, so to speak, in the electromagnetic vortex of the sunspot. They speed along spiraling paths with increasing velocities and are finally projected into space like stones from a slingshot. The magnetic fields of sunspots could accelerate protons and heavier nuclei up to energies of the order of 10 Bev.



BETATRON EFFECT of the increasing magnetic field of a sunspot (*green lines*) causes particles to accelerate in a spiral.

Donald Menzel and W. W. Salisbury, when they were working together at Harvard University, proposed a different mechanism for the acceleration of cosmic-ray particles in the neighborhood of the sun. They based their speculation on the assumption that the sun emits radio waves of very large wavelength. Presumably these waves arise from mechanical turbulence in the highly ionized gases that form the solar atmosphere. Any charged particle which finds itself along the path of a wave is accelerated by the electric field of the wave in a direction at right angles to the path of the wave. However, as soon as the particle acquires some velocity, the magnetic field associated with the wave deflects the particle in a forward direction. By this means a particle may build up an energy of 10 or 100 Bev. Since the particle always lags behind the wave, it will find itself after a while in a position where the electric field of the wave is opposite to its velocity and it will begin to lose the energy it has accumulated. But if the wave field is disturbed at the right moment, as could easily happen under solar conditions, the particle might escape with its maximum energy.

These two theories have a common difficulty. The space around the sun contains strongly ionized gases and is therefore a good conductor of electricity. One cannot produce a strong electric field in a conducting medium, just as one cannot produce a high voltage with a transformer whose secondary winding is short-circuited. What the theories must provide, therefore, is some mechanism by which a suitable region of space is swept clean of the ionized gas before the particles are accelerated.

Meanwhile, since it is unlikely that the sun contributes more than a modest fraction of the total cosmic radiation observed at the earth, we must continue to look for other possible sources of cosmic rays. If we are to keep the required strength of the cosmic-ray sources within reasonable limits, we must assume that the particles originate inside our galaxy, the Milky Way. According to the best estimate, the Milky Way contains approximately 100 billion stars, most of them confined to a flat volume shaped roughly like a grindstone. The diameter of the galaxy is about 100,000 light years, its thickness about 1,500 light years. In the space between stars there are enormous wandering clouds of gas, mostly hydrogen. If the gas of the clouds were distributed uniformly throughout the galaxy, its density would be about one atom per cubic centimeter. Despite this extreme dilution, the total amount of matter in the clouds is approximately equal to the amount of matter in the stars. In addition to the clouds of gas, there are clouds of dust whose total mass is about one per cent that of the stars.

A question hotly debated among astronomers at present is whether magnetic fields exist in the galaxy. From the theoretical point of view, one would expect the wandering gas clouds to carry with them magnetic fields created at the expense of their kinetic energy. From the experimental side, it is known that the light of distant stars is partly polarized, and it is generally assumed that this polarization occurs when the light passes through dust clouds made of microscopic elongated grains oriented in certain preferred directions. A magnetic field provides a natural explanation for the orientation of the dust particles. However, there are other possible explanations, and we still lack conclusive astronomical evidence for the existence of magnetic fields in interstellar space.

This question is of very great importance in the interpretation of cosmic rays. If there is no magnetic field, cosmic-ray particles travel along straight lines through the Milky Way until they escape or collide with nuclei of hydrogen in interstellar matter. A proton has about one chance in 500 of undergoing a collision on traversing the whole galaxy; the heavier particles have a somewhat greater collision probability. Since the sun is situated in the median plane of the galaxy about 30,000 light years from its center, one would expect that, in the absence of magnetic fields, cosmic rays should reach us at different intensities from different directions. A larger fraction of the cosmic radiation should come from the direction of the center.

Nothing of the sort has been observed: the intensity of cosmic radiation from the different regions of the sky does not vary by more than a fraction of one per cent. This uniformity suggests very strongly that magnetic fields are operating to produce a random distribution of cosmic rays in space. Indeed, the cosmic-ray evidence is perhaps the strongest argument presented so far for the existence of these fields.

One may assume that comparatively strong fields exist inside the gas clouds, while the space between clouds is almost completely field-free. Then a cosmic-ray particle travels a straight path until it strikes a cloud. Once inside the cloud, it describes a complicated orbit and eventually emerges with practically no recollection of the original direction of its motion. According to this model, cosmic rays scatter back and forth between clouds, and it may take a particle produced near the median plane a very long time to reach the border and escape into intergalactic space. Some particles would never do so; they would come to the end of their lives by colliding with atomic nuclei of interstellar hydrogen.

The composition of cosmic rays offers an important clue as to the extent to which cosmic rays may be trapped within the Milky Way. When an alpha particle or a heavier nucleus collides with a nucleus of interstellar hydrogen, it breaks up largely into free neutrons and protons. Free neutrons change into protons with a mean life of about 20 minutes. Thus every collision of an alpha particle or heavier nucleus produces several protons, and these protons have approximately the same velocity as the original particle. We know how many

OBSERVATORY ON MOUNT WRANGELL in southeastern Alaska was established this summer by New York University and the University of Alaska. Its altitude (14,000 feet) and latitude (62 degrees North) make it a unique station for the study of cosmic rays.

alpha particles and heavier nuclei are present in cosmic rays and how far they travel, on the average, before colliding. If we assume that these particles never escape from the galaxy, we can compute the number of protons thus produced. We find that this number is more than enough to account for all of the protons in cosmic rays, even if we assume that no protons are accelerated directly by the mechanism responsible for production of the other components.

In short, our observations prevent us from assuming either that cosmic rays escape freely from the galaxy (because that is contrary to their distribution) or that they are completely trapped (because that is contrary to their composition). But there seems to be no serious objection to the assumption that they are partly trapped. Their distribution can be accounted for if the mean life of the particles before escape from the galaxy is of the order of several million years, and in that period a large fraction of the heavier nuclei would avoid disintegrating collisions (on the average an alpha particle, for example, collides with another particle once in 170 million years).

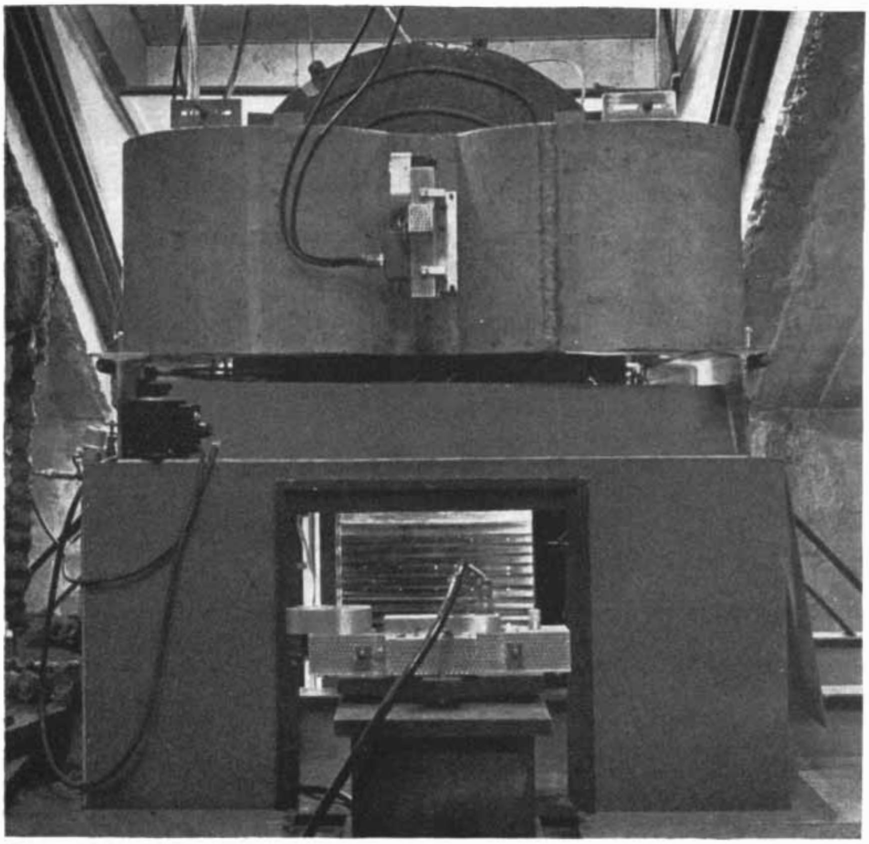
It is reasonable to suppose that in most stars particles are accelerated by processes similar to those which take place in the sun. If all cosmic rays originate from stars, the average star in the galaxy must produce several million times more cosmic radiation than the sun, and some stars must eject particles of very much higher energy, to account for the radiation we receive. We know, as a matter of fact, that the sun is a comparatively inactive star. It is possible that the bulk of the radiation may come from a few types of stars with special characteristics. Double stars, whose two partners possess strong magnetic moments and revolve rapidly around a common center of gravity, and variable stars, whose exceedingly strong magnetic fields appear to reverse direction in a period of a few days, have been singled out as important cosmic-ray sources. But the most prominent candidates of all are the supernovae.

Supernovae are gigantic explosions. One occurs every few hundred years in our galaxy. The explosion releases an amount of energy perhaps equivalent to the total mass of the sun. According to some theories, a star bursts into a supernova when it has exhausted its supply of hydrogen (the fuel that keeps the star hot) and its rotational velocity has dropped below a critical level. At this point gravitational attraction, no longer balanced by centrifugal force or by internal pressure, causes the star to collapse until its core is just one enormous lump of nuclear matter. The star blows up in a tremendous explosion whose products are mainly nuclei of the heavy stable elements. It is possible that cosmic rays are secondary products of this outburst. In the initial phase of the explosion lumps of nuclear matter much heavier than the nuclei of any of the ordinary elements may be thrown into space with velocities approaching the speed of light. These fragments would be highly unstable and would disintegrate, ejecting protons, alpha particles and other nuclei. The ejected particles, with energies further increased by electrostatic repulsion of the highly charged fragment from which they originated, would form the cosmic radiation. Even if cosmic rays were produced entirely in instantaneous bursts, several hundred years apart, we should still expect the observed cosmic ray intensity to be constant, because the particles presumably circulate in the Milky Way for millions of years.

Lyman Spitzer of Princeton University has suggested another idea. Dust particles in the neighborhood of a supernova, accelerated by the pressure of the tremendous light flash that accompanies the outburst, might break up into cosmic rays upon colliding with nuclei of hydrogen in space. This process does not account very well for the production of particles with energies above several billion electron volts.

All the theories considered so far have one feature in common: they assume that cosmic-ray particles attain their full energy in a very short time, through some violent process occurring either in a star or in the immediate neighborhood of a star. One must also consider the alternative possibility that these particles are not energetic to start with but acquire their high energy gradually by the action of extended electromagnetic fields as they travel through space. An acceleration mechanism of this kind has been suggested by Enrico Fermi, who points out that energy is exchanged whenever cosmic-ray particles collide with gas clouds. When a particle collides with a cloud coming toward it, it bounces off

OBSERVATORY ON MOUNT WILSON in southern California is used to study cosmic rays by physicists from the California Institute of Technology. It is best known for the work done there on the V-particles, elementary constituents of matter heavier than protons.



CLOUD CHAMBER AND MAGNET are employed in the investigation of cosmic rays at the University of California. In chamber at bottom are a series of horizontal lead plates.

with increased energy; when it collides with a receding cloud, it loses energy. On the average, a particle obtains a small net gain of energy, largely because the number of head-on collisions is slightly greater than the number of overtaking collisions. This energy gain is proportional to the energy of the particle at any given moment. Therefore the particle energy increases exponentially with time, like a savings account.

The Fermi mechanism is effective only if the average energy gain per collision with a cloud is greater than the energy loss by ionization in interstellar matter between collisions. Since the energy gain increases and the energy loss decreases with increasing particle energy, this requirement sets a lower limit to the energy of the particles that can be further accelerated. In other words, particles must be shot into space with more than a certain energy, which is different for different kinds of particles. Fermi estimated that the minimum injection energy is about 200 million electron volts for protons, about one billion for alpha particles, and about 20 billion for oxygen nuclei and increasingly larger for the heavier nuclei.

The large value of the injection energy required for the heavier components makes it difficult to understand how these can be present with any appreciable intensity. Moreover, alpha particles and the heavier nuclei collide with interstellar hydrogen much more frequently than protons do. Therefore they have a smaller chance of gaining large amounts of energy through the suggested acceleration mechanisms. Thus Fermi's original theory, which assumes a complete trapping of the particles in the galaxy, does not account for the fact that the energy distribution of alpha particles and heavier nuclei in the cosmic radiation is similar to that of protons.

One may possibly find a way out of these difficulties by the assumption, already made earlier in this article, that the cosmic-ray particles are only partly trapped, so that their mean life in the galaxy is determined primarily by their probability of escape rather than by their probability of collision. The mean life of protons, alpha particles and heavier nuclei is then approximately the same, and their energy distribution is likewise approximately the same.

The energy spectrum of particles accelerated by Fermi's mechanism depends on the product of the mean life and the average energy gain per unit of time. Since, by assuming only partial trapping, we have decreased the estimated lifetime, we must correspondingly increase the estimate of the energy gain. This decreases the required injection energies and thus makes the Fermi mechanism more plausible for the heavy nuclei.

At present no hypothesis about the origin of cosmic rays is unequivocally supported by theory or experiment. What is worse, few of the many hypotheses that have been put forward can be definitely disproved. I favor the following general picture: The sun and the other stars eject protons and nuclei of heavier elements at energies comparable to those now attained by man-made accelerators. They do so by an electromagnetic process or a combination of such processes. Some stars may be unusually strong sources of the particles. The particles then diffuse through interstellar space, being trapped within the galaxy by irregularly distributed magnetic fields for an average of several million years. During their random motion they undergo further acceleration through some mechanism of the kind suggested by Fermi.

One can think of several investigations to test this thoroughly tentative picture. The fact that cosmic radiation contains no protons with less than about one billion electron volts may be an important clue. It would be interesting to know whether low-energy protons are also absent from the solar radiation that reaches the earth after flares. The lack of high-energy electrons and photons in cosmic rays needs investigation. Collisions of cosmic-ray particles with interstellar hydrogen produce pi mesons, which then decay into mu mesons, which then decay into electrons. They also produce neutral mesons, which decay into photons. Thus some electrons and photons should be present in the cosmic radiation, even if these particles are not produced at the source. They may have escaped detection thus far only because their number is small.

The magnetic field of the galaxy cannot effectively trap particles beyond a certain energy. Thus there should be a high-energy cut-off in the energy spectrum of cosmic rays. If this cut-off could be determined experimentally, it would afford valuable evidence on the strength of the magnetic fields in the galaxy.

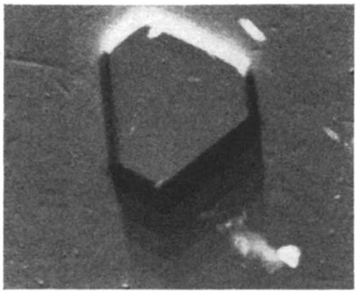
There is little doubt that cosmic-ray research eventually will contribute as much to our knowledge of the universe as it has contributed to our knowledge about particles and nuclear forces.

Kodak reports to laboratories on:

selecting photographic plates for electron micrography...our ambitions in the organic chemical business...an inexpensive new team to take and show 8mm movies

Electron microscope

From work we've done with step wedges in the electron microscope emerge some reasonably plain facts that may be helpful in selecting photographic plates for electron mi-



crography. The wedges are made by successive gold-palladium shadowings of silver halide crystals with increasing obliquities, as pictured in the above electron micrograph.

The archaic-sounding *Kodak Lantern Slide Plates* still seem to be the best all-around bet for recording what the ultra-modern electron microscope reveals. They're inexpensive, they provide a wide range of sensitometric characteristics through choice of developer and development time, they're fine-grained, and we stock them in the usual sizes for the electron microscope. There are *Kodak Lantern Slide Plates, Medium* and *Kodak Lantern Slide Plates, Contrast.* We used to think that the latter gave slightly higher contrast in areas of low exposure, but we now must confess that whatever the differences between them to light exposure, to electron exposure they're pretty much alike. (The medium plate does have slightly finer grain.) The step-wedge project does, however, reveal some aces up our sleeve for the benefit of the electron micrographer with a special problem, viz.:

Kodak Spectroscopic Plates, Type III-O are much faster and have a more uniform density gradient over the exposure range, but have coarser grain than Kodak Lantern Slide Plates.

Kodak Spectroscopic Plates, Type IV-O are about three times as fast to electron exposure as Kodak Lantern Slide Plates and only slightly more grainy.

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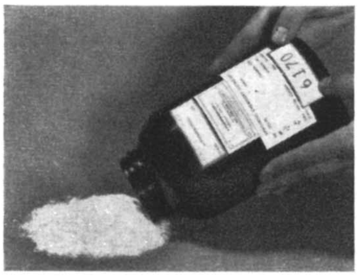
Ambition

Tie a pair of benzene rings together, replace one of the end hydrogen atoms with a fluorine atom, and



what have you got? You've got a compound known as *4-Fluorobiphenyl*, and what the use of it can be is a matter that, frankly, does not concern us much. Any singularly useful properties it may have are apparently not well known, for our inventory of the compound, pictured above in its entirety, seems to be well balanced to the world's present needs. It is a representative of our group of fluorinated aromatics—poor relations (so far) of the currently booming family of fluorinated aliphatics. It isn't that we bet on the wrong horse when we began making fluorobenzene and the three fluorotoluenes some 20 years ago. We don't figure that way. We do figure that here is one more group of organic compounds that an interested investigator, whenever he turns up, can count on us to have in stock for him. This sounds incredibly public-spirited, but it just happens to be the nature of our Eastman Organic Chemicals business.

4-Fluorobiphenyl *(Eastman 6170) is just one of many hundreds of such examples citable from the list of more than 3500 compounds in List No. 38 of Eastman Organic Chemicals. A copy (if you haven't one at hand) is available without charge from Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y. (Division of Eastman Kodak Company).*

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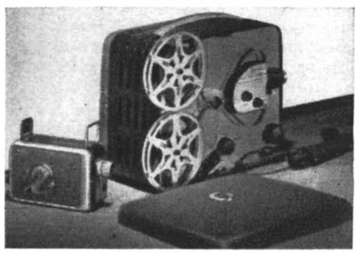

potential professional value, it's no sin to have a little fun with it once in a while.

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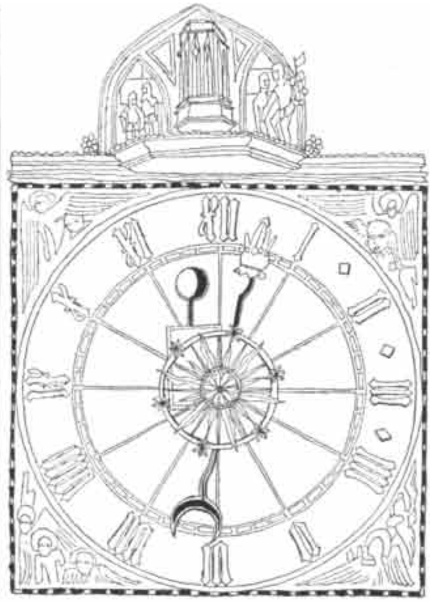

AEC Report

Reactor developments are featured in the Atomic Energy Commission's 14th semi-annual report, covering the first six months of 1953. Four steps forward were achieved in this period: a homogeneous reactor generated useful amounts of electricity; the experimental breeder reactor proved it could manufacture more fissionable material than it burns; the first submarine reactor went critical; a chemical processing plant to recover fissionable material from used fuel elements went into operation.

The report disclosed that a third submarine reactor, for a vessel of "significantly higher speed than the first two nuclear-powered submarines," is being designed. The Navy has indicated that the first two may have speeds of 35 knots, 10 knots higher than the fastest conventional submarine. Work on a power plant for a large surface ship has stopped, but the Commission will continue to develop the pressurized water reactor that was planned for it. The design is said to have promise for a central station power plant.

The AEC completed this year the $4 million Argonne Cancer Research Hospital in Chicago. Among specific medical projects, the report mentions the use of neutrons from the Brookhaven pile for treating brain tumors. Patients are injected with a solution containing boron, which concentrates in the tumor. The boron captures pile neutrons and breaks down, emitting alpha particles which destroy the tumor tissue. The treatment has been tried on a number of "terminal cases." Some responded "impressively." As much as six months of "useful time" was added to patients' lives.

Some other items in the report:

New ways for finding uranium in the ground are being developed. In one of them uranium is detected by its concentration in the plant life of a region.

Disposing of radioactive wastes by fixing them in ceramic bricks has proved practicable. A pilot plant is being designed.

A "new, faster and more efficient way" to separate radium from naturally occurring mixtures of radium and barium has been found. This is the first improvement to be made over the Curies' original technique.

The AEC disclaims responsibility for this year's tornadoes and other "abnormal" weather.

New Commissioner

Joseph Campbell, vice president in charge of business affairs of Columbia University, has been appointed a member of the Atomic Energy Commission. He fills the place of T. Keith Glennan, who resigned last year. Campbell, a certified public accountant, was chairman of the eastern college group that set up the Brookhaven National Laboratory and was for a time treasurer of Associated Universities, Inc., which operates the laboratory. His appointment brings the AEC up to its full five-man strength. The other commissioners are: Lewis L. Strauss, Thomas E. Murray, Henry D. Smyth and Eugene M. Zuckert.

Stoddard Out

George D. Stoddard resigned as president of the University of Illinois last month after the trustees of the University voted 6-to-3 that they lacked confidence in his administration. The no-confidence resolution was introduced by Harold ("Red") Grange, the former football player.

Stoddard's relations with the trustees and the state legislature had been marked by a number of disputes. Two of the most prominent revolved around his stand on the controversial cancer drug Krebiozen and his participation in the activities of UNESCO.

Research on Krebiozen has been pushed by Andrew C. Ivy, head of the University of Illinois Medical, Dental and Pharmacy schools. Ivy was temporarily suspended by the Chicago Medical

Society for "promoting a secret drug," and the substance was condemned as useless by the American Medical Association and the American Cancer Society. Last year Stoddard ordered Krebiozen research stopped at Illinois. He forced Ivy to take a leave of absence, declaring that the latter's sponsorship of the drug was detrimental to the best interests of the University.

The trustees have now ousted Stoddard and appointed Ivy head of the Department of Clinical Science and Distinguished Professor of Physiology.

Stoddard was a leader in setting up UNESCO. This got him into trouble with the Illinois legislature, some of whose members, he said, regarded these activities as "only one step from communism." When he returned from a 1950 UNESCO meeting in Paris, the trustees informed him that the presidency of the University was "a full-time job."

After his ouster, 18 department heads of the University condemned the trustees' action and commended Stoddard's "stand for honesty in science and integrity in education." Park Livingston, president of the trustees, published a lengthy criticism of Stoddard in the Chicago *Tribune*, including an allegation by a state representative that there were "50 reds, pinks and Socialists" on the University staff in 1950. Stoddard denied the charges in detail.

New Director for UNESCO

The United Nations Educational, Scientific and Cultural Organization has elected Luther H. Evans, Librarian of Congress, as its Director General. He succeeds Jaime Torres Bodet, of Mexico, who resigned last November. The election of a U. S. citizen occasioned some surprise. Many member nations had opposed it for fear that the U.S., which supplies about one third of the agency's budget, would then dominate it politically.

As soon as Evans took office he was embroiled in a debate over the problem of subversive employees. The U.S. delegation at the UNESCO meeting had argued that the director should have the power to discharge persons who were "likely" to be subversive. Other delegations protested this position. Evans said that it seemed "reasonable and wise . . . to discharge employees if I conclude they are guilty of subversive activity toward the government of any member state." But he added: "Any dismissals will be based on facts alone, not simply the request of a government. We shall exercise our own judgment."

A convention setting up the European Organization for Nuclear Research was signed by 12 nations last month. This organization, initiated by UNESCO, will build a laboratory at Geneva, Switzerland. Great Britain, not one of the 12 original members, has indicated that she will join the organization and contribute funds for its support.

For Distinguished Writing

Julian S. Huxley, British biologist and writer, is this year's winner of the £1,000 Kalinga prize awarded by UNESCO for "distinguished popular writing in science." The prize was established by an Indian industrialist and bears the name of an ancient Indian empire. Huxley was the first director-general of UNESCO. Among his popular books are *Essays in Popular Science*, *Scientific Research and Social Needs* and *Man in the Modern World*.

End of Lysenkoism?

Trofim D. Lysenko, who since 1948 has been the ruler of Soviet botany and a symbol of Soviet science, seems to have lost his throne with Stalin's death. He was denounced recently in a Soviet botanical journal and in the general organ of the Soviet Academy of Sciences. The criticisms were of Lysenko personally, not of the Michurinist theory of the inheritance of acquired characteristics.

The writers in the botanical journal declared that Lysenko was a scientific monopolist who placed himself above criticism, failed to train young scientists lest they become competitors and resolved technical questions by administrative decree. They charged that his ideas on the origin of species were in error and opposed to those of Darwin and Michurin. The Academy denunciation said that Lysenko's Institute of Genetics had failed "to make theoretical contributions of practical value." This is a serious indictment, because Lysenko's strength lay in the supposed practical achievements of his system.

A translation of a remarkable document by Lysenko himself was published in the U.S. recently by *Science*. It was a eulogy of Stalin written for *Pravda*, and in it Lysenko gave credit where credit was due. Stalin, he disclosed, was the real author of the Lysenko theories: "Comrade Stalin found time even for de-

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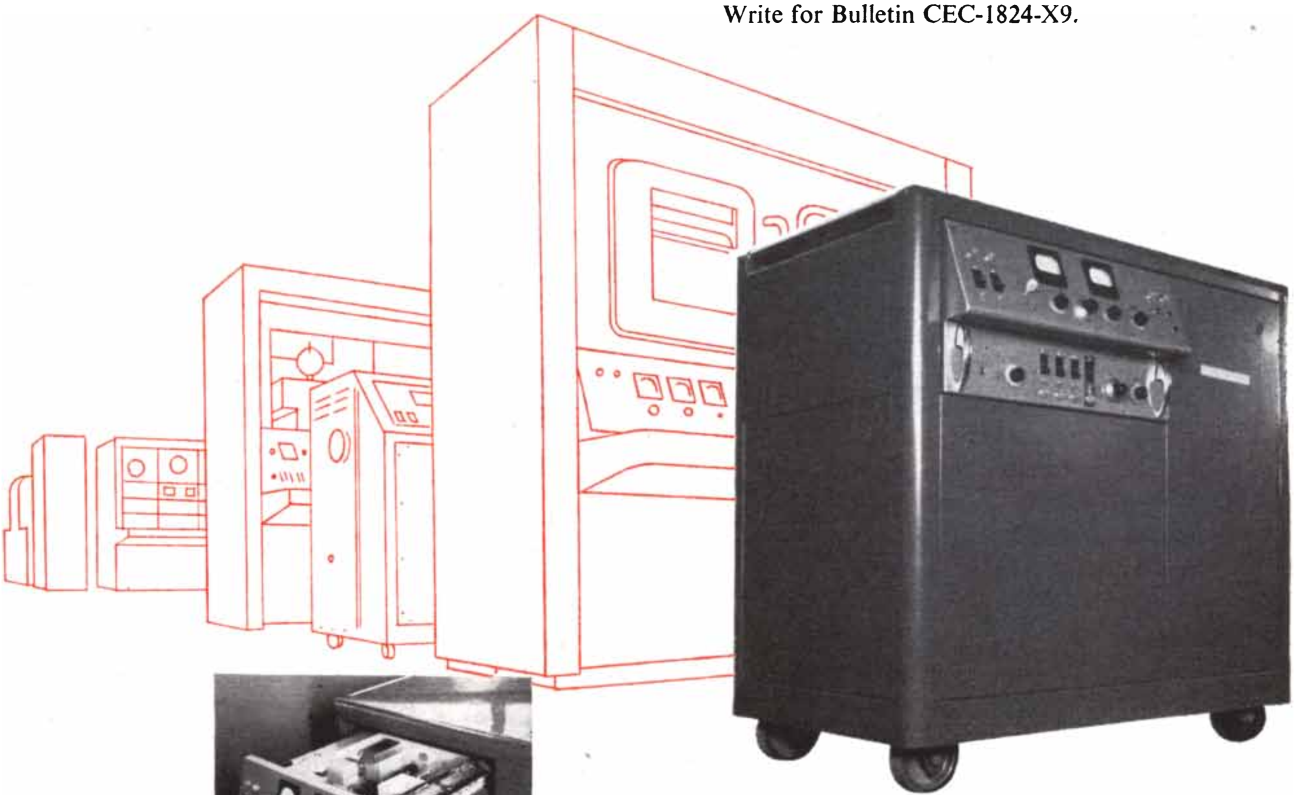
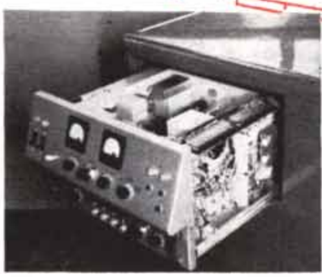
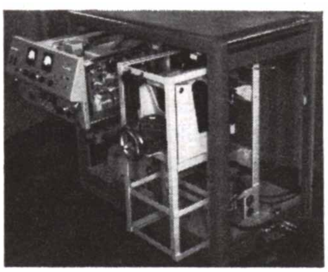
Write for Bulletin CEC-1824-X9.





All components are accessible: either by removing side panels or by pull-out chassis containing circuits and controls.



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analytical instruments for science and industry tailed examination of the most important problems of biology. . . . He directly edited the plan of my paper 'On the Situation in Biological Science,' in detail explained to me his corrections, provided me with directions as to how to write certain passages in the paper."

Standards Demilitarized

The National Bureau of Standards has been relieved of its weapons development and testing work, which had become more than half of its assignment. Secretary of Commerce Sinclair Weeks announced last month that four of the Bureau's technical divisions, with perhaps 1,600 employees, would be transferred to the Defense Department. The shift, said Weeks, will be "the means of strengthening the Bureau's basic program" of pure research and maintaining standards of weights and measures. It was recommended by Mervin J. Kelly, chairman of a committee now evaluating the Bureau's work and functions.

Medicine's Record in Korea

During the Korean war the death rate among U.S. casualties was cut to half of that in World War II (4.5 per cent), which itself had been the lowest in military history. U.S. Army medical authorities, announcing this record last month, gave the greatest share of the credit for reducing mortality among the wounded to the helicopter, which permitted prompt evacuation of wounded men to base hospitals.

Infectious disease also was much better controlled. The new drug primaquine almost completely eliminated malaria among U.S. troops. Improved vaccines greatly reduced smallpox and cholera. Dysentery and diarrhea were only half as frequent as during World War II, thanks to better sanitation techniques and to an improved chemical for sterilizing water.

Serious psychiatric disorders were cut to one-third the World War II rate by means of a new "first aid" method. Psychiatric officers treated disturbed men at the front, and often prevented crack-ups by prescribing a good meal, fresh clothes and a night's rest. Sixty per cent of the soldiers who got first aid returned to duty.

Fuel Revolution

Last year for the first time oil provided more of the energy used in the U.S. than did coal. Figures recently released by the Bureau of Mines give a vivid re-

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flection of the nation's fuel trend. From its 1917 high of 99 million tons, anthracite production fell last year to 40 million. Soft coal was down to 465 million tons from its peak of 630 million in 1947. In 1900 coal supplied about 90 per cent of the energy consumed in the U.S.; last year it accounted for 34 per cent, as against 39.4 per cent for oil, 22.5 per cent for natural gas and 4.1 per cent for water power.

The chief move away from coal has taken place in railroading, which once burned 132 million tons annually and last year used 38 million. The constantly expanding steel industry, however, is still completely dependent on coal, and the electric utility industry has raised its coal consumption from 27 million tons to 103 million in the past 20 years. Coal producers believe that research on new methods of mining, transportation and use will restore soft coal to a dominant position. They expect to sell 800 million tons annually by 1975.

