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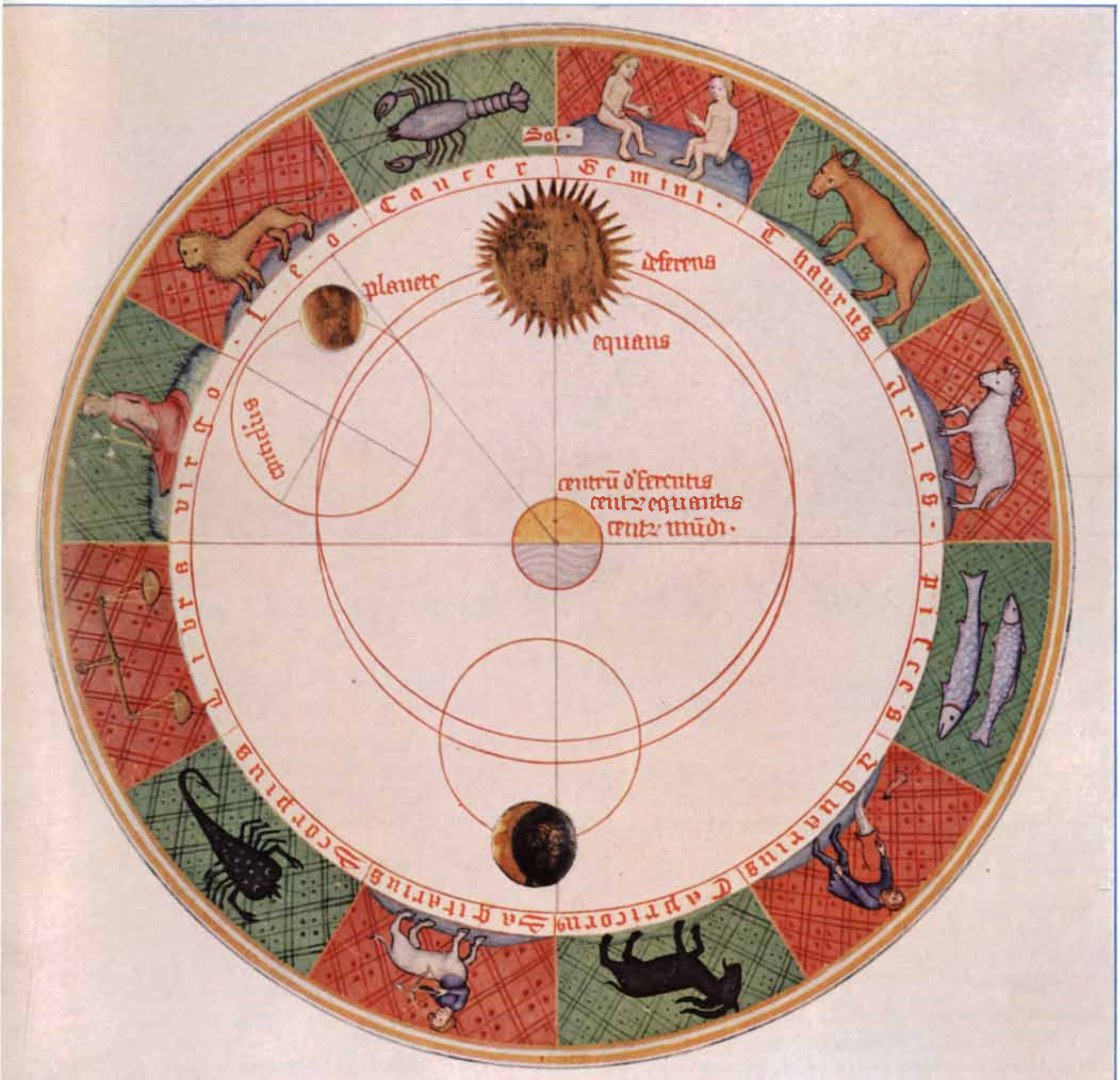
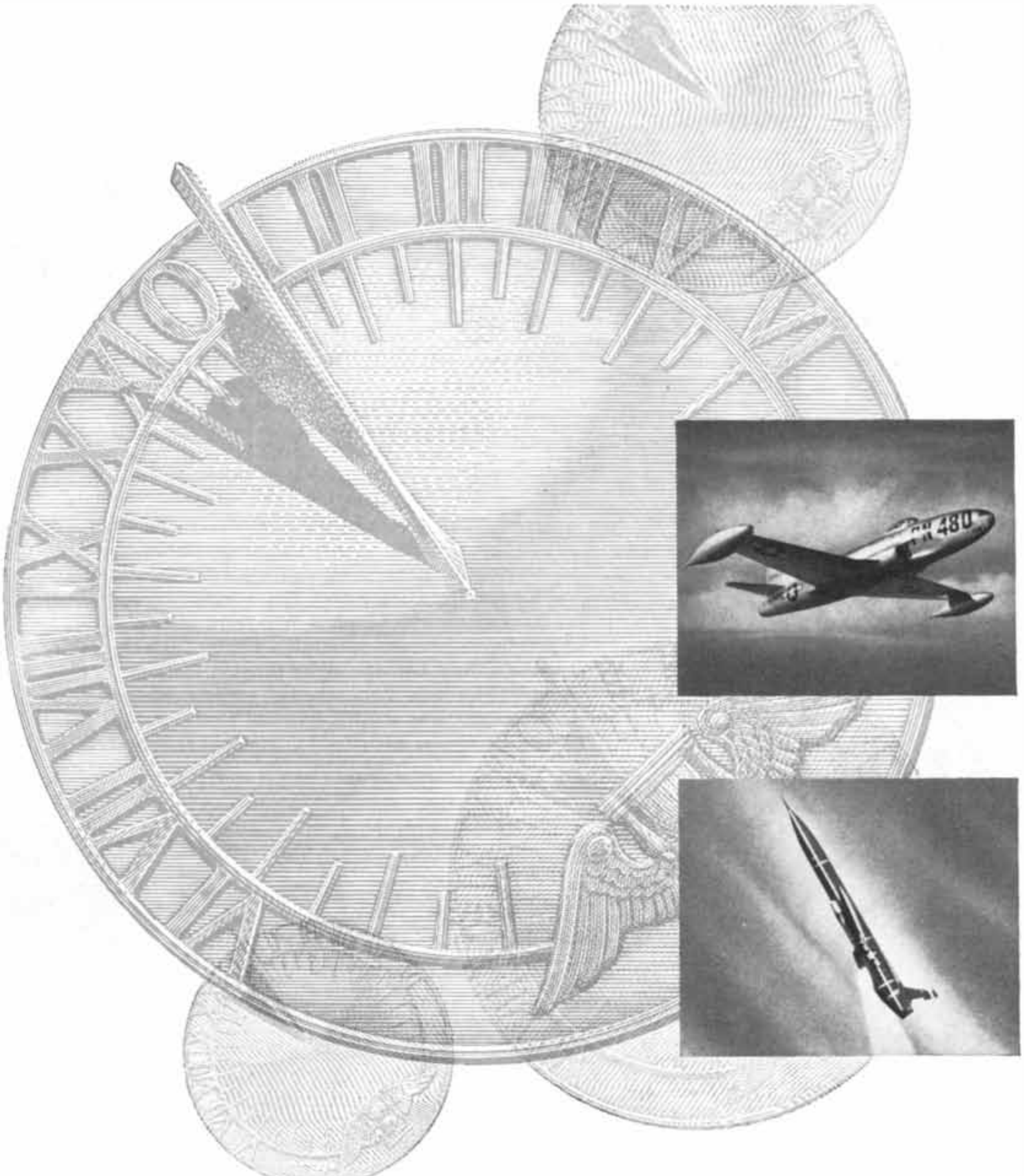


THE UNIVERSE

FIFTY CENTS

September 1956



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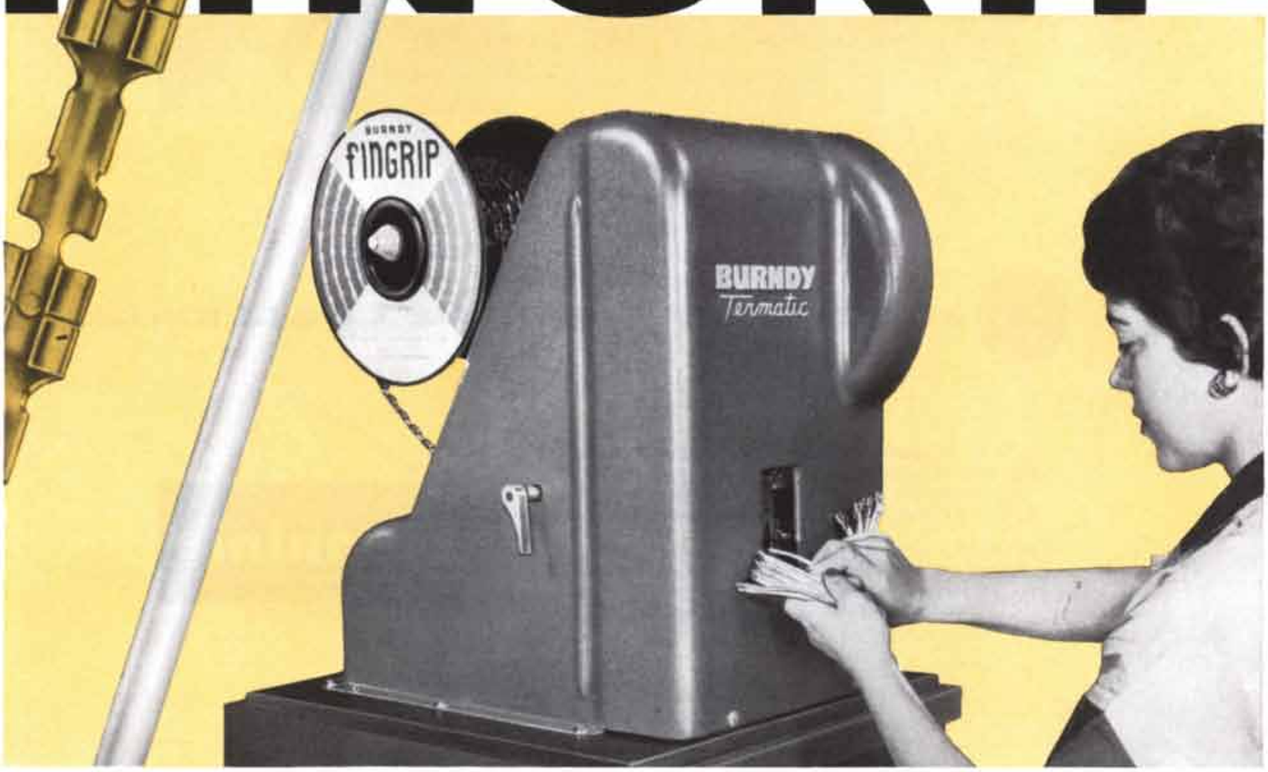

Omaton Division, BURNDY • Norwalk, Connect. • Toronto, Canada • Factories: New York, Calif., Toronto

Established 1845 **SCIENTIFIC AMERICAN** September, 1956 Volume 195 Number 3

ARTICLES

DEPARTMENTS

THE COVER

The picture on the cover shows a typical pre-Copernican cosmology. It accompanies a German text translated in the 15th century from the Arab astronomer Alchabitius, or Abd-al-Aziz. The earth is in the center. The sun (*top*) travels around it. The planets (*upper left*) and the moon (*bottom*) move in epicycles. Around all of these objects is the fixed firmament of the stars, here represented by the signs of the zodiac.

THE ILLUSTRATIONS

Cover from the Pierpont Morgan Library

[*Editor's note: All illustrations in this issue are from the Mount Wilson and Palomar Observatories unless otherwise indicated.*]

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87	Nolan Patterson from Black Star
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95	Harvard College Observatory
98	Harvard College Observatory
100	Harvard College Observatory
105	Radcliffe Observatory (*top*)
106	Washburn Observatory, University of Wisconsin
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128	Sara Love (*bottom*)
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KANIGEN®

amorphous nickel alloy coating

Kanigen is a uniform, hard, corrosion-resistant nickel-phosphorus coating. It can be applied to iron, copper, nickel or aluminum and their alloys as well as ceramics, glass and thermo-setting plastics. This is achieved through a chemical bath without the use of electricity. The coating (probably a solution of nickel phosphide in nickel) exhibits many desirable properties not normally associated with metals or metal plating.

POROSITY

Kanigen nickel-phosphorus coatings, deposited 0.0002" thick on polished steel specimens, display no evidence of porosity when submitted to test in aerated, 185° F water.

Kanigen deposits, 0.0002" thick on polished steel, exhibit zero porosity when subjected to the ferroxyl test for locating pores.

Gaseous diffusion tests show no porosity in a 0.00025" thick Kanigen coating.

A thin coating of aged radioactive iron isotope, emitting soft X-rays which are effectively shielded by nickel, was electro-deposited on mild steel discs. Kanigen was then deposited over the iron isotope in thicknesses of 0.0002", 0.0004", 0.0006", and photosensitive plates exposed to the coated discs. The radiographs thus obtained were free of spots, indicating zero porosity in the Kanigen deposits.

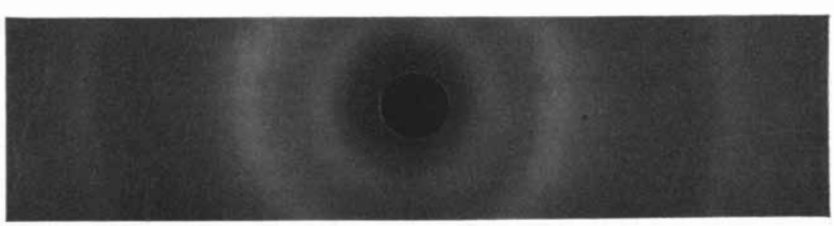
SALT SPRAY RESISTANCE

Kanigen coatings, deposited on cold rolled steel, withstand salt spray test exposure for more than double the time required by ASTM-B-117-49T. When failure finally occurs, the rust spots show no tendency to spread even when the part is left in the salt spray chamber for 1000 hours or more.

The satisfactory performance of Kanigen coatings under salt spray test conditions (and in actual service) depends in great part on the surface condition of the basis material. Smooth, fault-free surfaces permit satisfactory deposition of Kanigen coatings with excellent salt spray test results. Materials which are characterized by pronounced discontinuities (excessive roughness or porosity, sand or slag inclusions, lack of homogeneity in the alloy structure) may not permit perfect Kanigen coating coverage. This condition often will promote premature salt spray test failure, giving an erroneous picture of the potential effectiveness of the coating.

ADHESION

Adhesion of Kanigen coatings is excellent. It is extremely difficult, however, to measure, or to report adhesion since there is no standard measurement technique for metal coatings. Reported values are in the order of 30,000 to 60,000 psi to steel. Kanigen coated steel specimens show no flaking or chipping of the plating when pulled to the breaking point in tension. When Kanigen plated bars are bent 180°, there will usually be checking of the coating parallel to the axis of the bend on the outside of the bend; however, no flaking occurs. Because of its high hardness, a Kanigen nickel-phosphorus coating will sometimes show compression or shear failure (especially in heavy coatings) on the inside radius of a 180° bend test specimen. This occasionally results in some apparent flaking. Actual microscopic observations, in many cases, has shown that the separation line is in the coating and not between the coat and the basis metal. The adhesive forces to the basis metal, in these cases, exceed the cohesive forces of the coating itself.



"X-ray" diffraction pattern showing halo effects denoting the amorphous structure of Kanigen

If you have a problem that a Kanigen application may solve or if you'd like further information, write:

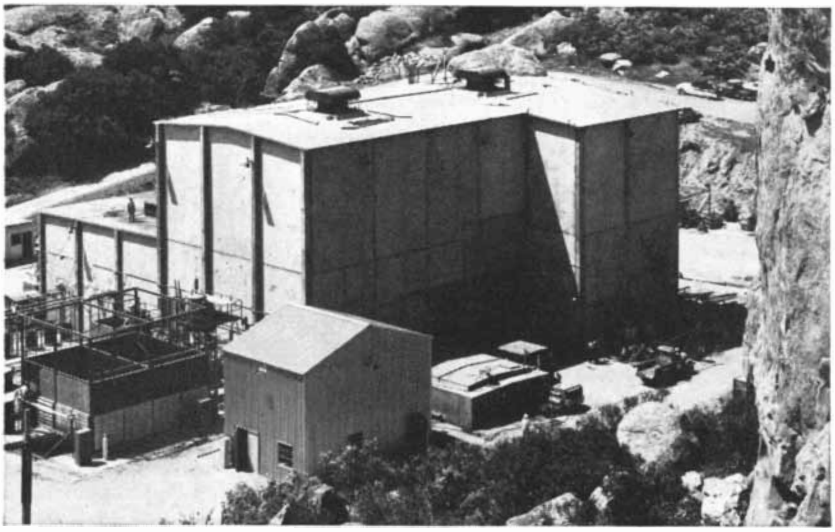
KANIGEN DIVISION, GENERAL AMERICAN TRANSPORTATION CORPORATION

135 South La Salle Street, Chicago 90, Illinois.

NUCLEAR NEWS FROM ATOMICS INTERNATIONAL

Nuclear reactors now being built for science and industry—for power and radiation

Within a single decade ATOMICS INTERNATIONAL engineers and scientists have developed a broad range of experience in the nuclear field through the design, construction and operation of a wide variety of reactors. This work includes four reactors completed and now in operation; four more reactors now in construction; and seven major engineering design projects completed.



Sodium Reactor Experiment nears completion in Santa Susana Mountains. It is being built and will be operated by Atomics International as a key part of AEC's nuclear power development program.

ATOMICS INTERNATIONAL, a division of North American Aviation, Inc., is a leader in the development of advanced reactor technology. A new power reactor concept, the Organic Moderated Reactor Experiment, is scheduled to be built by ATOMICS INTERNATIONAL for the Atomic Energy Commission at the National Reactor Testing Station in Idaho. This promising experiment will use an organic material—a carbon-hydrogen compound—in the dual role of moderator and coolant.

The diversified nuclear program at ATOMICS INTERNATIONAL includes:

1. Sodium Reactor Experiment. Located in Santa Susana Mountains, near Los Angeles. Fuel: either slightly enriched Uranium, or Thorium and U-233. Output: 20 Thermal Mw. Though experimental, the reactor will be equipped with heat exchanger and turbogenerator by Southern California Edison, who will feed 6.5 Mw of electric power to the surrounding area.

2. Full-scale Sodium Graphite Reactor Design. Fuel: same as above. Heat output: in the order of 250 Thermal Mw. Power Output: Uranium—75 Mw; Thorium—100 Mw; Thorium (after further development)—125 Mw. Capital costs, with full generating equipment, around $300 per Kw with Uranium, expected to be reduced with Thorium eventually to $200 per Kw. Power costs would thus decrease from 11.1 mills/kwh to 6.5 mills/kwh.

3. Water Boiler Research Reactor. Designed and built by ATOMICS INTERNATIONAL for use on Atomic Energy Commission research projects. Fuel: enriched Uranium. Power 5 watts. Flux: 10^8n/cm^2/sec (thermal). Experimental facilities include exposure holes, through-tube and vertical thermal column.

4. Livermore Research Reactor. For Atomic Energy Commission's laboratories at Livermore, Calif. A higher power version of the Water Boiler Research Reactor designed to operate at 500 W. These were the first two reactors in California.

5. Medical Research Reactor. Designed for a southern California university. Fuel: Uranyl sulphate, highly enriched with U-235. Power: 50 kilowatts. Thermal neutron Flux: 1.7 x 10^{12}cm^2/sec. Provision for gamma intensities to 1.3 reb/min per kw, fast neutron intensities of 4 reb/min per kw; also utilization of pure gamma activity of fission gases. Excellent exposure facilities for patient therapy and biological research. First reactor specifically designed for medical use.

6. Industrial Research Reactor for Armour Research Foundation of Illinois Institute of Technology, Chicago. Similar to 5 above, with experimental facilities for industrial applications. This reactor is now operating on a planned schedule that includes "time" for participating companies. This is the first reactor designed specifically for private industrial research.

7. General Research Reactor for Atomic Energy Research Institute, Japan. Similar to the Armour and Medical Research reactors described above. This will be the first nuclear reactor in the Far East, and is slated to be completed in 1957.