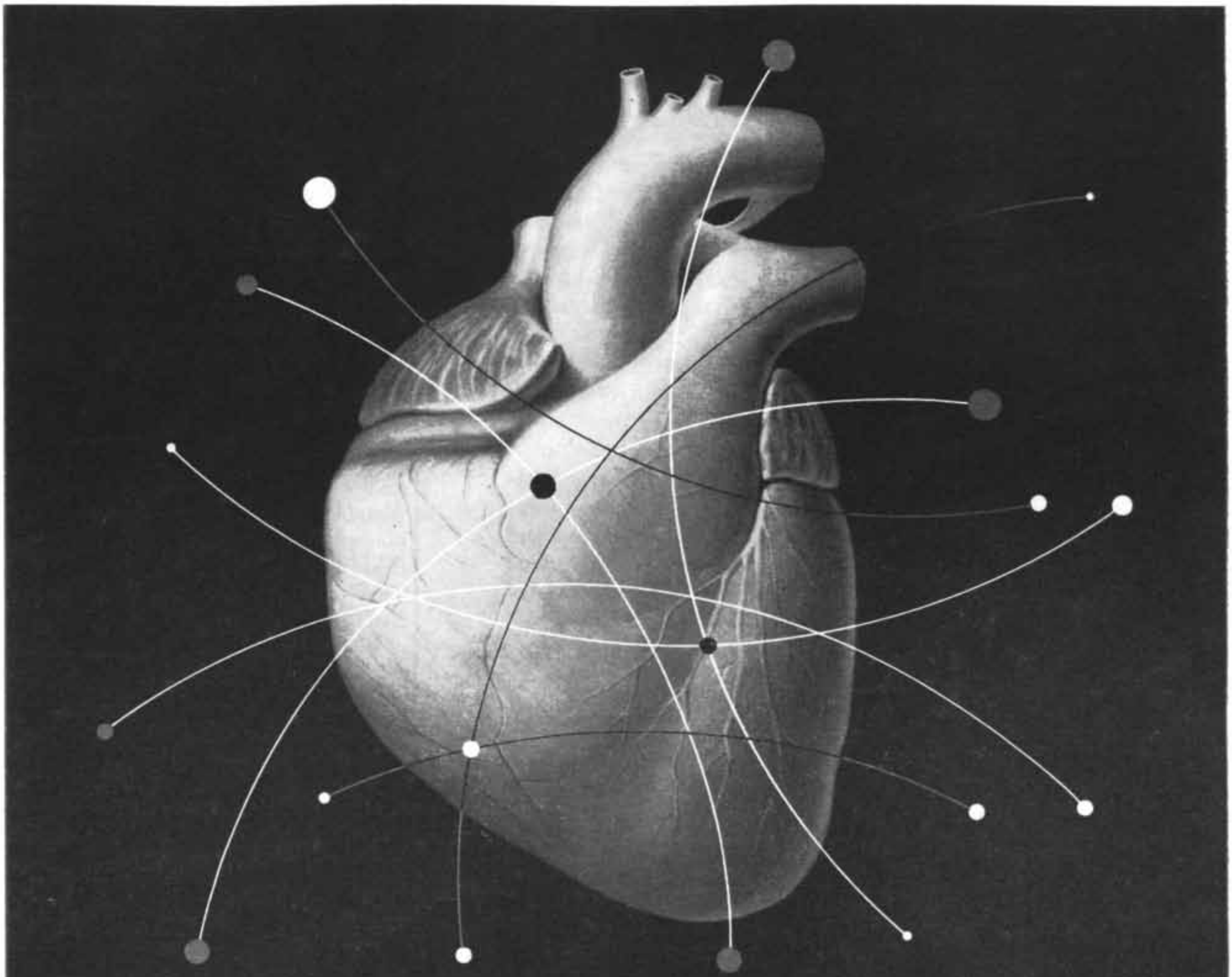
One Field?

Vaclav Hlavaty, a Czech refugee mathematician now at Indiana University, announced last month that he had solved Albert Einstein's new field equations and identified the all-unifying principle that some physicists have been seeking. According to Hlavaty, the picture of the universe is simpler than Einstein had expected. The electromagnetic field, he said, underlies everything; it explains energy, matter and gravitation. After some "further mathematical work" Hlavaty believes it will be possible to test his theory by experiment and also to reconcile relativity theory with quantum mechanics.

Asked by the New York *Herald Tribune* to comment on Hlavaty's work, Einstein said: "Dr. Hlavaty is working with great energy in the field of generalized gravitation theory. He tries to find methods for the solution of the field equations. The task is very hard and, as far as I know, no considerable progress has been made. Independently of this situation, I am convinced that any attempt to popularize this highly abstract matter in the daily press and otherwise can produce nothing but confusion in the minds of non-specialists. I will in any case not be guilty of participation in such endeavor."

Artificial V

V-particles, until now observed only in cosmic rays, have recently been produced artificially by the Cosmotron at



Diagnosis by Sound

The development of an ultra sensitive microphone by Altec engineers has done much to solve one of the basic diagnostic problems in medicine. By reproducing the sounds of valvular action of the heart this microphone has given early indication of organic malfunction. Similar microphones developed by Altec accurately measure the overpowering blasts of jet engines . . . indicating human tolerance of sound and measuring efficiency of engines. The Altec Companies are truly expert in diagnosis by sound.

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the Brookhaven National Laboratory. W. B. Fowler, R. P. Shutt, A. M. Thorndike and W. L. Whittemore report in *The Physical Review* that at least two "definite examples" of the mysterious V-particles have turned up in a series of 4,000 cloud chamber photographs of a high-energy neutron beam. The neutrons, emitted from a carbon target bombarded by a proton beam of 2.2 billion electron volts, passed through a lead plate and the steel wall of a cloud chamber. The Brookhaven physicists believe that the V-particles were produced either in the lead or in the steel.

V-particles (see "The Multiplicity of Particles," by Robert E. Marshak; SCIENTIFIC AMERICAN, January, 1952) get their name from the fact that they are unstable and break up into two components whose divergent paths in a cloud chamber look like an inverted "V". They come in neutral, positive and negative forms.

The two particles observed at Brookhaven were neutral. The negative part of the V into which they split was identified as a pi meson. The scientists are not quite sure what the positive branch was; its track resembled a proton's more than a meson's. If it was a proton, the energy calculations from the recorded tracks agree very closely with the figures from cosmic ray V-particles.

Although the Cosmotron reached the billion-volt energy range more than a year ago, its use as a research tool has barely begun. So delicate are the adjustments involved in its operation that most of its running time thus far has been devoted to tuning it up.

Ultrasonic Soldering

Aluminum would be a more useful material if it were not so difficult to solder. Its tough oxide coating prevents molten solder from "tinning" (alloying with) the metal. Removal of the film with a corrosive flux or by scraping has been tried without much success. The British have now found that ultrasonic treatment seems to do the job effectively. Sound vibrations at a frequency slightly higher than the audible limit of 16,000 cycles per second can break up the film in a fraction of a second and uncover the entire surface on which they act.

Leo Walter, a British engineer, described the process in the magazine *Materials & Methods*. The soldering iron contains a nickel rod within a wire coil. Nickel is a "magnetostrictor": it changes its length when subjected to varying magnetic fields. When a high-frequency alternating current flows through the

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coil, the nickel rod expands and contracts in unison with the alternations. The oscillating rod transmits these vibrations through the heated tip of the soldering iron to the aluminum surface, and they wear away the oxide film.

One of the chief uses of the method is in repairing aluminum castings with small cracks or holes in the surface, which up to now have had to be discarded because there was no way to fill the cavities.

Gas Chromatography

A new kind of chromatography which is said to be more sensitive than the liquid ion-exchange column has been invented in England by A. J. P. Martin, who won a Nobel prize for his previous work in chromatography, and A. T. James, both of the National Institute for Medical Research. It separates the compounds in a mixture in vaporized instead of liquid form.

The process takes place in a thin glass tube several feet long. The tube is packed with a claylike material called celite and is surrounded with a jacket through which hot vapor circulates. A sample of the liquid to be analyzed is forced through the column by a steady, gentle stream of nitrogen. As the mixture enters the heated column, it begins to vaporize. The components vaporize at different rates, and the nitrogen drives the successive vapors through the tube, with the most readily vaporized substance heading the parade and the others following in orderly fashion behind. Each substance signalizes its arrival at the end of the column by changing the color of a solution there. The color changes are detected by photocell, which records its readings on a rotating drum.

Martin and James say their "gas-liquid partition chromatography" method is faster and easier than ordinary distillation and can handle much smaller samples—as little as one hundredth of a gram. It has successfully separated liquids whose boiling points are only one third of a degree apart. The method makes possible longer tubes and hence more efficient separations than in liquid chromatography. Moreover, it is easier to detect changes in the composition of a gas than in a liquid stream.

Super Freezer

A refrigerating engine capable of maintaining a temperature of only three-tenths of one degree above absolute zero has been built at Ohio State University. Designed by C. V. Heer, C.


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B. Barnes and J. G. Daunt, its operation depends on a valve-like action of certain metals at very low temperatures. If a strip of lead is cooled to about one degree absolute, it can be switched from superconducting to the normal state by applying a magnetic field. In the normal state it conducts heat about 100 times as easily as when superconductive (the opposite of its behavior with electricity). Thus it can act as a "heat valve" by being changed from one state to the other.

The refrigerator consists of a paramagnetic salt (potassium chromium alum) attached by lead strips to the substance to be cooled and to a bath of liquid helium. The salt is the "refrigerant," taking the place of Freon in an ordinary refrigerating system. The operating cycle is as follows: First the salt is magnetized, while the lead valve to the helium is open (heat-conducting) and that to the refrigerated substance closed. As the salt molecules align themselves in the magnetic field, they give off heat, which passes to the liquid helium through the open valve. Then the valves are reversed, *i.e.*, the salt-to-helium strip is demagnetized and the salt-to-refrigerated material strip magnetized. Now the salt is demagnetized. The resulting disarrangement of its molecules absorbs heat, which is drawn from the refrigerated material through the open valve.

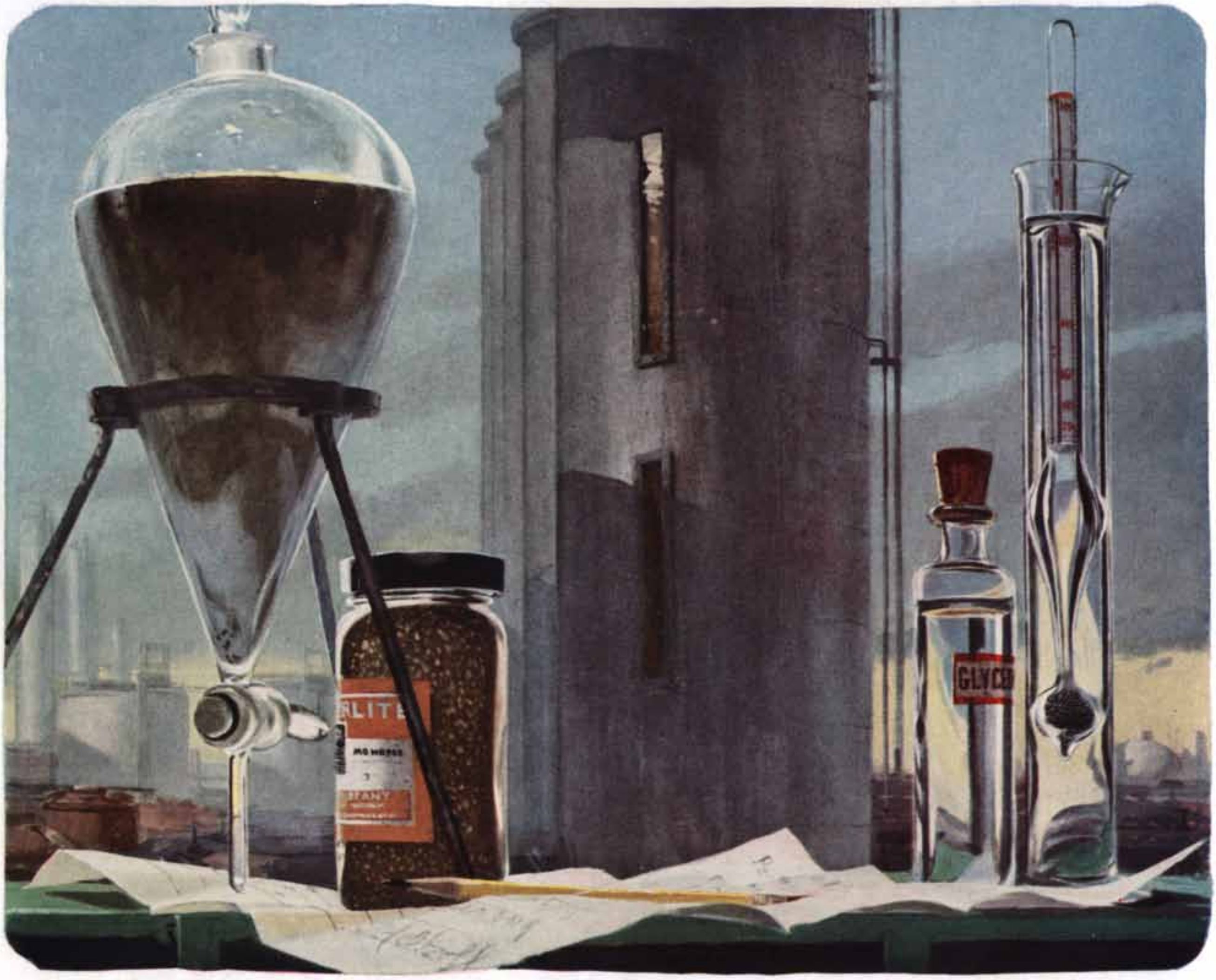
The Ohio State physicists, who report their work in *The Physical Review*, believe that the refrigerator can be refined to go to still lower temperatures. They plan to use it for making a visible helium bath and for experiments on nuclear magnetism at two-tenths of one degree absolute.

Vaccine for Brucellosis

A strain of bacteria that needs streptomycin to live has been found effective as a vaccine against brucellosis in animals, it is reported by Sanford Elberg and Mendel Herzberg, bacteriologists at the University of California.

The two experimenters had developed a strain of *Brucella* bacteria which metabolizes the antibiotic, and they planned to inject a live vaccine of this strain into animals along with streptomycin, then stop giving the antibiotic and thus starve the germs to death. In practice, they found that they did not need to give streptomycin at all. The bacteria apparently lived long enough without it to cause a mild infection and immunize the animals. The experimenters have had promising results with mice, guinea pigs and goats and are now trying the vaccine on monkeys.

NEW STANDARDS OF CHEMICAL PURITY



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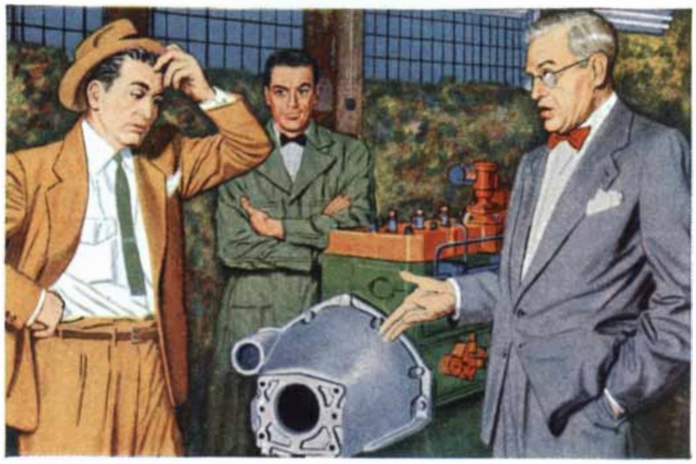

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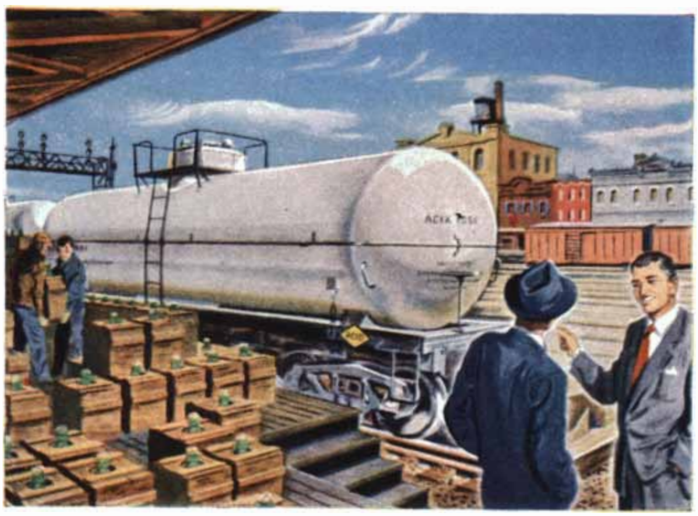

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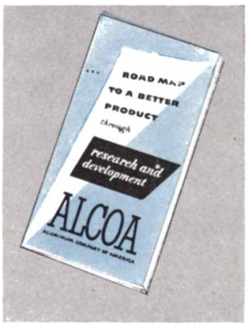

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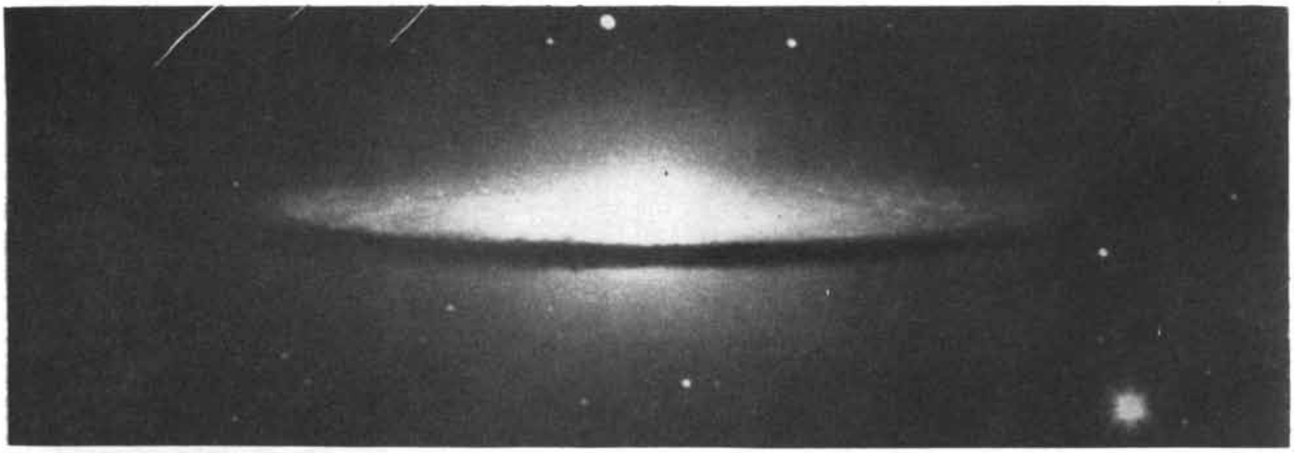
Why Do Galaxies Have a Spiral Form?

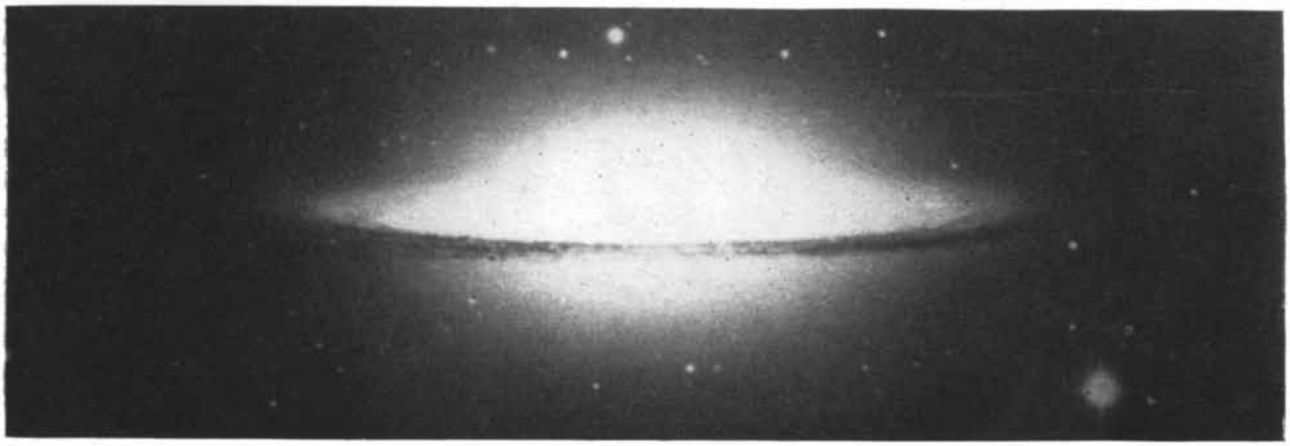
Some do and others do not, suggesting an evolutionary sequence. The answer awaits more knowledge of how the forces of turbulence and magneto-hydrodynamics affect the attenuated matter of space

by Cecilia H. Payne-Gaposchkin

Wherever we look in nature we can see spiral forms: the uncurling fern, the snail, the nautilus shell, the hurricane, the stirred cup of coffee, the water that swirls out of a washbowl. Perhaps we should not be surprised to see spirals in the great star systems whirling in space. Yet they remain a great, intriguing question. Why are some galaxies spiral and others not? What are the forces that make a galaxy take the shape of a gigantic pinwheel? Do the spiral galaxies give us clues to the evolution of the universe? These questions have stimulated the imagination of astronomers for 100 years.

It was just a little more than a century ago that the Irish astronomer William





TWO POPULATIONS of stars are demonstrated by these photographs of the galaxy N.G.C. 4594. The top photograph, made in blue light by the 100-inch telescope on Mount Wilson, tends to show Population I. The bottom one, made in red, shows Population II.

Parsons, third Earl of Rosse, looking through his 6-foot reflecting telescope in Parsonstown, first recognized a spiral nebula—the "Whirlpool" in Canes Venatici, the constellation of the Hunting Dogs that chase the Great Bear (Big Dipper) across the northern sky. Lord Rosse was immensely excited by his discovery. The spiral structure in nature always means growth, motion, change. As Lord Rosse remarked: "That such a system should exist without internal movement seems to be in the highest degree improbable." He thought that it indicated the operation in space of dynamical laws which "we may perhaps fancy to be almost within our grasp."

But the more Lord Rosse studied spiral nebulae, the "more mysterious and more unapproachable" he found them. With each increase in the power of telescopes the structure became "more complicated and more unlike anything which we could picture to ourselves as the result of any form of dynamical law of which we find a counterpart in our [stellar] system."

Lord Rosse did not know that our system, the Milky Way, is itself a spiral galaxy. Nor did astronomers yet realize that the faint nebulae shown by their telescopes were island universes like ours, at distances far greater than they had imagined. If there is change and evolution in those distant whirling galaxies, man will not be able to detect it in decades or centuries or perhaps even millennia of watching. Indeed, the absence of any visible change was one of the things that later helped astronomers realize how much vaster the universe must be than anyone had dreamed.

A century of work by astronomers has brought us little nearer than Lord Rosse to an explanation of the why of spiral galaxies. But we know a good deal about the how. We have examined their structure with our large telescopes and have made out many of the details. Because the spiral galaxies tend to be the

WHIRLPOOL NEBULA, the plane of which is perpendicular to our line of sight, reveals the spiral pattern in all its subtlety. Located in Canes Venatici, it was the first spiral found. This photograph was made by the 200-inch telescope on Palomar Mountain.

brightest and most conspicuous in the sky, it was first thought that most galaxies were spiral, but the big telescopes have disclosed increasing numbers of non-spiral ones. Today we can divide galaxies into three general types: irregular, spiral and elliptical. The suspicion is growing that these types represent three stages in the evolution of a galaxy. Most of the elliptical galaxies are small and faint; the spiral ones are nearly all large and brilliant.

For the study of spiral galaxies the great spiral in Andromeda is an unrivaled subject. It is probably the nearest to us, and certainly one of the largest and brightest. The Andromeda spiral has already yielded great prizes to astronomers. It was the finding of very bright Cepheid variables (pulsating stars) in the Andromeda spiral in 1925 that showed conclusively that the spirals were distant island universes. These same stars furnished the yardstick for measuring the immensity of galaxies—how immense they are was underlined only this year by certain observations which doubled all stellar distances. The spiral in Andromeda also yielded, through spectroscopic study, the secret of how fast galaxies rotate, and thereby made it possible to calculate their mass. Finally, the Andromeda spiral disclosed the existence of two distinct populations of stars in a galaxy, and that discovery has illuminated the whole problem of galactic evolution.

The two populations in the Andromeda spiral combine to give that system its characteristic appearance. Its spiral arms are composed of Population I—glowing gas clouds, dust and brilliant stars, the brightest of which are blue and about 100,000 times as luminous as our sun. The body of the galaxy, comprising about 90 per cent of its approximately 100,000 million stars, consists of Population II. These stars are much less bright than the blue stars of Population I: the brightest are red giants about 200 times brighter than our sun. The body of the

ANDROMEDA NEBULA is tilted at an oblique angle to our line of sight. Two million light-years distant, it is the spiral closest to our own Milky Way. This photograph, which was made by the 100-inch telescope, covers only the central regions of the galaxy.

galaxy has no spiral structure whatever. It appears quite featureless—a rather flattened mass greatly concentrated in the center and thinning out uniformly toward the edges. Where Population II is thickest, Population I is unknown.

What we see when we look at a photograph of the system is the graceful spiral arms. One of the first things we want to know is: In the whirling motion of the galaxy, do the arms lead or trail? Fortunately the great disk is tipped, from our point of view, at such an angle that we can tell which edge is tilted toward us and therefore should be able to determine in what direction it is turning. This is not true of many other spirals, which present themselves to us either on edge or perpendicular to our line of sight. Most astronomers agree that the arms of the Andromeda spiral trail.

The spiral coils are delineated by dark streaks whose ends are silhouetted against the galaxy's bright center. If we looked only at the supergiant stars of Population I we might miss the main point. The most significant fact is the close relationship between these stars and the dark material. Where dark material exists, there the blue supergiants are found, *and there only*. A searching study of the Andromeda spiral with the 200-inch telescope shows a chain of blue stars that seem to spring from the edge of the brilliant nucleus and to be neatly aligned along a wisp of dark material. As we move outward across the face of the system, we cross dark spiral lanes, with luminous stars imbedded in them. The intervening bare spaces are peppered with Population II stars. These gaps between the absorbing arms are so transparent that distant galaxies can be seen to shine through them.

The dark material is probably dust, and where there is dust there is likely to be gas also. Hot, luminous stars such as those in Population I excite interstellar gas clouds, causing them to glow, and we should expect the spiral arms of

IRREGULAR GALAXY in the constellation of Sextans is characteristic of what is suspected to be an early stage of galactic evolution. Some of the presumed later stages are depicted on the following pages. This photograph was made by the 200-inch telescope.

the system to be outlined by shining nebulae. So indeed they are, when we look for them in the right way. The nebulae should shine brightly in red light, which can pass most freely through the dust that obscures the blue radiations from the glowing gas. With photographic plates and filters attuned to the red light of hydrogen we can see strings of bright nebulae in the outer regions of the Andromeda galaxy—nebulae coiled in spirals almost as neat as those springing from the dark streaks near the nucleus. And where there are bright nebulae, there must be blue stars.

This is the picture of the Andromeda spiral built up by photographs made with the 200-inch telescope on Palomar Mountain. In most spiral systems the thickest dust clouds tend to lie along the inner edge of a bright spiral arm, though this is not easily perceived here. The absorbing streaks are forked and shredded into a pattern so complex, however, that attempts to trace any regularity have so far proved fruitless. Of the gross spiral arrangement there can be no doubt, but the structure does become more complicated, as Lord Rosse prophetically observed in 1850, with each successive increase of optical power.

The Andromeda galaxy is a large, luminous spiral of intermediate type. If, as has long been surmised, our own galaxy is like it, we should be able to duplicate and supplement these observations with studies of our own system. Three years ago Walter Baade of the Palomar Mountain Observatory, after describing the major features of the Andromeda spiral, remarked: "Another problem which we should be able to attack now is that of the spiral structure of our galaxy. . . . One guess we can probably safely make, that our sun is located in a spiral arm, because the brighter stars and the dust surround our sun in all directions along the Milky Way. I know . . . that you would like to see the arm or a piece of it demonstrated *ad oculos*. So would I." In the interven-

OPEN SPIRAL N.G.C. 2403 in the constellation of Camelopardus may represent a stage of galactic evolution later than that of the galaxy on the opposite page. Its arms suggest that they have just begun to form. This photograph was made by the 200-inch.

ing three years we have got our wish.

Several roads converged. The first was the well-trodden route already followed in tracing the outer spirals in the Andromeda system. By red-light photographs, a series of bright nebulae in the Milky Way was mapped. But their distances had to be measured by a roundabout laborious method which depends on locating the stars that illuminate the nebulae. Observers at the Yerkes and McDonald observatories first located three short sections of spiral "arm" in the Northern Hemisphere, and these studies are now being extended to the Southern Hemisphere. Local obscurations still impose formidable barriers, but the structure is gradually being patched together. As in distant galaxies, the spiral structure of the Milky Way has been found to be greatly complicated by forking and streaking.

Another route was by way of spectroscopy. The spectra of some distant stars in our galaxy are marked by traces of interstellar matter. Observation of the Doppler effect on light passing through this matter gives the speeds of its atoms. Light from distant stars shows several groups of atoms moving with different speeds relative to us. Here again direction is shown but not distance, which must be deduced from the galaxy's expected change in rotational speed relative to distance from its gravitational center. Since each group of atoms may

TIGHTER SPIRAL, N.G.C. 3031 in the constellation of Ursa Major, may be a stage still later than the one depicted on the preceding page. This photograph was made by the 200-inch.

be considered part of an absorbing lane, we can get a gross picture of the spiral arms outlined by dust clouds.

The third route has led to results so sweeping that it may well be the superhighway to future progress. It employs the relatively new technique of radio astronomy, probing the sky with radiation of a wavelength about 100,000 times greater than that of visible light. If there are atoms in space, most of them will be hydrogen, the commonest element. The hydrogen atom emits radio waves with a wavelength of 21 centimeters. Receivers tuned to this wavelength are now mapping the hydrogen gas pervading our stellar system. Distances are again deduced by a roundabout method, using the radial speed of the gases, accurately measured by tuning the receiver, along with the galaxy's expected changes of rotational speed with distance from its center. Because radio waves can penetrate interstellar dust much better than light, they open a wider field of observation. Several maxima of hydrogen emission already have been traced in convincing spirals more than halfway around the galactic circle. Better still, they confirm the more fragmentary pattern set by the bright nebulae.

We know without any possible ambiguity which way our own galaxy is turning. Hence we can tell whether the

STILL TIGHTER SPIRAL, N.G.C. 7217 in the constellation of Pegasus, somewhat resembles the elliptical nebulae on the succeeding pages. This photograph was made by the 200-inch.

arms lead or trail. If the districts identified by the bright nebulae, the absorbing atoms and the radio observations really are spiral arms, or sections of them, then the arms are trailing.

To sum up, a spiral galaxy consists of a body of Population II stars with a filling of Population I (gas, dust and stars) which is highly flattened and rotates more rapidly than the main body. The arms usually spring fairly symmetrically from the concentrated nucleus and coil about it with varying amounts of forking and shredding. The rotation at the edges is slower than near the center, just as the outer planets in the solar system travel slower than those near the sun. Hence the arms trail.

Take away all Population I material from a typical spiral galaxy, and you have an elliptical one; take away only Population II, and you have an irregular galaxy, though it will still show spiral arms. From this it is possible to conclude that the typical spiral galaxy represents a stage intermediate between the irregular and elliptical systems. One can go a little farther. Spiral arms contain blue supergiant stars, which are known to be relatively young. Moreover, the arms themselves cannot be old, for their rotational velocities must tear them to shreds in less than 100 million years. Irregular galaxies contain blue supergiants, so they must be young. Therefore only elliptical systems can be old. The order

GIANT GLOBULAR NEBULA, N.G.C. 4486 in the constellation of Virgo, may represent a stage of galactic evolution later than the spiral. This photograph was made by the 200-inch.

of development must be from irregular through spiral to elliptical.