ATOMICS INTERNATIONAL has complete designs for reactors with a variety of fuel moderator and cooling systems for various applications, and offers a complete program of services in connection with all reactor projects, including:

- Advice on most suitable reactor type for a specific use
- Assistance in reactor site selection
- Aid in meeting AEC requirements
- Coordination of reactor plans with building plans
- Installation supervision
- Training of operating and maintenance personnel
- Assistance in fuel loading and initial reactor operation
- Design counsel in later modification or expansion
- Assistance in public information

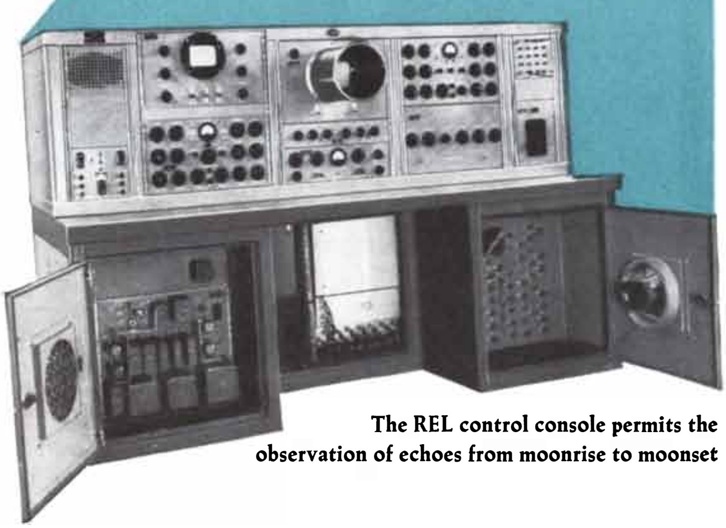
Dr. Marlin Remley of Atomics International activates Armour Reactor—first for private industry.

If you are interested in any phase of our activities, ATOMICS INTERNATIONAL is staffed and equipped to help you. Please write: Director of Technical Sales, Dept. SA-N5, ATOMICS, INTERNATIONAL, P.O. Box 309, Canoga Park, California. Cable address: ATOMICS.

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

PIONEERS IN THE CREATIVE USE OF THE ATOM



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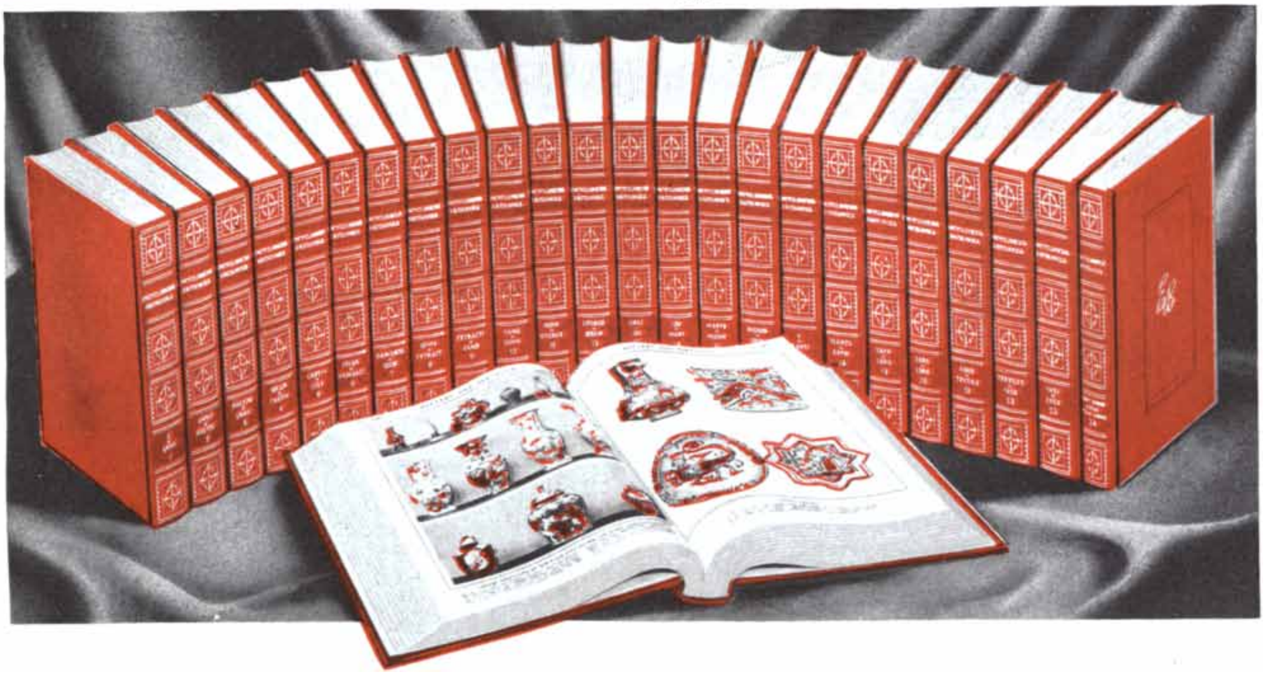

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How to tame a tempest in your lab

A manufacturer we know had something akin to a tempest—his catalysts were acting up and needed something to subdue them. He, too, found the solution by using oil. In this case it was versatile white mineral oil which came to the rescue, as it has for many researchers and manufacturers. Here is what happened.

This manufacturer came to us because he thought we might be able to help him devise a carrier for alkali metals and anhydrides for organic synthesis. The properties desired were a free miscibility with organic products, freedom from unsaturated hydrocarbons, high distillation range, and a high flash point. Some other requirements were that the product provide a seal against contact with air, that it inhibit foam formation, contain no carbonizable substance, have a low rate of oxidation—and a few others besides.

Upon studying the fine points of this manufacturer's request, we found that one of our specialized grades of white mineral oil not only seemed to fill the bill very nicely, but, in addition, offered several other cost saving benefits that had not been anticipated. The manufacturer tried our product, confirmed our prognosis, and needless to say, is not only buying a good quantity of this grade of white oil from us, but is very happy that it occurred to him to bring his problem to us in the first place.

White oils are already renowned for the amazing number of ways they can be used—having long since run the gamut from abrasives to zinc. Yet, month after month, we—and our customers—keep coming up with new and practical ways of putting these highly refined mineral oils to work.

If you think you might have a problem in which one of our numerous grades of white oils might be put to work for you, don't hesitate to get in touch with us—so that we can supply you with exactly the right product—of U.S.P., N.F. or Technical grades—and if none of these meet your requirements, we'll tailor-make one that will. Just write, call or wire.

White Oils . . . one of industry's most versatile products

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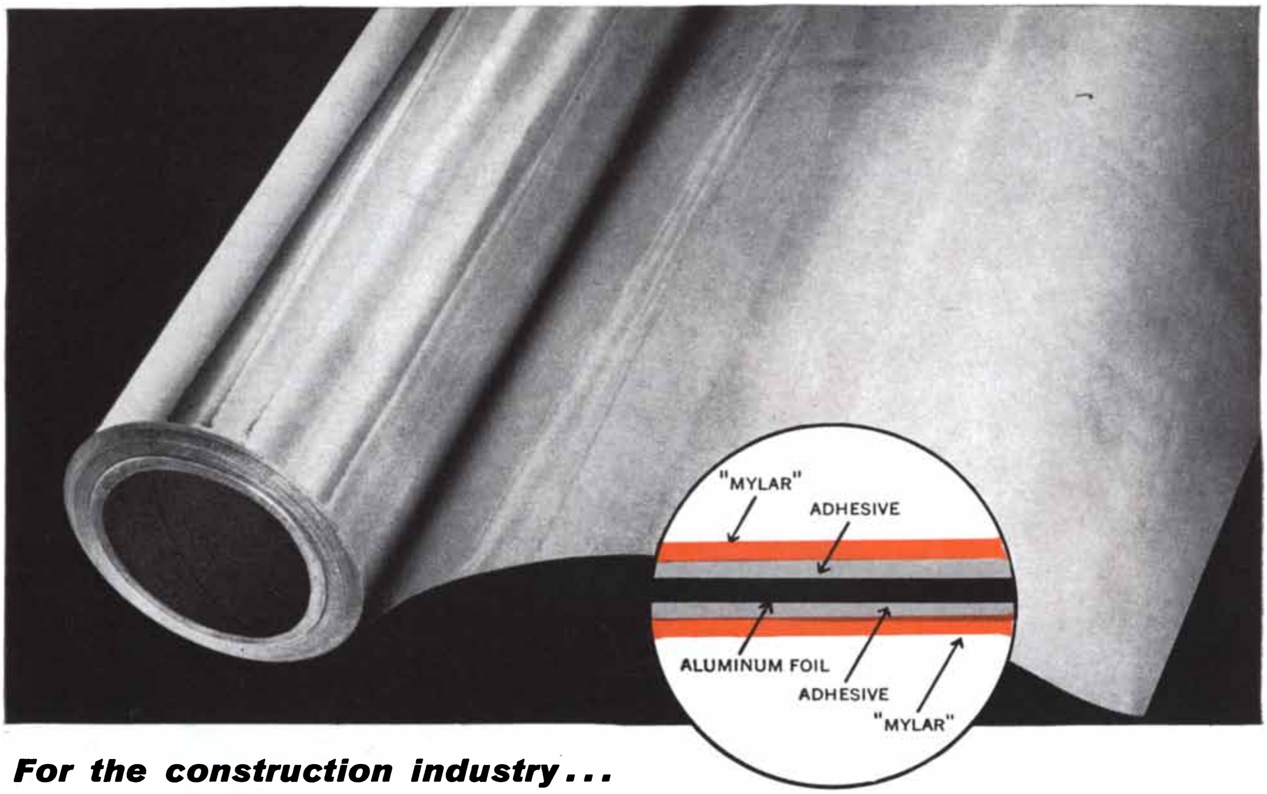

For the construction industry...

A NEW BARRIER ARMORED WITH "MYLAR" REDUCES MOISTURE PERMEABILITY TO ZERO!

Food Fair Company's new frozen-food warehouse in Linden, N. J., uses vapor barrier made of Du Pont "Mylar" and foil. The barrier is easily applied and sealed tightly with pressure-sensitive tape of the same material. Men shown walking on the vapor barrier illustrate the extra toughness and abrasion resistance of this lamination with "Mylar".

Thanks to a new material made of Du Pont "Mylar"* polyester film and aluminum foil, industrial constructors have a completely new moisture-barrier material for more effective control of humidity. Already, this new material is being used in warehouses for frozen-food storage, special rooms for the operation of extra-sensitive electronic equipment and storage facilities for military equipment.

This new laminate with "Mylar" is strong yet light in weight — there's no need for extra support frequently used for heavier moisture barriers. Since this flexible material comes in roll form, it's much easier to install than rigid barriers. When slit into tape widths with a pressure-sensitive adhesive, this same laminate provides an effective seal to join the sheet together. Most important, this laminate of "Mylar" and foil provides *zero permeability* to moisture vapor!

Here is another example of how Du Pont "Mylar", used alone or in combination with other materials, is improving old products and helping create new ones. For more information on properties, applications and types of "Mylar" available, send in the coupon below. Be sure to indicate specific application you have in mind.

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***MYLAR** *is Du Pont's registered trademark for its brand of polyester film.*

In Canada, "Mylar" is sold by the Du Pont Company of Canada Limited, Films Div., P. O. Box 660, Montreal, Quebec.

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MYLAR®
POLYESTER FILM

E. I. du Pont de Nemours & Co. (Inc.)
Film Dept., Room S-9, Nemours Bldg., Wilmington 98, Delaware

☐ Please send information on properties, applications and types of "Mylar" polyester film available (MB-4).

☐ Please send information on moisture-barrier material made with "Mylar".

APPLICATION__________
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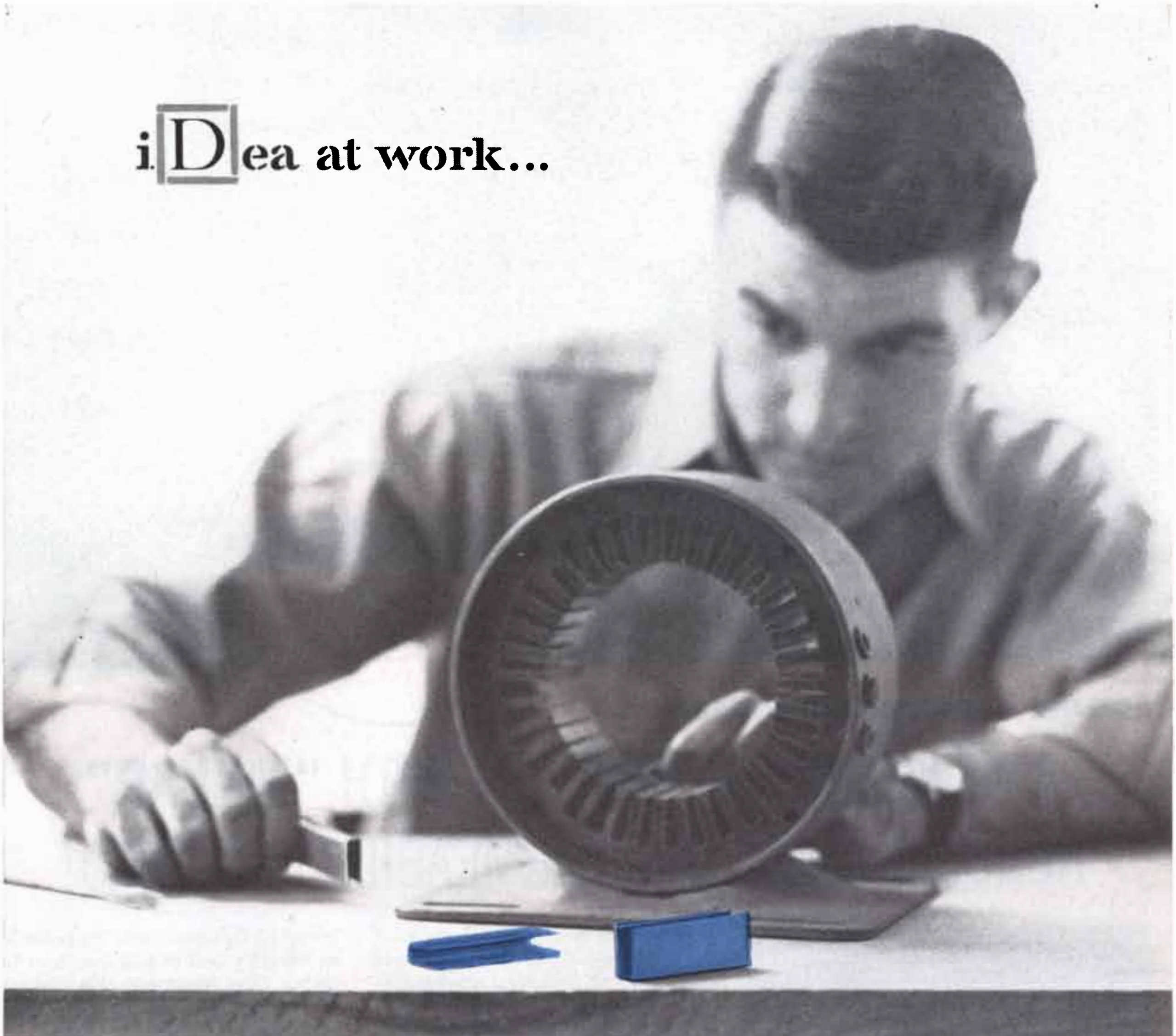

Why Dobeckmun's Dobar-M® is blue. When Dobar-M (made with Mylar*) was first introduced by Dobeckmun, customers were so impressed with this superior insulation material they wanted to be able to recognize it instantly, anywhere. Because of Dobeckmun's extensive manufacturing facilities, it was a simple matter to color Dobar-M a bright, electric blue. This new blue color tells you you are achieving maximum dielectric strength in a minimum of space in slot cell insulation for integral and fractional horsepower motors. The development of Dobar-M is typical of Dobeckmun engineering which takes ideas and puts them to work for you. Whether you need tapes, layer or slot cell insulation materials, the next step is to call Dobeckmun . . . today.

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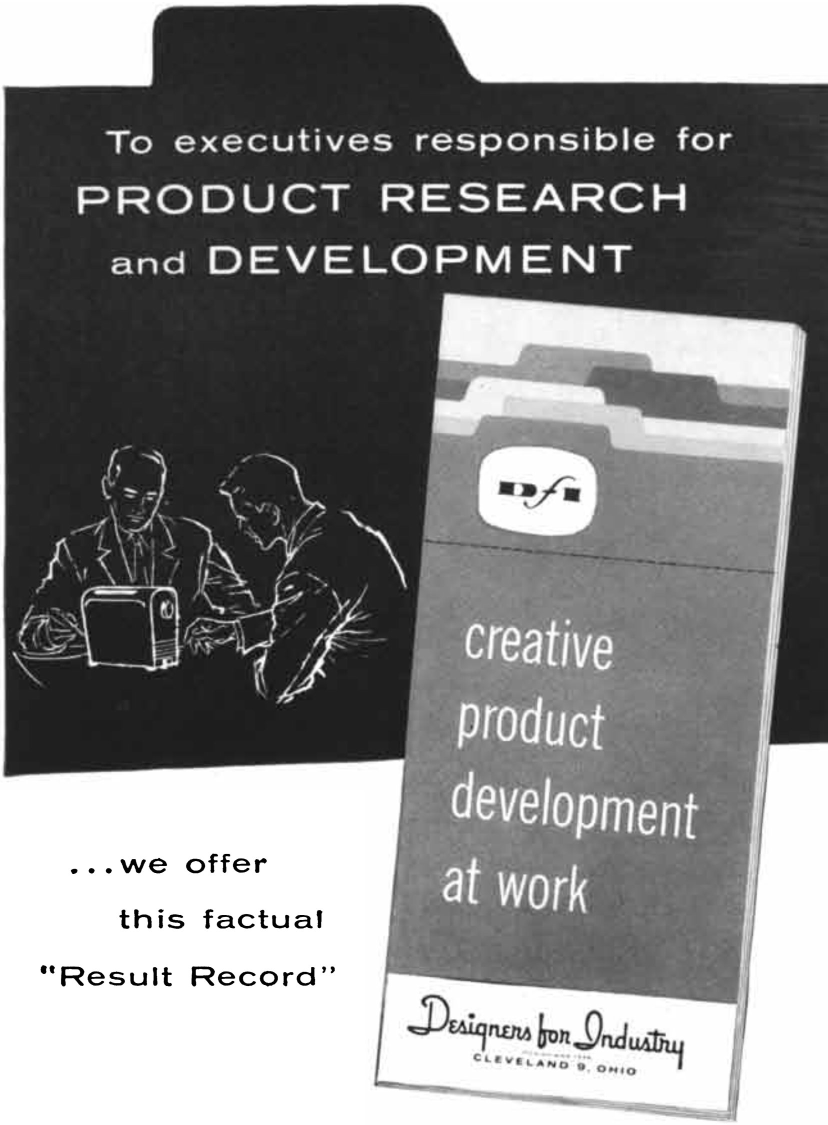

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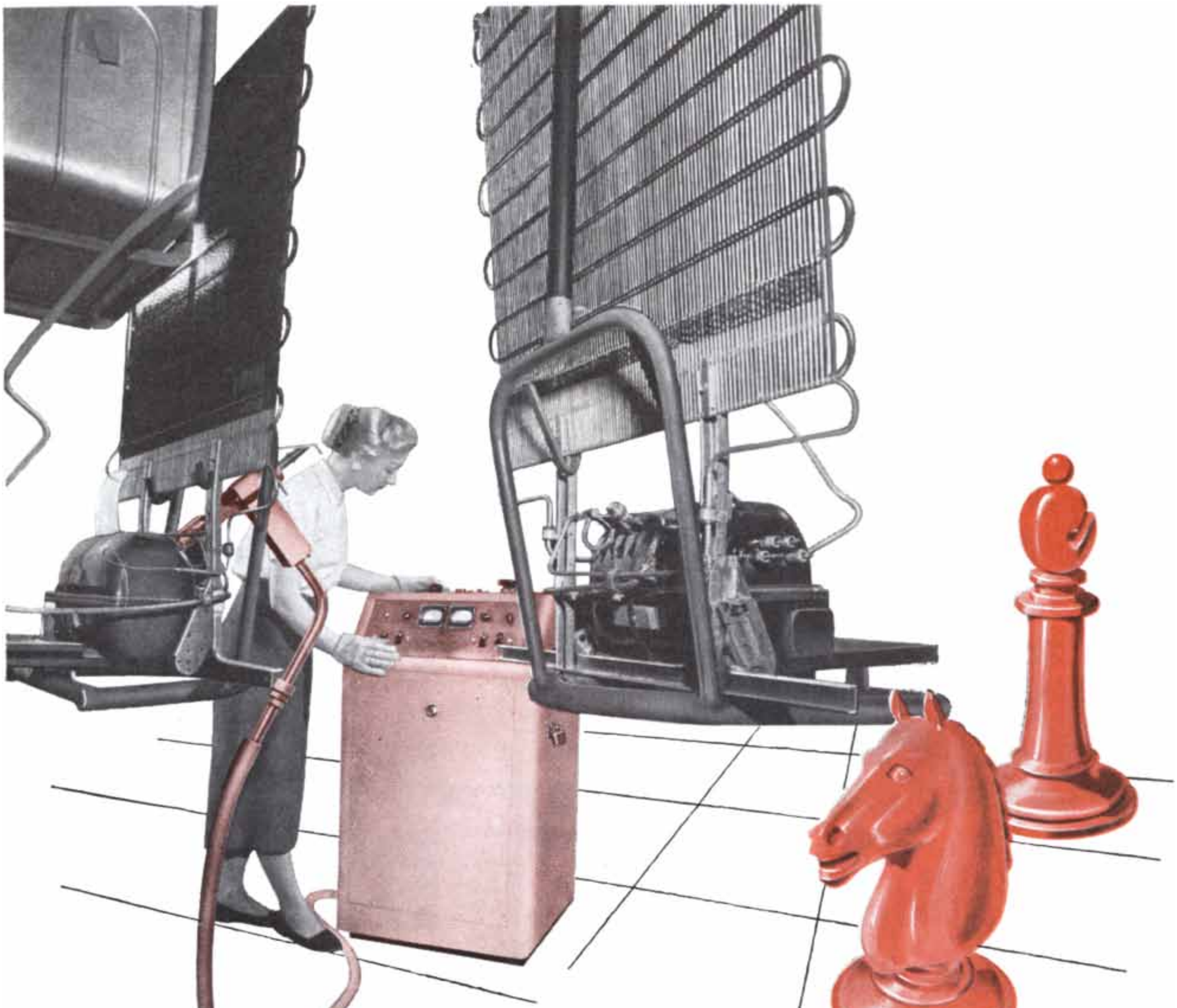

Successful strategy—better product—new profit level

Like chess champions, management today is capitalizing on scientific systems to stay ahead of competition. Your business, too, can profit many ways through the unique teamwork offered by Consolidated Electrodynamics Corporation. For example, Hotpoint Co., a leading refrigerator manufacturer achieved an infallible system for testing hermetically sealed refrigerator units. Hotpoint was determined to make a better refrigerator for lower cost. Two members of the Consolidated family—the Rochester Division, manufacturers of high-vacuum equipment, together with Consolidated's Analytical and Control Instrument Group—joined forces to design, manufacture and install a fast production line system that has become, literally, the talk of the entire industry.

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If you are interested in increased product dependability, manufacturing economies and tighter production control, it will pay you to send for Consolidated's latest bulletin. It tells how you can use the scientific equipment and techniques of the Consolidated group to make profitable progress a reality in your business. Write for Bulletin 42, "Your Next Move for Profit and Progress."

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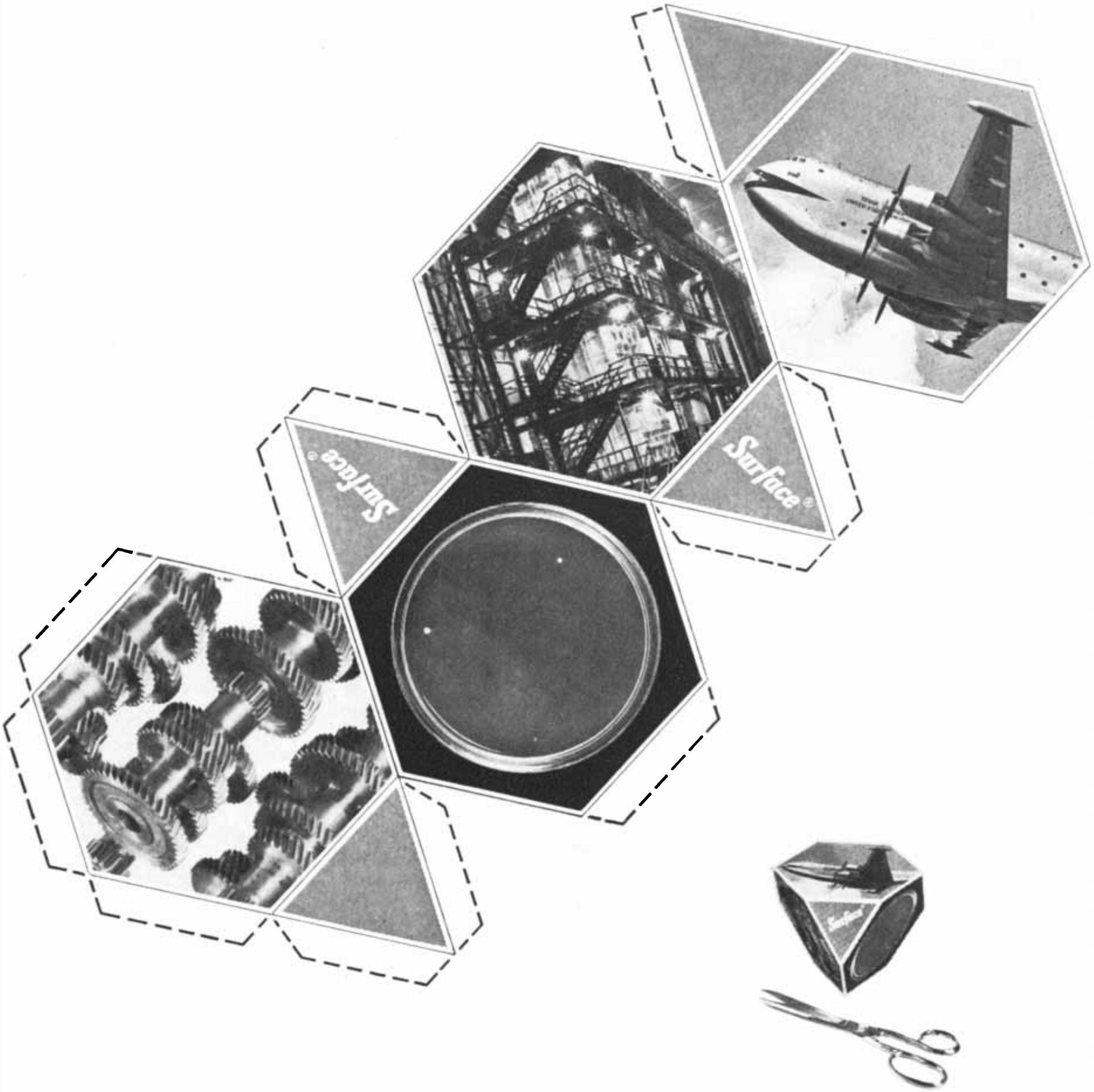
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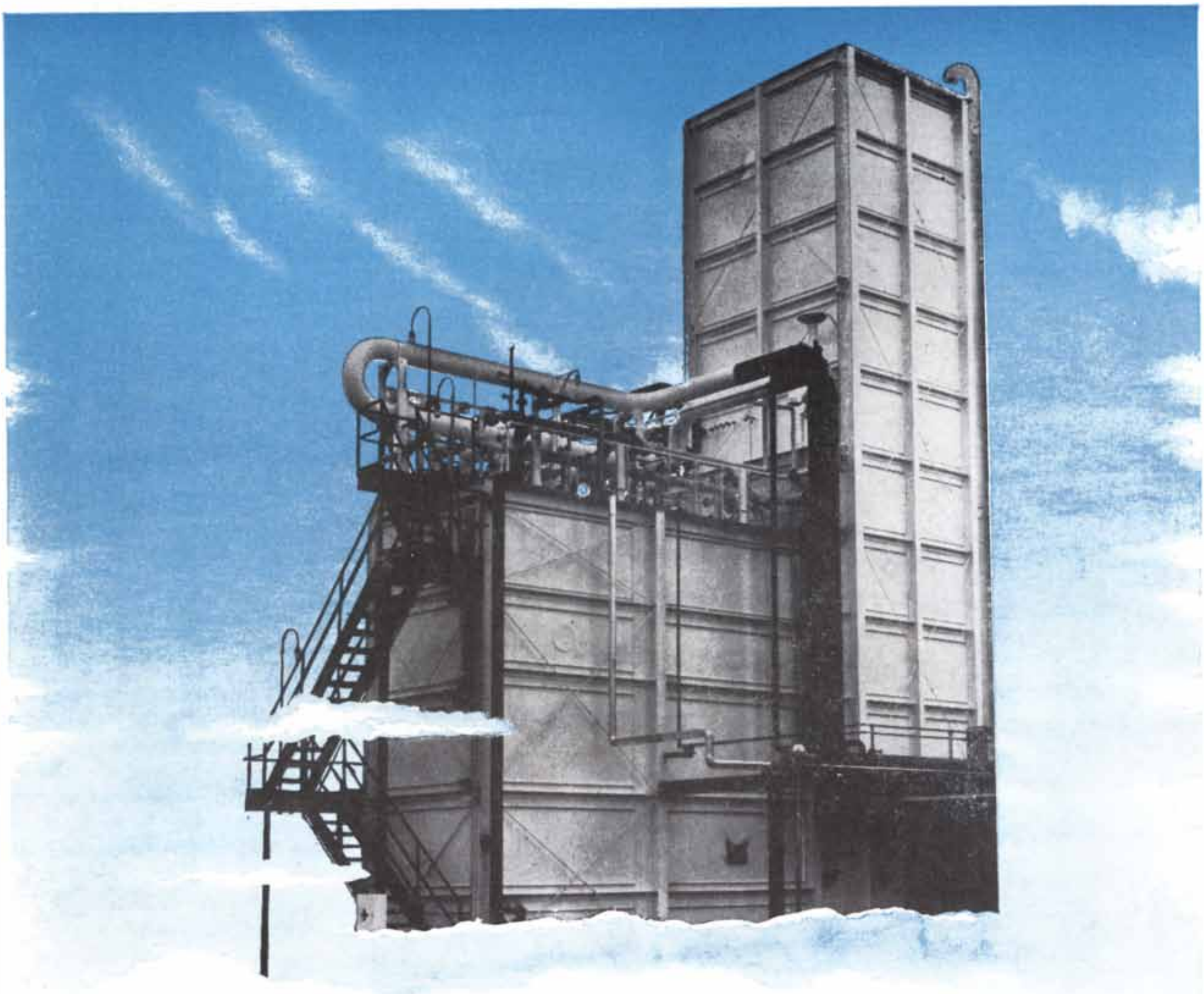

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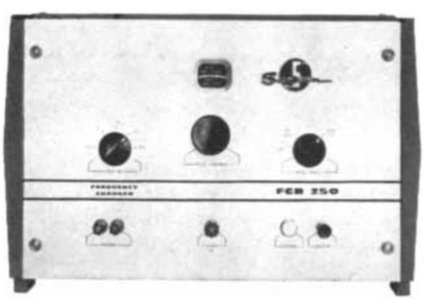

LETTERS

Sirs:

The four primitive men in opera hats and capes [SCIENTIFIC AMERICAN, June] reminded me of Hilaire Belloc's poem "The Big Baboon":

The Big Baboon is found upon
The Plains of Cariboo:
He goes about with nothing on
(A shocking thing to do).
But if he dressed respectably
And let his whiskers grow,
How like this Big Baboon would be
To Mr. So-and-so!

ESTEBAN POPPER

Buenos Aires, Argentina

Sirs:

I was very interested in the article on pneumatic buildings in the June issue of *Scientific American.* Yet I was . . . disappointed that you made no mention of . . . Buckminster Fuller's popularized but little understood geodesic dome. Last year his architects, designers and engineers developed what today is the largest rigid plastic enclosure: 55 feet in diameter. This clear-span geodesic dome (a three-quarters sphere) is made of glass-reinforced, flame-resistant polyester resin. It is designed and tested to withstand winds of more than 150 miles per hour. The 363 components in the form of giant diamonds and circular cake pans, with gasket-like joints, can

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U. S. Air Force Photo

An Air Force cargo plane delivers vital Air Force supplies to an overseas base.

AIR MATERIEL COMMAND IS GLOBAL LINK BETWEEN RESEARCH AND COMBAT UNITS

Supplying the Air Force with the right equipment, at the right place at the right time is the mission of Air Materiel Command. Its procurement, supply and maintenance operations fill the area between research and development on one side and combat units on the other. It is the largest business in the country.

Because our Air Force is operating in all quarters of the earth, AMC is a globe-circling operation with its headquarters centered at Wright-Patterson AFB near Dayton, Ohio.

The vital logistic mission for the Air Force involves billions of dollars in procurement, thousands of airplanes, and more than a million different kinds of supply items. Organizationally, AMC includes fourteen air materiel areas, or major area depots, located in the United States, Europe, North Africa, and the Pacific. Geographically, air materiel operations extend throughout the free world.

Working with weapons systems contractors in private industry, AMC procures the equipment which has been developed and tested by the Air Research and Development Command, and distributes the equipment to combat units as needed. The never ending objective of the Air Materiel Command is to maintain an instant combat readiness, logistic-wise, in this era of super speeds and super weapons to support Air Force operations at any point on the globe. The philosophy of Air Materiel Command is that such readiness must be characterized by the closest interrelations of combat and logistic elements, by speed, flexibility, mobility and economy.

This is one of a series of ads on the technical activities of the Department of Defense.

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be put together in approximately 100 man-hours. Used in the Arctic as a "radome," this geodesic structure allows light to diffuse through its translucent parts so that no shadow is cast in the interior. Its nonmetallic structure is ideally suited for its present use. Psychologically it releases the occupants from the "mole-like" existence of pressure locks and dark-interiored pneumatic radomes, moving them into the surface world of light and space. . . .

Fuller's techniques have always been regarded as impossible, visionary, impractical. It is unfortunate that, now that their usefulness has been proved, it has not been through the support of civilians, but of the military. Fuller's domes have been put up in isolated places, where few can observe the truth of his work. Yet many have seen the Ford Rotunda in Dearborn, Mich., a translucent dome 1/29th the weight of a conventional dome. Steps are now being taken to build a dome over the new stadium which is being contemplated for Brooklyn. Such a dome would be twice the diameter of the largest clear-span structure yet built. . . .

Though this structure would bring Fuller's work home to the American people, Fuller has already been winning acclaim abroad, at international trade fairs and architectural exhibitions, through the display of a geodesic dome made of heavy waterproofed *cardboard*. For one who has spent some time in Asia attempting to cope with the problem of sheltering the millions of people there, as I have, such a development is highly significant. In the subcontinent where millions live in mud houses, the average structure may cost up to $300 for one room eight by ten feet (depending on the availability of wood for framing and rafters, roofing material and foundation material). One can quickly picture the development of presses to turn out cheap paperboard geodesic domes as quickly as newsprint. In the flood disasters in India and Pakistan last fall, shelter was the prime emergency. If from airborne transports geodesic cardboard domes could have been dropped in a great parachute operation, the end of the flood would have been a different story.

SHELDON WEEKS

New York, N. Y.

Sirs:

To be careless of the distinction between *using* a sign or an expression and

New trends and developments in designing electrical products . . .

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The basic function of a permanent magnet is to provide a specific magnetic flux across a given air gap. The basic problem for the designer is to select a magnetic material with the optimum combination of magnetic and physical properties to fulfill this function.

Since the permanent magnet has considerable influence on the final size, cost, and efficiency of the product, it is important to know the primary characteristics of each of the seven available General Electric Alnico grades.

Each of these grades offers specific advantages in available energy, unit cost, and physical properties. No one grade excels in all of them.

In terms of energy product, cast Alnico 5 has no peer among magnetic alloys. Its 5 million minimum gauss-oersteds is 43% higher than Alnico 6.

Its demagnetization curve (Figure 1) shows that Alnico 5 has the highest residual induction of all the Alnicos, as well as relatively high coercive force. This means that a smaller cross-sectional area and less total volume will be required to maintain a given air gap density.

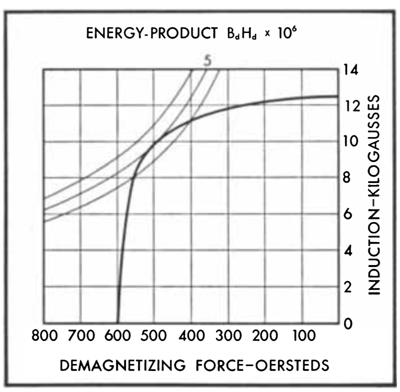

Fig. 1 — Alnico 5 Energy Product and Demagnetization Curves

Thus, where there are space restrictions, as in hearing aids, Alnico 5 has more available energy per unit volume. Where there are weight restrictions, as in airborne magnetrons, Alnico 5 offers more available energy per pound. And where there are cost considerations, as in loud speakers, Alnico 5 provides maximum external energy per dollar.

At the opposite extreme, Alnico 3 has one of the lowest energy products of the Alnicos — 1.38 million gauss-oersteds (Figure 2). About 3½ times more Alnico 3 than Alnico 5 is required to produce a given air gap field energy requirement.

However, because of its lower cost, Alnico 3 offers important savings in applications like toys and novelties, where performance and weight are not critical factors.

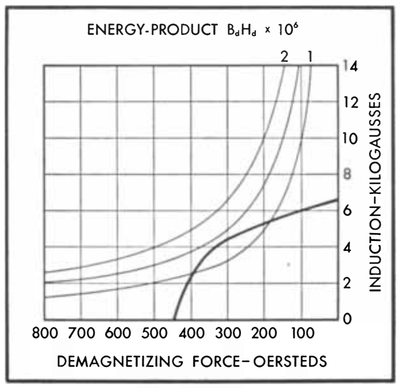

Fig. 2 — Alnico 3 Energy Product and Demagnetization Curves

Despite its relatively low energy product, Alnico 3 still provides more external energy, at lower cost, than does 37% cobalt steel — the best of all the magnet steels.

G-E Alnico 6 has an energy product of 3.5 million gauss-oersteds, ranking second only to Alnico 5. But the primary advantage of this grade lies in its flatter, more stable demagnetization curve (Figure 3, see top of next column).

Alnico 6 has ability to provide useful field energy under dynamic operating conditions. And in certain applications, Alnico 6, despite its lower energy product, will produce a higher gap flux density than Alnico 5.

For motors, generators and lifting applications, where the magnet is operating under varying demagnetizing influences, Alnico 6 offers greater stability and high useful recoil energy.

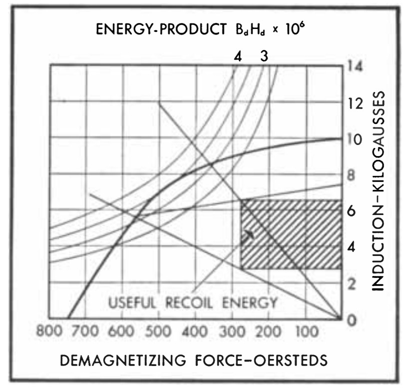

Fig. 3 — Alnico 6 Energy Product and Demagnetization Curves

Generally speaking, permanent magnets' physical properties are seldom the primary consideration when selecting magnetic materials. However, in certain high rotary speed applications, such as rotors, physical strength is of major importance. This necessitates the use of a sintered, instead of a cast, Alnico grade. These sintered magnets have tremendously improved physical properties, with but a slight sacrifice in magnetic properties.

Sintered Alnico 2, for example, has more than 20 times the tensile strength of cast Alnico 2. And, it has 10 times the transverse rupture strength, in addition to more uniform magnetic properties. Approximately the same order of structural improvements holds true for sintered Alnicos 4 and 5.

Selecting the proper magnetic material is a crucial and complex part of the design problem. If you would like the assistance of a G-E Magnet Engineer in this, or any other, stage of your permanent magnet design, write: *Metallurgical Products Department of General Electric Co., 11199 E. 8 Mile Blvd., Detroit 32, Mich.*

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mentioning one ill becomes a metamathematical (indeed, a metametamathematical) article such as "Gödel's Proof," by Ernest Nagel and James R. Newman [SCIENTIFIC AMERICAN, June]. For, without this distinction, metamathematics (and other metalanguages) could scarcely exist; and, if this distinction is not consistently marked by some typographical convention (quotation marks or italics, for example), then endless confusions between mathematics (or other object languages) and metamathematics (or other metalanguages) result.