Near at hand we can see a galaxy which may be beginning its spiral stage. The Large Magellanic Cloud has long been classed as irregular. It has all the characteristics of Population I: blue supergiants, bright nebulae, obscuring material. Placed beside a "barred spiral" galaxy, however, it shows an astonishing resemblance to the spiral system (*see photographs on pages 98-99*). The Large Magellanic Cloud also has some signs—an occasional nova, a few globular clusters, certain pulsating stars—of a developing Population II.

Yet all this is merely descriptive prologue to the main problem. We can analyze spiral systems into dust, gas and stars; we can even date them. We know far more about the structure and composition of spiral arms than Lord Rosse knew. But we still do not know why galaxies develop arms, still less why those arms take the spiral form. Recently hope for further progress toward the answer has been raised by two powerful new words in the astronomer's vocabulary.

The first of these is "turbulence." Perhaps the problem of galactic development will be solved in terms of gas turbulence. Gases, unlike dust, have viscosity or stickiness and move in irregular eddies when pushed beyond a certain

ELLIPTICAL NEBULA N.G.C. 147 is one of the two small companions of the great spiral in Andromeda. This photograph, made by the 200-inch, resolves individual stars in the system.

critical speed. Interstellar dust caught up in these eddies may outline them, just as smoke shows currents in air.

If we have analyzed the arms of galaxies correctly, they are fairly localized lanes of dust, which ride on atomic winds that blow about the galaxy with a rotational motion. But the theory of turbulence is at once powerful and treacherous, and its application to problems of galactic structure is still young.

The second new word in astronomy is "magneto-hydrodynamics." Interstellar space is now known to be pervaded by magnetic fields. Presumably they are produced by electric currents circulating in space. Modern theory begins to visualize a galaxy as a tremendous electro-

BARRED SPIRAL NEBULA N.G.C. 7741 (*left*), photographed by the 200-inch, is magnet, with currents of electrons flowing not through wires but through the viscous, turbulent eddies of gas swirling about its center. Electromagnetic forces seem competent to do what turbulence alone cannot do: they might form discrete arms and even lead to the formation of stars and clusters of stars.

The modern theory of a galaxy promises to be as intricate as the now richly observed structural details. Ten years ago in our hypotheses of cosmic evolution we were thinking in terms of gravitation and light pressure. Yesterday we realized that viscosity and turbulence had roles to play. Tomorrow we may contemplate a galaxy that is essentially a gravitating, turbulent electromagnet.

compared with the Large Magellanic Cloud (*right*), photographed at Boyden Station.

How Is a Protein Made?

These giant molecules are constructed in fantastic variety out of 22 amino acids. The mechanism of their synthesis is perhaps the greatest challenge facing the modern biochemist

by K. U. Linderstrom-Lang

Proteins make up a large part of every living organism and play a central role in all of its vital processes. There is hardly an activity of the living cell in which they do not take a leading part. In the nucleus of the cell they are believed to be partners of the nucleic acids in exerting genetic control over the cell's development. In the cytoplasm they form the great system of enzymes which catalyzes and directs the cell's chemical processes. And as constituents of various cell granules, such as mitochondria and microsomes, they serve as agents for many special functions. Above all, proteins possess the property which particularly distinguishes living matter: they assist in and control their own reproduction.

It is no wonder that many consider the problem of how proteins are made the most important question in the study of life. It is also no wonder that it is probably the most difficult question. Proteins are the most complex molecules we know. All of them are composed of just a few elements: mainly carbon, hydrogen, oxygen, nitrogen and sulfur. But proteins are very large molecules, and they can combine these few elements in a multitude of different structures. Each type of cell, each organ of the body, makes its own specific kinds of proteins, and these differ in every species of living thing. The name protein, originated by the 18th-century Swedish chemist Jöns Jakob Berzelius, was taken from the Greek word *prōteios*, meaning of the first rank. But because the proteins are so rich in form and function, so varied in molecular size, shape, composition and properties, one is tempted to violate history and derive their name from Proteus, the Greek god of the sea who could assume any shape he desired.

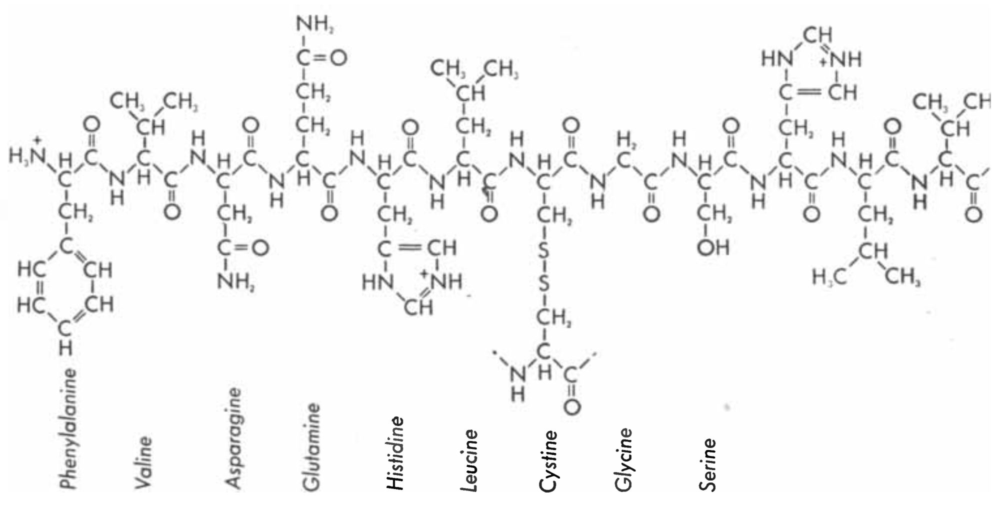
Indeed, the number of possible shapes that proteins might take is so vast that a mathematical brain might conclude that from a statistical point of view life is completely improbable. How does the cell build exactly the structures it needs, rejecting the huge number of alternatives statistically just as probable?

A cell builds proteins from simple molecules it takes from its surroundings. To do this it is supposed to require energy, which is delivered by metabolic reactions involving the same molecules that serve as the building blocks. The problem of how the cell synthesizes proteins has two aspects: (1) Why does it need energy and how is the energy used? (2) What is the nature of the selective mechanism by which the cell manufactures from the disordered nutritional material just the proteins it needs?

Before taking up these questions it is necessary to understand something of the structure of proteins [see "Proteins," by Joseph S. Fruton; Scientific American, June, 1950]. We owe our knowledge of protein structure to a great number of scientists who have worked on it over a period of half a century. Much of this brief review will be based on recent findings by Frederick Sanger at Cambridge University and by Linus Pauling and his co-workers at the California Institute of Technology.

Proteins are built up of amino acids, which unite, with a loss of water, to form peptide chains. The backbone of a peptide chain is the sequence –C-C-N-C-C-N-C-C– (*see diagram on the opposite page*). It is linked together by "peptide bonds," occurring between CO and NH groups in the chain. The amino acids form side chains attached to the backbone. Since 22 amino acids are known to occur in proteins, there may be as many as 22 different side chains. The peptide chain may be very long: sometimes 300 to 400 amino acids are strung together in a single chain.

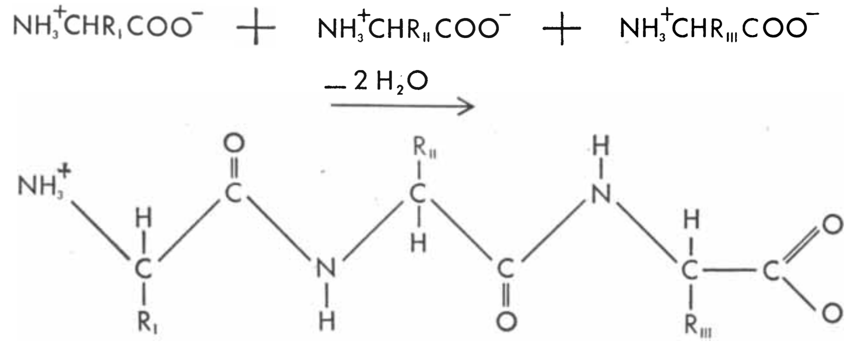
The hormone insulin is a good ex-



PROTEIN COMPLEXITY is illustrated in this formula for one of two peptide chains in the much-studied protein molecule of insulin. The long chain running across the page is a

ample of the specificity of the proteins' structure and of the great wealth of possible forms they might take. Insulin is manufactured by cells in the Islets of Langerhans in the pancreas. Its molecular structure is known to consist of two relatively short peptide chains, one with a molecular weight of 2,400 and the other 3,600. They are called the A-chain and B-chain, respectively. The B-chain is pictured in the diagram below. Superficially one can see no regularity in its make-up; just why the chain must have the particular sequence that it has in order to act as insulin is a secret still held by the cell. In synthesizing this chain the cell rejects a large number of other possible structures which it might make from precisely the same proportionate amounts of the same 16 amino acids. In fact, 6 times 10^{59} different arrangements might be made simply by shifting the sequence of the amino acids along the chain. If a batch of B-chains were prepared containing just one molecule of each of these possible kinds, its total weight would be about 1,000 billion times that of the earth! And this is a relatively short chain of a relatively light protein.

The peptide chain may be called the primary structure of proteins. Recently it has been found that in most proteins the chains are not straight but curled up in the form of a spiral or helix. This may be called the secondary structure, characterized by side chains sticking out from a relatively dense core. The molecule is held in shape by the well-known hydrogen bonds between the backbone's CO and NH groups. Many proteins are believed to consist of groups of associated helices, held together in parallel by chemical bonds or by general molecular forces. In the insulin molecule, for instance, the A and B chains may be short helices linked together by sulfur-sulfur bonds of the amino acid cystine and stabilized by physical forces. This tertiary type of structure can form huge proteins with a molecular weight of 48,000 or more.

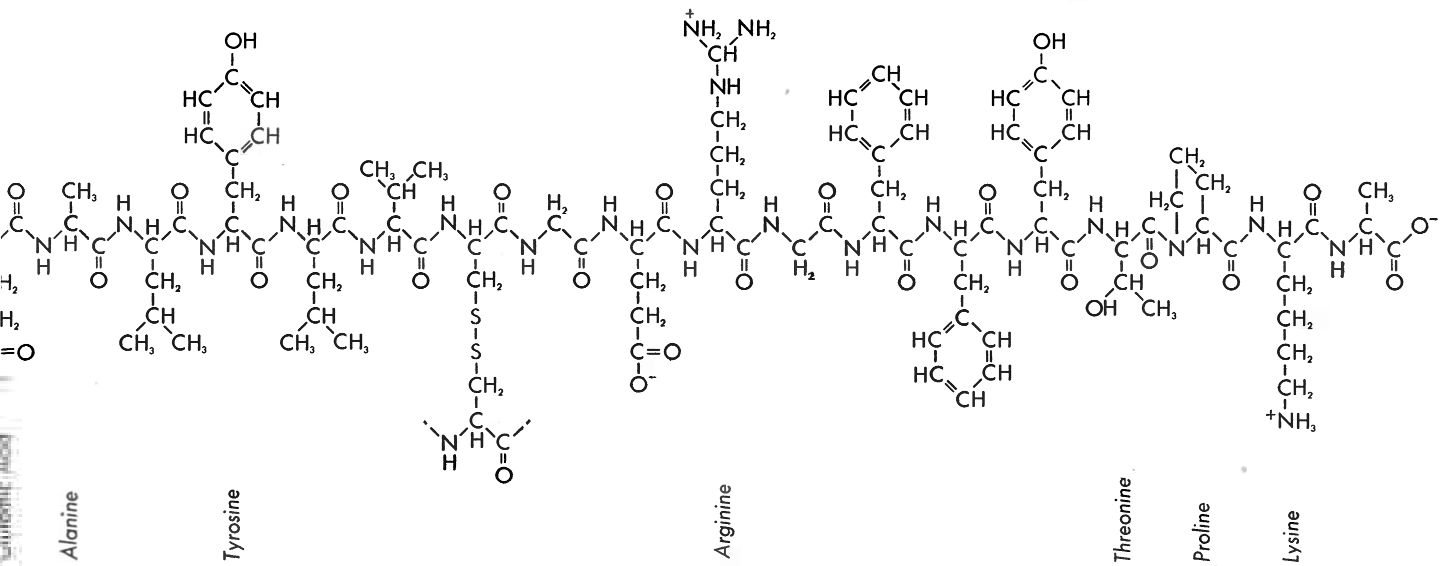


BACKBONE of a protein is this peptide chain formed with loss of water from carbon dioxide (CO) and ammonia (NH) groups in amino acids. R represents amino acid side chains.

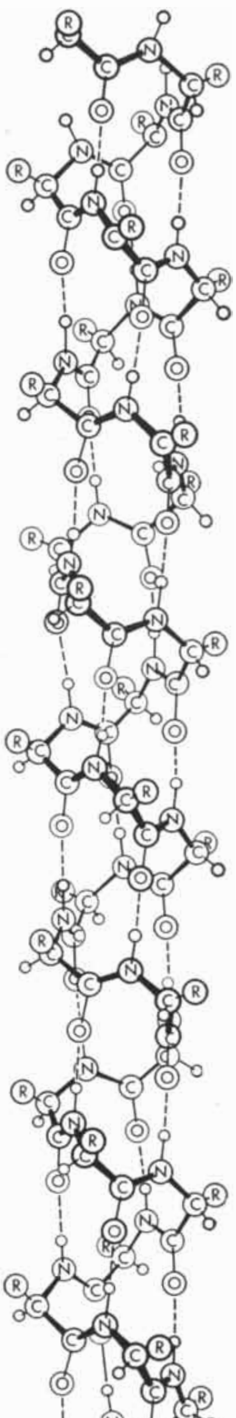
Whether the most important step in protein synthesis is the formation of a plain peptide chain with the proper sequence of amino acids or the folding of the chain into secondary or tertiary structures is a question that must be left open. Apparently the selective mechanism that determines the structure exerts itself most decisively in the establishment of the sequence of amino acids.

Let us now consider the sources of the energy involved in protein synthesis. The crux of the energy problem is in the making and breaking of the peptide bonds. Specific catalysts in the cells, called proteolytic enzymes, speed up both the opening and the closing of peptide bonds. The detailed mechanism of the catalysis is not yet known, but it is believed that the enzyme combines with the reacting materials or with the protein in a lock-and-key fashion to make the synthesis or breakdown possible (*see illustration at top of page 104*). Amino-acid side chains play an important part in this lock-and-key system. Different proteolytic enzymes, each having a different specificity or fit, combine with different side chains, thereby catalyzing the hydrolysis of different peptide bonds.

The synthesis of peptide chains from amino acids is a far less "likely" process, in chemical terms, than the reverse, that is, the splitting of peptide bonds. When submitted to the catalytic action of a suitable mixture of proteolytic enzymes, proteins are completely broken down to amino acids—a process that occurs in our



repetition of the peptide backbone (*top of page*), with 16 different amino acids linked in as side chains, giving the molecule its particular form and character. Since all 22 amino acids may form side chains, the number of their possible combinations is astronomical.



STRUCTURE of a peptide chain in three dimensions may have the form of a helix. The helix above, proposed by Linus Pauling and Robert B. Corey of the California Institute of Technology, has 3.7 amino acids per turn.

digestive tract after we eat protein. Processes such as the breaking of peptide bonds are known to give up "free" energy in the form of heat, just as the potential energy of a load allowed to fall from one level to another is transformed into heat. How, then, does the cell provide the energy to reverse the process? It does it by coupling the unlikely process of synthesis with a likely process which carries it along, as a load may be lifted by means of a heavier one, using a rope and pulley. The cell seems to have two different methods of driving the synthesis reactions: it can either push or pull them. In the first case the energy required is put in before synthesis; in the second, afterward *(see schematic illustration at bottom of page 104)*.

The following series of reactions illustrates one way in which the pushing process may work. To begin with, energy is put in by the oxidation of phosphoglyceroaldehyde, an important intermediate compound in the metabolism of carbohydrates. When it is oxidized, this compound is coupled by a likely enzymatic reaction with inorganic phosphate to form phosphoglycerylphosphate. The latter then delivers its phosphate, again by a likely enzyme reaction, to adenosine diphosphate, forming phosphoglyceric acid and adenosine triphosphate (ATP), the famous biochemical energy carrier. In the third step ATP delivers a phosphate to an amino acid, thereby creating an amino acid acylphosphate. Finally, in a fourth step this amino acid reacts with another, liberating inorganic phosphate and forming a dipeptide.

The last two steps are still rather hypothetical, but ATP is known to act as a phosphate carrier to effect the formation of a peptide bond in the synthesis of the peptide glutathione and certain other cases. So far, however, no enzymes able to catalyze these steps have been isolated. It is unlikely that proteolytic enzymes can do the job. They can, however, catalyze reactions in which an amino acid breaks into a peptide and expels one already there. Such a shunting process can proceed in both directions practically without change in free energy. It produces no net synthesis. However, it can rearrange amino acid sequences. Sometimes long-chain peptides may be built up stepwise by the breakup of a series of dipeptides to add members to the chain. This is called transpeptidation.

The foregoing is but one example of the many processes by which the general metabolism of the cell furnishes energy to make the synthesis of proteins possible. We come now to the second major

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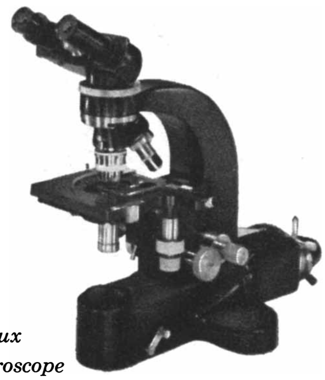

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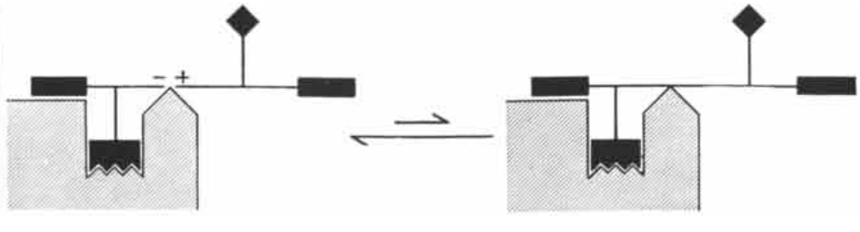


LOCK-AND-KEY system of enzyme catalysis may make or break peptide bond. Shaded area is proteolytic enzyme fitting peptide side chain and reversibly opening or closing the bond.

question: How does the cell's selective mechanism work to form specific proteins?

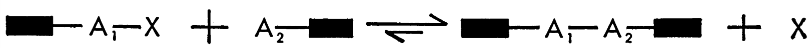
The enzymes that catalyze the steps in the synthesis of a protein are themselves proteins; hence there is an element of self-reproduction in the synthesis. Since the enzymes are specific for each reaction step or group of steps, a certain selective mechanism is implied in the pattern of enzymes in the cell. But the enzymes in cells of different organisms seem to be very much alike, and their range of specificity is broad: they are keys, but in many instances pass-keys which fit a number of different locks. This is true even of the proteolytic enzymes.

We must therefore look for some basic principle that can permit the cell to exercise a much finer selection. Here we must resort to conjecture, for this is a field in which little is yet known. The British biologist J. B. S. Haldane and others have suggested a hypothesis which seems to have much in its favor. They compare the synthesis of a protein to the making of replicas of a sculpture by the mold and cast method. Certain known processes of synthesis, especially the formation of antibodies and viruses, do

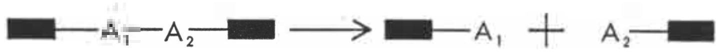
How a Cell May Supply Energy for Synthesis of a Protein

When the synthesis is "pushed," an amino acid ■—A_1 *reacts with an energy-producing substance* X—B *in a likely process:*

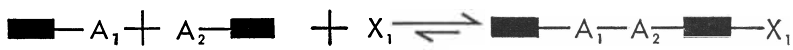
The product ■—A_1—X *then reacts with another amino acid* A_2—■*:*



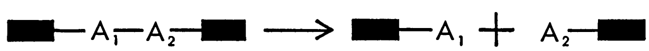
The condition for a good yield of this product is that the fall in free energy of the process of separating X and B is greater than that of the breakdown of the product:

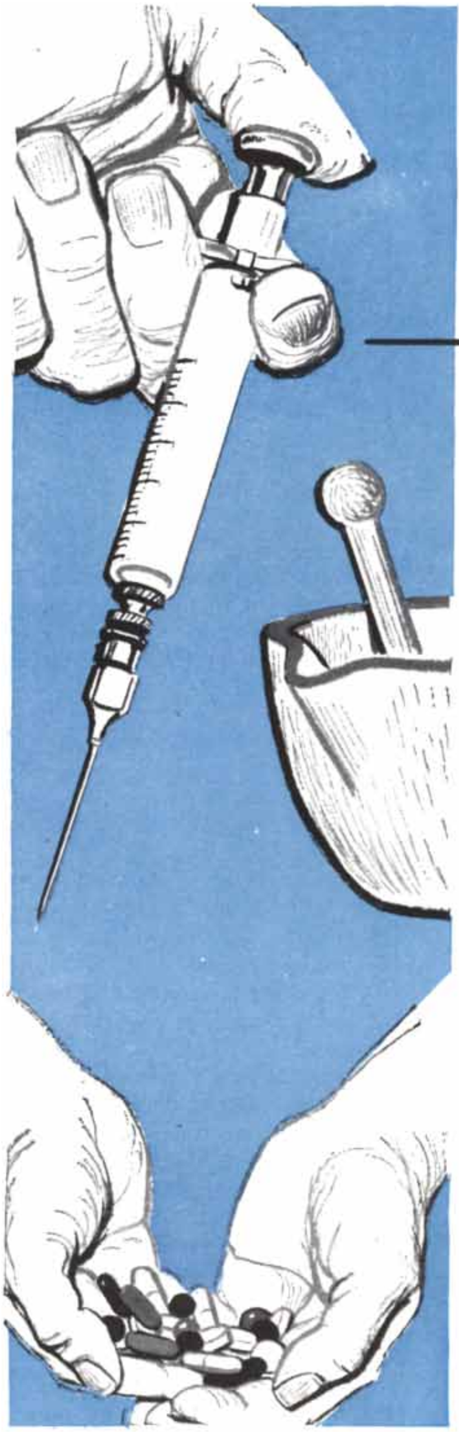


When the synthesis is "pulled," the two amino acids are first combined with a substance X_1*, and the product then reacts with a substance* B_1*:*



The condition for a good yield of this synthesis is that the fall of free energy of the process which combines X and B is greater than that of the breakdown of the product:





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indeed resemble such a procedure, with the cast closely fitting the mold and reproducing it in great detail.

We may assume that both the mold and the cast are proteins, which are interchangeable or perhaps even identical. The cast is fitted to the mold by means of the pairing of amino-acid side chains. Not only do their molecular shapes fit each other, but they are drawn together by attractive molecular forces such as we have already mentioned. The complete mold or cast, however, is built not from single amino acids but from peptides as the structural elements. The appropriate peptides are drawn from a "pool" according to their fitness to the mold. The formation of the peptide bonds joining them, which requires relatively little energy, is assumed to be effected by a non-specific proteolytic enzyme assisted by a synthetic pull of the "likely" process of adjustment of the cast to the mold. The cast is then pulled from the mold by some unspecified mechanism without disturbing the primary structure of the molecules. Possibly the peptide chain's development into secondary and tertiary structures has something to do with its separation from the mold.

It should be emphasized that this picture, which is inspired by certain suggestions recently put forward by the English biochemists J. D. Watson and F. H. C. Crick, entirely neglects the question of the part played in protein synthesis by the nucleic acids. These interesting substances, which have a backbone composed of carbohydrate and phosphate, are considered by many workers to be active synthesizers. The Belgian investigator Henri Chantrenne suggests that they may effect specific peptide-bond synthesis by phosphate transfer after the manner of ATP, to which they are closely related. However, the fact that nucleic acids are genetic regulators, that they are present in cells whenever protein synthesis occurs, and that they are important as transforming factors and as initiators in virus formation does not necessarily mean that they participate intimately in the synthesis of the primary peptide chain. They seem to be far too unspecific for this process, if what we have learned from the insulin molecule turns out to be valid for other proteins as well. It seems more likely that their providential control of living form and of cell differentiation originates in a balanced interplay of activation and suppression of possibilities inherent in the assembly of proteins in the cell. The manner in which this control is enforced, however, is obscure.

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How Do Cells Differentiate?

An unspecialized egg gives rise to all the specialized tissues of an organism. The study of this marvelous phenomenon engages two disciplines of the modern biology: embryology and genetics

by C. H. Waddington

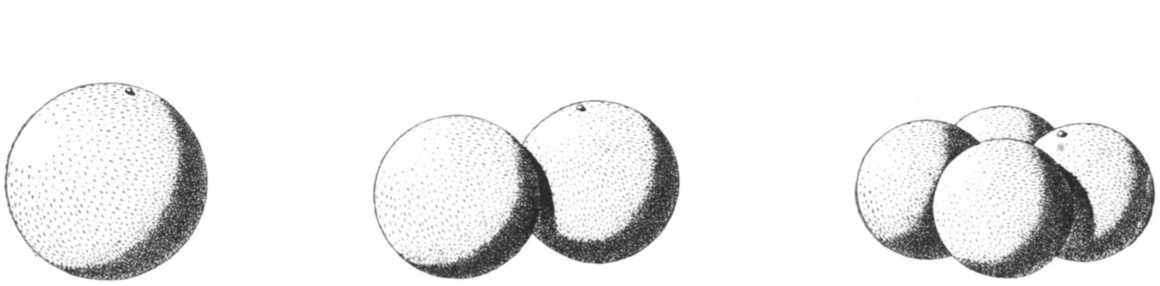
How is it that a single fertilized egg, a tiny blob of apparently formless protoplasm, can become a man—with eyes, ears, arms, legs, heart and brain? How from one generalized cell do we get the myriad of different specialized cells that make a human body? This puzzle, differentiation, is of course one of the great questions of biology. The process of differentiation has always seemed particularly mysterious because there are so few phenomena in the non-living world that might give us clues as to how it takes place. In the inanimate realm we do not often come across a situation in which parts of a single mass of material gradually diverge from one another and become completely distinct in character. Yet in all living things, except perhaps the viruses, differentiation is a basic law of nature.

For half a century biologists have been searching for the answers to this question by two main methods of attack: the modern sciences of embryology and genetics. On one hand they have been investigating directly by experiment how the embryo develops, and on the other they have studied how the genes control the processes of development. Let us start with the embryological approach.

The problem was bogged down for a long time in a debate between two theories first described by Aristotle in the fourth century B.C. One school argued that the newly fertilized egg contains all the organs of the animal in miniature, and that these preformed parts merely grow and enlarge to produce the adult. The second view, supported by Aristotle, was that the organs are formed only gradually by interaction among simple parts or constituents of the egg. Aristotle called this process "epigenesis," and epigenetics is still an appropriate name for the embryological approach to the problem.

When modern investigators began to experiment on animal embryos, they seemed to find support for both of the ancient theories. They cut an egg of a simple animal in half, or removed a part of the egg, and let the remaining part develop. In some types of animals, the fragment of egg developed into an adult with certain parts missing, which suggested that the egg contained preformed and rather rigidly localized rudiments of the adult organs. On the other hand, in other cases a complete and normal adult grew from the amputated egg. It was clear that epigenetic interactions must have taken place in these eggs.

The first experimenter to carry out a controlled study of such interactions was the German embryologist Hans Spemann, of the little Black Forest town of Freiburg. He operated on early embryos of the common newt. As the eggs of this animal develop, the first visible structure to appear is a small depression, called the blastopore, which eventually will become the main part of the intes-



PRELUDE TO DIFFERENTIATION is depicted by the early stages in the life of the marine animal Amphioxus. In the first drawing is the fertilized egg. In the second the egg has divided into two cells. In the third the two cells have divided into four. In the fourth tine. Spemann cut out the region of the blastopore from one egg and grafted it into a second egg in a different position. There it not only continued to develop but influenced the cells surrounding it. They then became the main organs of the embryo, *e.g.*, the central nervous system and the rudiments of the spinal column.

Here was a clear-cut case of exactly the kind of interaction suggested by the epigenetic theory. Spemann called the blastopore region the "organizer" of the embryo. Soon organizers very similar to the one he had discovered in his salamander were found in many other classes of vertebrate animals. Such organizers were found to be responsible for the formation not only of the main embryonic axis but of many secondary organs which arise rather later: the ear, the nose, the lens of the eye, and so on. Sometimes the organizer region is relatively sharply demarcated and precisely localized. In other eggs it may be more diffuse, and the interactions may take place in a graded way, one end of the region being more powerful than the other. But in either case, the development of organs is determined by the interaction between some dominant part of the egg and its more receptive surroundings.

Now an organ has two aspects. It consists in the first place of specific types of tissue, which can come into being only by differentiation of the cells. But further than that, the tissues in an organ are arranged in certain relations to one another that give the organ its characteristic shape. Of course in the last analysis the shape of an organ presumably is an expression of the nature of the tissues composing it, but it is convenient to make a rough distinction between the formation of specific tissues and the molding of these tissues into organic structures. Most recent work has concentrated on the first of these problems: the nature of the chemical processes by which the embryonic cells become differentiated.

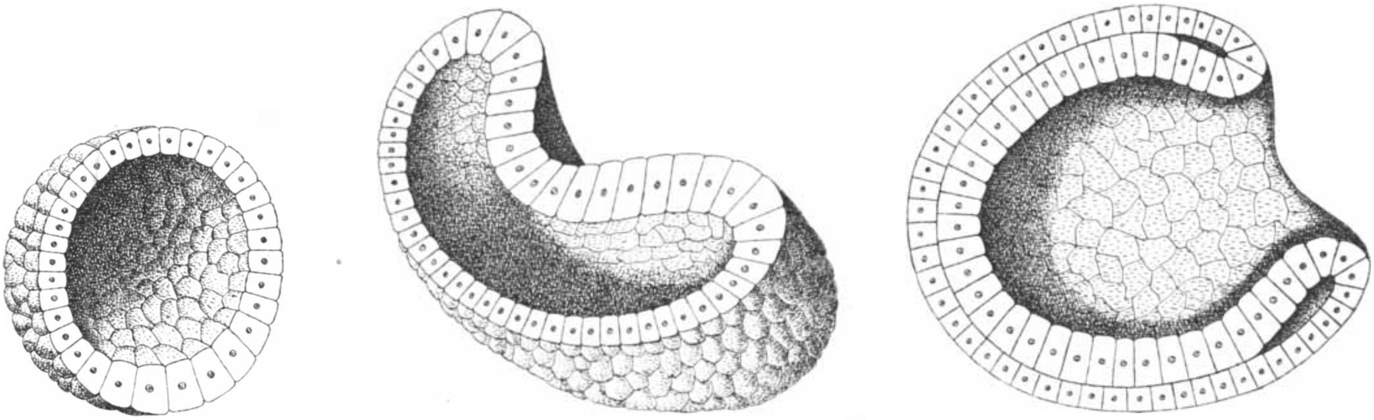
It was natural to suppose at first that the organizer could act only as a living entity. But in 1932 it was discovered that an organizer is able to influence its surroundings even after it has been killed! This discovery was made simultaneously in the newt embryo by a group of German workers including Johannes Holtfreter (who is now at the University of Rochester) and in the chick embryo by myself at Cambridge University. It seemed that we might be on the verge of a critically important advance: that the influence of the organizer on development might be traced to some chemical substance which could be extracted from it. Several groups of workers tried to identify the substance, but their hopes were too optimistic and their picture of the situation too simple. The trouble is not in finding a substance that will act like the organizer in inducing cellular differentiation but that *too many* substances will do just that. Within a year or two Joseph Needham, Jean Brachet and I had proved conclusively that methylene blue, a substance which cannot by any stretch of the imagination be supposed to exist in the normal embryo, will bring about the formation of nerve tissue when injected into the embryo. It seems useless to look for some master substance in the cells which will give us the key to the understanding of differentiation. The place to study differentiation is in the reacting tissue, which actually carries out the differentiation. Only during a certain period of development is this tissue able to react to the organizer stimulus; it is then said to be "competent." The way to a deeper insight into the nature of development is through a fuller understanding of competence.