The distinction cannot be stated both briefly and exactly; but, roughly, it is this. A sign or an expression is said to be *mentioned* if and only if it serves as its own name; it is said to be *used*, otherwise. Signs and expressions are *used* in both object languages and metalanguages, but they are *mentioned* in metalanguages (and, of course, metametalanguages, etc.) only. "Paris is a city," for example, is an expression in an object language. For in it all four signs are *used*; and, of course, it is about things other than signs and expressions. But " 'Paris is a city,' for example, is an expression in an object language" is an expression in a metalanguage. For in it some signs—namely, the first four—are *mentioned*; " 'Paris is a city' " serves as its own name. " 'Paris' has five letters" is also an expression in a metalanguage. For in it the first sign is *mentioned*; it serves as its own name. (Note that, though the metalinguistic " 'Paris' has five letters" is true, the object-linguistic "Paris has five letters" is false.)

"Gödel's Proof" sometimes marks this distinction with quotation marks, as in this metametamathematical statement: . . . The statement " 'x' is a variable" belongs to metamathematics [p. 75]. It sometimes marks it with italics: The "sentential" variables (which correspond to sentences or statements) are certain letters: *p*, *q*, *r* and so on [p. 77]. It sometimes marks it not at all: Consider the arithmetical expression 2 + 3 = 5 [p. 75]. This should read: Consider the arithmetical expression "2 + 3 = 5," or: Consider the arithmetical expression *2 + 3 = 5*.

In one instance, indeed, failure to mark this distinction results in a sentence that clearly violates the rules of English syntax and that, when patched up with (say) quotation marks, fails to do the job that it was written to do. The instance is the "translation" of the fourth axiom of the sentential calculus: If ducks waddle implies that $\sqrt{2}$ is a number then (either Churchill drinks brandy

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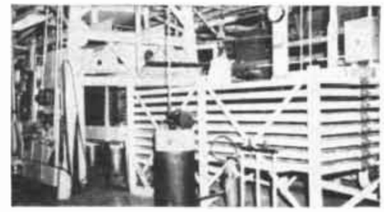

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or ducks waddle) implies (either Churchill drinks brandy or $\sqrt{2}$ is a number). Rendered into English, this "translation" reads this way: If "ducks waddle" implies that $\sqrt{2}$ is a number then either "Churchill drinks brandy" or "ducks waddle" implies either "Churchill drinks brandy" or "$\sqrt{2}$ is a number." But, since this rendering is clearly in a metalanguage, and since the axiom that its un-English original was designed to translate is (like all axioms) in an object language, this rendering clearly won't do. What would do is this: If it is the case that, if ducks waddle, then $\sqrt{2}$ is a number, then it is the case that, if Churchill drinks brandy and/or ducks waddle, then Churchill drinks brandy and/or $\sqrt{2}$ is a number. The article confuses an implication sentence (what it was groping for in its "translation" of the fourth axiom) with a statement about implication, and its carelessness about the distinction between *using* and *mentioning* signs and expressions helps it to do this. (Incidentally, "either . . . or," which suggests the exclusive "or," is a misleading translation of "v" or the inclusive "or"; "and/or," used in the last rendering, is preferable.)

MARTIN STEINMANN, JR.

University of Minnesota
Minneapolis, Minn.

Sirs:

On page 76 ["Gödel's Proof"; SCIENTIFIC AMERICAN, June] the "meta-chess theorem" is ". . . if White has only two Knights, it is impossible for White to mate Black." Among the inadequacies of this statement are:

1. The Kings must be on the board at all times.

2. The Knight can mate without help of the King or any other piece. This "smothered" mate is often a threat and sometimes executed.

3. When Black has *only* the King, he can easily force a draw against White with the King and two Knights, but it is *possible* for White to win under these conditions, for Black can make the fatal mistake. "It is impossible for King and Bishop or King and Knight to win against the *lone* King" is a correct meta-chess statement.

4. King and two Knights can force a win against King and properly placed Pawn. For example, the King and one Knight restrain the enemy King, while the other Knight blocks the Pawn. At the right moment the second Knight ad-

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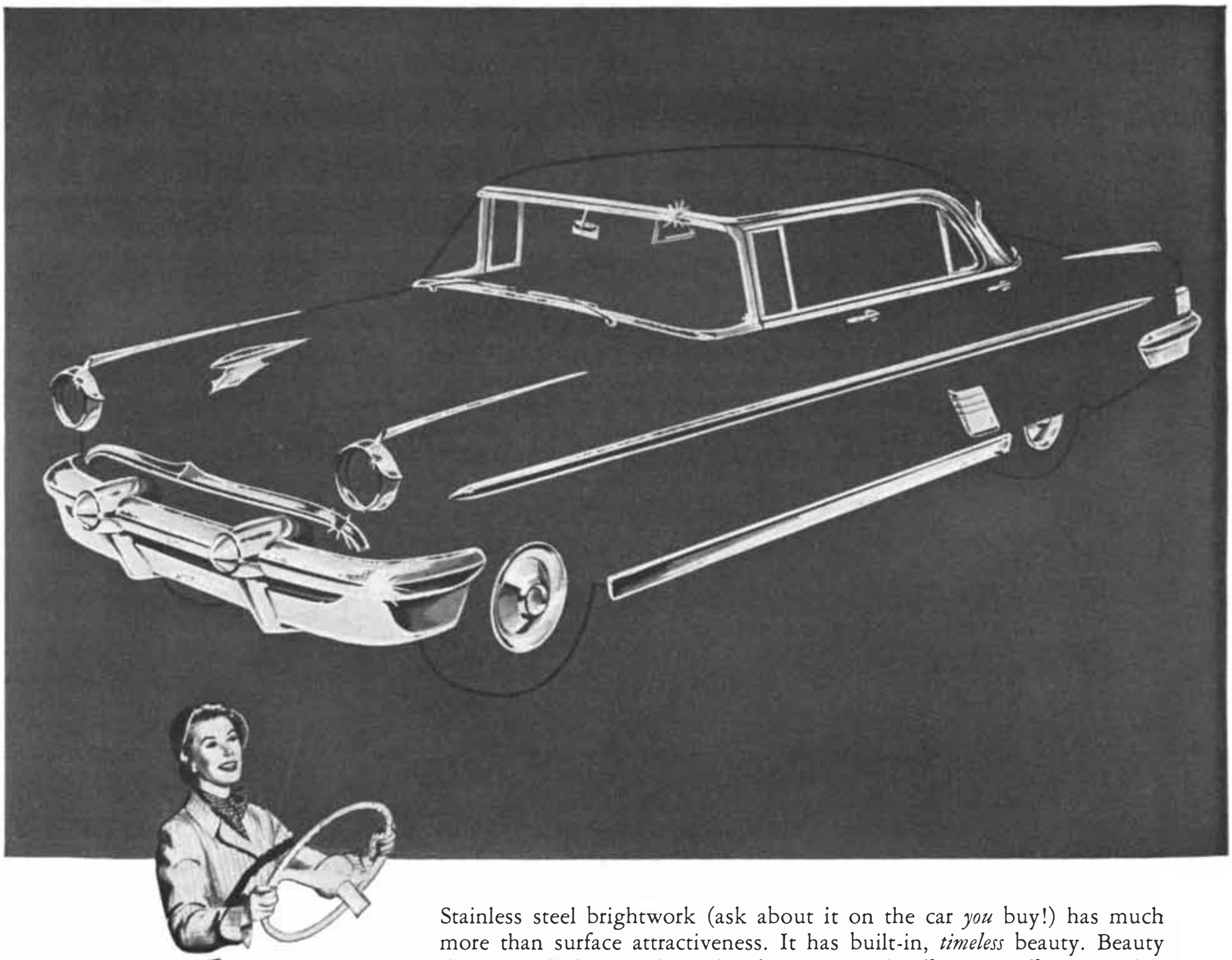

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THOMAS W. FINUCANE

Tennessee Chess Association
Kingsport, Tenn.

Sirs:

The distinction between the use and the mention of signs is of course fundamental, as Mr. Steinmann rightly notes. It is a distinction with which we are intimately familiar, and we enforced it consistently with the help of appropriate notation in the typescript of the article. However, in some cases (though not in all) our notational devices were modified partly because in the editors' judgment our notation made the article more difficult for the general reader to follow. Once the distinction between use and mention is clearly made, as we think our article has in effect made it, it is at least debatable whether it is essential to thrust the point on the reader's attention on every occasion, especially in a nontechnical essay such as ours. We might add, in defense of the editors' alterations, that the rigorous notational enforcement of the distinction is often relaxed even in books and papers addressed to specialists. As to the illustration for the fourth axiom of the propositional calculus, Mr. Steinmann's censure is well-taken if one assumes that "implies" is being employed as a metalinguistic predicate; we were using the word, however, as an alternative colloquial rendering of "if-then."

It is also a valid point that the "metachess theorem" about mating with two Knights is loosely phrased. It would be correct to state that if White has only two Knights, and Black only a lone King, White cannot *force* a mate against Black.

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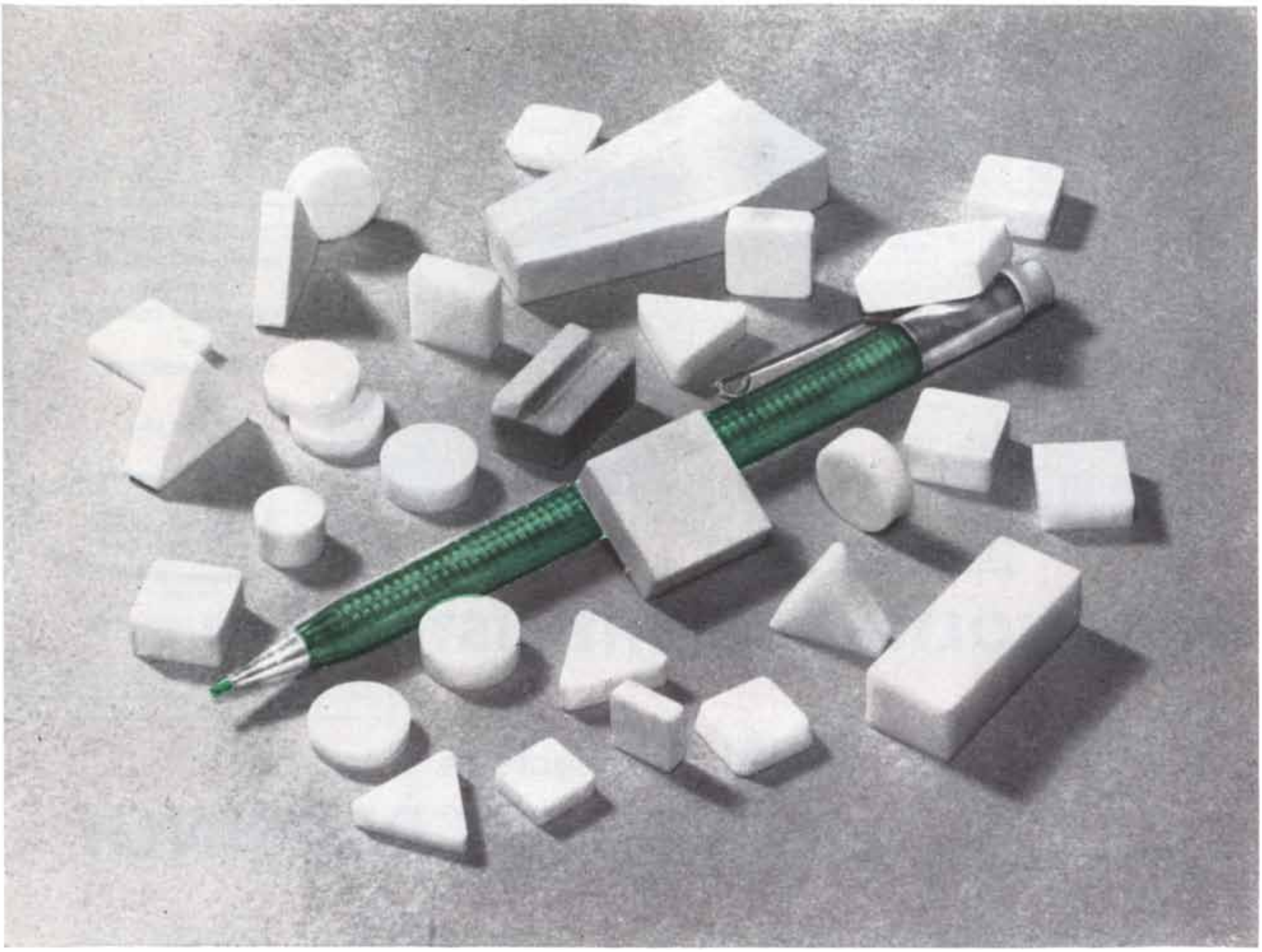

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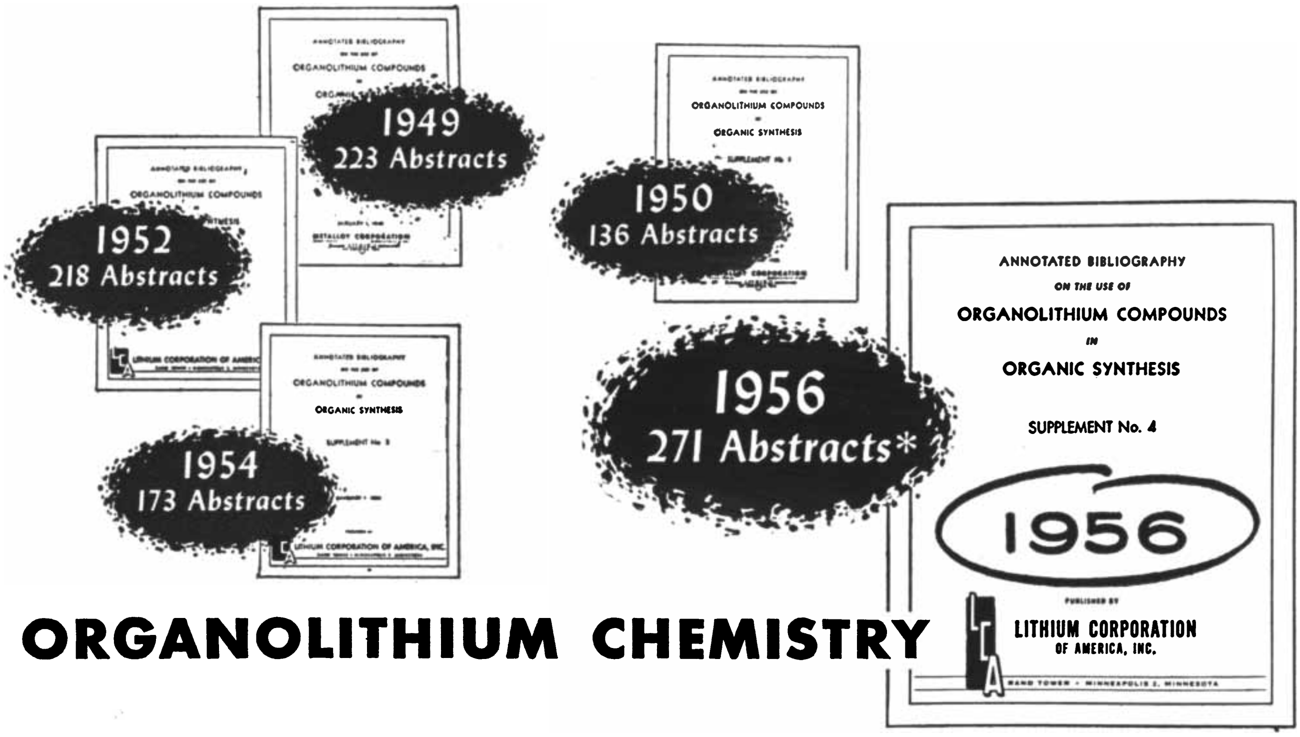

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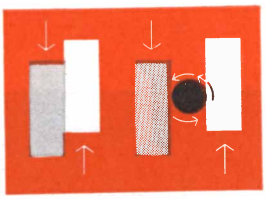

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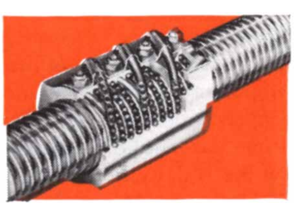

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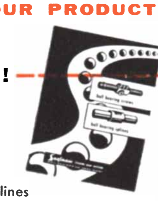

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a report by LINDSAY

In its restless search for knowledge, science has brought us to the threshold of space, our eyes on the infinity of the universe while we are continuing our investigation of the many mysteries that still exist here on our own planet. One of the richest, most exciting of these virtually unexplored realms lies in that little known group of versatile metals—the rare earths.

There are 15 rare earths—atomic numbers 57 through 71—and together they occupy about .012% of the earth's crust. They are remarkably alike in their chemical behavior because of their atomic structure. The main difference lies in the disposition of the three outermost electrons. The difference is always slight; the heavier rare earth atoms have a smaller radii, hence are denser than the lighter ones.

This characteristic makes separation difficult, but it also makes the rare earths ideal subjects for the study of the magnetic properties of materials and to test various theories of physical chemistry and physics. The rare earths may hold the combination that will unlock many of the secrets of nature.

Industry, too, is turning to the rare earths in a search for materials to improve products and processes. And they have found that the rare earths offer enormous potentials. Already many of these metals are being used in a variety of industrial fields.

Rare earth chloride is a combination of the chlorides of cerium, lanthanum, neodymium and praseodymium with smaller amounts of samarium, gadolinium and less common rare earth chlorides. From this material comes misch metal used in lighter flints and as an additive in many grades of steel. Rare earth chloride also serves in the production of chrome, dentifrices, silk, aluminum, fertilizer and catalysts.

Cerium, most common of the rare earths, is widely used, in its oxide form, as a polishing agent for optical and other forms of glass. Cerium hydrate is an ingredient in the production of the special glass used to view highly radioactive operations.

The rare earths have drying properties that can be useful in the production of better paints. And, neodymium and praseodymium have potential value as colorants in the manufacture of ceramics.

The petroleum industry is investigating the use of rare earths as catalysts in their cracking plants. And this unique group of metals shows promise in catalytic polymerization—a problem in the manufacture of many synthetic fibers and plastics.

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Much of the interest in rare earth and thorium chemicals has been sparked by Lindsay scientists. Since the days of the incandescent gas-mantle lamp, in the last years of the 19th Century, Lindsay has worked and pioneered in this field. Expansion has come as researchers at Lindsay and in science and industry have uncovered new uses for the rare earths. Just recently Lindsay has expanded its ion

exchange installation and now has 100 columns in operation at its West Chicago plant for the separation of some of the "rarer" rare earths in commercial quantities and in purities up to 99.99%.

If you think there is even a remote possibility that the rare earths might have significant applications in your industry, you may find it worthwhile to talk with our technical people. The data obtained through our years of research is available to you and we can supply you with rare earths in quantities from a gram to a carload.