It is here that the hereditary genes come into the picture. In all likelihood the competence of the cell for differentiation is a complex state of affairs, involving many different chemical systems. We know that there are many genes in the nucleus of a cell and that each gene controls the formation of one or more of the substances produced as the cell develops. Thus the set of gene-controlled processes must be the system of reactions involved in the state of competence.

The most obvious question to ask is: What is the nature of each individual gene reaction? But, before considering that, there is another point which may be almost as important and is perhaps easier to approach. We are dealing with a complex system of reactions, one starting from each gene, and finishing up with all the numerous constituents of an adult tissue. Do any general features characterize the system as a whole?

There is one important general feature. An adult animal consists of a number of different organs and tissues which are sharply bounded off from one another. The liver does not merge gradually into the pancreas and that into some other organ. Cells develop into one type or the other; they do not form graded intermediates. Further, there is a strong tendency for these normal end-products to be produced even if conditions during development have been somewhat abnormal. We can, for instance, cut pieces out of the embryo or cause other experimental alterations, and the embryo will still produce a normal adult.

This means that development must be



drawing, after more divisions, the cells are marshaled into a hollow ball called the blastula. In the fifth one side of the blastula has begun to turn inward. In the sixth the cells form a cup called the gastrula. The hole at the right of the gastrula is the blastopore.

ORGANIZER is demonstrated by grafting a piece of the blastopore region from one newt's embryo into another. In the first drawing the original blastopore is at the bottom; the graft is at the dark spot at the top. In the second and third drawings the graft rolls into the interior of the embryo. In the fourth drawing the horseshoe-shaped structure is the rudiment of the central nervous system induced by the graft. At the bottom right is the nervous system of the original embryo.

organized into a number of distinct systems. One system of processes will bring about the development of, say, the nervous tissue. A different system will produce liver or kidney or some other tissue of the body. Moreover, each system must be stabilized in some way so that it gives its normal end-product even if it has to go by an unusual way to get there.

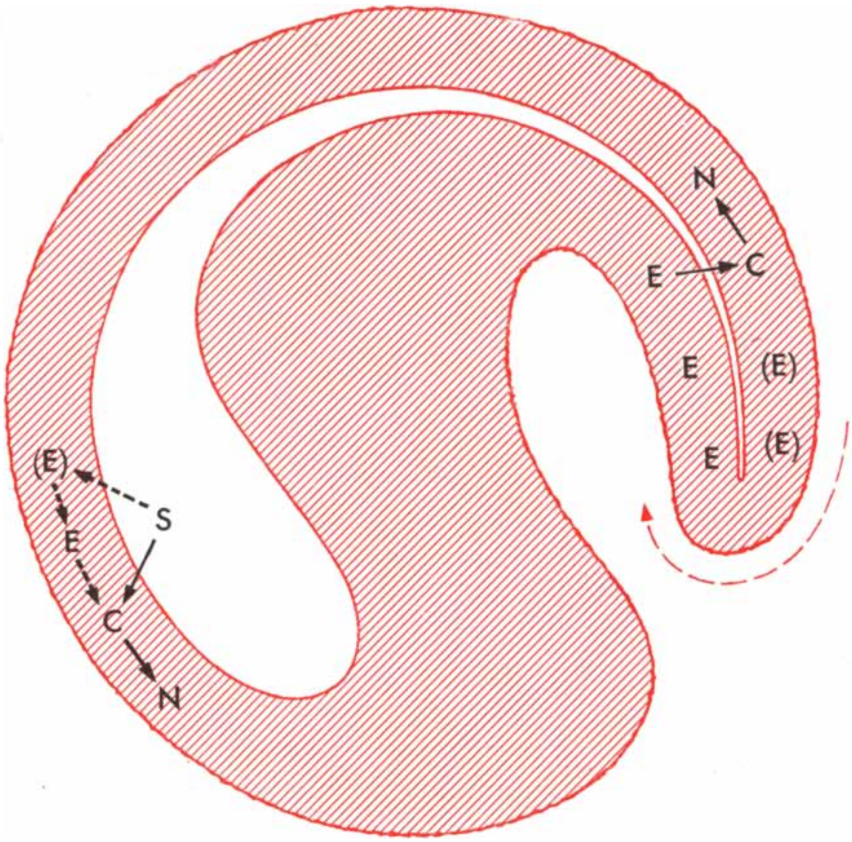
This shows us the kinds of facts we have to account for. One of the great tasks for embryology in the immediate future is to explore the ways in which systems with properties of this kind can arise. There are several different ways by which we could seek to account for the fact that development is channeled into separate, distinct pathways. For instance, if the product of the reaction itself makes the reaction go faster—that is to say, if the processes are autocatalytic—it is easy to see that once a process has begun to form a particular product, that product will encourage the process to go still further in the same direction, and thus exclude any other possible product. Similarly, if the product of one reaction inhibits the progress of some other reaction, then as soon as the first process gets under way it will tend to prevent the second from occurring. Common sense is enough to offer certain general suggestions of this kind, but we badly need a thorough theoretical study of the various conceivable types of interaction between processes. Beyond that, we need an experimental analysis of developmental processes, aimed at discovering which of the theoretical possibilities are realized in practice.

For the self-regulating feature of the embryo's development, we can find models in the field of engineering: automatic ships' compasses, automatic pilots and other feedback mechanisms for which the name of cybernetics has recently become fashionable. In cell differentiation we must be dealing with chemical cybernetic systems. The properties of biological enzymes should make it possible for such systems to be built up in several different ways, but we still know remarkably little about them. Very probably much of the work required to understand these systems will be done on systems of isolated chemical substances which may at first sight seem to have little or nothing to do with embryology.

I have found it helpful to make a mechanical picture of the set of differentiation systems, each of which leads to one definite end-result and is balanced internally by some sort of cybernetic mechanism. Let us imagine the cells as a group of balls perched on the top of a slope. On this slope we may suppose there is a radiating system of valleys. As each ball rolls down, it must pass into one valley or another. Once it has started down a given valley, its fate (the end-product it will become) is determined, for it will be very unlikely to roll over the intervening hill into another valley, and even if some abnormal condition temporarily pushes it part way up the bank, it will tend, like a bobsled, to slide back to the bottom of its chute and continue its normal course. I have used the name "epigenetic landscape" for this picture of the developing system.

Our other principal task is a detailed study of the chemical processes that go on in a cell as it moves from its embryonic beginnings to its final differentiated state. When it was discovered that many substances could act like the organizer to induce differentiations, most people argued that they must be acting in a secondary way. Suppose that all the cells of the embryo contain some substance which can induce the formation of, for instance, nervous tissue. Suppose further that in most cases this substance is concealed or inactivated, but that it can be liberated by certain types of cell metabolism. Then one would expect that the organizer gets its peculiar properties from its specific metabolism. Following this line of thought, several groups of investigators have measured the metabolism of the organizer against that of other regions of the egg. They have duly found that the organizer has certain special metabolic characteristics, and it is quite clear that these are essentially involved in its developmental activity. For instance, in the eggs of the sea urchin the fundamental developmental system consists of two gradients of activity, one of which is most powerful at the upper end of the egg, the other at the lower end. The thing that varies along these gradients is the intensity of processes of cellular metabolism, and on these variations depends the differentiation of the parts of the egg.

Eggs and embryos are, of course, exceedingly small things, and the technical difficulty of studying the metabolism of parts of the egg is very large indeed. Some subtle types of supersensitive apparatus have been worked out which enable one to operate with minute quantities of material. One of the most refined is the well-known Cartesian diver. This old toy, which apparently has nothing to do with the French philosopher Descartes, after whom it is named, is a tiny vessel of thin glass with



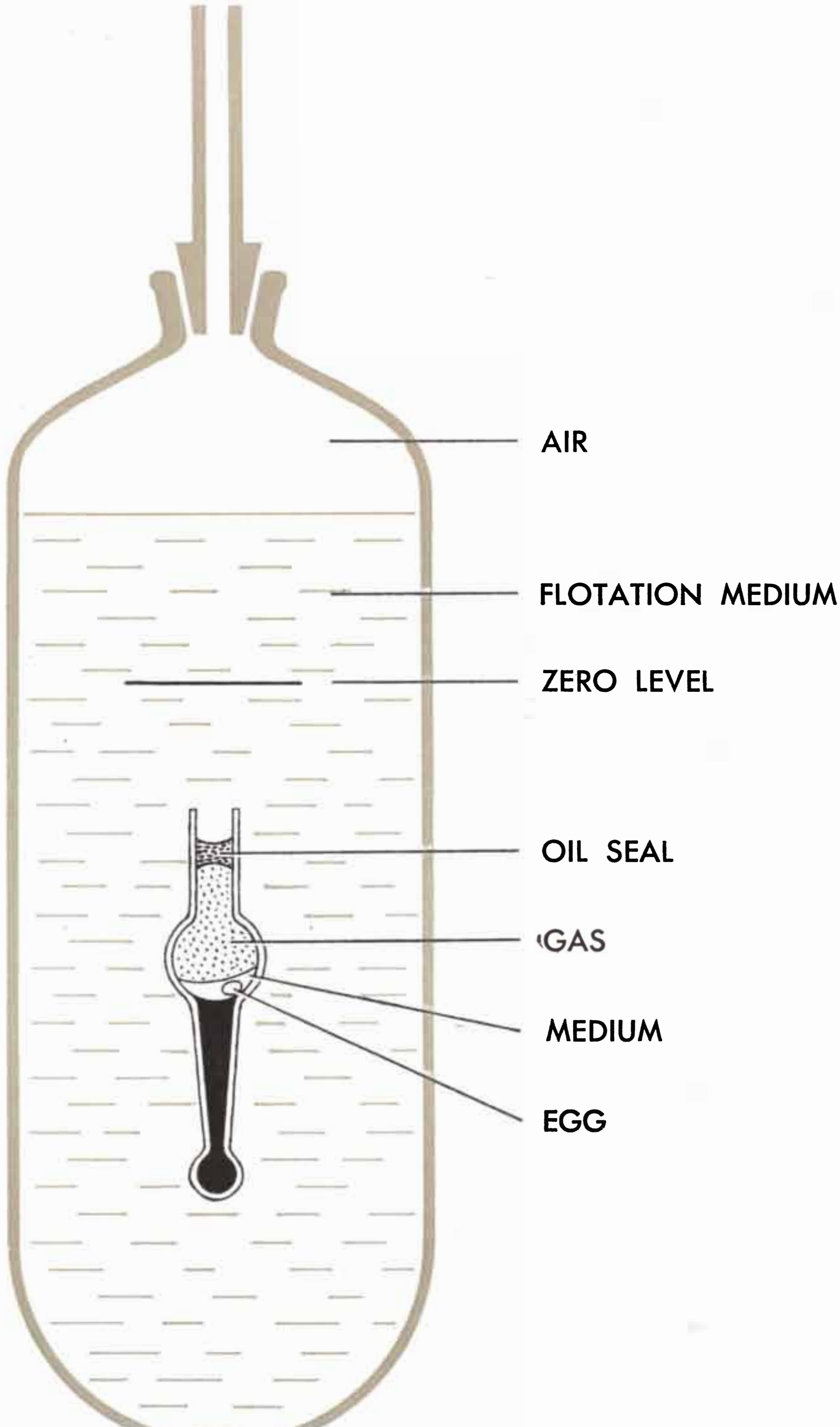
TWO HYPOTHESES of organizer action are illustrated by this cross section of a newt's embryo. At the right is the organizer region. Tissue containing an inducing substance in an inactive form labeled (E) moves into the interior of the embryo. There (E) becomes an active form E, which reacts with the competent tissue C and causes it to become the nervous tissue N. At the left is a diagram showing how a chemical substance S might produce nervous tissue either directly by acting on C or indirectly by causing (E) to be converted into E.

an open neck. In this neck a drop of oil is placed and the whole thing is immersed in a flask of water. As the diver sinks below the water surface, the pressure of water from above forces down the oil drop, compresses the air in the vessel into a smaller volume and so makes the glass bubble sink further. It can be made to float at a predetermined level, however, by adjusting the atmospheric pressure on the surface of the water in the flask. If now we have inside the stabilized diver a small piece of tissue which is using up oxygen or giving out carbon dioxide, this will alter the volume of the gas inside the diver and thus affect its buoyancy. This change can be measured by altering the atmospheric pressure until the diver just floats at its original level. The apparatus provides an exceedingly sensitive method of measuring minute changes in gas volume; with it one can measure respirations which involve as little as one millionth of a cubic centimeter of gas.

With such instruments we have acquired in the last few years a large amount of information about the respiration of various parts of the egg and other aspects of metabolism which are technically easy to measure. Unfortunately these processes are not always the kinds that seem most likely to lead to an understanding of cell differentiation. Differentiated cells probably are distinguished from one another principally by their protein constituents. We still know exceedingly little about how proteins are formed, and biochemical investigation of protein production in embryos has not yet made much progress.

Like so many projects in biology, this investigation may turn largely on finding a suitable experimental material. The whole of embryology suffers at present from operating too much in terms of complex entities. Instead of considering the development of nervous tissue or liver tissue, each of which contains many substances, we must be able to investigate the development of some single substance. Again, instead of thinking in terms of transplanting lumps of material from one part of the embryo to the other, we shall have to start experimenting on the constituents of a single cell. We have as yet no good material in which we can follow quantitatively the synthesis of some specific protein and investigate the effect of various conditions on this process.

The genetic study of development is not open to this reproach. In genetics we can easily study one kind of unit involved in development, namely the gene. One of the most important things that has been going on in genetics recently is the attempt to connect individual genes with the specific single substances for whose production they are responsible. In microorganisms such as



CARTESIAN DIVER is used to study differentiation by measuring the gain or loss of gas by tiny bits of tissue. It was first applied to the measurement of respiration by K. U. Linderstrom-Lang, the author of the article in this issue entitled "How Is a Protein Made?"

yeasts or fungi, which have a very simple body and a somewhat simpler biochemical system than more complicated animals, a change in a single gene often produces an obvious alteration in only one chemical constituent. Frequently this constituent is an enzyme, that is to say, one of the biological catalysts on which the functioning of the cell depends. It is probable, indeed, that all genes exert their influence through enzymes, and data from microorganisms suggest that each gene has an effect on a particular enzyme. If this is so, it would be logical to suppose that the gene manufactures the enzyme. It is not by any means certain that the matter is really as simple as all that. There may be several steps between the gene and the enzyme, in which case a number of different substances would be involved. We should then be dealing with a chemical system not very different from the one discussed in connection with the competence of embryonic tissues.

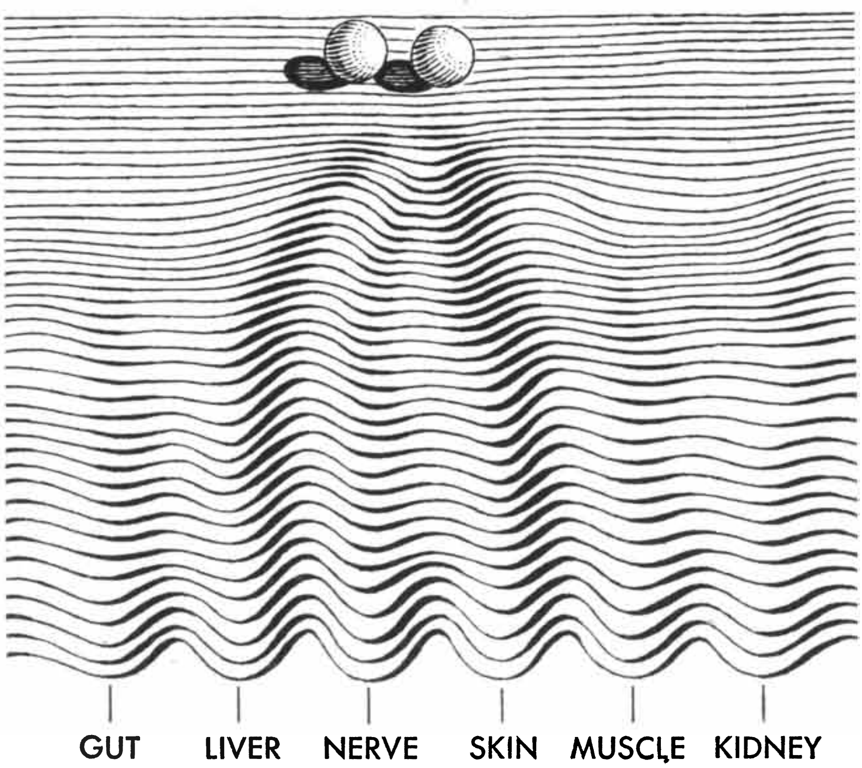
From the point of view of cell differentiation, however, this work in microbiology is not so helpful as one might think. The microorganisms are the very creatures that show the least amount of differentiation. Genes exercise their control, it is generally believed, by interacting in different ways with different regions of the cytoplasm in the egg. In microorganisms there is little or no specialization of different regions of cytoplasm, so we cannot hope to get from them any direct information about this fundamental relationship between genes and cytoplasm.

We have, however, found some valuable indirect clues. It has been known for some time that a strain of yeast growing in a sugar solution will often develop the ability to ferment that type of sugar although it could not do so originally. It forms what is known as an adaptive enzyme for doing so. Biochemists and geneticists have learned that in general a strain of yeast can form an adaptive enzyme to a particular sugar only if it has a hereditary capacity to do so. In other words, the forming of an adaptive enzyme depends on the presence of the appropriate gene. This gene must, however, be activated by the presence of the sugar. The situation is an extraordinary parallel to what we imagine must happen when specific genes are activated in certain cytoplasmic regions of the egg. Since each adaptive enzyme is a specific protein, we have here an opportunity to study quantitatively the physical and chemical factors involved in protein synthesis. Sir

Cyril Hinshelwood at Oxford University, Sol Spiegelman at the University of Illinois, Jacques Monod in Paris and others are already pursuing this line of inquiry.

From this protein study has come the stimulating suggestion that between the gene and the final enzyme there may be intermediates which, once formed, can reproduce themselves, for some time at least, even if the gene that produced them is removed. Several authors recently have come to the conclusion, some rather hastily, that they had evidence for the existence of such substances, and they have given them a variety of names—plasmagenes, cytogenes and so on. In several cases further investigation showed either that the evidence was not as good as had been thought or that the suggested plasmagenes were actually foreign virus particles or something of a similar nature. In a certain number of cases, however, there is fairly convincing evidence for the existence of plasmagene-like bodies. One of the best known is found in the little Paramecium. In this single-celled organism the cell develops certain substances which can be recognized by the fact that they stimulate the production of specific antibodies when they are injected into rabbits. The development of each substance is controlled by a corresponding plasmagene. The plasmagenes again are under the control of nuclear genes, and the nucleus itself is influenced by the condition of the cytoplasm of the cell. The cytoplasmic state can be altered by growing the animals at different temperatures or by changing their environment in other ways. Each cytoplasmic condition activates a certain gene to manufacture its corresponding plasmagene, and that in turn produces the final cell constituent.

It seems likely that something similar goes on in embryonic development. The different regions of the egg can be supposed to activate particular groups of genes in the nuclei which enter them; the activated genes then control the differentiation of cells. The first step in this will be the production of immediate gene products which may or may not be endowed with the power of self-reproduction, like plasmagenes. The Belgian embryologist Brachet has argued that certain minute particles which can be discovered in cells, the so-called microsomes, are the actual plasmagenes. These particles, just barely visible under ordinary microscopes, can be separated from the rest of the cell by ultracentrifugation. Brachet supposes that they are the immediate agents of protein synthesis in the cytoplasm, operating under the ultimate control of the nuclear genes. There is as yet no absolutely convincing proof of this. We badly need to develop



EPIGENETIC LANDSCAPE is an abstract representation of differentiation. The balls roll down the slope into one or another valley leading to a specialized organ of the adult.

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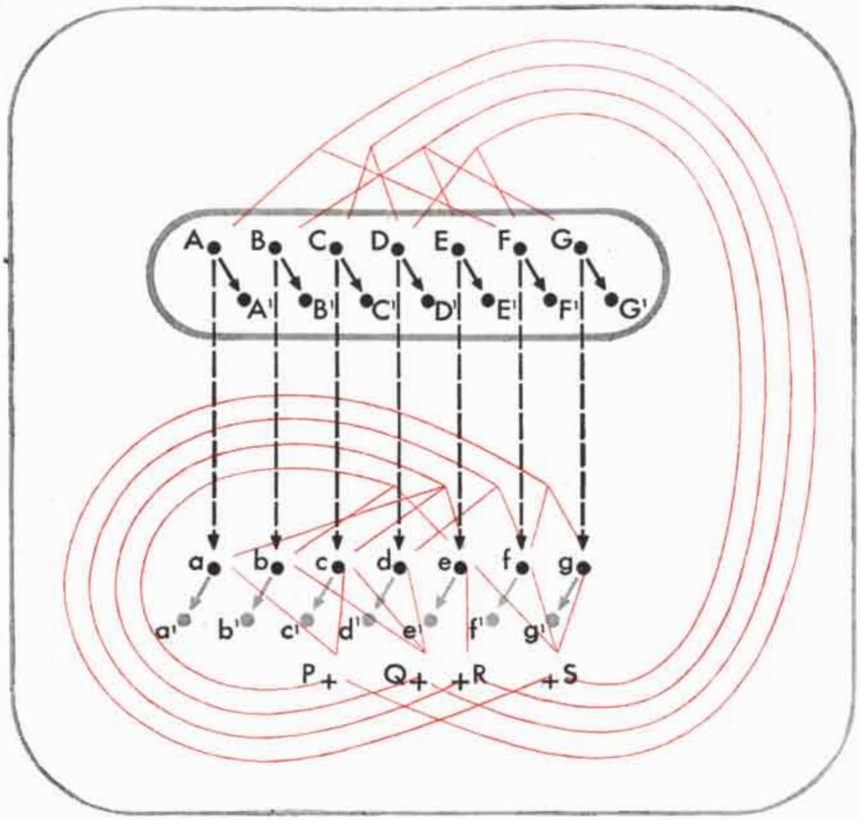
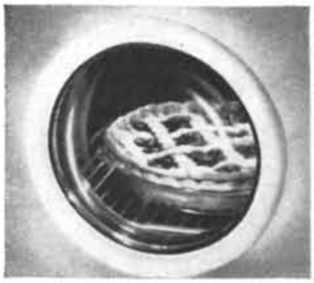


DEVELOPMENTAL SYSTEM within the cell must be an elaborate network of chemical interactions. The genes in the nucleus (A, B, C, etc.) not only form replicas of themselves (A^1, B^1, C^1, etc.) for the next division of the cell but also must produce "immediate gene products" (a, b, c, etc.). These may or may not be "plasmagenes," able to form duplicates of themselves (a^1, b^1, c^1, etc.). They must interact, however, to produce the cell proteins (P, Q, R, etc.). These in turn condition the activities of both the gene products and the genes.

techniques for investigating more thoroughly the relation between these microsomes and the nucleus, for instance by isolating the microsomes from one cell and transplanting them into another whose development would normally be different.

The gene-plasmagene and gene-microsome story is the place at which the two sciences of genetics and embryology are coming together most closely. It also introduces the last pair of actors in our account. These are the two nucleic acids, usually known as DNA (desoxyribonucleic acid) and RNA (ribonucleic acid). They are always present in those parts of the cell most deeply involved in the production of new substances, and it seems most probable that nucleic acid of one kind or the other is essential for the production of any protein. There seems to be no doubt that DNA, a constituent of the chromosomes that house the genes, must be in some way closely connected with the genes themselves, which contain protein. RNA always occurs in high concentration in any region of cytoplasm in which rapid synthesis of proteins is proceeding. The microsomes, for instance, contain large quantities of RNA but little or no DNA. According to one present theory, the DNA-containing chromosomes manufacture RNA, which passes out of the nucleus into the cytoplasm and there becomes attached to the microsomes and takes part in the synthesis of the cellular proteins.

Here again we are standing on the challenging frontier of unexplored territory. We may flatter ourselves that we are converging on the secret of differentiation from all sides, but the advances we have made so far do more to reveal the extent of the area still to be explored than to provide satisfying explanations. The older surgical methods of experimental embryology and the general genetical studies have given us some clues as to the over-all nature of the system we are dealing with. But they emphasize, on the one hand, the need for developing a broad picture of it and, on the other, the importance of getting down to concrete chemical detail. Thus every part of the advancing front of knowledge must look for support to every other, and the order of the day all along the line must be to press on.



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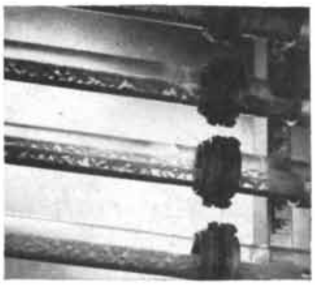

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3 Heat Resistant

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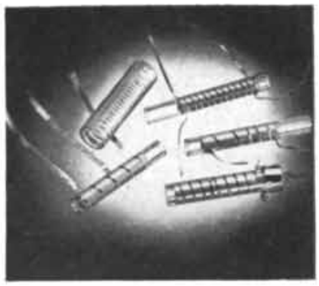

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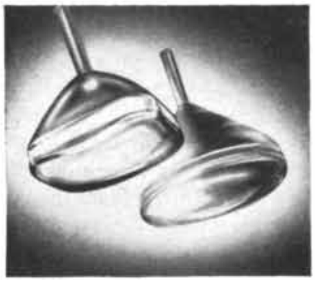

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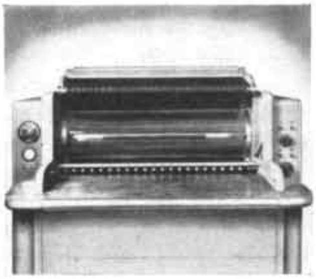

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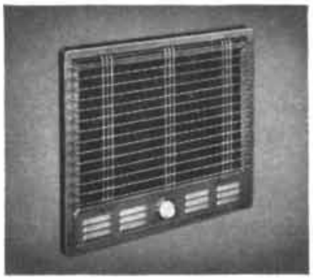
Glass can accurately control and transmit light with permanent reliability. Good examples are all around you but one rather unusual one is the glass cylinder in this printing machine. It transmits the ultraviolet rays produced by a mercury arc lamp.



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What Is Memory?

The means by which the brain stores the rich variety of human experience is completely unknown. The nerve physiologist tries to apprehend the mechanism with cleverly designed experiments

by Ralph W. Gerard

A textbook of biochemistry widely used early in this century had a famous passage on the memory of linseed oil. Exposure to light makes the oil turn gummy. A brief exposure may not cause any observable change. But on later illumination the oil will change more rapidly than if it had not already been exposed. The oil "remembers" its past experience and behaves differently because of it. Its memory consists in the fact that light produces, among other things, substances which aid the light-induced oxidations that make it gummy.

However far removed this may be from remembering the Gettysburg address, it clearly points up one way in which memory can work—by means of material traces of the past—and the difficulty of defining what memory is. Actually the behavior of the oil and of a human being memorizing the Gettysburg address are but extremes of a spectrum of such behavior in nature. Between these extremes there is a pretty smooth continuity, and any concept which defines memory much more narrowly than "the modification of behavior by experience" will run into trouble. Consciousness, for example, is not necessary to memory, for men remember, and recall under hypnosis, innumerable details never consciously perceived.

Where, then, shall we draw the line? A pebble, rubbed smooth in a stream, rolls differently from the original angular stone. Experience has here modified behavior; the past has been stored in a changed structure. Yet this does not greatly interest us as an instance of memory. Perhaps we should restrict the notion of memory to changes in systems which participate actively in causing the change. Then linseed oil "remembers," and so does the bulging calf muscle of a ballet dancer. Does a developing embryo "remember" the major steps, and missteps, in the long evolution of the species? Do trees "remember" good and bad seasons in the thickness of their rings? Is a film a memory of light in chemicals and a tape recording a memory of sound in magnetism? Is a library a memory of thoughts in books and a brain a memory of thoughts in protoplasm? Even to identify memory, let alone explain it, is no simple matter.

Without memory the past would vanish; intelligence, often called the ability to learn by experience, would be absent, and life would indeed be "a tale told by an idiot, full of sound and fury, signifying nothing." Today the search for the fundamental mechanisms of memory in the nervous system is being pressed with hopeful enthusiasm. The smell of success is in the air and great developments seem to wait just over the next ridge.

Let us consider as memory only that exhibited in man and in such sophisticated behavior as is usually close to conscious awareness. One great problem is: Why do certain impressions become conscious upon reception while others do not; why does awareness accompany some acts, not others; what, in general, invests certain neural events with a phosphorescence of subjective recognition? This question remains unanswered, but the answer is likely to come in terms of the evolution of awareness of certain types of neural events as useful to the organism.

Memory involves the making of an impression by an experience, the retention of some record of this impression and the re-entry of this record into consciousness (or behavior) as recall and recognition. The initial impression need not have entered awareness in order to be retained and recalled. Anyone asked to recall what he has just seen in a room or in a picture does a less complete job than a subject under hypnosis even years later. I have been told of a bricklayer who, under hypnosis, described correctly every bump and grain on the top surface of a brick he had laid in a wall 20 years before!

Guesses have been made as to how many items might be accumulated in memory over a lifetime. Some tests of perception suggest that each tenth of a second is a single "frame" of experience for the human brain. In that tenth of a second it can receive perhaps a thousand units of information, called bits. In 70 years, not allowing for any reception during sleep, some 15 trillion bits might pour into the brain and perhaps be stored there. Since this number is more than 1,000 times larger than the total of nerve cells, the problem of storage is not exactly simple.

Whether or not all incoming sensations are preserved as potential memories, there is an important time factor in their fixation. Youthful, repeated or vivid experiences seem most firmly fixed. They are the last to survive disrupting conditions—old age, brain damage, concussion or mental shock—and the first to return after a period of amnesia. A goose seems to fix upon the first moving object it sees as its mother and thereafter follows it about. An infant, suddenly frightened by a barking dog, may fear dogs for the rest of its life.

More often experiences force themselves into attention and memory only gradually. Even learning to perceive is a long, troublesome matter. Adults gaining vision for the first time must labor for months to learn to recognize a circle and to distinguish it from a triangle, let alone to see letters and words.

After any experience, apparently considerable time must elapse between the arrival of the incoming nerve impulses and the fixing of the trace. If a photographic plate acted similarly, it could not be developed at once after exposure but only some time later. Recent experiments in our laboratory have emphasized this phenomenon. Hamsters daily were run in a maze and were given an electric shock afterward. When the shock was given four hours or more after the run, it did not influence the learning curve. (The question of cumulative damage is irrelevant here.) A shock one hour after the run impaired learning a little, and as the shock was brought closer it interfered more and more, until at one minute after the run, it destroyed learning completely. Clearly some process of fixing continues for at least an hour.

The nature of the fixing process must be left for the moment, while some related phenomena of memory are noted. One is a type of erasing. A memory wizard who can glance through a newspaper and then name the word at any position in any column on any page makes an effort to forget this mass of information at the close of a performance so as not to "clutter up" his memory. Perhaps similar is the removal by a presuggested signal of an instruction to a hypnotized subject to perform some act after arousal. In such instances stored experience traces seem to be expunged, but whether they are really irrecoverable is perhaps not fully established. Recall alone may be at fault, as in simple forgetting.

A second phenomenon has to do with the alteration of memory traces. The memory left by an experience can change progressively. Memory, as has been well said, is reconstructive rather than reduplicative. It is also highly associative. Pictures redrawn from memory at intervals become more regular (details are smoothed out) or more exaggerated (some salient feature is caricatured) or an object different from the original (a chair looks more like a horse at each redrawing).

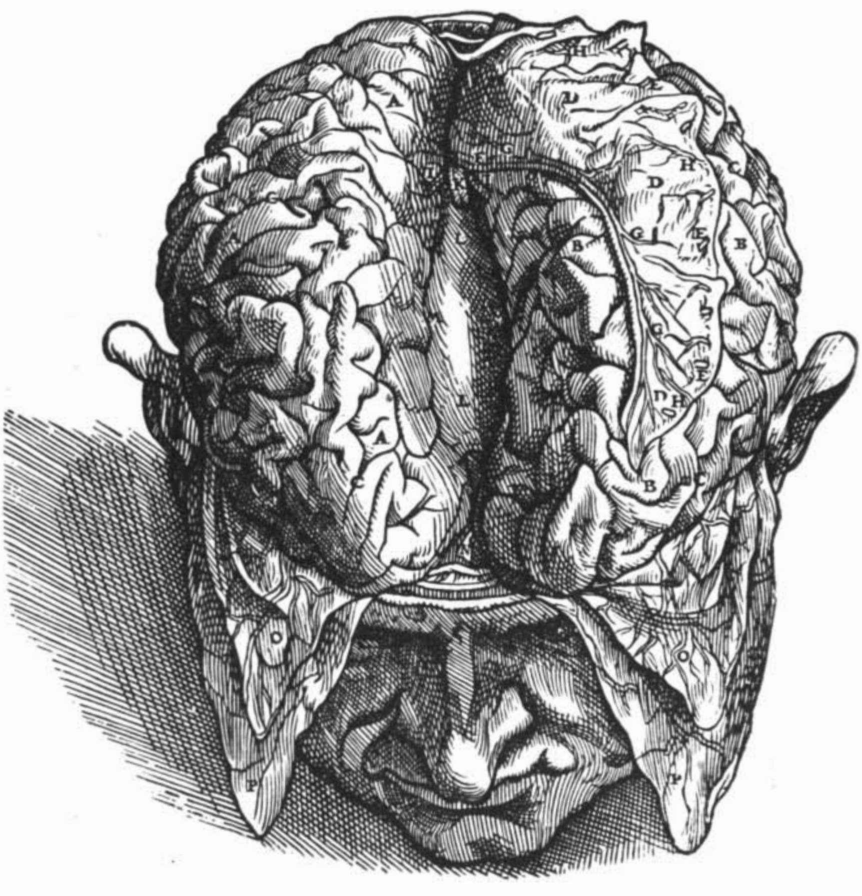
Besides fixation and storage, there remain recall and recognition. Failure to recall does not imply loss of the trace: witness the frequent experience of temporary inability to say a familiar name "just on the tip of my tongue." The most intriguing problem about memory, however, is not the existence but the tremendous specificity of recall. Both in its positive and negative aspects—as seen in dreams, in amnesia, in suppression and repression, in hypnosis, in hysteria and dual personality—recall offers bizarre phenomena, formidable to explain.

One day not long ago, as I left a lecture room I caught a fleeting glimpse of the head and shoulders of a person half-silhouetted against a window over a hundred feet away. I knew at once with certainty the name of the person standing there, although he had not crossed my path nor his name my mind for more than 15 years. A chord, a note, a word, a line can recall a long past experience. Or it may reawaken an intense emotion without the connected experience; I know of a young man who invariably faints at the sight of a stethoscope, yet has no general fear of doctors or illness and no idea of why he reacts so uncontrollably.

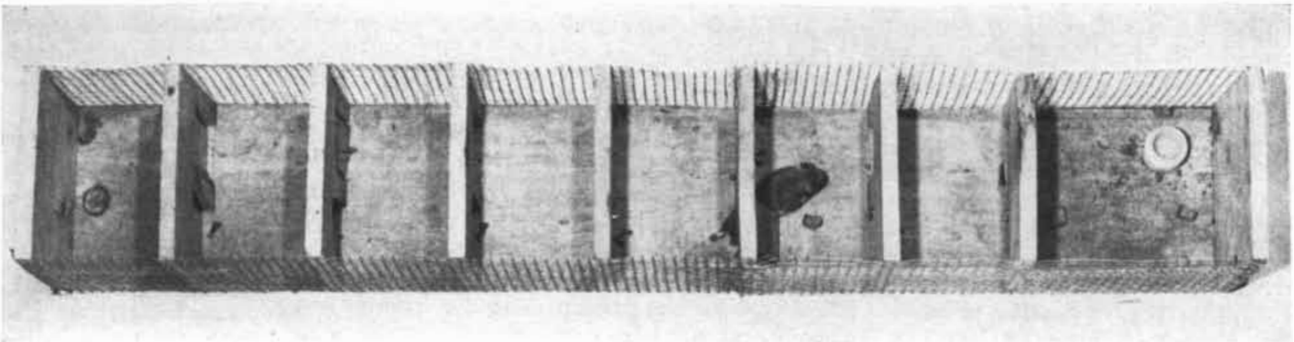
Recall may sometimes be disguised, seemingly to protect the subject from the anguish of fear or shame or pain. Parts of a story that touch upon a personal problem are often "forgotten" only to appear, modified, in a dream. A man who was unable to recall the telephone number of a girl friend while visiting her city dreamed of red objects that night and recognized in the morning that the numerical position of the letters *r*, *e*, *d* in the alphabet gave the missing number. This opens the door to the whole edifice of symbols. An unsophisticated youngster, directed under hypnosis to dream about bed-wetting, may report his dream in Freudian symbols which only an experienced psychoanalyst—or another naive youngster under hypnosis!—can recognize as referring to bed-wetting.

Finally, what of the compulsive neurotic whose affliction is banished when some infant experience is dredged up during psychotherapy? What of the psychoneurotic soldier, unable to recall a battle beyond a certain point, who relives under pentothal all the horror of seeing a companion's head blown off and is then able to remember and talk about it? What of aphasics, who can recognize words by sight or by sound but not both? And what of dream experiences, not actually sensed but presumably due to intrinsic brain activity, which may be recalled in wakefulness or only in other dreams, if at all? The problem of recall and its specificity is the real challenge to neurophysiology.

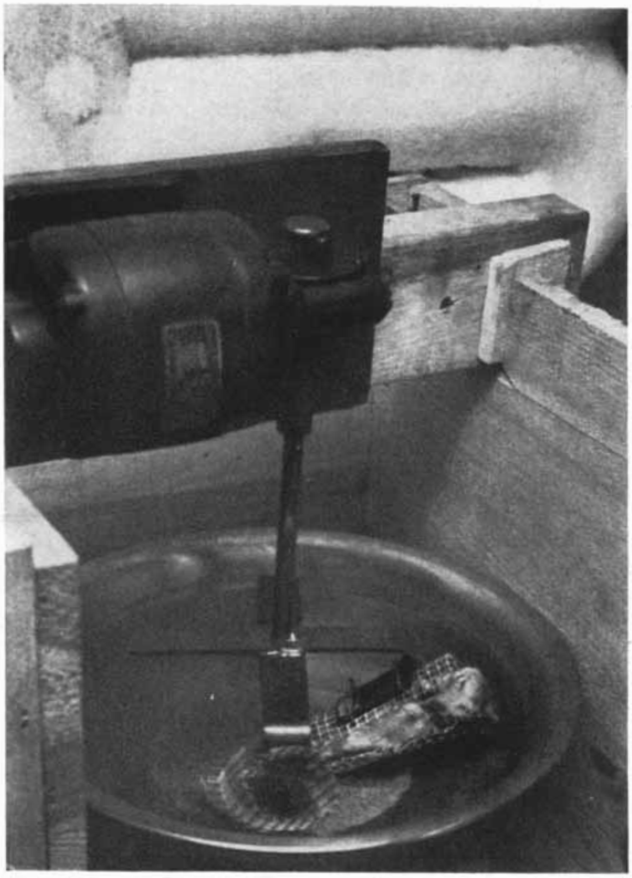
The human brain is composed of some 10 billion nerve cells, more or less alike, which interact in various ways. Each cell contributes to behavior, and



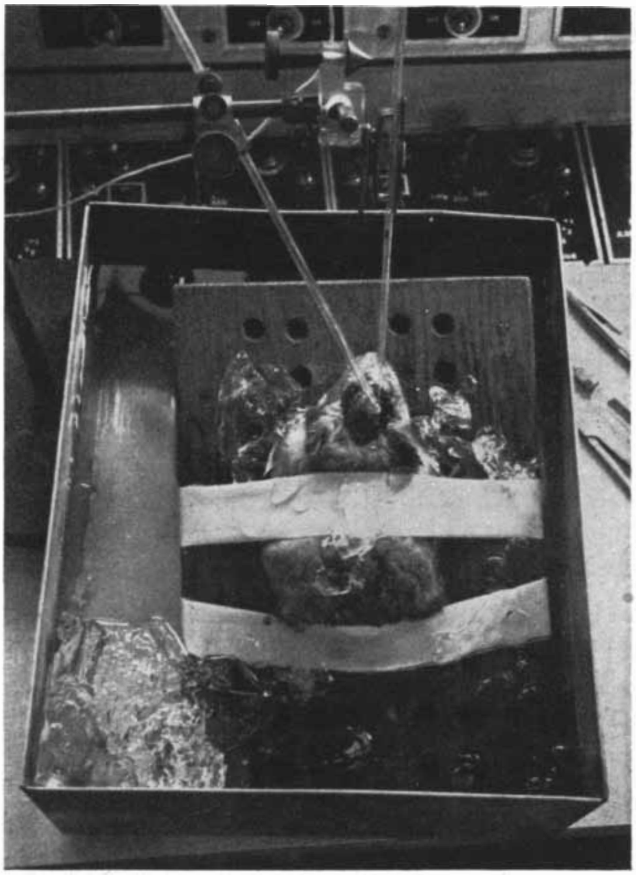
THE BRAIN was dissected by early anatomists seeking clues to its function. This woodcut is from the famous *De Humani Corporis Fabrica* of the pioneer Andreas Vesalius.



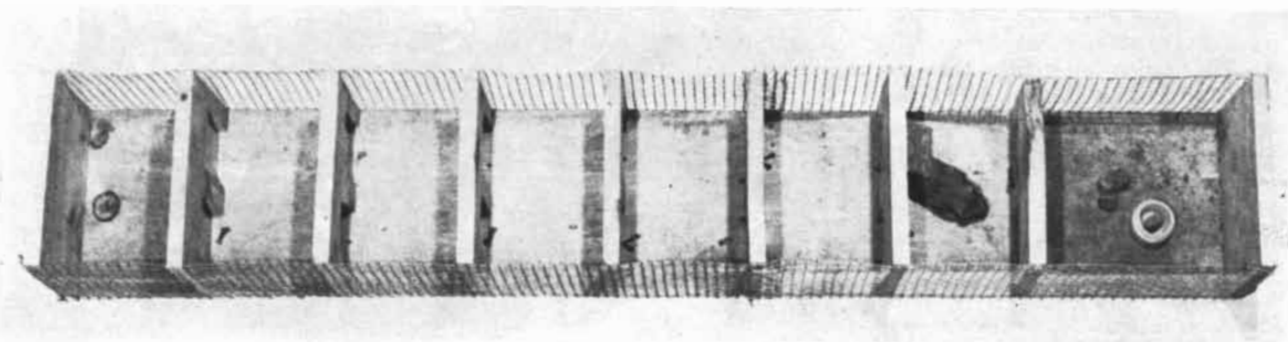
HAMSTER RUNS THROUGH MAZE as part of a memory experiment conducted by Robert E. Ransmeier at the University of Chicago. Each barrier in the maze has two doors, one open and one locked. After training hamster reaches food (*right*) in a few seconds.



HAMSTER IS CHILLED in a refrigerator. When its temperature is 40 degrees Fahrenheit, the electrical pulse of its brain ceases.



ANOTHER HAMSTER IS TESTED by electroencephalograph to determine the temperature at which the electrical activity stops.



HAMSTER RUNS THROUGH THE MAZE AGAIN after it has been chilled to wipe out the electrical activity of its brain. The investigators discovered that hamsters trained to run through the maze suffered no impairment of this ability because of the chilling.

presumably to mental activity, by firing impulses or failing to fire. All the phenomena of memory must be explained in terms of the temporal and spatial patterns of these discharges.

If experience is to modify behavior, the activity of neurons connected with an experience must alter their subsequent activity patterns. Two general questions regarding the neural trace must be asked, and both can be given a reasonable, if not a certain, answer today. The first is: Does memory depend on a continuing activity or on some static residue, some structural alteration, left behind by past activity? Is a river the water flowing in it or the channel the water cuts? The answer today is tending strongly toward the latter. The second question is: Is the structural trace (or dynamic process) for each memory located in a particular region, or are memory traces suffused through the brain in some way? Are memories marks placed on violin strings or are they wave trains playing over these strings? The latter would imply dynamic memory, but the trace could still be structural, like the wiggled groove on a phonograph record. Whether the trace is localized or diffuse, its exact nature is a third, if somewhat subsidiary question. Current investigations suggest that there are multiple patterns of local traces rather than a single well-localized one, but the nature of the trace is almost pure guess.

A dynamic memory would depend on the continuous passage of nerve impulses or on the maintenance of some active metabolic or potential change in neurons, presumably reinforced by the repeated arrival of impulses. A nerve impulse traveling around a closed loop of connecting neurons would be a mechanism for such a dynamic memory, each remembered item depending on the activity of a particular loop or net of neurons. (Actually, since there are more memories than neurons, different memories would have to share portions of path, but this is physiologically possible without snarling traffic.) Such a memory device would, however, be metabolically expensive, and if the impulses really left no long-enduring trace, memories would be completely and irrevocably lost once the activity stopped.

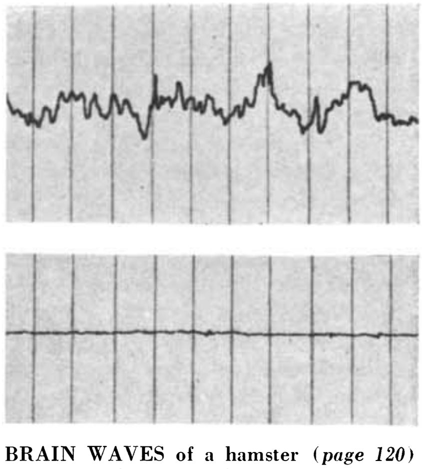
There is a simple way to test the question as to whether a memory is purely dynamic. One need only stop all nerve impulses in the brain momentarily and observe whether a memory is lost. The problem, of course, is to stop the impulses reversibly. In sleep or under anesthesia the brain slows down but remains electrically active, and memories are largely undisturbed. But the brain's electrical activity can be stopped in several ways. When a hibernating animal, such as the hamster, is cooled to a body temperature of 40 degrees Fahrenheit, needles thrust into its brain fail to pick up electrical activity; it seems reasonably certain that the reverberating impulses are frozen in their tracks.

Another way of stopping the circulating nerve messages is to stimulate the neurons simultaneously by a vigorous electric shock, so that all the neurons presumably are unable to respond to a normal impulse. Such a shock does produce a period of complete electrical silence, measured in seconds or minutes. If the lower brain, controlling respiration, is included, the normal messages for breathing are suspended. Brain neurons may also be made electrically inactive by withholding oxygen for some two minutes or by withholding sugar. In all these cases the animals recover rapidly after the temporary treatment, and their memory can be investigated.

The experiment is now straightforward. Hamsters are first taught a simple maze. They are then hibernated or given electric shock or made to breathe nitrogen for a few minutes. After recovering, they are tested for their retention of learning. If they remember the way through the maze, the memory did not depend upon reverberating circuits or upon any other purely dynamic process. They remember!

This by no means excludes the initial dependence of memory on neuron activity. The passage of impulses is necessarily involved in the initial experience that leaves a memory trace. The fact that repetition makes for better memory reminds us of the analogy of the river cutting a channel in its bed. Indeed, the reason it takes time to fix a memory trace in the brain may be that impulses must circulate over their selected pathways many times in order to leave behind an enduring material change.

What, then, is this enduring static trace? Muscle fibers react to continued exercise by increasing their content of hemoglobin-like pigment; the meat becomes darker. No one has described an enduring chemical change in nerve or brain as a result of activity, but it must be conceded that this is a difficult quest and has not been undertaken very seriously. Muscle fibers swell and become hypertrophied on exercise. It has been shown recently that nerve fibers also swell slightly as they conduct impulses, and the swelling persists at least for minutes and hours if not for days and



BRAIN WAVES of a hamster (*page 120*) **are damped by chilling. Normal waves at top.**

years. Nerve fibers also show alterations in potential which outlast the active period by many minutes. Any of these changes might occur at the critical junction between one neuron and the next—the synapse or gap across which conduction is considerably more precarious than it is along the uniform nerve fiber. The change might then make the passage of subsequent impulses easier or more difficult.

Certain it is that activity can facilitate and inactivity hinder the subsequent passage of an impulse across a synapse. This has been learned from experiments on simple spinal cord reflexes involving only one sensory neuron, one synapse and one motor neuron in each arc. If some of the sensory nerve fibers serving the knee-jerk reflex are stimulated, say a hundred times a second for 10 minutes, and are then tested with a single stimulus, the number of motor fibers responding (in effect, the size of the knee-jerk) is increased tenfold above the normal response to a single shock. The increased responsiveness dies out in two or three phases, one lasting for seconds and one certainly for hours. This suggests that the local trace left behind may have involved several changes. Conversely, when impulses are prevented from reaching the synapses of this reflex for days or weeks, by cutting the sensory nerve connections, the reflex elicited by a single shock is strikingly below normal. After a few shocks, however, the response begins to improve, and again the return toward normal seems to involve more than one phase.

Many suggestions have been made as to what kinds of changes may alter the response at a synapse. They must be structural—either in the fibers and contacts or at the molecular level, where displacement of ions might alter the electric potential or displacement of atoms change the chemistry. One observed change, already noted, is the swelling of fiber end-bulbs induced by activity. The swelling should favor the transmission of impulses. Actually this explanation is a modern version of one of the earliest theories of memory: that activity somehow causes a nerve fiber to sprout new twigs near its termination and so to increase its effective contact. Neurons from brains of older persons have in fact been reported to branch more extensively than those from the young, and the notoriously poor memory of old people for recent events might be attributed to the neurons' inability to grow more twigs or to accommodate more connections. A closely related suggestion, that electric-shock treatment of some psychoses is successful because it destroys certain existing connections and permits neurons to make "healthier" ones, is based upon the observation, made on transparent tadpole tails, that electric shocks cause nerve filaments to be torn off.

Another mechanism enjoying some current popularity is chemical. Since every type of cell of every individual of every species has its own chemical personality, and since this differentiation of cells depends on proteins, the specificity of memory might be due to changes in nerve proteins. Each trace could be limited to one or a few molecules in an end-bulb of a neuron. The body cells that manufacture and release antibodies against invading organisms "learn," as we know, from experience. When typhoid proteins, for instance, enter the body the first time, antibodies are produced slowly and in small amounts. But years later, when almost no antibody remains in the blood, a new invasion by this specific protein is met by a prompt and vigorous release of antibody that nips the disease before it gets started.

It is far from explained just how the passage of nerve impulses would alter protein molecules at a synapse, or how, in turn, an altered protein composition would aid or hinder the passage of a nerve impulse. Yet some such chemical mechanism cannot be discarded, for nerves and synapses can be highly specific and can change their specificity. For example, if an extra muscle is transplanted into the back of a salamander, the nerve to which it becomes attached will make the transplanted muscle contract simultaneously with the normal flexor if the transplant is a flexor muscle or with the normal extensor if it is an extensor. Somehow the central synapses have "discovered" what kind of muscle is attached at the far end of the motor neuron and they let through nerve impulses

RAT'S BRAINS were incised by Karl S. Lashley of Harvard University and the Yerkes Laboratory of Primate Biology to determine the role of cortical connections in memory. This diagram shows the brain of the rat from the top *(center)* and both sides. Each red line represents an incision made in a single rat. None of the cuts impaired performance in maze.

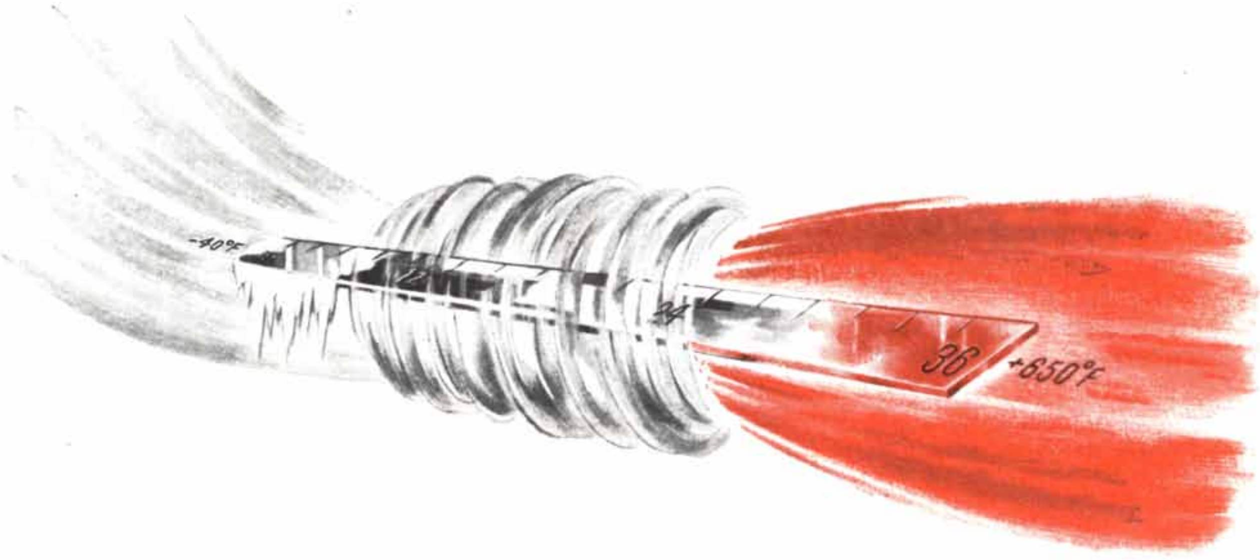
at the proper time for a muscle of this sort.

The essence of all these suggested mechanisms is that a given end-bulb of a neuron, initially ineffective, can become and remain effective as a result of activity. Indeed, mathematical theories of the behavior of complex nerve nets demand only such an assumption to account for the basic properties of memory. Moreover, the total number of end-bulbs on the neurons of the brain, some 10 trillion, about matches the number of bits of information the brain may store during a lifetime. But then each memory would have to have its exact microscopic spot in the brain, would have to stay put through life, and would somehow have to be deposited, once and once only, at a given end-bulb, despite the wide sweep of impulses through the brain during each experience. This raises sharply the problem of localization.

The degree of localization is probably the key problem of memory. If we could expect to find a given memory at a given place in the brain, our experimental problem would be comparatively simple. We would locate the region and compare structural, chemical or physical changes there in animals with and without the appropriate experience. Some years ago there was an exciting report that electrical stimulation of a small spot in the cerebral cortex caused trained dogs to make a conditioned leg movement, while in unconditioned or deconditioned animals the same region was inactive. Alas, this claim has not been substantiated. There is, however, valid evidence of a kind of memory localization. When the exposed brain of a person under local anesthesia for a brain operation is stimulated electrically, various conscious effects are produced. Stimulating the occipital lobe, which receives the sensory fibers from the eyes, gives visual sensations. Similarly, stimulation of other specific regions produces sounds and skin sensations. These responses are not related to specific past experiences. However, other regions of the brain, particularly the temporal lobe, do respond to stimulation with the conscious recall of quite specific events from an individual's past.

The particularity, however, is at best only roughly localized, and localization largely vanishes when we look at the effects of brain damage. Large sections of nearly any part of the brain can be destroyed without loss of particular memories or, indeed, without disturbance of the memory function. Human brains have been extensively damaged by trauma, by tumors or abscesses, by loss of circulation, by operative removal, or by the shriveling away of extreme age. In these cases the ability to learn new things, to make sound judgments, to see new relations and to imagine new ideas may be profoundly disturbed, but the recollection of past experience is likely to remain reasonably intact. The frontal lobes of mental patients would not be amputated so freely as they are today if any serious defect in memory resulted.

So we are left with good reasons for believing that memories depend on static changes left behind by the passage of nerve impulses; that these changes occur somewhere along the paths the impulses traveled and are most likely at particular synapses; that the traces are to some extent gathered in certain regions, but that extensive brain damage is not accompanied by comparable losses of memories. One line of escape from the dilemma is to assume, as we can quite reasonably, that a given memory is not



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represented by one specific local change but by a pattern of many changed loci—a pattern with sufficient redundancy so that if part of it is destroyed the rest will still suffice to represent the memory.

Such a view raises serious difficulties, but they do not appear to be insurmountable. For example, if thousands of neuron endings are involved in one memory, how can the brain store the huge number of memories we have assumed? Actually such indirect coding could greatly increase its storage capacity. Ten letters, each used to represent one item, give 10 items; but 10 letters used in groups as words give a vast number of items. Such patterned memory traces might also actually change with time, as particular neurons or synapses dropped out of the ensemble, and so permit the alteration of memories observed on successive recalls.

We come finally to the problem of recall. Recall is a matter of attention, a selecting or rejecting of particular memory traces. Here enter all the intriguing phenomena of specificity, suppression, symbolization and the like. The physiological explanation of these is certainly not yet at hand. Perhaps the best clue now available is the control of cortical activity and of conscious awareness by nerve centers in the older and deeper parts of the nervous system. Much recent experimentation has shown that these primitive jumbled masses of nerve cells in the upper part of the brain stem exercise a profound influence on the more recently evolved neurons of the cerebral cortex. Impulses from these deep cell groups continuously spray out to the cortex to regulate its activity. An excess of stimulation leads to cortical overactivity and convulsive seizures, followed by the unconsciousness of exhausted neurons. When the impulses are few and the cortex is comparatively inactive, the brain waves slow down and normal sleep results. One is tempted by the picture of an electron beam scanning the tube face of a television camera, picking up impressions left by the outside world from one tiny region after another. But whether such beams of nerve impulses, playing upon the cortex, do actually control attention, whether they are responsible for the evocation of specific memory traces, only the future can decide.

We are beginning to have some reasonable guesses as to the "gadgets" that would serve as a memory mechanism—guesses sufficiently concrete to permit testing by rigorous experimentation. I think it is realistic to hope for an understanding of memory precise enough to permit experimental modification of it in men.

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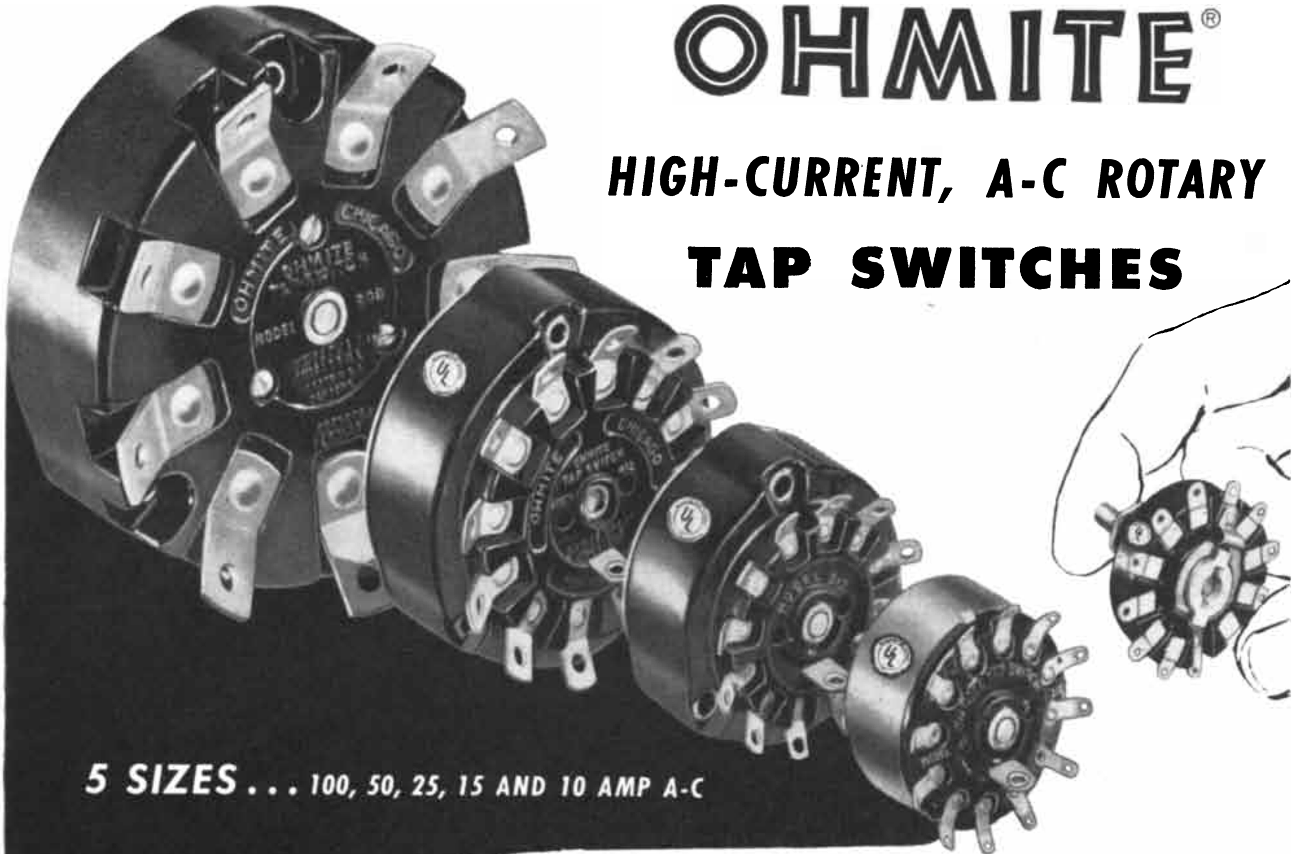

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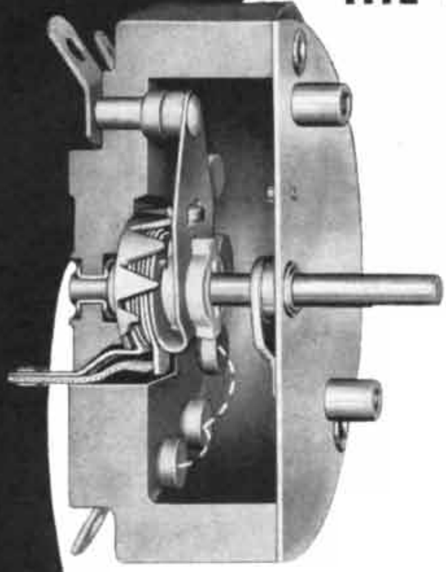

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What Is Probability?

Some mathematicians argue that it is "statistical"; others, that it is "inductive." The author believes that there are two kinds, both essential to the future progress of science

by Rudolf Carnap

The articles in this issue on fundamental questions of science give an illuminating picture of the way scientists work. No one reading these articles can fail to be impressed with the great importance to science of hypotheses—the daring guesses on slender evidence that go into building new theories. The question I should like to raise in this final article is: Can the method of scientific inquiry be made more precise? Can we learn to judge the hypotheses, to weigh the extent to which they are supported by the evidence at hand, as an investigator judges and weighs his data?

The question leads at once into the subject of probability. If you query scientists about the meaning of this term, you will discover a curious situation. Practically everyone will say that probability as used in science has only one meaning, but when you ask what that meaning is, you will get different answers. Most scientists will define it as statistical probability, which means the relative frequency of a given kind of events or phenomena within a class of phenomena, usually called the "population." For instance, when a statistician says the probability that a native of the U. S. has A-type blood is 4/10, he means that four out of 10 people have this type. This meaning of probability has become almost the standard usage in science. But you will also find that there are scientists who define probability in another way. They prefer to use the term in the sense nearer to everyday use, in which it means a measurement, based on the available evidence, of the chances that something is true—as when a jury decides that a defendant is "probably" guilty, or a weather forecaster predicts that it will probably rain tomorrow. This kind of probability amounts to a weighing of the strength of the evidence. Its numerical expression has a meaning quite different from that of statistical probability: if the weather man were to venture to say that the probability of rain tomorrow was 4/10, he would not be describing a statistical fact but would simply mean that, should you bet on it raining tomorrow, you had better ask for odds of 4 to 6.