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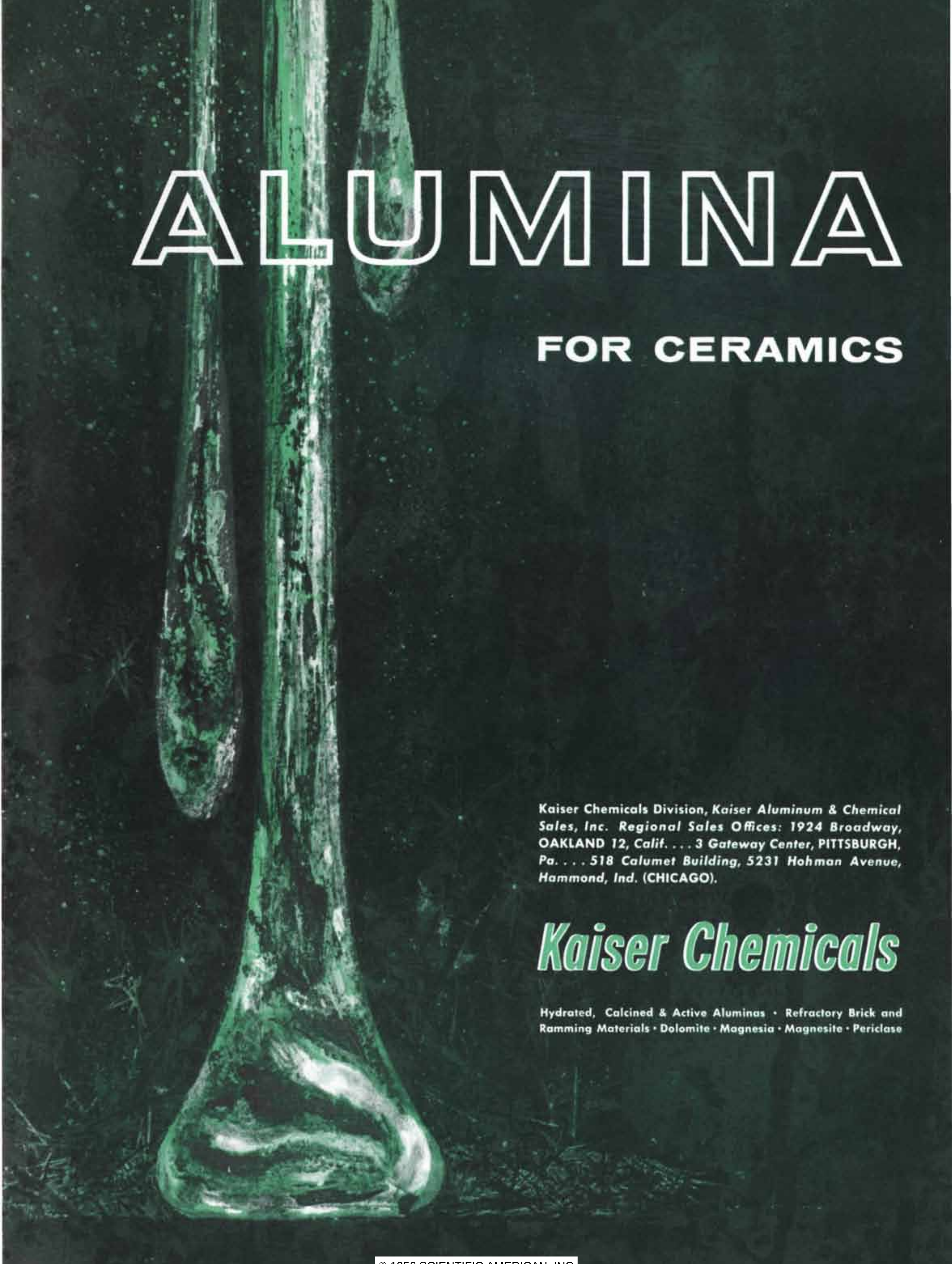
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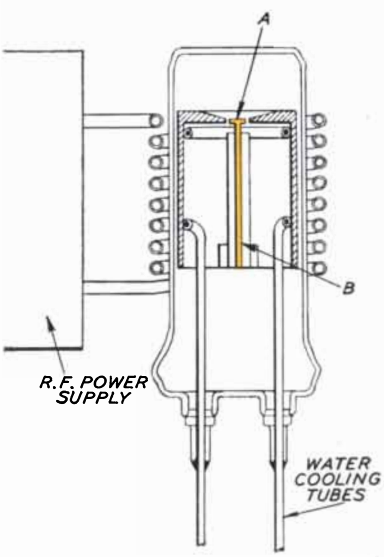
The New Sylvania RF Lamp is explained by a Sylvania engineer to actress ***DANI CRAYNE***, appearing in ***"THE UNGUARDED MOMENT"*** a Universal-International picture, print by ***TECHNICOLOR***. Called the most significant advancement in lighting since the Edison lamp, the RF lamp is powered by high-frequency radio waves. The light-emitting source is composed of a Norton high-purity refractory which Sylvania uses to produce the most uniform concentrated light ever devised. After inventing this outstanding new lamp, Sylvania engineers turned to Norton Company as a dependable source of high-melting, stable materials.

The commercial success of this new lamp required exact duplication of refractories from lamp to lamp. Hence, Norton experience in producing and duplicating high quality refractories gave invaluable assistance to the development of a new Sylvania product.



Norton Refractories used in the RF lamp are shown in yellow: (A) tantalum carbide target, the light-emitting source; (B) zirconium oxide target-support centers the target in the RF field. High-frequency waves from an induction heating coil pass through the glass envelope, into the concentrator, and heat the refractory target, resulting in a great increase in both volume and uniformity of light emission over the usual incandescent type lamps.

Another Norton assist . . .

Specially engineered refractories aid in developing Sylvania's revolutionary RF induction lamp

The development of the new Sylvania RF lamp is another good example of how Norton refractories engineers can team up with your engineering or development staff to surmount temperature barriers, provide new high-stability materials and otherwise help speed your technical progress.

Take advantage of this cooperation. Let Norton know-how assist your program for product development or improvement. Norton high-melting, fusion-stabilized materials are *engineered and prescribed* to give you the best possible ℞ — the most effective combination of physical characteristics plus thermal, chemical and electrical properties. For details, call in your Norton Refractories Engineer. Or write to NORTON COMPANY, Refractories Division, 547 New Bond Street, Worcester 6, Mass. *In Canada:* A. P. Green Fire Brick Co., Ltd., Toronto 5, Ontario.

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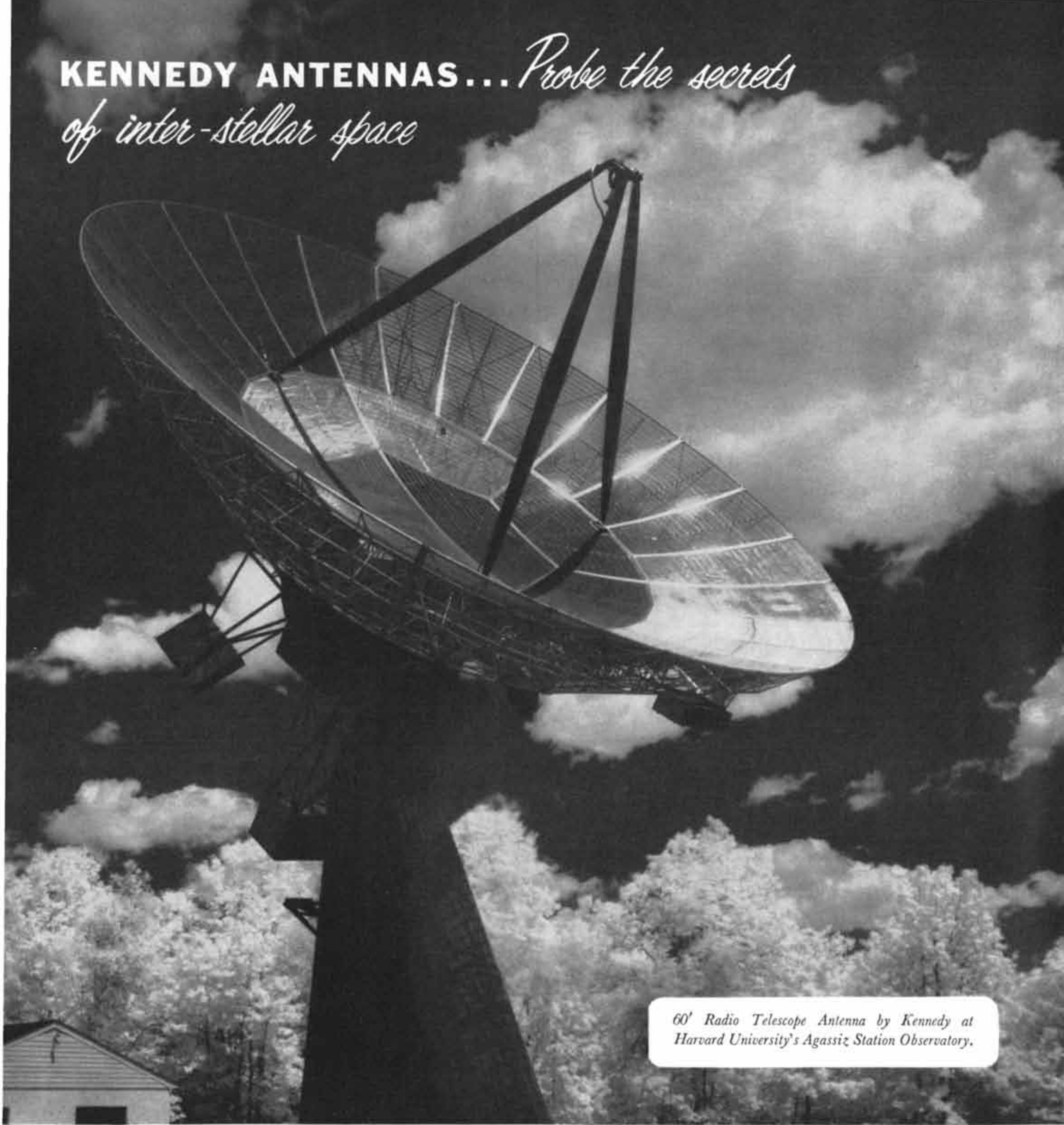

60′ Radio Telescope Antenna by Kennedy at Harvard University's Agassiz Station Observatory.

Somewhere in the nearly empty reaches of outer space, two hydrogen atoms collide. After a 100-million year journey at the speed of light, the signal generated by that accidental collision reaches a super-sensitive radio telescope antenna in Massachusetts and is recorded — and so one grain more is added to man's knowledge of the universe.

Modern miracles like this happen every day at Harvard University's Agassiz Station Observatory, where a giant new radio telescope, with its 60′ Kennedy antenna, is taking man further back in time . . . and further out into space . . . than he has ever been before.

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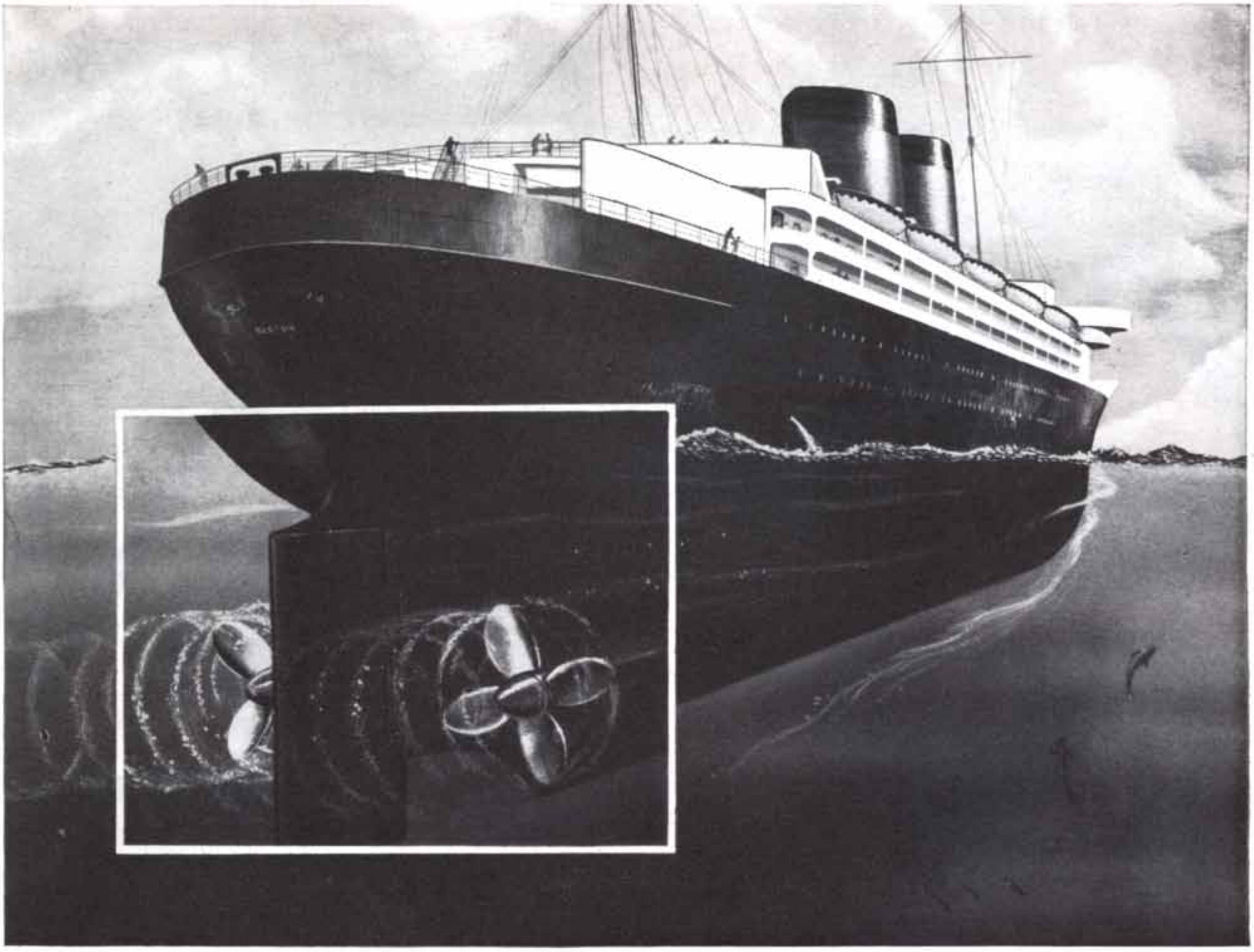

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The British Admiralty found, in 1870, that adding *tin* to "cartridge brass" greatly increased its resistance to corrosion at sea. Hence the alloy known today as "Admiralty Metal." Since those days, many other copper alloys have been developed with even greater resistance to corrosion.

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Whether your product goes to sea or serves ashore, the *workability* of copper's many alloys is another advantage to you. They join readily . . . are easy to form . . . plate and polish beautifully . . .

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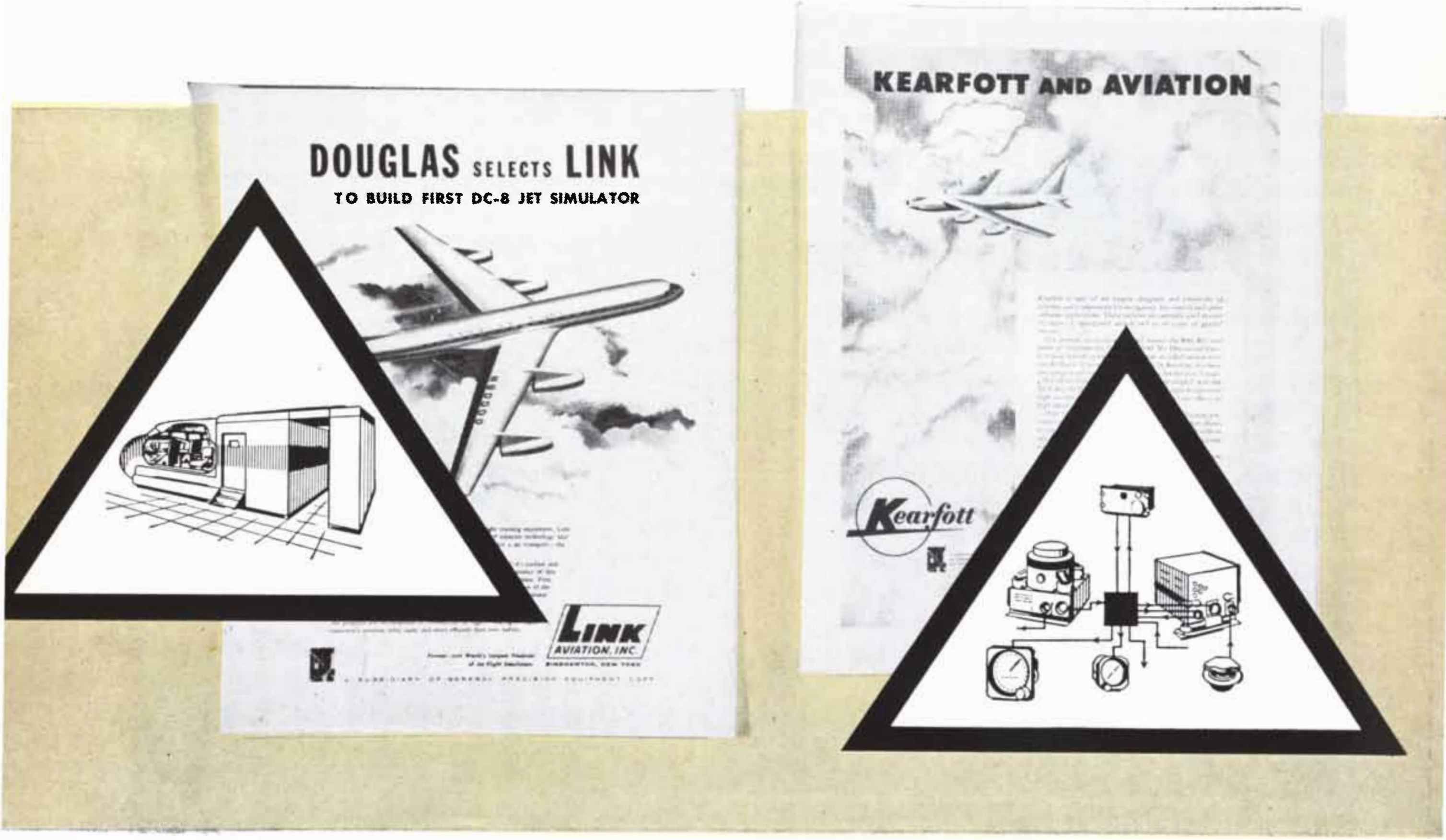

TECHNOLOGICAL

GPE

AERONAUTICAL SYSTEMS

have made vital contributions to the progress of jet aviation and its expansion into the civil transport field. Many have won recognition as the finest in the industry, bench marks of American technology.

Whole generations of airmen, for instance, have been trained in flight simulators developed and produced by Link, pioneer of on-the-ground flight training. This GPE Company has delivered over 800 jet flight simulators—more than all other manufacturers put together. It has just been selected, on the basis of superior technology and equipment, to produce America's first simulators for jet air liners. Link-developed DC Computer Systems in Link supersonic simulators are the only ones meeting the needs of these advanced aircraft.

Equally dominant are the gyro-magnetic compass systems of Kearfott, another GPE Company. This company's new lightweight J-4 Compass System weighs only

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BENCH MARKS

18 pounds. Yet it provides accurate heading information at all latitudes, is rugged enough to maintain its high accuracy despite the jolts and speeds of jet flight. The Air Force has just selected it as standard for all new fighter craft. Kearfott's N-1 Compass System has been the navigational standard for Air Force bombers for 5 years.

Still another member of the GPE Group, General Precision Laboratory, has developed and is currently making quantity deliveries of the most advanced airborne navigation systems in use. These GPL systems, which are self-contained and fully automatic, have flown millions of operational miles with unprecedented accuracy. Their adaptations to civilian jet needs—GPL's RADAN Systems—are expected to make equally far reaching contributions to the commercial jet transport field—in the way of increased safety, fuel economy, passenger convenience and efficient use of limited air space.

These are but some of the accomplishments in aviation for which GPE Companies, working in conjunction with the Armed Services, are responsible. Librascope, an important member of the Group, produces outstanding instruments and equipment for the field. Librascope's computers, its highly advanced equipment for photo-reconnaissance work and photogrammetric equipment for the interpretation of photo data, its periscopes, pilot and navigator finders, are all leaders. Several GPE Companies are deeply involved in inertial guidance, guided missile projects and certain nuclear power applications.

In all GPE achievements in the numerous industries in which the companies work, GPE Coordinated Precision Technology plays an important part by inter-relating the wide range of skills and resources of the Group. This operating policy, and each company's unremitting insistence on highest quality, are major reasons for the frequency with which GPE systems and equipment continue to set standards in their fields.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

SEPTEMBER, 1906: "Frederick Soddy discusses the unknown store of energy contained in the chemical elements, and the prospect of making it available. None of the material changes dealt with in chemistry is very profound. Radioactivity has brought more fundamental changes into view. The large internal energy exhibited by the radium atom cannot be regarded as peculiar to radium. Uranium was known long before its radioactivity was discovered, and represents another perfectly normal chemical element. Yet uranium, since it produces radium with evolution of energy, must possess all the internal energy of radium and more. It is probable that the elements as a class all possess great internal energy, and that their characteristics of stability and permanence, and the failure of all attempts to change them by artificial means, are due to the existence of this internal energy. The forces at our disposal compared to those which are exhibited when an atom suffers change, are of a different and lower order of magnitude, and it is not to be expected therefore that transmutation will become possible until we can control more powerful agencies than are at present available. Suppose that a way were known in which the element uranium, for example, which disintegrates to the extent of a thousand-millionth part annually, could be made completely to disintegrate in the course of a year. From one gramme of the element more than a thousand million calories could be evolved, and this, if it could be converted into electrical energy, would be equivalent to more than 1,000 kilowatt-hours, and would suffice to keep a 32-candle-power lamp burning continuously throughout the year. By the expenditure of about one ton yearly of uranium, costing less than £1,000, more energy would be derived than is supplied by all the electric supply stations of London put together."