This concept is called inductive probability. A scientist makes a judgment of the odds consciously or unconsciously, whenever he plans an experiment. Usually the probability ascribed to his hypothesis is stated not in numbers but in comparative terms; that is, the probability is said to be high or low, or one probability is considered higher than another. To some of us it seems that inductive probability could be refined into a more precise tool for science. Given a hypothesis and certain evidence, it is possible to determine, by logical analysis and mathematical calculation, the probability that the hypothesis is correct, or the "degree of confirmation." If we had a system of inductive logic in mathematical form, our inferences about hypotheses in science, business and everyday life, which we usually make by "intuition" or "instinct," might be made more rational and exact. I have made a beginning in the construction of such a system, using the findings of past workers in this field and the exact tools of modern symbolic logic. Before discussing this system, let me review briefly the history of the inductive concept of probability.

The scientific theory of probability began, as a matter of fact, with the inductive concept and not the statistical one. Its study was started in the 16th century by certain mathematicians who were asked by their gambler friends to determine the odds in various games of chance. The first major treatise on probability, written by the Swiss professor Jacob Bernoulli and published posthumously in 1713, was called *Ars Conjectandi*, "The Art of Conjecture"—in other words, the art of judging hypotheses on the basis of evidence. The classical period in the study of probability culminated in the great 1812 work *Théorie analytique des probabilités*, by the French astronomer and mathematician Pierre Laplace. He declared the aim of the theory of probability to be to guide our judgments and to protect us from illusions, and he was concerned primarily not with statistics but with methods for weighing the acceptability of assumptions.

But after the middle of the 19th century the word probability began to acquire a new meaning, and scientists turned more and more to the statistical concept. By the 1920s Robert Aylmer Fisher in England, Richard von Mises and Hans Reichenbach in Germany (both of whom have died within the last few months) and others began to develop new probability theories based on the statistical interpretation. They were able to use many of the mathematical theorems of classical probability, which hold equally well in statistical probability. But they had to reject some. One of the principles they rejected, called the principle of indifference, sharply points up the distinction between inductive and statistical probability.

Suppose you are shown a die and are told merely that it is a regular cube. With no more information than this, you can only assume that when the die is thrown any one of its six faces is as likely to turn up as any other; in other words, that each face has the same probability, 1/6. This illustrates the principle of indifference, which says that if the evidence does not contain anything that would favor one possible event over another, the events have equal probabilities *relative to this evidence*. Now a second observer may have additional evidence: he

	STATISTICAL DISTRIBUTIONS: NUMBER OF BLUE	STATISTICAL DISTRIBUTIONS: NUMBER OF WHITE	INDIVIDUAL DISTRIBUTIONS		METHOD I: INITIAL PROBABILITY OF INDIVIDUAL DISTRIBUTIONS	METHOD II: INITIAL PROBABILITY OF: STATISTICAL DISTRIBUTIONS	METHOD II: INITIAL PROBABILITY OF: INDIVIDUAL DISTRIBUTIONS
1.	4	0	1.	● ● ● ●	1/16	1/5	1/5 = 12/60
2.	3	1	2.	● ● ● ○	1/16	1/5	1/20 = 3/60
			3.	● ● ○ ●	1/16		1/20 = 3/60
			4.	● ○ ● ●	1/16		1/20 = 3/60
			5.	○ ● ● ●	1/16		1/20 = 3/60
3.	2	2	6.	● ● ○ ○	1/16	1/5	1/30 = 2/60
			7.	● ○ ● ○	1/16		1/30 = 2/60
			8.	● ○ ○ ●	1/16		1/30 = 2/60
			9.	○ ● ● ○	1/16		1/30 = 2/60
			10.	○ ● ○ ●	1/16		1/30 = 2/60
			11.	○ ○ ● ●	1/16		1/30 = 2/60
4.	1	3	12.	● ○ ○ ○	1/16	1/5	1/20 = 3/60
			13.	○ ● ○ ○	1/16		1/20 = 3/60
			14.	○ ○ ● ○	1/16		1/20 = 3/60
			15.	○ ○ ○ ●	1/16		1/20 = 3/60
5.	0	4	16.	○ ○ ○ ○	1/16	1/5	1/5 = 12/60

INDUCTIVE PROBABILITY METHODS are illustrated in an example which is tabulated above. Four balls are to be drawn in succession from an urn. They are identical in every way except that some are blue and some white. Nothing is known, however, about the proportion of blue to white balls in the urn. First we want to decide on the initial probabilities in the experiment—the probabilities before the first ball is drawn. We list (under "Individual Distributions") all the possible ways in which the drawing can turn out. Now we apply the principle of indifference, which says that if the evidence contains nothing that favors one possibility over another, all possibilities must be considered equally probable. There are two ways to apply the principle to this example. The first is illustrated under "Method I." Since there are 16 possible cases, dividing the probabilfty equally among them gives each a probability of 1/16. But there is another way to look at the table. Instead of taking into account the order in which blue and white turn up, we can concentrate only on the total numbers of blue and white in a drawing—all blue, three blue and one white, and so on. This classifies the table into "Statistical Distributions," which are indicated by the brackets on the left. There are five statistical distributions. If the principle of indifference is applied to them, then each has a probability of 1/5, as shown in the first column of "Method II." Now the individual distributions within each statistical distribution are assigned probabilities that are again determined by the principle of indifference. The first statistical distribution (four blue) has only one member, so it gets the full amount of the probability to be distributed, or 1/5, as shown in the second column of "Method II." The second statistical distribution (three blue, one white) has four members, so the probability must be split four ways, 1/20 to each. Similarly, the remaining three statistical distributions are divided into their individual members. At the extreme right hand of the table, all probabilities are converted to a least common denominator of 60 in order to facilitate comparing and combining them. Method II is superior to Method I because it assigns probabilities to future events on the basis of the frequency of their past occurrence.

may know that the die is loaded in favor of one of the faces, without knowing which face it is. The probabilities are still the same for him, because as far as his information goes, each of the six faces has an equal possibility of being loaded. On the other hand, for a third observer who knows that the load favors the face numbered 1 the probabilities change; on the basis of his evidence the probability of the ace is higher than 1/6.

Thus inductive probability depends on the observer and the evidence in his possession; it is not simply a property of the object itself. In statistical probability, which refers to the actual frequency of an event, the principle of indifference is of course absurd. It would be incautious for an observer who knew only that a die had the accurate dimensions of a cube to assert that the six faces would appear with equal frequency. And if he knew that the die was biased in favor of one side, he would contradict his own knowledge. Inductive probability, on the other hand, does not predict frequencies; rather, it is a tool for evaluating evidence in relation to a hypothesis. Both the statistical and inductive concepts of probability are indispensable to science; each has valuable functions to perform. But it is important to recognize the distinctions between the two concepts and to develop the possibilities of both tools.

In the past 30 years the inductive concept of probability, which had been supplanted by the statistical concept, has been revived by a few workers. The first of these was the great English economist John Maynard Keynes. In his *Treatise on Probability* in 1921 he showed how the inductive concept is implicitly used in all our thinking about unknown events, in science as well as in everyday life. Yet Keynes' attempt to develop this concept was too restricted: he believed it was impossible to calculate numerical probabilities except in well-defined situations such as the throw of dice, the possible distributions of cards, and so on. Moreover, he rejected the statistical concept of probability and argued that all probability statements could be formulated in terms of inductive probability.

I believe that he was mistaken in this point of view. Today an increasing number of those who study both sides of the controversy, which has been going on for 30 years, are coming to the conclusion that here, as often before in the history of scientific thinking, both sides are right in their positive theses, wrong in their polemical remarks. The statistical concept, for which a very elaborate

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In 1939 the British geophysicist Harold Jeffreys put forward a much more comprehensive theory of inductive probability than Keynes'. He agreed with the classical view that probability can be expressed numerically in all cases. Furthermore, he wished to apply probability to quantitative hypotheses of science, and he set up an axiom system for probability much stronger than that of Keynes. He revived the principle of indifference in a form which seems to me much too strong: "If there is no reason to believe one hypothesis rather than another, the probabilities are equal." It can easily be shown that this statement leads to contradictions. Suppose, for example, that we have an urn known to be filled with blue, red and yellow balls but do not know the proportion of each color. Let us consider as a starting hypothesis that the first ball we draw from the urn will be blue. According to Jeffreys' (and Laplace's) statement of the principle of indifference, if the question is whether the first ball will be blue or not blue, we must assign equal probabilities to both these hypotheses; that is, each probability is 1/2. If the first ball is not blue, it may be either red or yellow, and again, in the absence of knowledge about the actual proportions in the urn, these two have equal probabilities, so that the probability of each is 1/4. But if we were to start with the hypothesis that the first ball drawn would be, say, red, we would get a probability of 1/2 for red. Thus Jeffreys' system as it stands is inconsistent.

In addition, Jeffreys joined Keynes in rejecting the statistical concept of probability. Nevertheless his book *Theory of Probability* remains valuable for the new light it throws on many statistical problems by discussing them for the first time in terms of inductive probability.

I have drawn upon the work of Keynes and Jeffreys in constructing my mathematical theory of inductive probability, set forth in the book *Logical Foundations of Probability,* which was

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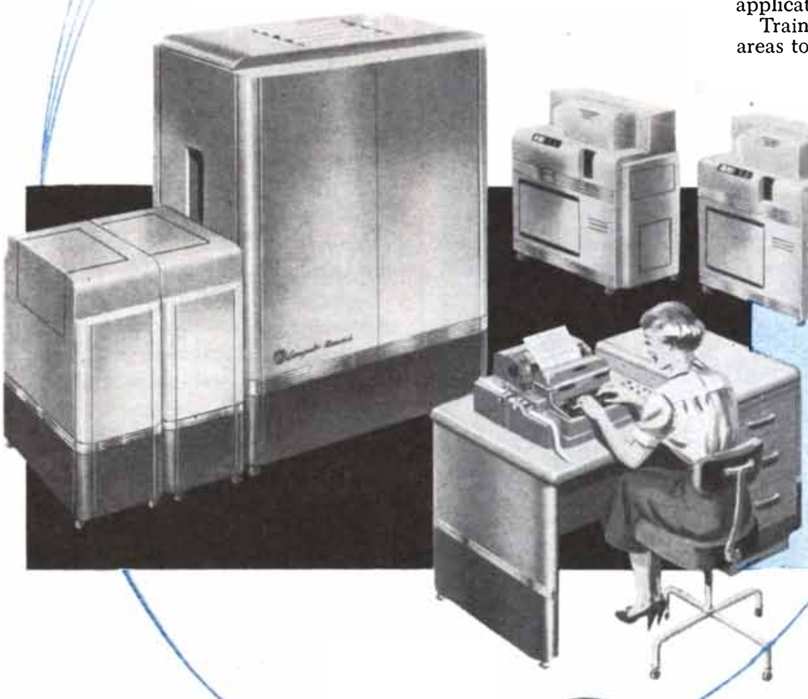

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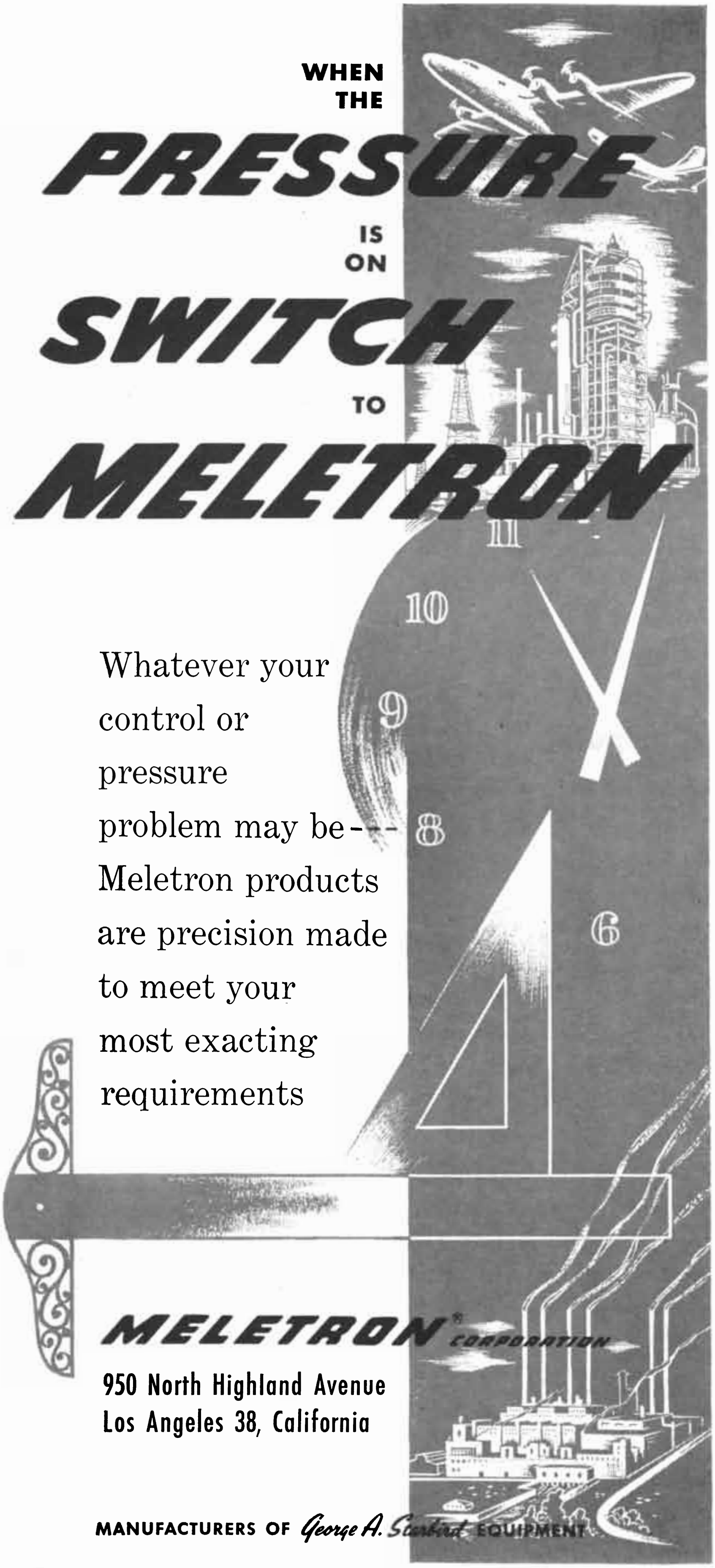

published in 1950. It is not possible to outline here the mathematical system itself. But I shall explain some of the general problems that had to be solved and some of the basic conceptions underlying the construction.

One of the fundamental questions to be decided is whether to accept a principle of indifference, and if so, in what form. It should be strong enough to allow the derivation of the desired theorems, but at the same time sufficiently restricted to avoid the contradictions resulting from the classical form.

The problem can be made clear by an example illustrating a few elementary concepts of inductive logic. We have an urn filled with blue and white balls in unknown proportions. We are going to draw four balls in succession. Taking the order into account, there are 16 possible drawings (all four blue, the first three blue and the fourth white, the first white and the next three blue, and so on). We list these possibilities in a table (*see table on page 129*).

Now what is the initial probability, before we have drawn at all, that we shall draw any one of these 16 distributions? We might assign any probability to the individual distributions, so long as they all added up to 1. Suppose we apply the principle of indifference and say that all the distributions have equal probabilities; that is, each has a probability of 1/16.

Let us state a specific hypothesis and calculate its probability. The hypothesis is, for example, that among the first three balls we draw, just one will be white. Looking at the table, we can see that six out of the 16 possible drawings will give us this result. The probability of our hypothesis, therefore, is the sum of these initial probabilities, or 6/16.

Suppose now that we are given some evidence, *i.e.*, have drawn some balls, and are asked to calculate the probability of a given hypothesis on the basis of this evidence. For instance, we have drawn first a blue ball, then a white ball, then a blue ball. The hypothesis is that the fourth ball will be blue; what is its probability? Here we run into a question as to how we should apply the principle of indifference. Let us try two different methods.

In Method I we start by assigning equal probabilities to the individual distributions. Referring to the table, we see that two of these distributions (Nos. 4 and 7) will give us the sequence blue, white, blue for the first three balls. Its probability is therefore 2/16. In only one of these distributions is the fourth ball blue; its probability is 1/16. The

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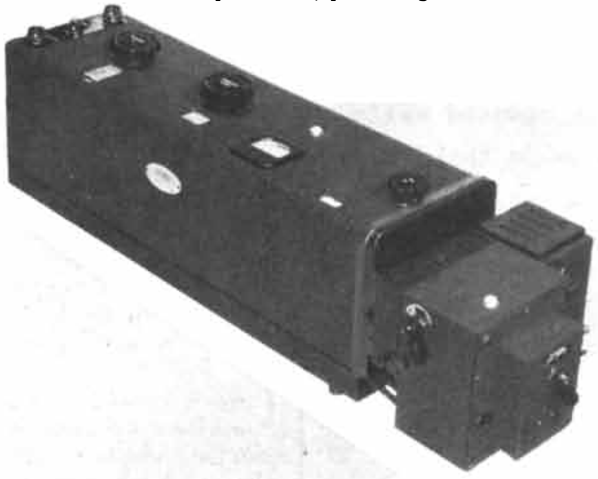

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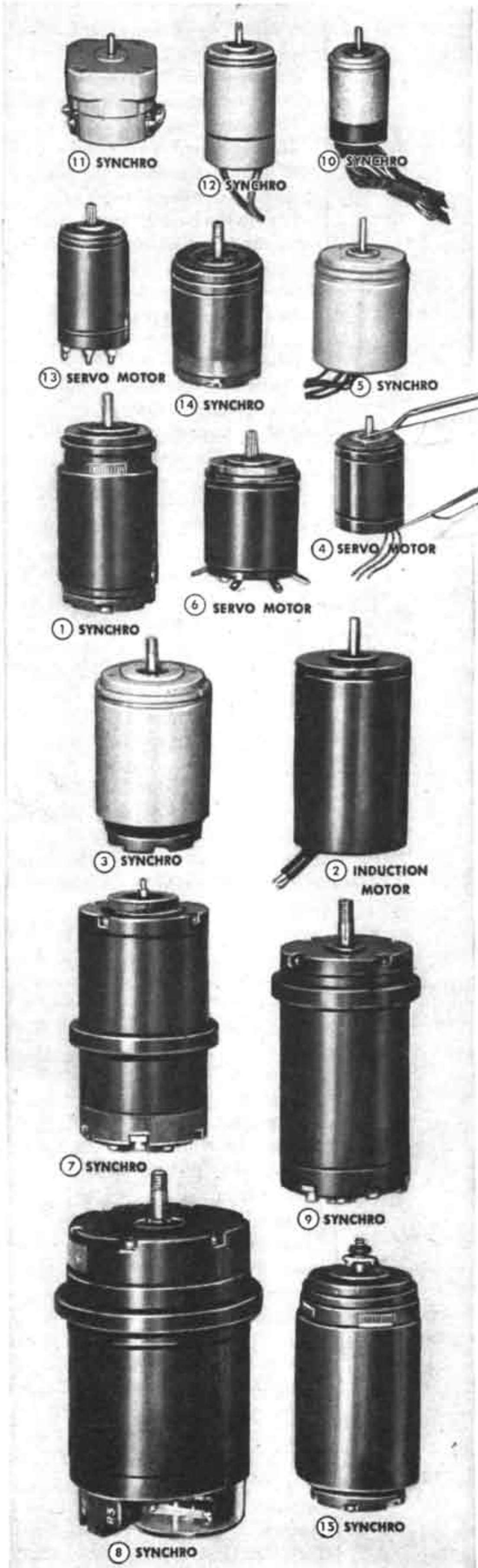
probability of our hypothesis on the basis of the evidence is obtained by dividing one into the other: *i.e.*, 1/16 divided by 2/16, which equals 1/2. In other words, the chances that our hypothesis is correct are 50-50: the fourth ball is just as likely to be white as blue.

But as a guide to judging a hypothesis, this result contradicts the principle of learning from experience. Other things being equal, we should consider one event more probable than another if it has happened more frequently in the past. We would regard a man as unreasonable if his expectation of a future event were the higher the less often he had seen it before. We must be guided by our knowledge of observed events, and in this example the fact that two out of three balls drawn from an unknown urn were blue should lead us to expect the probabilities to favor the fourth's also being blue. Yet a number of philosophers, including Keynes, have proposed Method I in spite of its logical flaw.

There is a second method which gives us a more reasonable result. We first apply the principle of indifference not to individual distributions but to statistical distributions. That is, we consider only the number of blue balls and of white balls obtained in a drawing, irrespective of order. The table shows that there are five possible statistical distributions (four blue, four white, three blue and one white, three white and one blue, two blue and two white). By the principle of indifference we assign equal probabilities to these, so that the probability of each is 1/5. We distribute this value (expressed for arithmetical convenience as 12/60) in equal parts among the corresponding individual distributions (*see last column of table*). Now the probabilities of distributions No. 4 and No. 7 are 3/60 and 2/60, respectively, and the probability of the hypothesis on the basis of the evidence is 3/60 divided by 5/60, or 3/5. In short, the chances that the fourth ball will be blue are not even but 3 to 2, which is more consistent with what experience, meaning the evidence we have acquired, should lead us to expect.

Method II, as well as Method I, leads to contradictions if it is applied in an unrestricted way. If it is used in cases characterized by more than one property difference (such as the difference between blue and white balls in our example) then all the relevant differences must be specified. Thus restricted, this system, which I proposed in 1945, is the first consistent inductive method, so far as I am aware, that succeeded in satisfying



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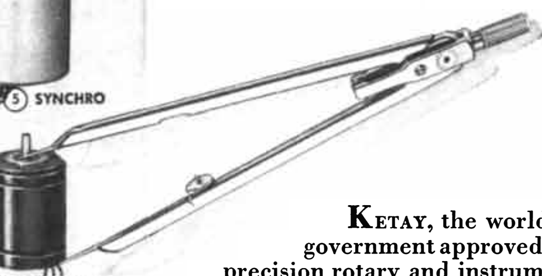

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the principle of learning from experience. Since then I have found that there are many others. None of them seems as simple to define as Method II, but some of them have other advantages.

Having found a consistent and suitable inductive method, we can proceed to develop a general procedure for calculating, on the basis of given evidence, an estimate of an unknown value of any quantity. Suppose that the evidence indicates a certain number of possible values for a quantity at a given time, *e.g.*, the amount of rain tomorrow, the number of persons coming to a meeting, the price of wheat after the next harvest. Let the possible values be x_1, x_2, x_3, etc., and their inductive probabilities be p_1, p_2, p_3, etc. Then p_1x_1 is the "expectation value" of the first case at the present moment, p_2x_2 of the second case, and so on. The total expectation value of the quantity on the given evidence is the sum of the expectation values for all the possible cases. To take a specific example, suppose there are four prizes in a lottery, a first prize of $200 and three prizes of $50 each. It is known that the probability of a ticket winning the first prize is 1/100, and of a second prize, 3/100; the probability that the ticket will win nothing is therefore 96/100. Applying the method I have described above, a ticket holder can estimate that the ticket is worth to him 1/100 times $200 plus 3/100 times $50 plus 96/100 times 0, or $3.50. It would be irrational to pay more for it.

The same method may be used to make a rational decision in a situation where one among various possible actions is to be chosen. For example, a man considers several possible ways of investing a certain amount of money. He can—in principle, at least—calculate the estimate of his gain for each possible way. To act rationally, he should then choose that way for which the estimated gain is highest.

Bernoulli, Laplace and their followers envisaged a theory of inductive probability which, when fully developed, would supply the means for evaluating the acceptability of hypothetical assumptions in any field of theoretical research and for making rational decisions in the affairs of practical life. They were a great deal farther from this audacious objective than they realized. In the more sober cultural atmosphere of the late 19th and early 20th centuries their idea was dismissed as Utopian. But today a few men dare to think that these pioneers were not mere dreamers.

BOOKS

An English philosopher's answer to the question: What is science?

by J. Bronowski

SCIENTIFIC EXPLANATION, by R. B. Braithwaite. Cambridge University Press ($8.00).

Richard Braithwaite has recently been elected to the chair of moral philosophy at the University of Cambridge. Lest this be thought to mark him as a ponderous man, let me preface what I have to say about his book by quoting first from his less formal writings. Shortly before the war he and his wife (they are both philosophers) announced the birth of their first child in a terse postcard: "We are calling the boy Lewis, after our favorite logicians, Ludwig Wittgenstein and Lewis Carroll."

Professor Braithwaite's new book says less about Wittgenstein (the founder of the Vienna school of logical positivism) than it might have 15 years ago, and nothing about Lewis Carroll. But the influence of these powerful and irreverent thinkers has not faded. For their appeal has always been that both were mathematical thinkers, and the training of the mathematician is dominant in Professor Braithwaite's outlook and in his exposition.

His book is exactly what its title promises: an elucidation of what we mean when we say that a science "explains" something. Optics explains how light is diffracted; genetics explains the distribution of the blood groups; psychoanalysis explains your dreams; the Bohr model of the atom explains the lines in its spectrum. What do these explanations have in common? What is the status of the concepts they use—the light wave, the gene, the unconscious, the electron? Are they discovered or invented? And how can they be defined?

Professor Braithwaite spends his early chapters on these questions. His answers here seem to me lucid, sensible and complete. They rest on two fundamentals in his outlook which I share, and which are probably common to all those who have grown up in the mathematical shadow of modern physics. One of these fundamentals is to regard a science as a way of arranging our experience so that it shall be compact and coherent. The other is to assume that such an arrangement ought to have the form of an axiomatic system.

For the first of these fundamentals, I shall let Professor Braithwaite speak with his own eloquence:

"To one who was studying physics when Einstein's General Theory of Relativity of 1916, and its confirmation by the eclipse expeditions of 1919, burst upon the learned world, the paradigm of explanation of a law will always be the explanation of gravitation provided by this theory. Newton explained the moon's revolution round the earth by subsuming it (together with other phenomena) under his law of gravitation; Einstein explained Newton's law of gravitation by showing that it was a consequence (an approximate consequence) of a law governing the structure of space and time. . . . I count my appreciation of Einstein's explanation of the law of gravitation as one of the keenest intellectual pleasures of my life. Any incorporation of a fact—be it a particular instance of a law or the law itself—into a deductive system in which it appears as a conclusion from other known laws is, by virtue of that incorporation, an explanation of that fact or law."

The example is a little odd, for most mathematicians are more impressed with the intellectual content of the Special Theory of Relativity of 1905 than with the General Theory. Yet it underlines one merit all through Professor Braithwaite's book: that he writes at first hand as a man to whom modern science is a natural and a personal passion. This is a feeling which has hitherto been unknown among philosophers; indeed, it is fairly rare among scientists.

What I have quoted also makes clear that Professor Braithwaite thinks of a scientific system as a hierarchy or, in an image he himself uses, as a pyramid. At the base are the observed facts. At the next level are the simplest laws that connect them, a few facts at a time. Above these is a layer of laws which connect sets of the lower-level laws. And these in their turn are connected by still more general laws at a still higher level.

At the highest level of generalization the laws usually connect very abstract concepts: the wave function, the biological organizers, the electron spin. We have no way of defining these concepts except by the laws themselves. The science is therefore most clearly presented in reverse. Its fundamental entities are the concepts, and its axioms are the laws which connect these. From them we can go down the pyramid, step by step, always by deductive steps, until at last we return to the level of observable fact. We believe that the concepts have meaning and the laws that connect them are true only because the facts we deduce from them are verified.

What is the status of these concepts which crowd science? Plainly they are in some sense a shorthand for the facts that fall under them. And for some time professional scientists have liked to think that the concepts can be defined precisely as a shorthand for the facts and nothing more. This is the operational view widely held in the U. S. under the influence of Percy Bridgman: length is a sequence of measurings; mass is what you do when you find the mass; a nucleon is an array of observations and nothing else. An equivalent idea has been current in England at least since 1918, when Bertrand Russell wrote: "The supreme maxim in scientific philosophizing is this: Wherever possible, logical constructions are to be substituted for inferred entities." The idea that all scientific concepts are purely logical constructions was also held by Wittgenstein and continues to be held by logical positivists. Professor Braithwaite does not hold it, but he states it very fairly:

"Electrons, on this view, are logical constructions out of the observed events and objects by which their presence can be detected; this is equivalent to saying that the word 'electron' can be explicitly defined in terms of such observations. Every sentence containing the word 'electron' can be translated without loss of meaning into a sentence in which there occur only words which denote entities (events, objects, properties) which are directly observable. It may be very difficult to make this translation, but it is always possible to do so."

This view was first criticized by F. P. Ramsey, the British child prodigy of mathematical philosophy who died before he was 30. It happens that Ramsey, who taught me (he was not a good teacher), died just before he was to have examined me, and I was examined by his friend Braithwaite instead. Braithwaite follows Ramsey's thought closely in his discussion of the shortcomings of the logical positivist attitude toward science. It is the right attitude in a science which is closed; it is hopelessly the wrong view when a science is still growing. For a logical construction which has been made to contain only the existing facts and relations cannot accommodate new relations. If your definition of mass, say, is operationally or logically exact, then it is too narrow; it leaves you no room to discover that mass is also equivalent to energy. The concepts of a growing science must be richer and more pliable than any logical construction from the sum of its known facts. Professor Braithwaite proves this elegantly and finally in the formal symbolism of mathematical logic, in an example simple enough to be widely understood. I count this the most important chapter in his book.

Professor Braithwaite then turns to another set of questions just as important in modern science. What do we mean by probability? Can we assign a probability to a belief as well as to a prediction? What strategy should we use to insure ourselves against the improbable?

Philosophers have asked such questions before, but with a display of ignorance of the work of modern mathematical statisticians which I can only call contemptuous. They write as if Pierre Laplace and Karl Pearson had said the last words on probability and estimation. Braithwaite is the first philosopher known to me who uses the statistical criteria which Jerzy Neyman introduced 20 years ago, and seriously discusses their relation to the newer work of Abraham Wald and of John von Neumann [*see Rudolf Carnap's article "What is Probability?" on page 128*].

Braithwaite makes the new ideas fundamental to the *definition* of probability. When in the past a scientific law has contained the statement that event A will turn up 7 times out of 10, this has been thought to require ideally an infinite sequence of trials. Like other notions which assume an infinity of actual repetitions, this has long seemed dubious, and

I myself tried to avoid it in what I wrote about *The Idea of Chance.* Braithwaite shows with a good deal of rigor that it can indeed be avoided. He frames his definition of a probability of 7 times out of 10 in such a way that deviations from this ratio in any finite sample are part of the definition. As a result, his development of probability reasoning is both realistic and new.

All this has a bearing on the standing of any scientific law. Scientists know what the layman seldom grasps, that a scientific law is not permanent. For in some form any scientific law contains either the word "every" or the word "all," and however many instances we may bring to support it, we can never exhaust these words. Therefore we can never be sure that we are right in accepting a law; we can only be sure that we must reject it when we find one instance that contradicts it. But suppose that a law also contains the word "some"—that is, contains a phrase such as "7 out of 10"—as the laws of atomic physics do. Then we cannot even be sure when we should reject the law; our rejection becomes as provisional as our acceptance.

Given a choice of laws, what is the prudent policy that we should follow? Professor Braithwaite discusses this problem with gusto, basing himself on the strategy first put forward by Wald, and his examples are always attractive. They are perhaps more artificial than they need be, for this kind of problem is not remote. For an example we need only look at the photograph of a meson shower published by Miss Schriel in *Naturwissenschaften* last year. The photograph contains about 16 meson tracks and no tracks of heavy particles. Is it therefore evidence for Werner Heisenberg's new theory, that there can be multiple production of mesons? Or is it a nuclear cascade in which all the heavy particles happen to be neutrons and have therefore left no tracks? And how much such indirect evidence must we piece together before we choose one theory or the other? These are the problems of the working scientist, and it is exactly because they are real that experimental physics is such a fascinating study today.