"In his presidential address delivered to the British Association for the Ad-

vancement of Science, Prof. E. Ray Lankester said: 'We have the discovery by Rutherford and others that radium is continually being formed afresh, and from that particular element in connection with which it was discovered—namely, uranium. Hypotheses and experiments as to the details of this process are at this moment in full swing, and results of a momentous kind, involving the building up of an element with high atomic weight by the interaction of elements with a lower atomic weight, are thought by some physicists to be not improbable in the immediate future.' "

"It is now known that hay fever is due to the invasion of the mucous membrane of the nose by the pollen of certain plants. At present a hundred and fourteen plants are known to have toxic pollen; wheat, rye, and quite a number of gramina form a part of them. The active principle of the pollen consists of a granular amylaceous material, and lasts a long while. The toxin of this granular material has been separated, and it has been used in manufacturing an antitoxin. We can scarcely hope to find an antitoxin that will permit of treating hay fevers due to different pollens. It will be sufficient indeed to prepare antitoxins corresponding to the principal toxic pollens. The antitoxin should be administered by preference in a powder—a mixture of sugar and antitoxic serum. It generally cures and confers a certain immunity. Out of 222 cases treated, these results were obtained: 127 successes (say 57 per cent); 71 improvements (say 32 per cent); 24 failures (say 11 per cent). The proportion is very encouraging."

"Great Britain may well be satisfied with the information collected in the Antarctic by Capt. R. F. Scott and his gallant companions. And what did Capt. Scott find after his memorable struggle up the glacier through the mountains? An enormous plateau at an elevation of about 9,000 feet, nearly level, smooth and featureless, over which he traveled directly inland for over 200 miles, seeing no sign at his furthest point of any termination or alteration in character. So far as could be seen from other journeys, glacial discharge from this great upland is very small, and practically it appears to be dead. Its accretion by fresh snowfall is insignificant, while on all sides along the flanks of the coastal mountains there are signs of diminution in the mass of ice. The great ice barrier east of Ross Island tells the same tale. This magnifi-

cent feature presents to the sea a face of perpendicular ice cliffs varying from 60 feet to 240 feet in height, and 450 sea miles long. Sir J. Ross mapped its position in 1841, and Capt. Scott finds that it has retreated on an average of 15 miles, varying much in different parts. Should this rate of retreat continue, the whole of this ice mass, as far as Capt. Scott saw it, will have vanished in 1,000 years."

"When the tall office building, in the course of its rapid evolution, had attained the height of 300 feet, it was freely predicted that the limit had been reached, and that future structures in New York City would be of more reasonable vertical dimensions. That prediction was made not much more than a decade ago; and yet to-day there is in course of construction in lower New York a building whose summit will reach heavenward for over twice three hundred feet. The new building, which will be in the form of a tower and will constitute part of an extension of the present Singer building at the corner of Liberty Street and Broadway, will contain 41 stories and the top of its cupola will be 612 feet above street level."

"We possess as yet only pretty vague data as to the average duration of flashes of lightning. Faraday thought he could fix it at a second. Dufour claimed that the flashes of lightning were instantaneous, and that their rapid succession gave the illusion of one flash of a certain duration. Herr Schmidt has just been devoting himself to a series of observations, employing a disk of 10 centimeters diameter bearing upon a black ground a white cross, the arms of which were two millimeters across, the disk being set in motion by clockwork with a speed of 50 to 60 revolutions a second. At certain flashes, the cross appeared a single time, very distinct; the duration of lightning was, therefore, inferior to the time of revolution of the disk, which would represent about a fiftieth of a second. In more numerous cases, the cross appeared two or three times, or even more, but with a decreasing luminous intensity; the lightning had, therefore, lasted during several revolutions of the disk."

"It is believed by Mr. James J. Hill, whose life work of developing, by the provision of transportation, the unoccupied lands of the United States has peculiarly fitted him to speak authoritatively on the subject, that the most serious economic question of the future will be to provide the food supply of the

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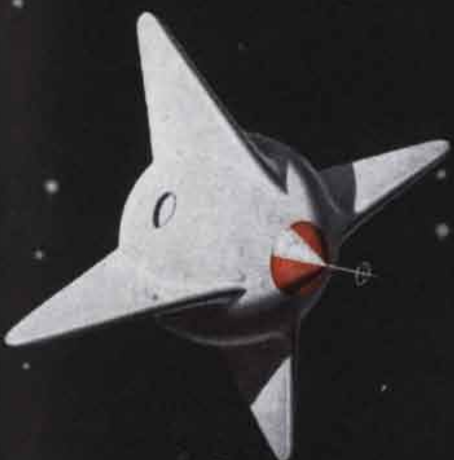
200,000,000 people who will be seeking homes and work in the United States by the time the present century has run half its course. Mr. Hill considers that agriculture, in the most intelligent and comprehensive meaning of the term, is something almost unknown in the United States. The methods by which the yield of the soil could be increased are three, and they are well known though little practiced. First is the rotation of crops, which is so little followed that the majority of our farmers have been raising, year after year, the same crops on the same land, until the soil is all but exhausted. The second method of increasing the yield is the liberal use of fertilizing material, and the third and most interesting of all is better tillage. The present tendency to regard manufacture and trade as the only forms of progressive activity, and the false notion that riches can be built upon these at the sacrifice of the fundamental form of wealth production, must give way to a recognition of the fact, once so well understood, that the soil is the foundation of all wealth and prosperity."

"It is nearly fifty years since the doctrine of natural selection was first published but until very recently no advance had been made over the work of Darwin. Hugo De Vries, the Dutch botanist, has now developed the doctrine that new species find their origin in sports, or 'mutants,' and that evolution, instead of being a gradual development due to the accumulation of minute variations, is rather a series of jumps, or abrupt changes from parent to child. According to this theory of mutation, natural selection still plays a part in determining the fitness of the individual to survive and perpetuate itself, but it does not necessarily imply the destruction of the parent type, as does Darwin's theory of evolution by natural selection."

SEPTEMBER, 1856: "At the meeting of the British Association for the Advancement of Science, held in Cheltenham, Eng., last month, Henry Bessemer, of London, read a paper on a new method of making malleable iron from pig iron, which deserves the attention of our iron manufacturers, as the process is very original, is stated to be perfectly successful, and destined to revolutionize the processes of manufacturing malle-



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able iron and steel. The idea occurred to him that if molten pig iron at a glowing heat were run into a chamber and a blast driven through it, the 5 per cent of carbon in it would unite with the oxygen of the blast, producing intense combustion, because carbon cannot exist at a white heat in contact with oxygen. He then put up a cylindrical vessel three feet in diameter and five feet high, like an ordinary cupola furnace, the interior of which he lined with fire brick. At about two inches from the bottom are inserted five tuyère pipes, having nozzles of fire clay. A blast of air of a pressure of eight pounds to the square inch is let into this cylinder a few minutes before the crude iron is allowed to flow into it from the blast furnace. The molten crude iron is then let in by its tap, and it soon begins to boil and toss about with great violence. Flames and bright sparks then begin to issue from the vessel's top; the oxygen of the air from the blower combines with the carbon in the metal, evolving a most intense heat producing carbonic acid gas, which escapes. By this simple process the heat generated is stated to be so intense that all slag is thrown out in large foaming masses, and all the sulphur is driven off, together with deteriorating earthy bases, so that the metal is completely refined—more pure than any puddled iron. It is also stated that one workman can convert five tons of crude pig into malleable iron in about 30 minutes by this process. Its advantages are painted in such dazzling colors that we are afraid to rely upon them implicitly. If they are such as Mr. Bessemer has described, a new era in the manufacture has dawned upon the world, and malleable iron will soon be reduced to a price but little above common pig."

"Five Englishmen have, according to the London *Times*, recently made the ascent of Mount Arrarat, in Armenia, which tradition points out as the place where Noah's Ark rested after the Flood. It is 17,323 feet above the level of the sea. It is stated that they reached the very summit, which never had been ascended by any person before."

"In all our Atlantic cities and villages where wood and anthracite coal are used for fuel, no smoke fills the atmosphere, and the houses have that clean and fresh appearance which excites the surprise of persons arriving here from England, where bituminous coal is employed for fuel. In various parts of our country, however, bituminous coal is now used for fuel, and it will yet become the great

Lesson from a bee...

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The cell structure of a honeycomb inspired this ingenious klystron grid-making technique. Pioneered and perfected by Varian as a mass production process performed chiefly under microscopes, it consists of forming a bundle of fine copper-plated aluminum wires into a solid, honeycomb-like structure . . . then etching out the aluminum.

The end product is a pure copper grid having extremely low microphonics, high power handling capacity and great rigidity . . . essential requirements for airborne klystrons.

Of all known methods, this has proven the *only* one that assures optimum grid performance and reliability under conditions of extreme shock and vibration. Painstaking techniques like this typify Varian's manufacture of more than 60 different klystrons for every application.

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KLYSTRONS, TRAVELING WAVE TUBES, BACKWARD WAVE OSCILLATORS, LINEAR ACCELERATORS, MICROWAVE SYSTEM COMPONENTS, R. F. SPECTROMETERS, MAGNETS, MAGNETOMETERS, STALOS, POWER AMPLIFIERS, GRAPHIC RECORDERS, RESEARCH AND DEVELOPMENT SERVICES fuel for manufacturing and domestic purposes, owing to the magnitude of our bituminous coal fields, in comparison with which the anthracite beds are mere specks. The reason why wood emits but little smoke is that it contains within itself a great amount of oxygen, to produce perfect combustion.—The reason why anthracite coal emits no smoke is that it contains no hydrogen, as bituminous coal does; it is mostly composed of carbon, which is not volatile, and only becomes so when it unites with its combining proportions of oxygen (C. O^2) in perfect combustion, producing carbonic acid gas. Bituminous coal is a hydro-carbon, that is, it contains hydrogen, a very volatile gas, which at a comparatively moderate heat escapes, and lifts up some of the carbon with it, thus producing carbonic oxyd (smoke). The addition of more oxygen to it at a high heat will produce perfect combustion, prevent smoke and increase the quantity of heat. The prevention of smoke, therefore, not only involves the removal of a disagreeable evil, but the saving of fuel also."

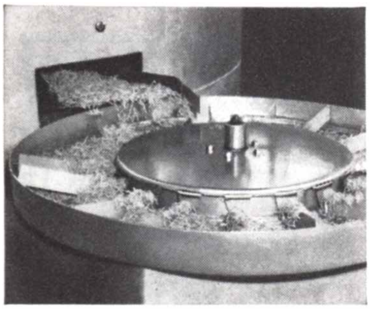
"At one time ozone in the atmosphere was suggested as being the cause of cholera, and lately it has been suggested as the cause of yellow fever. This subject was brought up at the late meeting of the Scientific Association at Albany. An inquiry was made whether ozone had been detected in the atmosphere of Norfolk while the yellow fever prevailed last year, also whether it had been observed in any place during the prevalence of cholera. No proof of its special presence in connection with cholera or yellow fever was presented. No doubt the state of the atmosphere is the cause of many diseases—it becomes poisonous to some constitutions under certain circumstances; but how refined must be the analysis to detect what that poison is in the atmosphere. No chemist has yet been able to detect what is called *malarian poison*."

"The British Scientific Association has for the past fifteen years been instituting inquiries and making experiments, through a committee of its members, with various kinds of seeds of various ages. Their labors tend to show that none of the seeds which were tested, although placed in the most favorable circumstances that could be devised, vegetated after the age of 49 years; and only 20 out of 288 species did so after 20 years, while by far the largest number lost their germinating power in 10 years."

Chinese-food fancier's delight: La Choy chop suey and golden-brown noodles!

Here's where Dowtherm really pays off for La Choy

UNIFORM TEMPERATURE WITH DOW HEATING MEDIUM ENDS DIRECT-FIRE PROBLEMS



Uniformly cooked La Choy noodles coming from the fryer.

La Choy Food Products, Archbold, Ohio, has always thought quality control most important. With their previous direct-fire heating system it was necessary for them to give close inspection to the noodles to maintain their high quality. In keeping with La Choy's policy of quality improvement they installed equipment heated with Dowtherm®.

Now, a gas-fired vaporizer heats the Dowtherm, and the Dowtherm vapors maintain the cooking oil at precisely the right temperature. No pump is required in the condensate return line, since the heating equipment is located above the vaporizer and flow is by gravity.

The uniform temperatures provided by this modern heat-transfer medium assure consistent quality . . . batch after batch after batch. Not one can in a thousand is rejected. And equally important—thanks to Dowtherm—every La Choy noodle reaches customers perfect in color and flavor!

Operating on a closed vapor system, Dowtherm minimizes fire hazards; provides temperatures to 750° F. at pressures below 150 p.s.i. Local overheating is eliminated.

If *your* product requires high process heat, further data on Dowtherm will prove valuable. Perhaps we can arrange for you to inspect in operation a system which employs Dowtherm. Write THE DOW CHEMICAL COMPANY, Midland, Michigan, Dept. DO826A.

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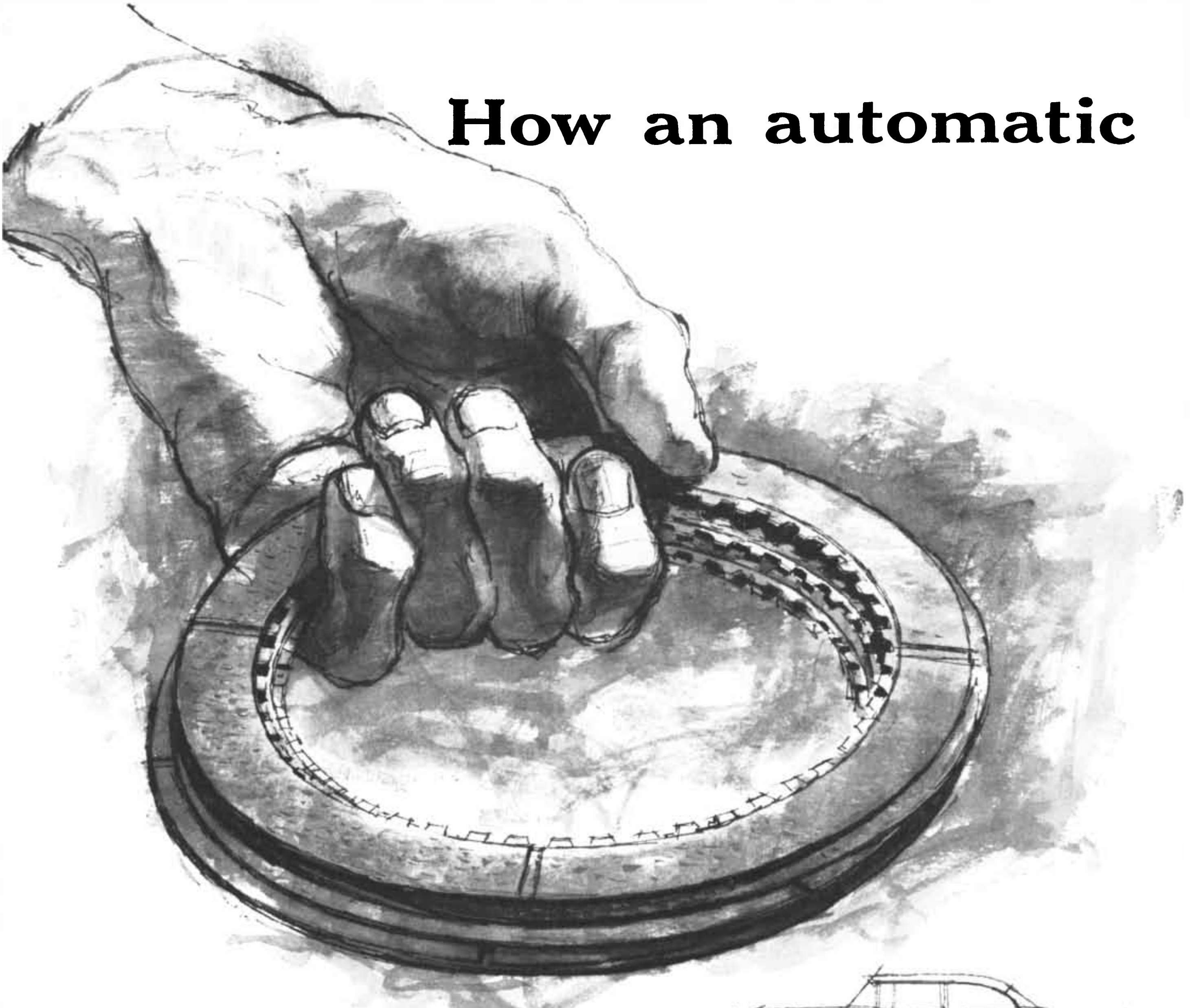
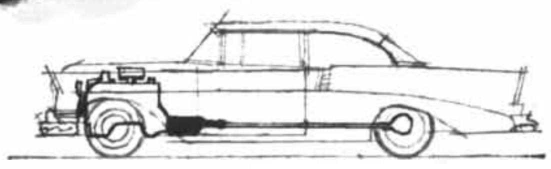
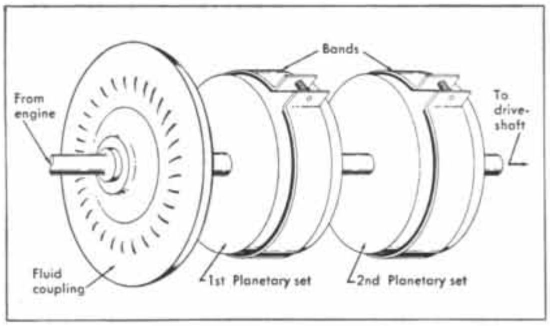
How an automatic

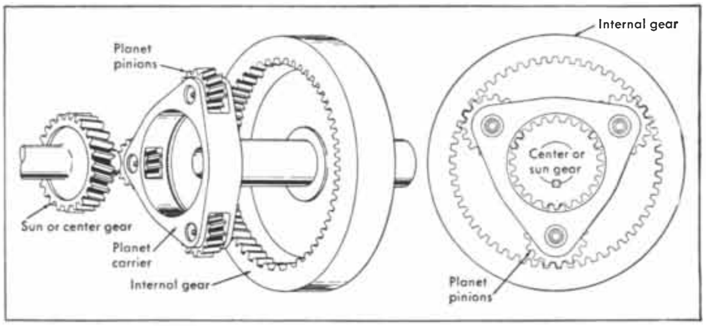


Cork-faced clutch plates like these—as many as thirteen in some automatic transmissions—help "shift gears" in about 70% of the automobiles made today.





This diagram shows the power train (less reverse gear) in a typical automatic transmission. The engine feeds its power through a fluid coupling into two sets of planetary gears. Each set supplies two gear ratios which together provide four different gear combinations.



Each planetary gear set includes a central "sun" gear and a carrier that holds several "planet" gears which mesh with an internally toothed gear. The drive shaft turns the sun gear. A separate driven shaft is fastened to the planet carrier. All gears are controlled by a system of hydraulically operated bands and multiple disc clutches.

THE AUTHORS

HAROLD P. ROBERTSON ("The Universe") is professor of mathematical physics at the California Institute of Technology. He was born in Hoquiam, Wash., and attended the University of Washington. After acquiring his doctorate at Cal Tech in 1925, he studied for three years under a National Research Council fellowship in Göttingen, Munich and Princeton. He was a member of the Princeton University faculty from 1928 to 1947, when he returned to Cal Tech. He first became interested in cosmology while studying in Europe. At that time he found a solution of Einstein's gravitational equation which seemed to explain the recession of nebulae that had been noted by V. M. Slipher of the Lowell Observatory. Investigating this and other applications of relativity theory to astronomy occupied much of his attention for more than a decade. He revised a prerelativistic suggestion of J. H. Poynting: that a particle absorbing and re-emitting radiation from the sun would eventually spiral *into* the sun. Now known as the Poynting-Robertson effect (says Robertson: "*I* didn't name it!"), this idea has proved important to meteor astronomy and cosmogony. The outbreak of World War II brought Robertson back to earth and classical mechanics. He joined a group of theoretical physicists working for the Office of Scientific Research and Development on the effects of bombs and projectiles, a subject now known as "terminal ballistics"—"a name which we invented in 1940 over a few cans of beer." As the U. S. began to take the aerial offensive in 1942, he was assigned to the Eighth Air Force and got into operations research: the quantitative analysis of military operations. After the war he returned to Princeton but was again attracted to Cal Tech by the proximity of Mount Wilson and the new 200-inch telescope being assembled on Palomar Mountain. He had barely settled down to cosmology again when he was called to Washington to direct research for the Weapons Systems Evaluation Group. In 1954 he was appointed to the newly created post of scientific adviser to General Alfred M. Gruenther, the Supreme Allied Commander in Europe. Even during this period he did not completely forsake cosmology: "I prepared on the side longish papers for the A.A.A.S. symposium in Berkeley (Christmas, 1954) and another for the 50-year anniversary of the theory of relativity held at Berne in July, 1955—having in between delivered a paper entitled "The Impact of Science on Military Thought, Organization and Operations" to the NATO Defense College. Now in the summer of 1956, "having spent fully half of the past 16 years on the borderline between science and the military, I am returning to the academic fold, fully resolved to get back into the exciting field whose general development I have attempted to portray in this article."