I have said enough to make plain my high opinion of Braithwaite's book. In the main it is the best account of the logic of scientific reasoning that I have read. But it does not seem to me to sustain its excellence quite to the end. Its last chapters are in fact more humdrum. For example, I am sure that his treatment of the problem of induction begins right: he will have nothing to do with the school of thought, continuing from Laplace to Carnap, which finds the laws of nature more probable every time we observe them. If repeated confirmation is not a justification of the laws of nature, what is, then? As a believer in Braithwaite's pyramid, or something like it, it seems to me plain that we must look for the evidence for the laws in the cross-connections between them. What we must adduce, I think, is the amount of simplification or order the laws bring into the wilderness of natural facts. Braithwaite stops far short of this; he is content to say that we know no more about the laws of nature than that they work. The policy he recommends is to make generalizations in the way in which they have worked before. This is a nice piece of modesty on the part of a philosopher, but for once it seems to me to go beyond the modesty of science.

Short Reviews

The Revolution in Physics, by Louis de Broglie. The Noonday Press ($4.50). De Broglie, winner of the Nobel Prize for his contributions to wave mechanics, here gives a masterful account of the extraordinary transformation of physics effected by the introduction of the quantum concept. In searching detail de Broglie examines Max Planck's quantum postulate, Niels Bohr's theory of the atom, the fundamental ideas of wave mechanics, including Erwin Schrödinger's great achievements, Werner Heisenberg's formidably abstract matrix system and the widely held probabilistic interpretation of nature, in which the most deeply felt convictions about space, time, matter and causation itself are displaced by a hair-raisingly complex system of disembodied psi waves and vague corpuscles bereft of precise position, velocity or trajectory. The average reader struggling to grasp this system gets very little help from de Broglie. His presentation is elegant but pitiless. It is true there is no mathematics in the story, but it bristles with tightly written sentences in a rhetorical algebra which is even harder to follow than the mathematical symbols would be. The dust jacket's claim that this is a survey for the layman is pure seller's puff. But specialists and advanced readers will find it a fascinating work; none like it has appeared before. In addition to offering a majestic synthesis of the evolution and structure of physics, de Broglie in a series of penetrating critiques exposes its insufficiencies. One of the most valuable and interesting chapters expresses the author's serious doubts about indeter-

minacy. Like Einstein, he is by no means convinced that the possibility has been permanently extinguished of finding hidden beneath the present statistical structure "a perfectly determinate reality." He warns of the danger that the progress of science may be hampered in our period, as has happened before, "by the tyrannical influence of certain conceptions that finally come to be considered as dogma." De Broglie ends the book by presenting a deterministic theory of his own, first published a quarter of a century ago and recently revived by the U.S. physicist David Bohm, which preserves quantum principles and attempts to reconcile the dual notion of the corpuscle and its associated wave. De Broglie's theory is stymied for the moment by mathematical obstacles, but it is gratifying to learn that several vigorous and talented investigators are concentrating on solving these problems, thereby clearing the way for a tough competitor against existing theories and a healthy re-examination of fundamentals. This is an absolutely first-class book, even if it is not a supreme example of the art of popularization.

YOU SHALL KNOW THEM, by Vercors. Little, Brown & Co. ($3.50). The author of *Le Silence de la Mer*, the most celebrated novel to come out of France during the Occupation, here stretches anthropology to his moral purpose by supposing that a party of explorers in New Guinea has come upon a tribe—or is it a pack?—of creatures poised so exactly on the genetic dividing line between man and beast that no one can say whether the new find is an exceedingly primitive human being or an exceptionally advanced ape. To test the question (which becomes urgent when a development company proposes to breed the new species for cheap manual labor), a British journalist offers his services as donor in an artificial insemination experiment. The female chosen for the crossbreeding becomes pregnant; the Englishman kills the eventual offspring and proclaims himself the murderer of his own son. He thus forces the courts, and in time Parliament, to wrestle with a question never entertained before by the legal mind: What precisely is a human being? Vercors has studied the recent literature of anthropology and presents his ticklish problem seriously and fairly—if with the melodramatic license of science fiction. Man's evolutionary eminence, he points out, is no longer as obvious as it once was; the gradations of species are more subtle than used to be thought. But his solution is disappointing. His test for membership in the human race—the sense of religion—must be defined so broadly that it begs the question; dogs, after all, may be said to worship their masters. The enigmas of science—to which he admittedly makes an interesting contribution—are seldom so blandly solved as in this ingenious but essentially illogical story.

ROBERT GROSSETESTE AND THE ORIGINS OF EXPERIMENTAL SCIENCE, 1100-1700, by A. C. Crombie. Oxford University Press ($7.00). Robert Grosseteste was chancellor of Oxford University, Bishop of Lincoln and a man of sufficient principle and courage to defend the Church against the usurpations of Henry III and the excessive exactions of Innocent IV alike. He was also one of the leaders of thought in the 13th century. His hundreds of writings included treatises on mathematics, physics, optics, astronomy, light, rainbows, the sphere, motion, color, logic, psychology, metaphysics, commentaries on Aristotle, pastoral subjects and polemical poems. In this careful historical study Mr. Crombie, a science historian at University College, London, demonstrates that Grosseteste was markedly influential in the development of modern experimental science. There were in Grosseteste's time practical men absorbed in "irreducible and stubborn facts;" there were other men, as Alfred North Whitehead has said, absorbed in "the weaving of general principles." Grosseteste's genius lay in recognizing more clearly than any of his predecessors that the progress of science depended upon a union of the passion for facts and for theories in which each would animate and reinforce the other. This procedure was epitomized in a famous passage by Francis Bacon: ". . . to educe and form axioms from experience . . . to deduce and derive new experiments from axioms . . . For our road does not lie on a level, but ascends and descends; first ascending to axioms, then descending to works." Crombie skillfully traces Grosseteste's influence on Adam Marsh, Roger Bacon, Albertus Magnus, William of Occam (who, one learns, is wrongly credited with inventing the principle of economy—Occam's Razor—which bears his name) and other 13th- and 14th-century investigators. The scientific method, to which Grosseteste gave powerful impetus, is generally regarded as distinctively modern. Crombie shows that this view accords too little credit to the past. He broadens our understanding of the evolution of scientific thought, demonstrates its continuity (history, like nature, evidently abhors

"**The long-haired star**" is what the ancient Greeks called the comet. Until recently, modern astronomers have not known much more about comets than the Greeks. Now, with the publication of THE COMETS AND THEIR ORIGIN by R. A. Lyttleton, ancient superstitions and modern irrationalisms are replaced by *"a new, coherent and testable theory,"** based on the New Cosmology. Here, at last, is an *"excitingly persuasive"** answer to the riddle of the comets. In addition to the new theory, Lyttleton provides a summary of the previously known facts, and 34 fine photographs.

$5.00 at bookstores.

**Scientific American*

THE COMETS AND THEIR ORIGIN *is published by the Cambridge University Press, publishers of notable books on the sciences since the time of Newton, and indeed before. The roster of distinguished Cambridge authors in recent years includes Lord Rutherford, Sir Arthur Eddington, Sir James Jeans, A. N. Whitehead, Bertrand Russell, George Gamow, Erwin Schrodinger in the physical sciences; in biological science Sir Charles Sherrington, Sir D'Arcy Thompson, Sir Macfarlane Burnet, and James Gray.*

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making jumps) and helps to kill the already tottering myth that the science of the Middle Ages was little more than commentary and sterile exegesis.

PASCAL, HIS LIFE AND WORKS, by Jean Mesnard. Philosophical Library ($3.75). Pascal has had many biographers, but his elusive personality, his precocity, his strange mixture of practicality and otherworldliness, his superlative literary and scientific gifts, promise that he will have more. Recent researches have shed new light on this "sublime madman," as Voltaire called him, and the author of this book, a well-known French scholar, here offers a sensitive, intelligent reappraisal of his life and work. Pascal's contributions to science included his famous arithmetical engine, researches in physics and many mathematical discoveries, notably in geometry and the theory of probability. Mesnard's study attempts no detailed evaluation of these achievements. It is concerned mainly with Pascal's development as a man. The book shows clearly that Pascal, despite a series of religious experiences in the course of which he grew increasingly mystical and devout, never abandoned his interest in science, or, for that matter, in such practical affairs as his sister Jacqueline's dowry or his operation, with the Duc de Roannez, of the first Paris omnibus service. Mesnard gives a large part of his work to Pascal's *Pensées*, to *The Provincial Letters* and to his devotion to Jansenism. Thus through reinterpretation of his works we are given fresh glimpses of Pascal's character: proud, aristocratic, skeptical, overbearing, hostile; also kind, charming, humane, simple, elevated. Yet the book leaves in doubt his innermost religious and philosophical convictions. Two things emerge, says Ronald Knox in his foreword, from the reading of this fascinating book: the veiled figure of a man, and the clear-cut outlines of a problem.

GALVANI'S COMMENTARY ON THE EFFECT OF ELECTRICITY ON MUSCULAR MOTION, translated by Robert Montraville Green. Elizabeth Licht ($4.00). This is a translation of the celebrated 1791 paper by Galvani, reporting the experiment in which he noticed that a frog's leg contracted violently under the influence of a spark discharge from an electrical machine. He followed this up with other work on the effects of what he called "animal electricity," researches which led to the invention of the voltaic cell and later to the electric telegraph and wireless. "Great things have small beginnings. What in Galvani's hands could move a muscle, brought Marconi's voice across oceans." The translator adds an introduction by Giulio C. Pupilli, Galvani's "academic heir" at the University of Bologna, and a dissertation on Galvani's discoveries by his nephew Giovanni Aldini. Altogether this makes a book of 97 pages.

Mr. Tompkins Learns the Facts of Life, by George Gamow. Cambridge University Press ($2.75). Cyril George Henry Tompkins, a bless-my-soul sort of bank clerk with an interest in science, an unquenchable curiosity and an ever-present tendency to fall asleep, is the creation of George Gamow, a wide-awake theoretical physicist with a gift for science popularization, a nice wit and a strenuous inclination to whimsy. On earlier occasions Professor Gamow has recounted Mr. Tompkins' slumberous adventures in curved space and in the interstices of the atom. In this book he contrives to get the little man injected into his own blood stream, where he meets his cells, glands and genes; this is followed by an excursion through the looking glass and a journey by Tompkins through his own brain. All this may sound pretty distressing, but it is a good deal better than it sounds, not only because Gamow knows his subject, but also because, even if he is not in Lewis Carroll's class, his images are fresh and his imagination is lively. The last chapter, a lecture on the mechanistic interpretation of life and an elaboration of Erwin Schrödinger's ingenious concept of negative entropy, is exceptionally skillful.

Evolution in Action, by Julian Huxley. Harper & Brothers ($2.75). It is an agreeable and a stimulating experience to read what Huxley has to say about evolution even if he says nothing essentially new and has said it several times before. These are the Patten Lectures, delivered at Indiana University and repeated in modified form as B.B.C. talks. They are concerned with natural selection, with the emergence of mind, with the "narrow and winding stairway of progress, and the steady advance of life up its steps of novelty." Huxley believes firmly in biological improvement, by which he means organic developments that promote variety, new properties, new and better ways of doing things and more complex systems of organization and cooperation. In this sense he has no difficulty in giving many interesting examples of progress, including human progress. It is doubtful that he settles all connected philosophical questions, especially the celebrated controversy "about the survival of the fittest, meaning the survival of the fittest to survive." But there is no doubt about the immense readability of his book, its erudition and its humanity.

WAVES AND TIDES, by R. C. H. Russell and D. H. Macmillan. Philosophical Library ($6.00). This is one of the first books, as Herbert Chatley points out in the foreword, in which the practical relations between waves and tides are fully brought out. Russell gives a clear account of the characteristics of ocean waves, how waves are generated, how fast they move, how they are reflected, diffracted, refracted, how they move material, how they are measured, the height of the biggest waves (perhaps 75 feet), the difference between plunging and spilling breakers, the effect of wave action on structures, the high speed and enormous energy of plumes of spray (which are capable of quarrying 5-ton blocks of solid rock and of moving 9-ton rocks hundreds of feet away from the low water mark). The discussion of tides by Macmillan is equally comprehensive and varied in interest. It deals with the history of the observation of tides, their effects on navigation, commerce and sea-power, modern tidal theories, tides and the weather, tidal streams, the interaction of the causes of waves and tides, the utilization of tidal energy, the future of tidal research. While much of this book is technical and addressed to specialists, there is no lack of material (including a number of spectacular photographs) to enlighten and entertain the average reader. One learns, for example, that a surf rider moves through the water because his board, perched on the front of a spilling wave, is perpetually sliding downhill; also, that it is very unlikely that there is such a thing as undertow, but even if it does exist, the forces producing it will carry a swimmer toward rather than away from the shore. "If he sinks he may be carried seaward; but if he sinks he has passed from the category of swimmers."

LOGIC AND LANGUAGE, edited by A. G. N. Flew. Philosophical Library ($4.75). This is the second collection of essays in a series whose purpose it is to make known recent linguistic developments in philosophy. The editor has selected articles from various philosophical journals and succeeds in presenting a balanced and representative picture not only of the current bustle among logical positivists, but of the lively concern over logical questions among philosophers uncommitted to any school or movement. Included in this collection are some rather difficult pieces, such as G. E. Moore's well known paper "Is Existence A Predicate?" J. J. Smart's "Theory Construction" and J. L. Austin's "Other Minds." But there are also entries which will appeal to "less strenuous and less enthusiastic laymen," for example: "Will the Future Be Like the Past?" by F. L. Will, "Every Event has a Cause" by G. J. Warnock, "On Grading" by J. O. Urmison, "Mathematics and the World" by Douglas Gasking. Professor Gasking's agreeable essay offers an ingenious demonstration of a proposition which philosophers believe but have a hard time getting others to believe; namely, that mathematics cannot be validated by experience. The mathematical system we use is not dictated by physical events but selected merely for convenience. We could, for example, use a multiplication table in which $2 \times 4 = 6$, $2 \times 8 = 10$, $4 \times 4 = 9$, etc., yet every activity in which these methods and this table were employed could be executed accurately. Our books would balance, our bridges would stand, our bombs would explode as prettily as ever. But it may be admitted that the new arithmetic would be much less comfortable than the subject we all know and love so well.

THE INTERPERSONAL THEORY OF PSYCHIATRY, by Harry Stack Sullivan. W. W. Norton & Company, Inc. ($5.00). Sullivan's interpersonal theory of psychiatry has double roots in the psychoanalytic theory of Sigmund Freud and the psychobiology of Adolf Meyer. He formulated it in an attempt to apply to psychiatry the more rigorous concepts, methods and precise language of the natural sciences. Since human living can be profitably gauged and evaluated in terms of human interaction, personal relations were of prime concern to Sullivan. And since he was developing a field theory of psychiatry, he touched upon all aspects of social living from anthropology to politics. This book, edited from unpublished lectures, begins with a statement of Sullivan's concepts and definitions and then traces the development of human living from infancy and childhood through the juvenile, preadolescent and adolescent phases. He indicates where and how each period offers opportunities and obstacles to the healthy growth of personality. His emphasis on the juvenile and pre-adolescent years has been of major clinical importance. Mental disorders are seen as ways in which interpersonal relations are mildly or seriously warped. The final section is devoted to social problems which Sullivan believed to be rooted in the needs of individuals and groups to preserve self-esteem, minimize anxiety and bridge the barriers of loneliness. Sullivan, who died in 1949, was a great clinician as well as a great teacher. His creative mind was hospitable to new ideas, willing to change as new evidence came to light. Despite occasional ambiguities and troublesome ellipses, this is a brilliant and important book.

The Natural History of Infectious Disease, by Macfarlane Burnet. Cambridge University Press ($4.50). The first edition of this popular book appeared in 1936. Since then the sulfa drugs, antibiotics and other weapons have so revolutionized the treatment of the infectious diseases that they have "now ceased to have any serious social significance in the advanced countries of the world." However, vast segments of the world's population do not enjoy these benefits, and there is need for much improvement in methods of prevention and care. In this second edition of his interesting book, Burnet, the great Australian authority on viruses, reminds us that practical progress in fighting infectious disease has been much more spectacular than advances in understanding of it.

Emotional Difficulties in Reading, by Beulah Kanter Ephron. The Julian Press, Inc. ($5.00). This is one of the few books on the emotional problems of reading that actually comes to grips with the subject. Dr. Ephron explains the necessity of recognizing reading difficulties as a neurotic symptom. She traces the sources of the trouble and the reasons for the choice of this particular symptom. She also tells how people with reading difficulty can be helped by psychotherapy and training.

The Quality of Learning, by Ronald Morris. Methuen & Co., Ltd. ($1.75). This sensible book by an English educator deals with the teaching of that increasingly large group of children who make up our "non-graded" or "slow" classes. Retarded children—I.Q. between 65 and 90—have the capacity to learn if properly taught. The book is a readable addition to the mounting information on this subject. It also indicates that Great Britain is in no way more advanced than the U.S. in the handling of the retarded child.

General Principles of Psychology, by Frederick E. Eastburg. Bruce Humphries, Inc. ($3.00). Dr. Eastburg

offers his interpretation of human psychology from the point of view of the late William McDougal of Harvard, who departed both from the introspective approach of Tichenor and from Watsonian behaviorism. McDougal's is called the purposive approach; it sees man as a composite body and mind whose controlling force is drive, motivation or purpose. The book covers all the usual areas of psychology and is usable as a college text.

LIFE AND WAYS OF THE SEVEN-TO-EIGHT YEAR OLD, by Barbara Biber, Lois B. Murphy, Louise P. Woodcock and Irma S. Black. Basic Books, Inc. ($4.50). The middle years of childhood have been comparatively neglected, though it is in these years that the basic patterns for social and intellectual living are formed. These four authors from the Bank Street College of Education chose five boys and five girls from a New York City progressive school to study in detail. The children were placed in various situations over a period of a school year (1937-1938). They were given many tests and were observed by two or more observers. The authors' findings are absorbing and well worth reading.

Notes

THE FURANS, by A. P. Dunlop and F. N. Peters. Reinhold Publishing Corporation ($18.00). A massive monograph on the chemistry of the furan compounds (derived from wood tars) and on the industrial applications of furfural and its derivatives. These include nylon, lysine, solvents and resins.

PROGRESS IN BIOPHYSICS AND BIOPHYSICAL CHEMISTRY, edited by J. A. V. Butler and J. T. Randall. Academic Press, Inc. ($9.50). The third volume of this annual includes articles on autoradiography, infrared spectra of biologically important molecules, physico-chemical studies of viruses, the biological action of ultraviolet and visible radiations, the microspectrometry of living and fixed cells.

ELECTRON OPTICS, by O. Klemperer. Cambridge University Press ($9.50). This second and much enlarged edition of one of the Cambridge monographs on physics gives an account of the salient principles, methods and applications of geometrical electron optics. An excellent handbook for advanced students and research workers, based on the latest work in the rapidly growing literature of this important subject.

What General Electric people are saying . . .

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Mr. Lang is Vice President in charge of Public Relations

". . . In large measure, our Puritan ancestors insisted that liberty was dependent upon the general education of the country's citizenry. Our industrial system, as we know it today, is dependent on the education of that same citizenry. If we lose sight of this fact, we also lose sight of the fact that under a totalitarian system every industrial plan, or scientific research plan, becomes a State-plan. Every manager in industry becomes, in reality, a civil servant. Political democracy and industrial democracy depend on each other, and both depend on education.

There are two great educational objectives in America. First, we must endeavor to combine the British concern for training the "natural aristocracy of talents" with: Second, the American tradition and insistence of general education for *all* future citizens. If we can do this, then our industrial society will prosper, and at the same time the necessary degree of instruction will be provided for all people so that in their hands "our liberties will remain secure."

at a Meeting of Charles Coffin and Gerard Swope Fellows, Schenectady, New York

L. P. GROBEL

Mr. Grobel is Supervisor, Generator Mechanical Engineering, Large Steam Turbine and Generator Department, Turbine Division

". . . Precision balanced rotors have given smoother running turbine-generators with a great reduction in the amount of balancing needed at installation. High-speed 3600-rpm units placed in operation in 1949 had an average bearing vibration of 0.42 mils. By contrast, in 1950, when many of the present precision-balancing practices were adopted, this figure dropped to 0.30 mils. And during the years 1950 and 1952, it has remained nearly constant at 0.26 and 0.27 mils, respectively.

The 1949 turbine-generators were good machines. Current reduction of 35 per cent in vibration simply means that today's precision-balanced machines have still less vibration. Over the same four-year period—1949 to 1952—there has been a decided reduction in the amount of balancing at destination. An average of 7.4 balancing trials were taken on the 1949 machines; this figure decreased to 5.2 a year later, became 2.4 in 1951 and 2.0 in 1952. During 1952, 58 per cent of all turbine-generators shipped needed no further balancing at destination.

G.E. Review

C. D. GREENTREE

Mr. Greentree is Manager, Engineering and Consulting Application Services Department, General Engineering Laboratory

". . . A most important early activity of the project engineer is to decide what is known and what is unknown. In almost any large project, only 5 to 10 per cent of the total effort is involved with new knowledge. Some 90 to 95 per cent of the total effort is concerned with the manipulation of existing materials, mechanisms and circuits into different combinations by means of known laws, formulas and design data. Furthermore the bulk of each manipulated combination is straightforward development and design engineering. I equals E over R, Force equals Mass times acceleration. But some portions of some of the combinations do contain the new idea, the tricky circuit, the new knowledge or data. The problem of the project engineer, with the help of his task engineers, is to spot where these are and furthermore to spot them with a high degree of technical accuracy. Then he must start work on these new idea areas first before spending time and money on the straightforward part which will be wasted unless the key portions work.

at The American Society of Mechanical Engineers Philadelphia, Pa.

HERBERT SCHREIBER, JR.

Mr. Schreiber is an Industrial Product Engineer, General Electric X-Ray Department

". . . The first and obvious requisite for cathode-ray sterilization is the penetration or accelerating voltage required for the product and container size. Here two factors control the ultimate decision; namely, 1) Is complete penetration required or will surface sterilization be sufficient? 2) Can the physical dimensions of the product to be irradiated be changed for a more practical solution? The question of complete sterilization as opposed to surface sterilization can only be answered by the ultimate aim of the user. In many cases it is only desired to extend the shelf life of the product and a surface sterilization will often accomplish this purpose. In addition the severity of any organoleptic changes is usually increased with higher penetration thereby making higher voltage a detriment rather than an aid. Of course, if complete sterility is required then the cathode-ray generator must necessarily have sufficient voltage to penetrate the entire sample. The only alternative here is a change in the thickness or mode of packaging of the product thereby decreasing the ultimate penetration required. The factors controlling this decision are the additional costs of higher voltage equipment as opposed to the costs of changes in product dimensions or packaging technics.

Cathode Ray Sterilization Symposium, Milwaukee, Wis.

THE AMATEUR SCIENTIST

About sundials and a cyclotron, the latter built by a group of bold high school boys

Conducted by Albert G. Ingalls

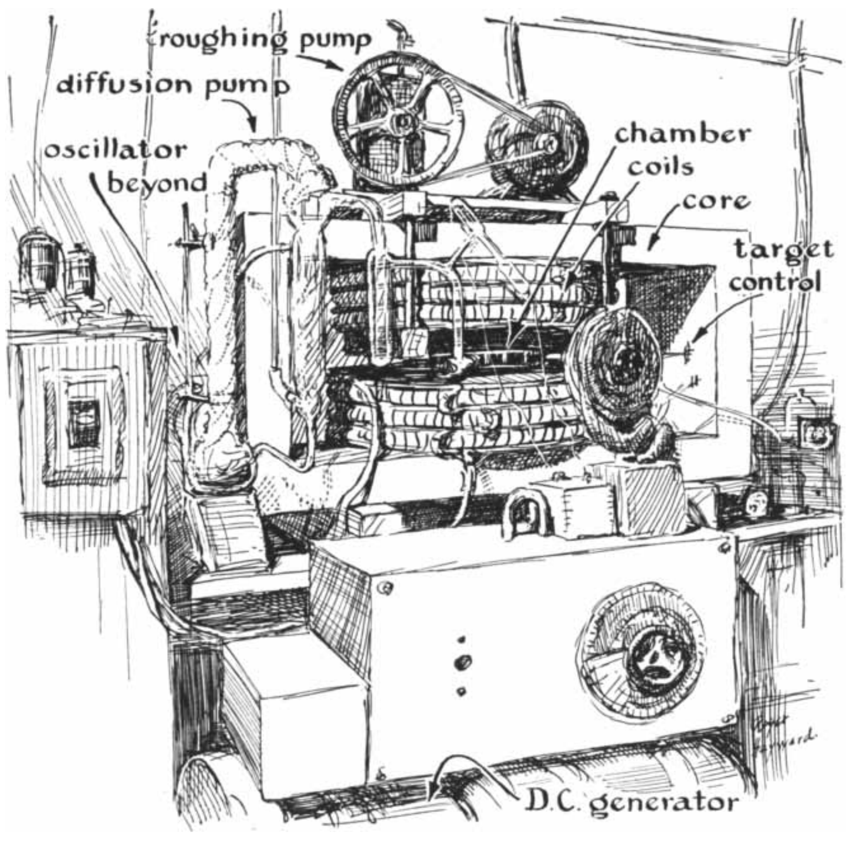
Contrary to the impression given by some editorial writers, screw drivers and soldering irons are far more common weapons among teen-agers than are zip guns and switch blades. In South Chicago recently policemen, answering a frantic matron's report that hoodlums in a vacant lot were aiming a cannon at her house, found a group from the local high school adjusting a 12-inch Newtonian reflector. Another gang, caught near Washington, D. C., turned out to be radio hams bouncing microwaves off the moon. A third, investigated by state troopers north of Philadelphia, were making static tests on a liquid-fueled rocket of their own design.

Similar gangs, many unknown to the police, are at work all over the country. The gang movement in amateur science appears to be growing, perhaps as a result of rising costs and the increasing complexity of scientific experiments. A worthwhile wind tunnel or a radiocarbon dating apparatus cannot be financed by the proceeds from a youngster's odd jobs. Hence the boys are learning to pool their resources. The combined pocketbooks, enthusiasm, energy and audacity of half a dozen youngsters seem to be equal to just about any project modern science has to offer.

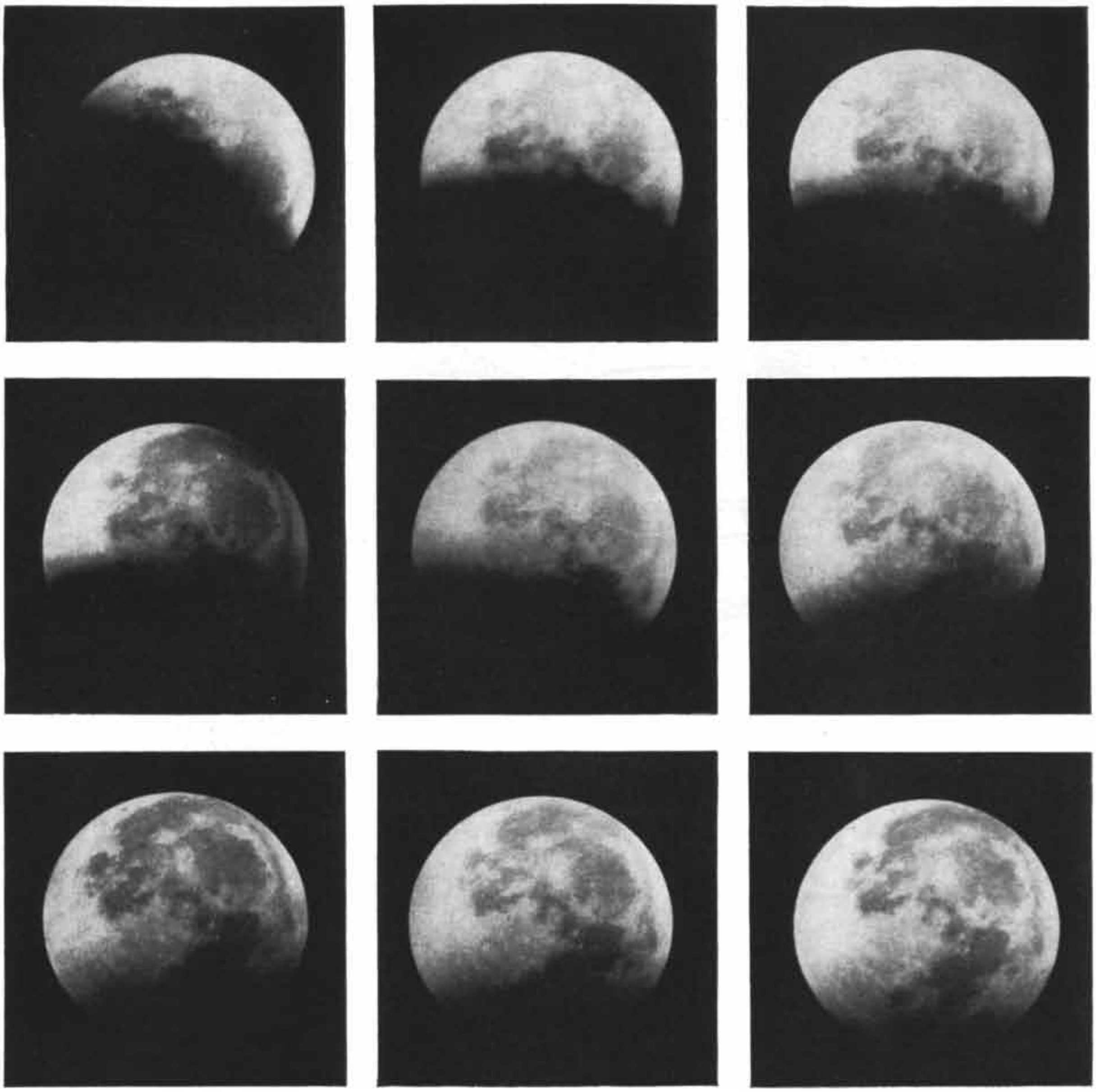
This includes even a cyclotron. A group of teen-agers in El Cerrito, Calif., decided to have one although they knew that even a small cyclotron may cost tens of thousands of dollars and require such finicky adjustments that nuclear physicists sometimes spend months getting the bugs out of it. The boys, lacking the mature judgment that so often prevents adults from having fun, built their cyclotron largely out of junk parts, and it worked fine! The following account of how they did the job is by Richard C. Sinnott, a member of the group who subsequently majored in engineering physics at the University of California.

"The nucleus of the idea of the El Cerrito cyclotron, like so many nuclei, was not well defined at the beginning. Lee Danner, Charles Williams, Karl Zellmann and I were all in the same physics course at El Cerrito High. Our physics teacher, Benjamin Siegel, had encouraged us in many outside projects. We worked first on a wind tunnel, then on a Tesla coil. When these projects were completed, we felt that bigger and better things should be tried. Since El Cerrito is close to Berkeley, we gradually developed the idea of trying a cyclotron. During a tour of the cyclotron at the University of California Radiation Laboratory we met Louis Wouters, who became our consultant and advisor.

"Many people thought that the idea of high school students building a cyclotron was ridiculous. Others, like Dr. Siegel and Dr. Wouters, encouraged our project. Looking for a sponsor, we had a talk with Frank Schallenberger, principal of El Cerrito High School, and he sent us with a warm recommendation to the Superintendent of Schools, Walter T. Helms. Mr. Helms set up an account for us. The cooperation of these men will always shine as an example, to me, of the attitude of true educators. They did not discourage us nor doubt our sincerity; they assisted us as best they could, both morally and financially, and the complex project of building a cyclotron was launched with great enthusi-

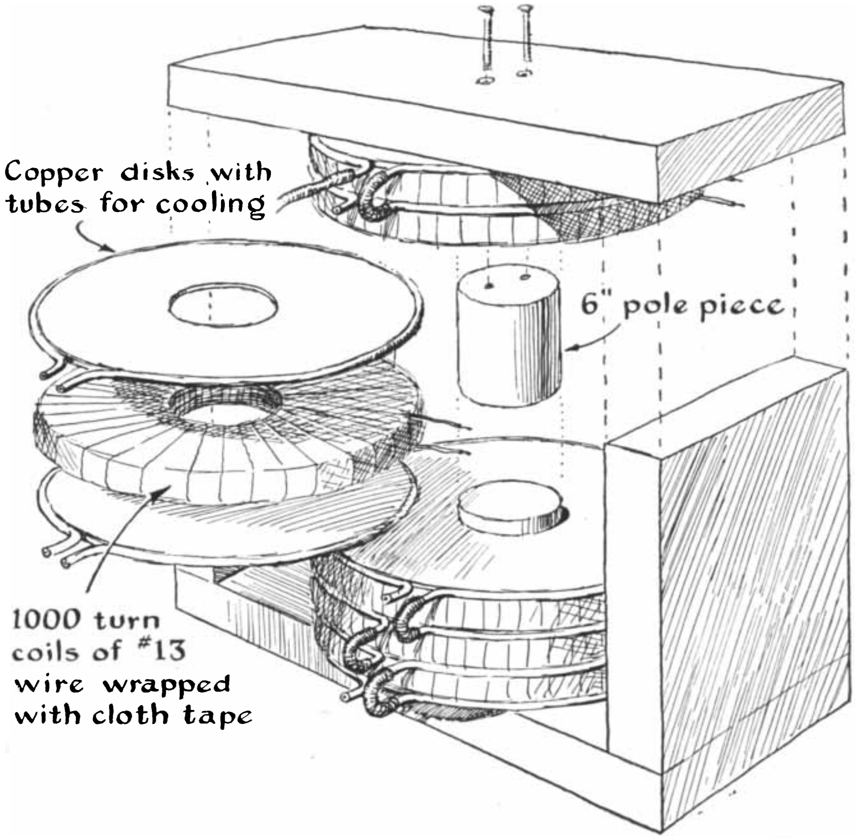


An over-all view of the El Cerrito cyclotron



An Amateur Photographs an Eclipse of the Moon

The lunar eclipse of January 29-30, 1953, gave Apollo Taleporos, an electronics engineer on the staff of the Columbia Broadcasting System, a chance to see how effectively such an event can be photographed with simple equipment. His six-inch Newtonian reflector, which has a focal length of 42 inches, was mounted on a tripod and the camera, a 35-millimeter, single-lens reflex, was held by hand in front of the 1¼-inch eyepiece. The condition of the sky was approximately .7, which means that stars of the fifth magnitude could be seen near the zenith. Except for scattered clouds, the night was cold and clear. All exposures were made with the camera stop set at *f*/3.5 and the film was Super XX panchromatic. Although in New York City, where the pictures were made, the moon entered the penumbra at 3:40.1, clouds prevented the start of photography until just after the end of totality at 7:29.1. The first three exposures were made at 1/25 second, the next two at 1/50 and the remaining four at 1/150. According to Taleporos the principal difficulty facing beginners in lunar photography is that of learning the proper exposure time and aperture setting. He solved this problem in advance of the eclipse by making a series of exposures each night as the moon grew from new to full, and keeping a careful record of the results.



Exploded view of the cyclotron magnet, coils and cooling system

asm and great hopes by four very young fellows.

"Let us deviate now to the more scientific aspects of the cyclotron. The operation of a particle accelerator is analogous to that of a gun. When a bullet is fired, the powder accelerates the lead slug, the barrel constrains the missile and directs it in a given path. In a cyclotron the bullet is a proton, and the constraining "barrel" is the magnetic field. The propulsive force is a high-voltage, high-frequency potential which accelerates the proton. The path of this bullet, however, is not straight but circular.

"The particle starts at the center of an evacuated circular chamber. Within the chamber a flat, hollow electrode in the shape of a half-circle, the 'dee,' applies the high-frequency alternating voltage that drives the proton. Professional cyclotrons usually have two dees; ours has only one. A strong magnetic field, acting perpendicularly to the plane of this flat dee, forces the particle into a circular path, which actually becomes a spiral path as the particle flies in wider and wider circles.

"Since a proton is a positively charged particle, it is attracted by negative charge. When the rapidly alternating voltage of the dee is negative, it attracts the proton into its hollow interior. While the proton is traveling through its half-circular path, the accelerating voltage on the dee is changing its sign. As the particle leaves, it is given a kick by the now positive electrode. The relationship between the magnetic field shaping the particle's path and the frequency of the high voltage is carefully chosen so that the particle keeps getting a kick each time it enters or leaves the dee. In the half-circle of the vacuum chamber that has no dee, it travels by inertia, still under control of the magnetic field. As its velocity increases, centrifugal force causes the particle to transverse a path of ever-increasing radius. At the end of this dizzy trip the proton collides with the target—a small plate made of the substance to be bombarded. The interaction of the accelerated protons with the matter of the target is then studied by various methods to solve riddles of nuclear physics.

"The machine can be broken down into these major parts: (1) The magnet and its power supply; (2) the electrical oscillator and its power supply; (3) the vacuum system; (4) the chamber in which the acceleration takes place; (5) miscellaneous power supplies, metering and control circuits, and so on. The construction of the machine more or less followed this sequence. Our first problem, therefore, was the magnet.

"The core of the magnet weighed about 1,000 pounds. We thought it would be ideal to make the core out of Norwegian soft iron, but it turned out that none was available at the time, so mild steel was used. The biggest problem with the core was machining. The tools in the shop at El Cerrito were not large enough, and the cost of having a commercial machine shop do the work was prohibitive. After much inquiry we found that the Central Trade School in Oakland would do the work free. The School had the facilities, and since the work had educational value for their students, they agreed to do it for us if we supplied the metal.

"Magnet wire was the next problem. At the time copper wire was scarce. We managed, however, to get about 300 pounds of No. 13 magnet wire. While the core was being machined, we wound six coils in the shop at El Cerrito High and the magnet was pretty much taken care of. It had about 6,000 turns of wire and required about 35,000 ampere turns for the necessary field. The pole diameter was six inches, which made it a six-inch cyclotron. The High School donated a welding generator which would supply 90 volts at 90 amperes. For regulation we ran the magnet far into saturation. The six coils were connected in parallel (1,000 turns) and at 90 amps we had 90,000 amp turns, far more than was needed.

"The next step was the oscillator. It was to be capable of an output of about 1,600 watts of radio-frequency power. We decided to build it at my home, and during its construction I gleaned some very important experience which I hope will be noted by those of you who have not yet worked with such equipment. I was 16 years old at the time, and the construction of such an oscillator was more dangerous than I realized. The power supply would put out 2,500 volts at about one ampere. The mechanical construction and wiring went well. Then came the big moment: turning on the power. For testing we used two 500-watt light bulbs as a dummy load. With a little adjusting the lights lit brilliantly. We were overjoyed until the lights suddenly sputtered and went out. After carefully shutting things down, I started looking around in the back of the oscillator for the trouble. About two minutes later I woke up and found myself pancaked against a wall about 10 feet from where I had been working, quite stiff and sore and somewhat dizzy. Luckily I had Karl Zellmann with me, which points to Rule No. 1: Always have another person with you when you work with lethal voltages. My errors, however, were manifold. The first thing I had forgotten was to keep my spare hand in my pocket. I had made a perfect ground with my right hand while tinkering with my left. The second thing I had forgotten was to put in a bleeder resistor for the power supply. The lights had gone out because a circuit in the oscillator had opened, disconnecting the power supply. But it had left a condenser charged to about 2,000 volts waiting for me. . . . We put a bleeder resistor in and eventually got the oscillator working to suit us.

"We now encountered the problem of the vacuum system; believe me it was not a brief encounter. Dr. Wouters introduced us to Edward Guyon, the glass blower for the physics department at the University of California. Mr. Guyon offered to make our glassware for us for practically nothing. He constructed our diffusion pump, traps, McLeod gauge and Pirani gauge, each item normally very expensive. He gave us hints on how to find leaks and how to obtain a high vacuum. We constructed our little system, minus the chamber, and got it working after about three weeks.

"Then came the chamber. This part of the project was tied in very closely with the vacuum system. The first chamber was designed to clamp around the pole pieces. It was in two sections and looked much like a doughnut when fastened together.

"Our goal was gradually coming into view when we put the chamber into place. We started the pumps and waited for the system to pump down; naturally it leaked. We worked for about a month trying various ways to make the system tight. One of the methods suggested incorporated the use of pneumatic gaskets, so we visited the Goodrich Development Laboratory in San Francisco. George Petelin, their chemist, let us use their facilities to make some experimental gaskets. These turned out well (so well, in fact, that when another rubber company saw them, we were offered a job). Still, after all this work, the chamber leaked. We finally got the system tight enough, however, for an experimental run. One night the oscillator was warmed up, the generator started, the secondary equipment checked, the door to the cyclotron room locked, and everyone excitedly went to the control room. With everything running smoothly, we began to regulate the magnetic field slowly, watching anxiously for the deflection of the meter that would tell us we had a proton beam. At last we got a slight deflection, showing a weak but definite beam of 1.5 microamperes. We were, to say the least, tremendously happy. Then the vacuum system began to leak. The chamber filament blew out and the dee started to arc to ground. The chamber just wouldn't hold a vacuum. We decided that we must completely change its design.

"The next chamber we planned was to be made of glass. Our design was again poor and we gave it up after about a month's work.

"During this time I met Harry Kennedy, the inventor of the union melt welder, who was awarded the Lincoln Medal for outstanding research in the field of welding. He has a very complete shop in which he and his able assistant, John Patterson, do research and experimental work on various ideas and problems related to industry. Mr. Kennedy expressed some interest in our little machine, and the next thing we knew he was designing and building with us a new chamber. His experience and natural 'feel' for such problems contributed to a very practical chamber design—a design which eventually was the key to successful operation of the machine.

"A detailed account of the difficulty involved in the design of this chamber may be of use to others who may some day be presented with similar difficulties in research. At first we had considered the chamber the least of our worries. As you can see, this premise turned out to be very wrong. In the following I will attempt a partial explanation of why so much trouble was had with what would appear to be a rather simple task.

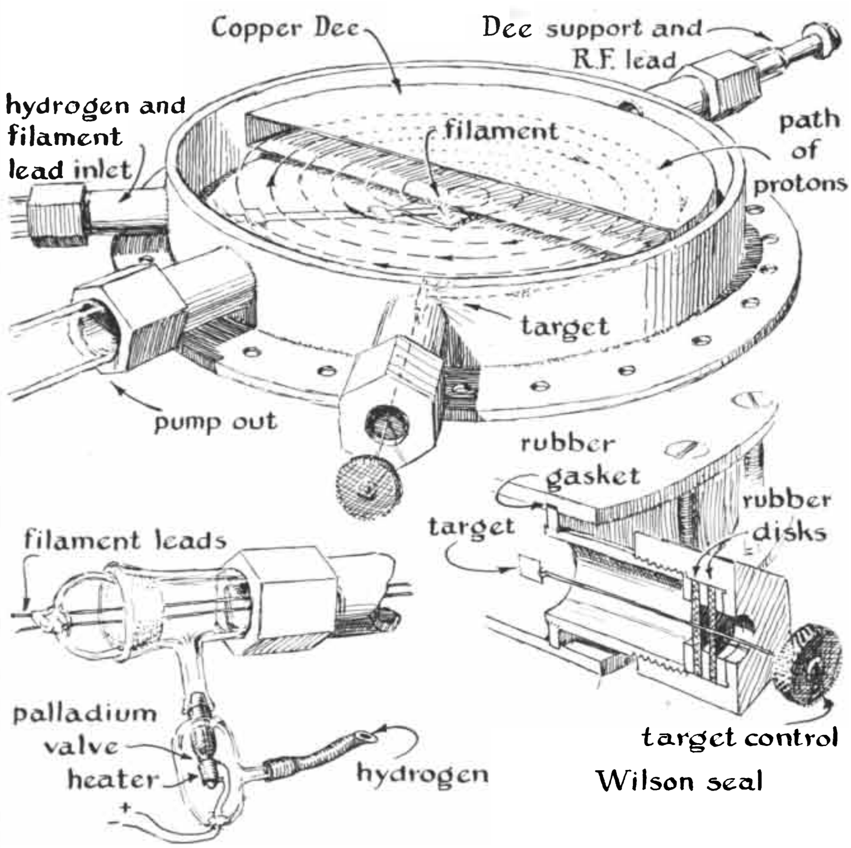
"Webster's definition of research runs: 'Careful search, a close searching. Studious inquiry; usually critical and exhaustive investigation or experimentation having for its aim the revision of accepted conclusions, in the light of newly discovered facts.' Careful search on almost any subject in modern science usually requires special equipment of some sort. In large industrial and Government-supported laboratories such equipment is readily available or easily financed. In small universities a research worker has a harder problem; he must use imagination and know-how to obtain his tools. A good researcher must also be able to correlate results. Answers to a given question in his work are often subtle and apparently ambiguous. He must be sensitive to his data and adept at careful scientific analysis of all the possibilities presented.

"Mr. Kennedy, whether he realized it or not, taught us these things by example during the designing of our vacuum chamber. He would think carefully about a problem, then take a piece of chalk and draw a sketch on the floor of his shop, enlarge on the idea, draw, discard, change, redraw, until he finally arrived at an excellent answer. We would then stand around the drawing and discuss it at length until we were all convinced it was best—best not only in final result but in process. He understood how difficult it would be to machine a given shape or assemble the machined pieces, and he took into account whether the final pieces could withstand the forces that might act on them.

"Upon Mr. Kennedy's suggestion we proceeded to construct the chamber as a separate entity, that is, not mechanically dependent on the magnet. This unit type of construction would permit us to seal the chamber and locate all leaks before placing it between the poles of the magnet. The design, needless to say, worked very well. The top and bottom of the chamber were made of ⅛-inch circular steel plates very carefully machined to tolerances of 1/1000 of an inch. The wall of the chamber was made of a slice of brass tubing of 6½ inches inside diameter. The bottom plate was soft-soldered to the brass, and the top plate sealed with a thin rubber gasket. Twenty-four brass screws around the periphery of the steel plates held the top on and allowed us to adjust the plates until they were parallel to better than 1/1000 of an inch. The target was introduced through a type of Wilson seal, as were the filament and hydrogen pipe, the pump-out and the die support. The filament assembly was easily removable for repair through a ground glass joint. Use of a steel top and bottom on the chamber reduced the magnetic gap to ¾ inch, which was desirable; it raised the magnetic field a considerable amount and, by virtue of the movable nature of one plate, allowed a sort of shimming of the field.

"We now had our chamber. Very anxiously we went to work installing it. It took a month or two to make other changes and improvements. Then everything was ready and once again we turned on our cyclotron. After a few false starts, we got seven microamperes of beam.

"This small deflection of a meter had



Details of the dee (top), *proton source* (lower left) *and target*

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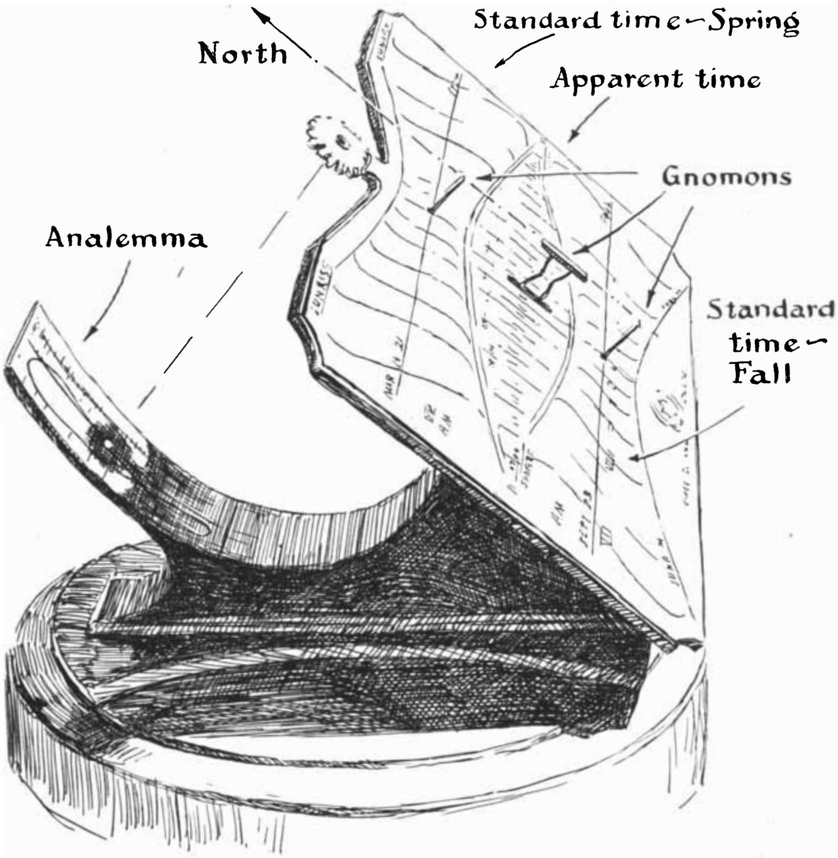

The Briggs sundial in Washington, D. C.

taken two years' work and the help and advice of many educated people. But the effort was well rewarded, as is any work sensibly directed with a definite goal in mind. I had gained what amounted to a million-dollar education: I had learned vacuum technique, gained a better feel for electronics, learned how to work with people and how to convince people of the usefulness of such projects. More tangibly, as a result of my part in the cyclotron I got a job immediately upon finishing college as a research physicist at the University of California Radiation Laboratory, where I could go on with the things that interested me and actually get paid for it.

"A big point in all this is that such a project inevitably requires much work, knowledge and cooperation from people other than those immediately associated with it. I feel that scientists and educators are pleased, interested and cooperative when they see someone engaged in such a project, particularly a young person. So resolve your ideas, recruit help and launch your project. Your rewards will be far greater than you can imagine—not only in increased scientific knowledge but in the experience you will gain in human relationships and understanding. Nothing is more gratifying than working with a group toward a common goal, surmounting obstacles together, sharing and criticizing each other's ideas and eventually twisting that knob and observing a tiny deflection of a meter that eloquently says, "Good going, you have done it."

An accurate sundial must be especially designed for its exact latitude and longitude. Each accurate dial is therefore unique. If the dial is removed to another latitude, the part that casts the shadow is no longer parallel with the earth's axis and therefore casts it incorrectly. At any other longitude the hour lines give incorrect time. This explains why the mass-produced cast-metal dials often seen on sale, though attractive, are found to be inaccurate even when set up level and correctly oriented to true north and south.

The principal pleasure from an accurate sundial is derived from designing and building it, and especially from the clear comprehension of the earth's ir-

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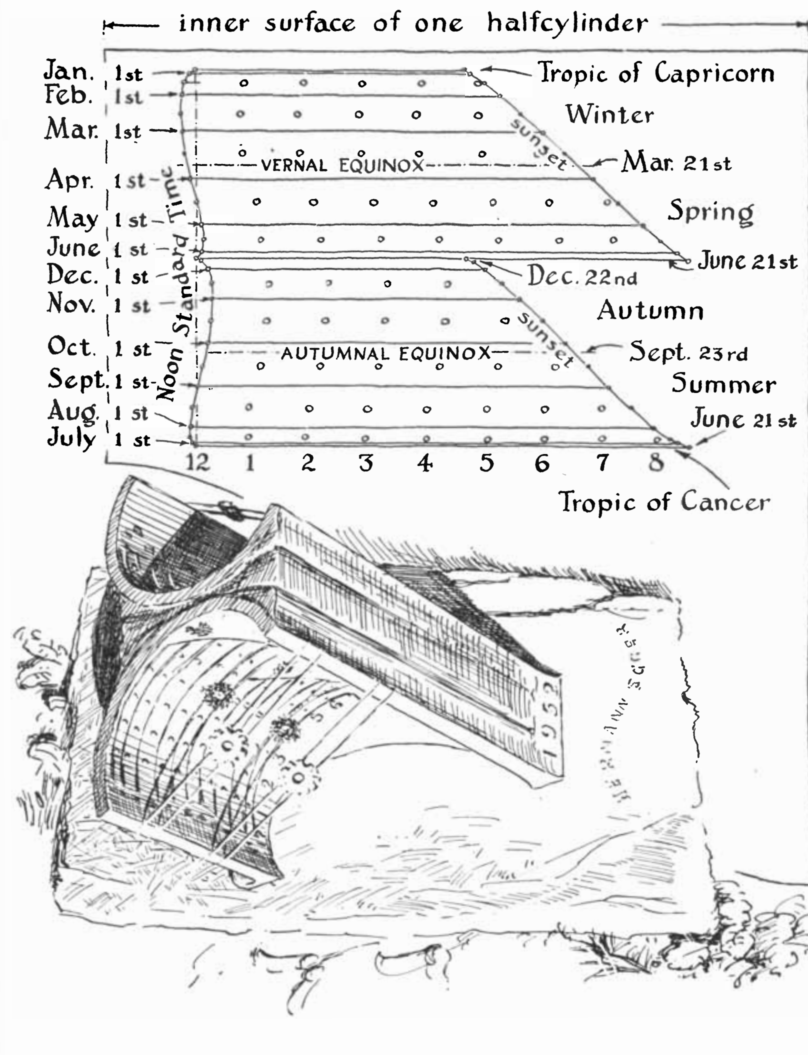
regular motions that is best absorbed while doing both. A sundial is seldom actually used as a timekeeper today, although in the blissful absence of a radio at my isolated summer camp I do often set my watch from a sundial which is accurate within two minutes. The object in building an accurate sundial is not really to ascertain the time but to win bets from friends who challenge its accuracy because it does not agree with their inaccurate watches.

The four accurate and scientific sundials this department describes herewith were designed by builders who had taken the necessary pains to study out the earth's motions. They are all direct-reading dials which tell the time without correction from graphs or tables or by mental calculation. In sundialing this is elegance.

R. Newton Mayall, co-author with Margaret Mayall of the book *Sundials, How to Know and Make Them,* designed the first of these dials and supervised its construction. It was given to the National Bureau of Standards by its staff, in appreciation of Lyman J. Briggs after his retirement as director. The details of its essential parts are shown in Roger Hayward's drawing on page 160.

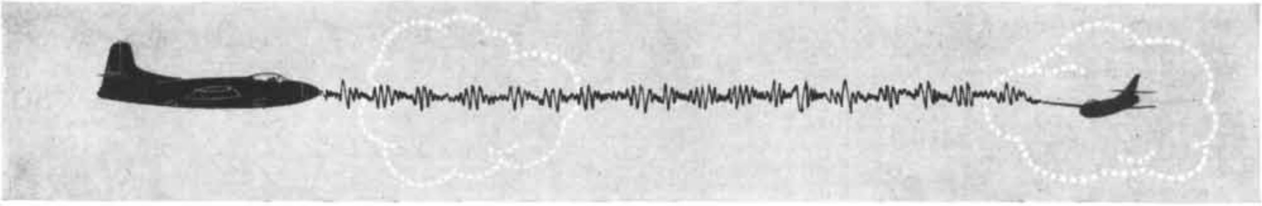
The central, elliptical part of the dial plate is a simple dial for telling the apparent (sun) time. It has a flat-topped gnomon (shaft) which casts its straight shadow to the left in the morning and to the right in the afternoon. The gnomon is parallel with the dial plate, which in turn is parallel with the earth's axis and therefore points to the celestial pole. If the earth revolved around the sun at a uniform speed in a circular orbit, and if it were not for the obliquity of the ecliptic, a simple sundial like this would always be accurate. Unfortunately for lazy sundial builders, the earth's orbit is not a circle but an ellipse, with the sun nearer one end than the other. When the earth



The Egger sundial in Switzerland

Radar eyes see in darkness, storm, or fog

to lock this twin-jet fighter on its prey . . .



—the Douglas F3D Skyknight

Out of Korea come new reports of the Douglas F3D Skyknight in action, downing Migs for the United States Marine Corps during advanced night and foul weather operations.

Designed for the U. S. Navy, the all-weather Skyknight flies at near-sonic speeds, operates from aircraft carriers as well as small advanced airfields. A side-by-side seating arrangement of pilot and radar operator results in closer combat teamwork—permits Skyknight's modern radar *search* and *fire control* equipment to be operated with maximum efficiency when against marauding enemy planes.

Performance of F3D Skyknight in action is another example of Douglas leadership in aviation. Planes that can be produced in quantity *to fly faster and farther with a bigger payload* are a basic rule of Douglas design.

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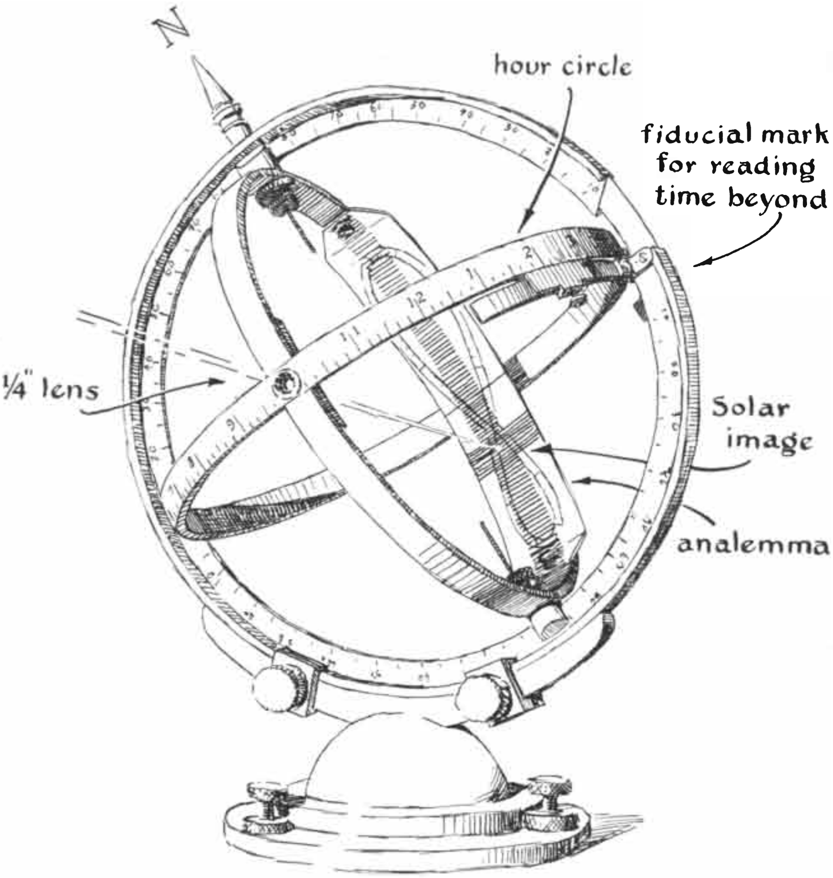

The Paul sundial in New York City

is nearer the sun, gravitation moves it faster, which makes the sun seem to move faster. The eccentricity of the earth's orbit and the obliquity of the ecliptic (which is due to the tilt of the earth's axis) combine to make sun time as much as 16½ minutes fast in November and 14½ minutes slow in February.

The difference in hour angle between the sun and a clock, which runs at a uniform rate, is the "equation of time." A plot of these differences through the year gives a curve shaped like the figure 8—the so-called "analemma" which is familiar on globes of the earth, where young people see it and embarrass older people by asking them to explain it. On the Briggs dial this analemma is mounted with a radius of curvature equal to its distance behind a small hole in a projection at the top of the dial plate. It is set off from the center far enough to the side to allow for the length of time that it takes the earth to turn from the center of the time zone to the longitude of the dial. Noon by sun time comes when the small spot of light from the sun bisects the meridian line of the analemma, but by clock time it is noon when the spot bisects the analemma curve. Civilization runs by the constant clock and not by the inconstant sun.

To obtain correct standard time from the analemma you must be on the spot at noontime, but you can obtain it at any even hour if each hour is marked on the dial by its individual analemma. This is what the upper and lower parts of the Briggs dial face consist of. Each part has its own chisel-edged gnomon. Dividing the analemmas into halves, as shown in the drawing, adds to the dial's attractiveness and permits the insertion of analemmas for each half hour, without confusion due to overlapping. The lines incised in the bronze are filled with bright red, the references to sun time with white, and those to the calendar, with blue. It is a beautiful dial.

Without knowledge of the Briggs dial Archibald Craig of Oxford, Pa., devised a direct-reading dial of a similar type in which entire analemmas from 8 a.m. to 4 p.m. are separately inscribed. Instead of designing the dial by calculation, he let the sun lay out each analemma, visiting the dial to mark the shadow every day for an entire year.

Hermann Egger, a geographer at the International Cartographic Office in

Midget with the giant brain

The Problem

To design and build a computer for airborne automatic control systems—with severe restrictions imposed on size, weight and operation under extreme environmental conditions; in short, a computer that would be small, simple, reliable, rugged—and easy to build and maintain.

At Hughes Research and Development Laboratories this problem was examined exhaustively, and it was concluded that a digital computer offered the best means for satisfying the requirements because of its ability to solve complex problems accurately and quickly.

Because the requirements of this application could not be met by existing digital computers, owing to their large size, the following developments were undertaken:

1. Simplification of the logical structure of the computer through the use of a mathematical theory of computer design based on Boolean algebra—but with retention of the operational versatility of a general-purpose computer.

2. Development of ingenious circuitry to utilize the new logical designs.

3. Achievement of minimum size by the use of subminiature techniques, including germanium diodes, subminiature tubes, and etched circuits.

4. Employment of unitized construction: plug-in units of flip-flop circuits and diode networks.

Need for subminiaturization, then, was a governing factor. Consequently, entire new techniques for making things not only vastly smaller, but at the same time easier to build and service, were developed by Hughes. This is a continuing process and there is indication of even more significant advancement in miniaturization for the future.

A major effort at Hughes is also devoted to adapting electronic digital computer techniques to business data processing and related applications—destined for far-reaching peacetime uses.

One of the subminiature switching circuits from the Hughes airborne electronic digital computer is examined by Dr. Eugene M. Grabbe (right), Associate Head, Computer Systems Department, Advanced Electronics Laboratory, and Phil A. Adamson of the Technical Staff.

ENGINEERS AND PHYSICISTS

Activities at Hughes in the computer field are creating some new positions in the Computer Systems Department. Experience in the design and application of electronic digital computers is desirable, but not essential. Engineers and physicists with backgrounds of component development or system engineering are invited to apply.

Assurance is required that the relocation of the applicant will not cause the disruption of an urgent military project.

ADDRESS: *Scientific and Engineering Staff*

Hughes

RESEARCH AND DEVELOPMENT LABORATORIES

Culver City, Los Angeles County, California

Zurich, Switzerland, says he invented the gnomic cylinder dial shown in the drawing on page 162. The Egger dial plate is tilted parallel with the earth's axis. As in the Briggs dial, the analemma is divided into two parts with two gnomons. However, instead of a flat dial plate Egger uses two cylindrical plates, one for the forenoon, one for the afternoon, set at 60-degree angles with each other. The gnomons are set at the centers of curvature as shown. In a variation not shown, two quarter cylinders are substituted for the half cylinders and the gnomon is set midway between the center of curvature and the cylinder. An advantage in using a cylindrical dial plate is that the hour angles are equal and the analemmas parallel and alike.

Egger says that a perfect sundial must meet the following requirements: It must show by a direct reading, at any hour of the day throughout the year, both the standard time and the date, and the date and hour markings must be spaced at almost equal intervals. He says that he has invented the only dials which fulfill these requirements. Any sundial in the future that casts the rays of the sun by means of four projection centers on two concave cylindric scales will be an Egger sundial, he says.

To obtain the time and the date from the sundial shown on page 164 you rotate and tilt the hour circle until a quarter-inch lens of 10-inch focal length behind a small round hole in the circle throws an image of the sun astride the line of the analemma. You then clamp it there. Russell Porter made a number of dials of this type, terminating in one built around a Pyrex flask, shown in this department in September, 1951. Herman L. Paul, a New York City machinist, saw the drawing of this dial and substituted metal circles for the flask. The outer circle is from a globe of the earth. It is placed in the earth's meridian and rotated until the axis it carries is parallel with the earth's axis. To avoid a broad shadow from the outer circle Paul removed a short segment from it and substituted a thin strip of metal. He says that the dial gives correct time within two minutes.

Neither instructions nor blueprints are available for building the dials described. Detailed instructions would require too much space and deprive a builder of his fun, while blueprints for merely copying the dials would suit but one location. "I had to study out what the whole thing meant," Paul said, adding that this was what gave him the most satisfaction. He digested the Mayall book until he clearly understood the principles common to all sundials.

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