WILLIAM A. FOWLER ("The Origin of the Elements") is professor of physics at the California Institute of Technology. Before he got his Ph.D. at Cal Tech in 1936, he had been one of the first men to receive a bachelor's degree in engineering physics at Ohio State University. Ever since he came to Cal Tech in 1933, Fowler has been associated with C. C. Lauritsen, first as a student and later as a physicist in the W. K. Kellogg Radiation Laboratory, which Lauritsen directs. "During World War II we worked on rocket ordnance in Kellogg, and one of the faculty members associated with us was the astronomer I. S. Bowen, who directed all photographic measurements in our field-testing program at Goldstone Dry Lake in the Mojave Desert and later at Inyokern. After the war Dr. Bowen became director of the Mount Wilson and Palomar Observatories, and early in 1946 he held a series of informal seminars in his home on nuclear problems in astrophysics and astronomy. Lauritsen and I and our students attended, and as a result of the interest that developed we decided to study experimentally in the laboratory those particular nuclear reactions which were thought to take place in stars. Research along these lines has been a part of our laboratory program since that time. In 1948 Jesse L. Greenstein came to Cal Tech, and his interest in the abundances of the elements in stars has stimulated much of our work. Fred Hoyle and E. E. Salpeter have been frequent visiting lecturers at Cal Tech, and from them we have learned about the basic mechanisms by which nuclear processes supply energy and synthesize elements in stars." Fowler spent the 1954-1955 academic year as a Fulbright lecturer and Guggenheim fellow in the Cavendish Laboratory at the University of Cambridge. While there he collaborated with the husband-and-wife team of G. R. and E. Margaret Burbidge in studying the synthesis of elements in stars. The Burbidges are

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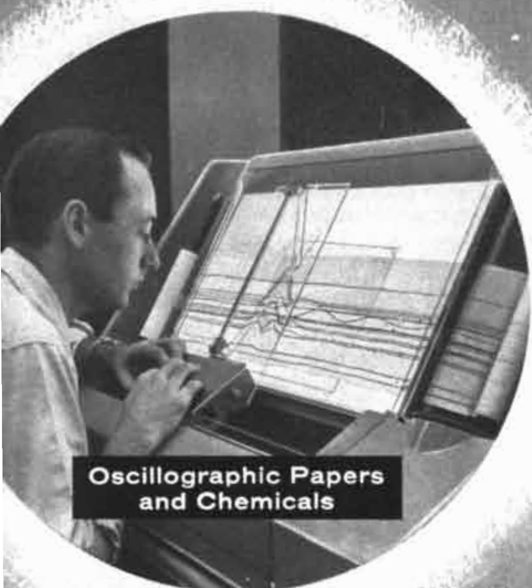

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BETTER THINGS FOR BETTER LIVING . . . *THROUGH CHEMISTRY* now returning the visit and continuing their investigations in Pasadena.

WALTER BAADE ("The Content of Galaxies") is astronomer at the Mount Wilson and Palomar Observatories. He was born in Schroetinghausen, Germany, in 1893 and attended the universities of Münster and Göttingen, receiving his Ph.D. in 1919. For 12 years he was on the staff of the Hamburg Observatory and towards the end of that period was also privatdocent at the University of Hamburg. He came to Mount Wilson in 1931.

JAN H. OORT ("The Evolution of Galaxies") is professor and director of astronomy at the University of Leiden in the Netherlands. He entered the University of Groningen in 1917 to study physics or astronomy, "two subjects by which I had been fascinated during my high-school years. There I soon came under the inspiring teaching of J. C. Kapteyn, who was one of the great pioneers of galactic research. This determined my further scientific life. From the beginning I was particularly attracted by problems of stellar dynamics, both for our own galactic system and for other systems, but always only insofar as the problems were directly connected with observations. This included, of course, the study of the interstellar medium, and now also includes radio astronomy. Besides, I worked on the Crab Nebula and on the origin of comets. I am intensely interested in the unknown that lies before us in radio astronomy. It will certainly teach us a great deal more about the present state of the universe. I am hoping that it may give us some observational insight into the beginning of the universe. We may also hope to begin to understand the origin of the spiral structure of galaxies. But it is so often the unexpected which is the most important." Immediately after he had graduated from Groningen, Oort was for two years a research assistant at the Yale Observatory. Since 1924, except for a three-year interruption during the war, he has been at Leiden. In 1935 he became general secretary of the International Astronomical Union, a post he filled for 13 years. "This means that international cooperation has had my warm interest. At present we are striving with a number of colleagues from France, Sweden, Belgium, Germany and Great Britain to found a Joint European Southern Observatory."

RUDOLPH MINKOWSKI ("Colliding Galaxies") is a member of the staff

FYI

FOR YOUR INFORMATION

Allied Chemical

DIVISIONS: Barrett, General Chemical, Mutual Chemical, National Aniline, Nitrogen, Semet-Solvay, Solvay Process, International

- *urethane foam*
- *missile propellant*
- *"dyestuffs" magazine*

This newsletter is designed to bring you information about unique applications of current chemicals. To offer advance knowledge on a variety of chemical developments. To preview chemicals with as yet undiscovered applications. In short, it's for your information.

* * *

URETHANE FOAM

In the hot, vital journal boxes which protect the axles of railroad trains, waste rags are used as a wick between the oil reservoir and the journal bearing itself. Waste is not the most efficient journal packing—it sometimes snags, and there is no consistency in its packing in the journal box. In the search for new materials, railroads are looking closely at urethane foam. It is very durable, it won't become snarled, and it is an efficient, predictable oil wick.

This is admittedly an unconventional use of urethane foam, but urethane based on isocyanates is an unusually adaptable material, and its service as journal packing merely serves to further demonstrate its mushrooming capabilities.

The properties of urethane are awesomely impressive. By varying the chemical formula, you can produce a foam that is rigid enough to jump on, soft enough to lie on, or flexible enough to stretch 700% of its length. It can be made porous enough to absorb 20 times its weight in liquid, tough enough to withstand pressure of more than 150 pounds per square inch.

Its heat resistance is on the order of 300°F., and urethane foams can actually be sterilized. On the other temperature extreme, it remains flexible all the way down to −30°F. Chemically, it is virtually inert, and is attacked only by strong acid and alkali.

We say these properties are impressive. They bring within definite range such science fiction matter as the 100,000-mile tire, shoe soles and heels that last 10 times longer than usual, paint that resists hobnailed boots, adhesives that will stick almost anything together, warm winter clothing that is light as a feather.

The important thing that you ought to remember about urethane is that it is versatile. Because of its variable pore structure, properties can easily be built into it for special purposes. From a large-cell sponge to a closed-cell foam, rigid or flexible foams, pre-formed foams or foams that are foamed-in-place. Urethane foams can be scrubbed with soap and water or dry cleaned, they can be sewn together or sewn to other materials, they can be painted or silk screened, they can be covered with fabric or left uncovered.

From these properties have come many ideas which have been put into concrete form and which you are already encountering. Crash panels on automobiles, expected to become standard equipment by 1958. Cushioning in furniture, automobile seats, aircraft seats. Carpet underlays. Interlining for coats. Many household items.

In several industries, urethane is being foamed in place. Airplane manufacturers use it to fill cavities in wings, ailerons and rudders, to increase the rigidity of control surfaces. Builders use it as a multi-purpose building material in walls, to insulate and sound-proof at the same time. Builders are also attracted by its resistance to mold, mildew and fire.

The chemistry that makes this possible is not very elaborate. Isocyanates are combined with polyester resins and water. Carbon dioxide is released, causing the chemical mixture to expand like a cake—some 30 to 40 times its original volume. Minor variations in catalysts and dispersing agents make possible the many variations already discussed.

National Aniline does not make urethane foams. We do make NACCONATE* isocyanates, and our Technical Service Department would be happy to advise you how to make and use urethane foams.

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MISSILE PROPELLANT

Recent meetings of the American Rocket Society have demonstrated increasing interest in ethylene oxide (C_2H_4O) as a liquid propellant system for missiles.

Ethylene oxide is a well-known chemical, and many of its properties are favorable for missile propulsion. One of its distinguishing characteristics in the rocket field is that, unlike most liquid systems, it can be used as a monopropellant or a bipropellant. When used as a monopropellant, no delicate mixing system is necessary between fuel and oxidizer, for there is no oxidizer.

A colorless gas, ethylene oxide condenses into a clear, colorless, mobile liquid at 10.7°C. and one atmosphere pressure. Its tendency to polymerize increases rapidly when the temperature goes above 30°C., and it decomposes with explosive violence when the temperature reaches 571°C. It is this powerful force in the reaction chamber which releases the hot gases to drive the rocket. It is an effective force because ethylene oxide's low heat of formation makes it a very high energy compound.

Other attributes of ethylene oxide also qualify it as a suitable missile propellant. Its handling characteristics are well established for safety. Its low freezing point of −111.3°C. prevents it from freezing in storage or in usage. Its moderate vapor pressure permits it to be used in light-walled containers. It is generally non-corrosive, absorbs mechanical shock well, and exhausts nonluminous products.

A key point is the availability of ethylene oxide. It is supplied as a liquid under very moderate pressure, usually 50 psig for storage. More technical data are available upon request.

"DYESTUFFS"

The quarterly house organ published since 1898 by the National Aniline Division of Allied Chemical is one of the oldest magazines of its type in the country.

Color for just about every application you can think of—foods, plastics, paper, leather, textiles—is just one of the topics discussed in issues of "Dyestuffs." Recent issues have also explored such subjects as isocyanates for urethane foam, antioxidents for paint, and chemical intermediates.

We would be happy to send you a copy of the latest issue of "Dyestuffs" or any of the technical data described above. Write INFORMATION SERVICE, ALLIED CHEMICAL, 61 BROADWAY, NEW YORK 6, N. Y.

of the Mount Wilson and Palomar Observatories and a research associate at the California Institute of Technology. He was born in Strasbourg and studied physics at the University of Breslau. After receiving his doctorate, he joined the faculty of the University of Hamburg in 1922. There his scientific interest, always rather close to astronomical problems, moved more and more into astronomy, and he concentrated on investigating the intensities and widths of spectral lines, particularly of the light emitted by nebulae. He went from Germany to Pasadena in 1935. There his work has been devoted mainly to supernovae, planetary nebulae and more recently to radio sources in the sky.

GEORGE GAMOW ("The Evolutionary Universe") has just accepted an appointment as professor of physics at the University of Colorado. Before that he was professor of theoretical physics at the George Washington University. His wide-ranging interests have led him into many fields, some as notably unfamiliar to most physicists as his studies of the transfer of genetic information by nucleic acid. A quixotic streak, which has enlivened his many popular books and articles, sometimes extends to his most serious scientific publications. On one occasion when he and Ralph A. Alpher were preparing a paper, they invited Hans Bethe of Cornell University to collaborate with them. The paper, which happened to concern the beginning of the universe, was therefore most appropriately authored by Alpher, Bethe and Gamow. He was born in Odessa and educated at the University of Leningrad. Before settling in the U. S. in 1934, he taught and did research at the universities of Göttingen, Copenhagen and Cambridge. He has worked in many fields: biology at the molecular level, the theory of radioactivity, the structure of the atomic nucleus, thermonuclear reactions in stars, the origin of the chemical elements and, of course, the evolution of the universe.

FRED HOYLE ("The Steady-State Universe") is lecturer in mathematics at St. John's College, University of Cambridge. He was born in Yorkshire in 1914; by the time he was six, he had taught himself the multiplication tables up to 12 times 12. Not all of his early experience with mathematics was so prodigious. One of his first teachers slapped him for miscounting the number of petals on a flower; his sense of justice was so outraged that he refused to return to the school. When he was 13

UNIBESTOS

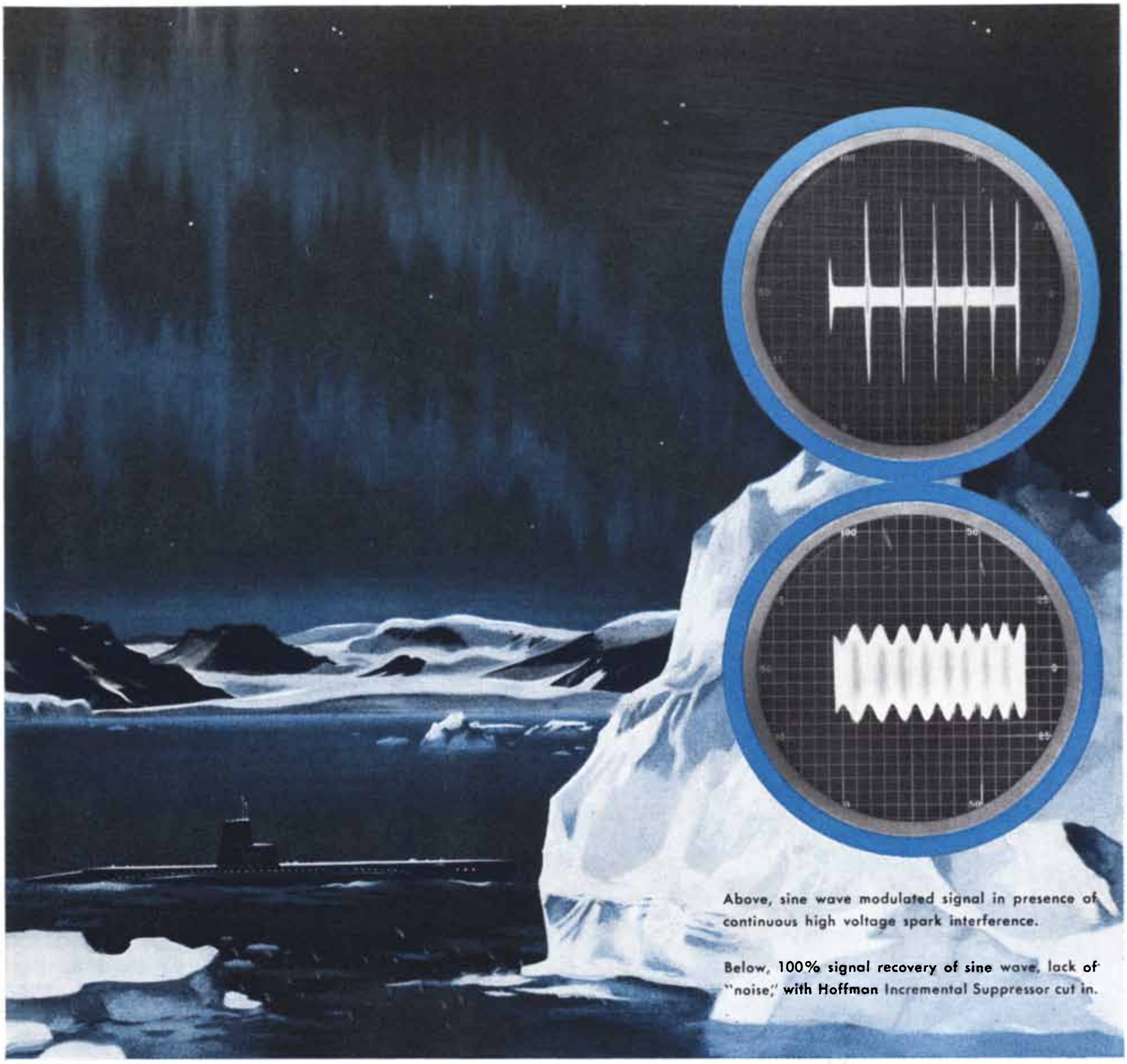
his parents bought him a three-inch telescope and allowed him to sit up all night with it. In 1939 he won a prize fellowship at St. John's. The next year he joined an Admiralty research group, but continued to devote much of his spare time to astronomy. After the war he returned to Cambridge.

ALLAN R. SANDAGE ("The Red-Shift") is assistant astronomer at the Mount Wilson and Palomar Observatories. He attended Miami University in Ohio, transferred "by the grace of Uncle Sam" to the Navy in 1945 and completed his undergraduate work at the University of Illinois in 1948. He acquired his doctorate in astronomy at the California Institute of Technology in 1953, having meanwhile joined the staff of Mount Wilson and Palomar. Few astronomers have set out on their professional careers so early in life. "As I recall, it was *Buck Rogers in the 25th Century* that steered me into astronomy at the unknowing age of 10. This unfortunate interest (from our neighbors' point of view) took the form of dragging a telescope, tables and other observing paraphernalia into our back yard at three in the morning to look at meteor showers and the like. For some reason the neighbors failed to understand the importance of such operations, and I failed to understand their need for sleep. Today, 20 years later, I sit sleepily at work on Palomar Mountain and wonder how young boys of 10 can take sleep so casually. From two to four A.M. *all* professional astronomers are sleepy. If questioned in this interval, most of them would express serious doubt as to whether astronomy was worth it all. (The doubts always disappear in the morning.) From 1951 to 1953 I was an assistant to the late Edwin P. Hubble. His principal interest was observational cosmology, and a bit of his enthusiasm rubbed off on all who knew him. The associations with Hubble, Milton L. Humason and Walter Baade have been the high points in my scientific career. At present my chief interest is in a slightly different field: that of the observational approach to stellar evolution. This is not so far afield from cosmology as might be supposed, since each discipline is an attempt to rewrite parts of the first book of Genesis. My principal outside activities are long back-pack trips in the California Sierra, fishing in both fresh water and surf, and a recently developed passion for horseback riding."

JERZY NEYMAN and ELIZABETH L. SCOTT ("The Distribution of Galax-

ies") are members of the Statistical Laboratory at the University of California. Neyman is professor and director of the laboratory; Miss Scott is assistant professor. Neyman was born in Bendery, Rumania; he was trained in mathematics and statistics at the universities of Kharkov, Warsaw, London and Paris. He came to the University of California in 1938, a year before Miss Scott, a native of Oklahoma, got her bachelor's degree there. How do statisticians get immersed in astronomy? Neyman explains: "For me personally cosmological problems are a relatively novel field. Up to 1950 I certainly did not think about them at all. By then C. D. Shane of the Lick Observatory had already completed a substantial amount of his survey of the sky and was struck by certain regularities in the general chaos of the distribution of images of galaxies on his plates. He paid us frequent visits in the Statistical Laboratory and discussed with us a number of problems in which he appeared to be intensely interested. Some of these problems were familiar to Miss Scott because she was originally an astronomer. Shane's enthusiasm was pretty soon matched by that of Miss Scott and, in due course, I also became fascinated. Particularly, I was attracted by a seeming simplicity of the chance mechanisms of the distribution of galaxies in space, combined with considerable mathematical difficulties involved in the actual development of a theory of distribution. Thus far there is no reasonably precise theory (and here I mean a mathematical theory) of the distribution of light-absorbing clouds in our own galaxy that could be incorporated into the general theory of the clustering of galactic images on photographic plates."

MARTIN RYLE ("Radio Galaxies") is a research fellow of Trinity College in the University of Cambridge. After graduating from the University of Oxford on the eve of World War II, he plunged into radar research and development for the Royal Air Force. In 1945 he received an appointment to the Cavendish Laboratory at Cambridge and there, with D. D. Vonberg, initiated radio observations of the sun. "You will see that I came to radio astronomy from a training in physics, via a period of intensive work in radio and radar engineering. Part of the latter was concerned with problems of aerial design, which experience has of course stood me in good stead in radio-telescope design. Although my direct approach has been by way of radio engineering, astronomy



HOW TO GIVE NOISE THE SILENT TREATMENT

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was an early interest." Since 1952 Ryle has been a fellow of the Royal Society.

HERBERT DINGLE ("Cosmology and Science") is professor of the history and philosophy of science at University College, London. He was born in 1890 and completed his education at the Imperial College of Science and Technology. "I began my scientific career under the late Professor A. Fowler at a time when his spectroscopic work was essential to the progress of the new Bohr theory of the atom. I was thus admitted to the actual scene of development of the quantum theory. At about the same time Einstein's general relativity theory came to the fore through the 1918 eclipse, and I had the privilege of working with A. N. Whitehead, who read the manuscript of my first book on the subject; and being in close touch with A. S. Eddington at the Royal Astronomical Society, so that I was at close quarters with two different and important views of the philosophical aspects of the theory. Add to this a natural taste for the broader aspects of scientific philosophy, and my type of career is pretty well determined." Aside from his notable contributions as an interpreter of modern physics, Dingle has been a leading figure in British astronomy. From 1951 to 1953 he was president of the Royal Astronomical Society.

E. U. CONDON, who in this issue reviews the collected proceedings of the atoms-for-peace conference held last summer in Geneva, was born in Alamogordo, N. M., near the site of the first nuclear explosion. He attended the University of California, getting his doctorate in physics in 1926. After two years of further study in Germany, he joined the Princeton University faculty in 1928, moved to the University of Minnesota for one year and then returned to Princeton. In 1937 he became associate director of the Westinghouse Research Laboratories. For six years, beginning in 1945, he was director of the National Bureau of Standards and left to head research and development for the Corning Glass Works. Condon has recently become head of the physics department at Washington University in St. Louis, and is spending this summer as visiting professor at the University of Wisconsin. For many years he has ranked among the leading theoretical physicists, particularly in the fields of quantum mechanics, nuclear reactions and the spectra of atoms and molecules. He has been president of the American Association for the Advancement of Science and of the American Physical Society.

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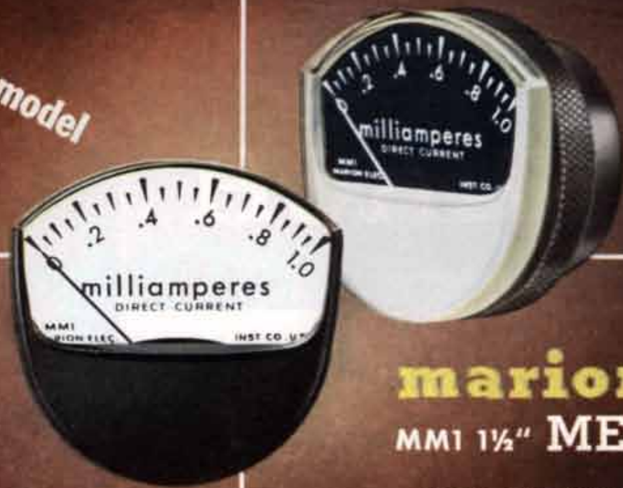

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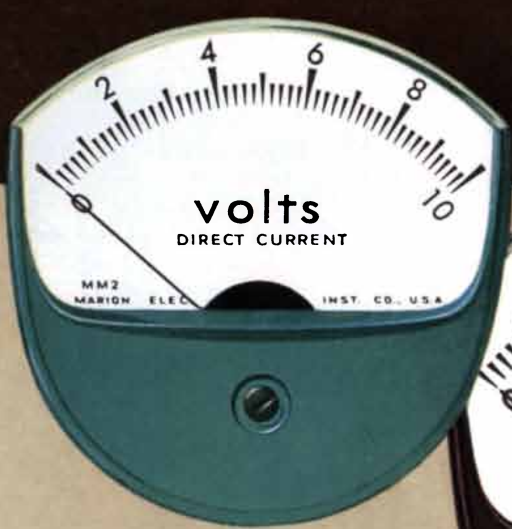

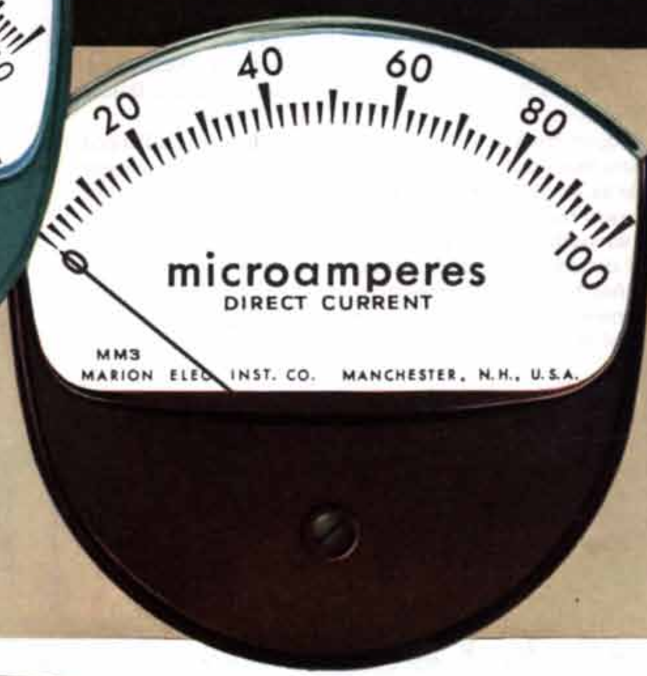

Medalists shown actual size

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RESEARCH

—and the world's deepest oil well

Drill pipe developed by J&L technology battles with forces four miles underground

On November 9 last year, in Plaquemines Parish, 35 miles southeast of New Orleans, a string of drill pipe pushed downward through the earth's crust to a depth of 21,483 feet to become the world's deepest oil well.

Drilling continued to a depth of 22,570 feet, exceeding the previous depth record by 1,088 feet.

J&L drill pipe was used exclusively in the drilling from the surface to the bottom of the hole. Hundreds of tons of J&L Casing and Tubing also were used in the well.

At the record depth, pressures were encountered to which drill pipe never before had been subjected. The steel pipe also had to battle high temperatures, corrosion and abrasion during the drilling. The pipe won the battle, without a single failure—where a failure could cost thousands of dollars.

The story begins back in 1919 when J&L metallurgists challenged the assumption that steel with manganese content over one percent was so brittle as to be commercially useless. They found that steel in the manganese range of one to three percent not only was ductile and high in strength, but displayed good resistance to shock. In a succession of developments, J&L technologists further improved its properties. After hundreds of laboratory and field tests on as many as fifty experimental steels, they finally produced steel with the right combination of properties for high-efficiency performance in deep well drilling.

Nor does the story end here. As wells reach down to even greater depths, J&L continues with developments of new grades of steel and better processing methods to meet the needs for stronger and tougher pipe. New steels with strengths 50 percent greater than those used in the record well already have been developed to meet the demands of the nation's petroleum industry in its never-ending search for oil.

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Richardson & Bass Drilling Rig No. 25. Rig and boilers are mounted on two barges sunk to the bottom of the marsh to provide a firm foundation.

Assembly-line adhesive bonds honeycomb to almost any skin

Fabricators are now able to make honeycomb panels with remarkable speed and economy out of practically anything. Such materials as plastic laminate, plywood, hardboard, aluminum, and stainless steel can be bonded to honeycomb in minutes—ready for drilling or any other necessary fabrication.

This amazing speed and versatility in panel construction stem from the assembly-line adhesives developed by the Armstrong Cork Company.

These adhesives are sprayed automatically on the honeycomb core and the skin material. Then, after both surfaces are dried in an infrared oven, they are joined face to face. One quick trip through the pressure rolls produces an instantaneous, permanent bond. There's no clamping or overnight curing . . . no need for jigs or presses. The panel is ready for anything from a table top to a curtain wall, depending on the skin you're using.

No matter what material you wish to bond to honeycomb, you'll probably find an Armstrong adhesive to do the job. For full information, write for your free copy of our 36-page manual on adhesives, coatings, and sealers. Armstrong Cork Company, Industrial Division, 8009 Inland Road, Lancaster, Pennsylvania. In Canada, write to 6911 Decarie Boulevard, Montreal.

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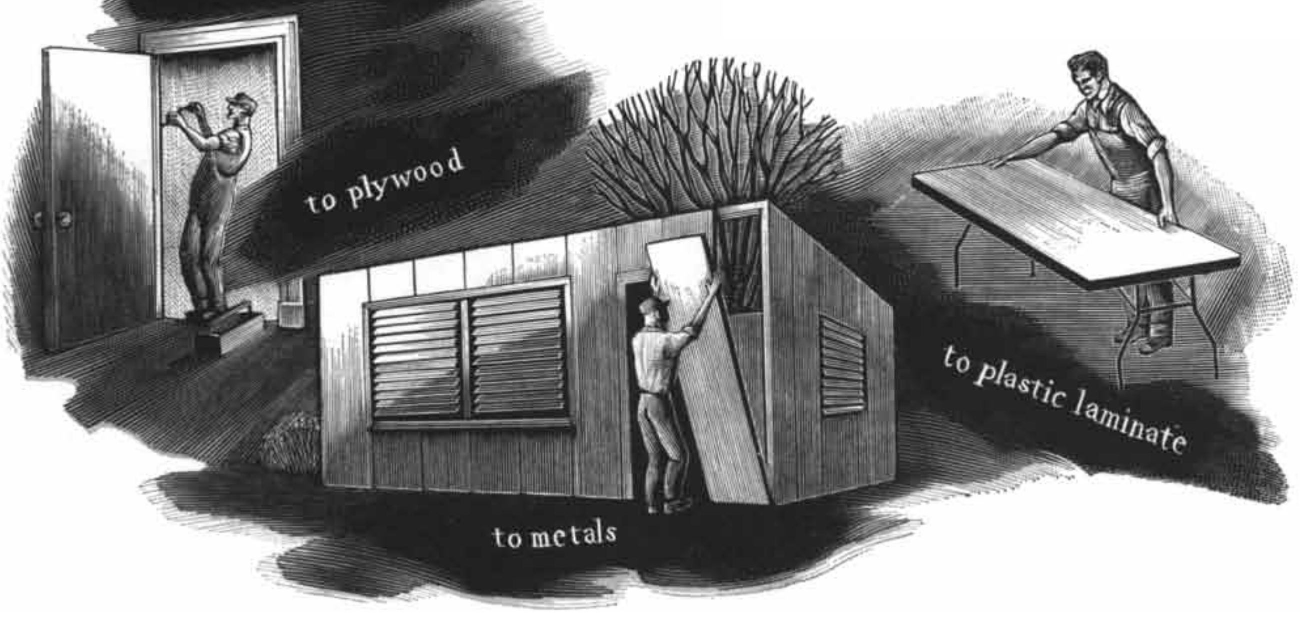


THE 200-INCH HALE TELESCOPE can be seen beneath its silvery dome in this photograph made on Palomar Mountain. Most of the astronomical photographs reproduced in this issue, and some observations critical for cosmology, were made with this instrument.

Established 1845 SCIENTIFIC AMERICAN September, 1956 Volume 195 Number 3

THE UNIVERSE

Presenting an issue about astronomy as it is related to cosmology: the study of the large-scale features of the cosmos. The following introduction traces the historic development of cosmological ideas

by Harold P. Robertson

Looking out on the night sky we are deeply impressed, as the billions of human inhabitants of this planet have been before us, by the majestic procession that wheels unceasingly by. Even early man saw, and speculated about, both the regularity and the irregularities of this nightly scene: the myriad stars rolling steadily across the heavens, the slight changes in the vista from one night to the next, the moon slowly wending her way backward through the star-studded firmament, the planets ("wanderers") roaming erratically through the field, the occasional fall of a "shooting star" and, less frequently, the eerie sweep of a comet.

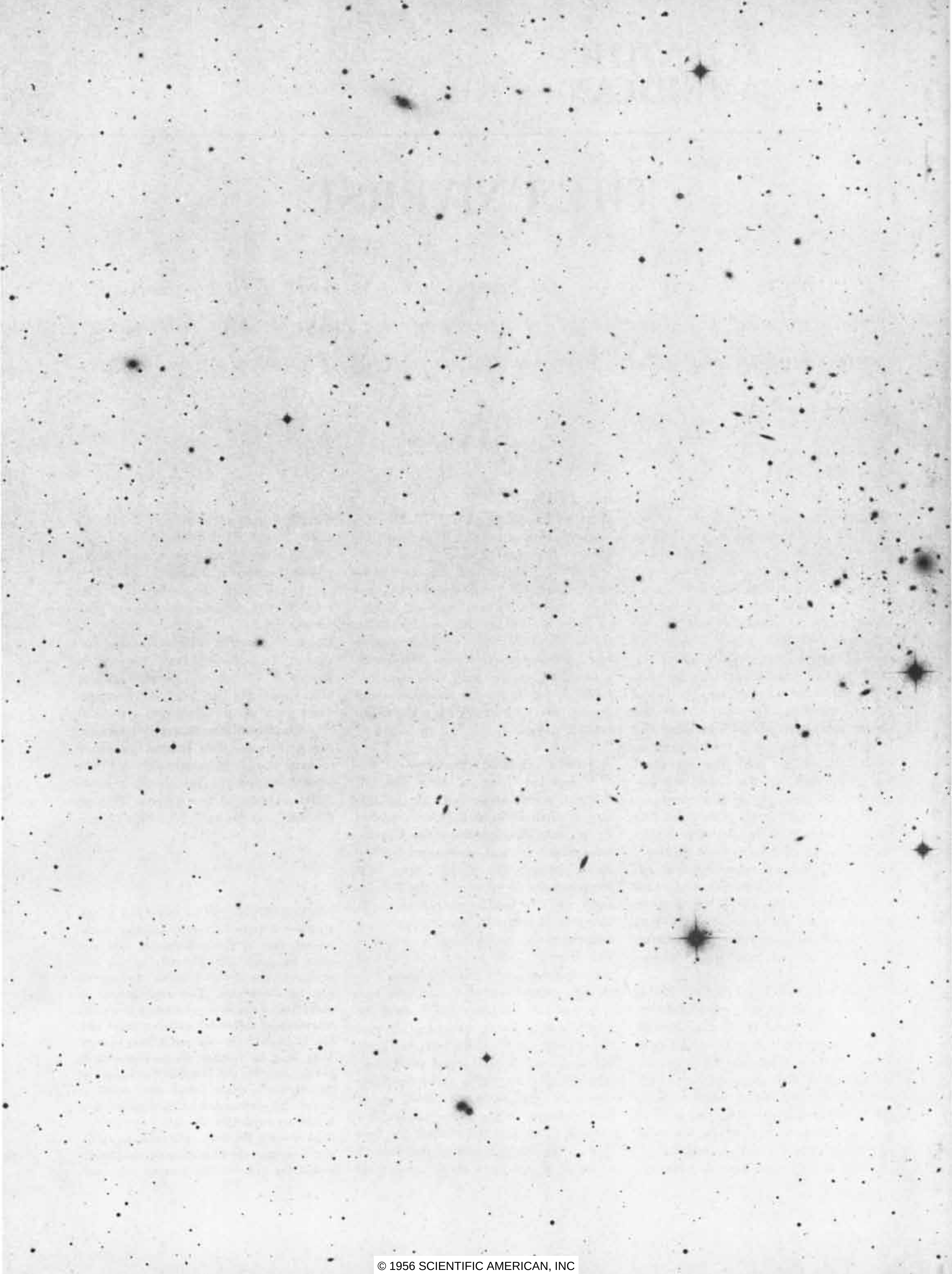
Quite naturally early man tended to think of himself as the center of it all—the hub about which this great spectacle turned. He ordered these celestial appearances, like the immediate physical surroundings with which he had to grapple, into a self-centered world—and sat serenely in the middle, the favored onlooker if not the master of all he surveyed.

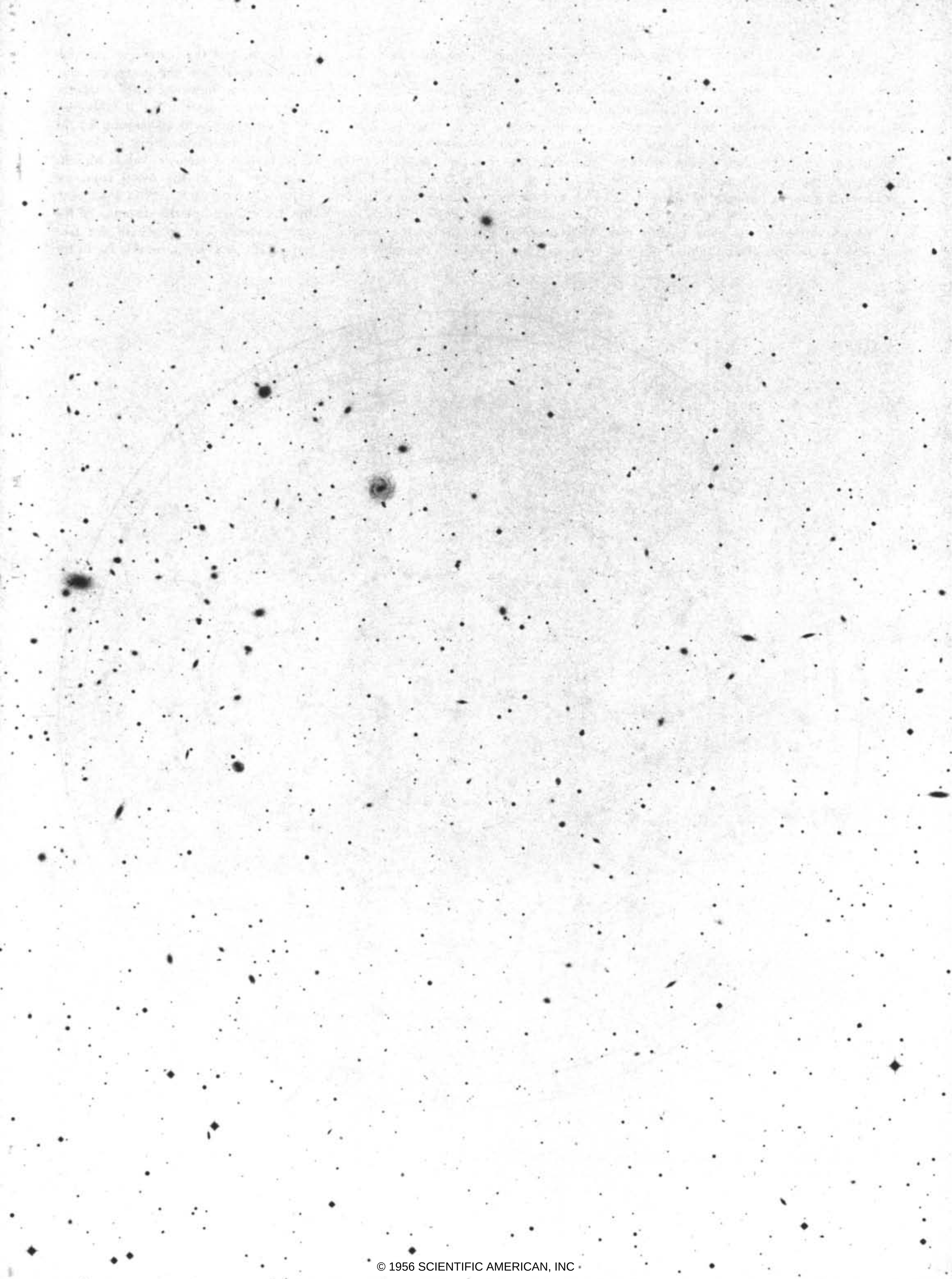
What happened to jut man out of this complacent rut? By what turn of the intellect did he come to relegate himself to his present position as the denizen of a middle-of-the-road satellite of an undistinguished star in a galaxy which itself is but an ordinary member of an uncountable universe of galaxies? How did this cosmic view develop, and what sort of universe do we see today?

These are the questions that the authors of the articles in this issue of Scientific American seek to answer, insofar as the present state of knowledge will allow. They tell of the current investigations, both observational and theoretical, into the make-up and history of galaxies and the age and extent of the visible universe as a whole. In this introductory account I shall sketch with a broad brush the path that man has taken in exploring his relation to the cosmos, dwelling briefly upon the major turning points.

Modern scientific cosmology is descended from a long line of thought which arose early in the history of civilization in Babylonia and in Egypt, was developed by the Greeks, was preserved and elaborated by the Arabs through the Middle Ages, was reconstructed by scholars of the Renaissance and was thus handed down to the men who transformed it and thereby inaugurated the present age of science. The scheme built by the Greeks and their followers was founded upon (1) an urge to understand the celestial system, and (2) a willingness to settle for a purely descriptive account of its motions. Their model of the universe grew out of Aristotelian physical principles: namely, that the earth and everything else under the moon was made up of four elements—earth, water, air and fire—which tended to move along the vertical to regain their natural positions in a series of spherical shells concentric with the earth, while the celestial bodies were formed of the quintessential ether, and in keeping with their unchanging perfection must maintain their position above the earth. The celestial bodies were thereby restricted to motion in concentric orbits and must be firmly attached to tangible spheres, because according to Aristotle a body can remain in motion only when in physical contact with something that causes it to move. Thus grew up the elaborate system of homocentric spheres carrying the moon, sun, planets and stars. Behind the sphere of fixed stars was presumably a Prime Mover, responsible for all the complicated motions of the spheres. Beyond the stars was the void: the finite, spheri-

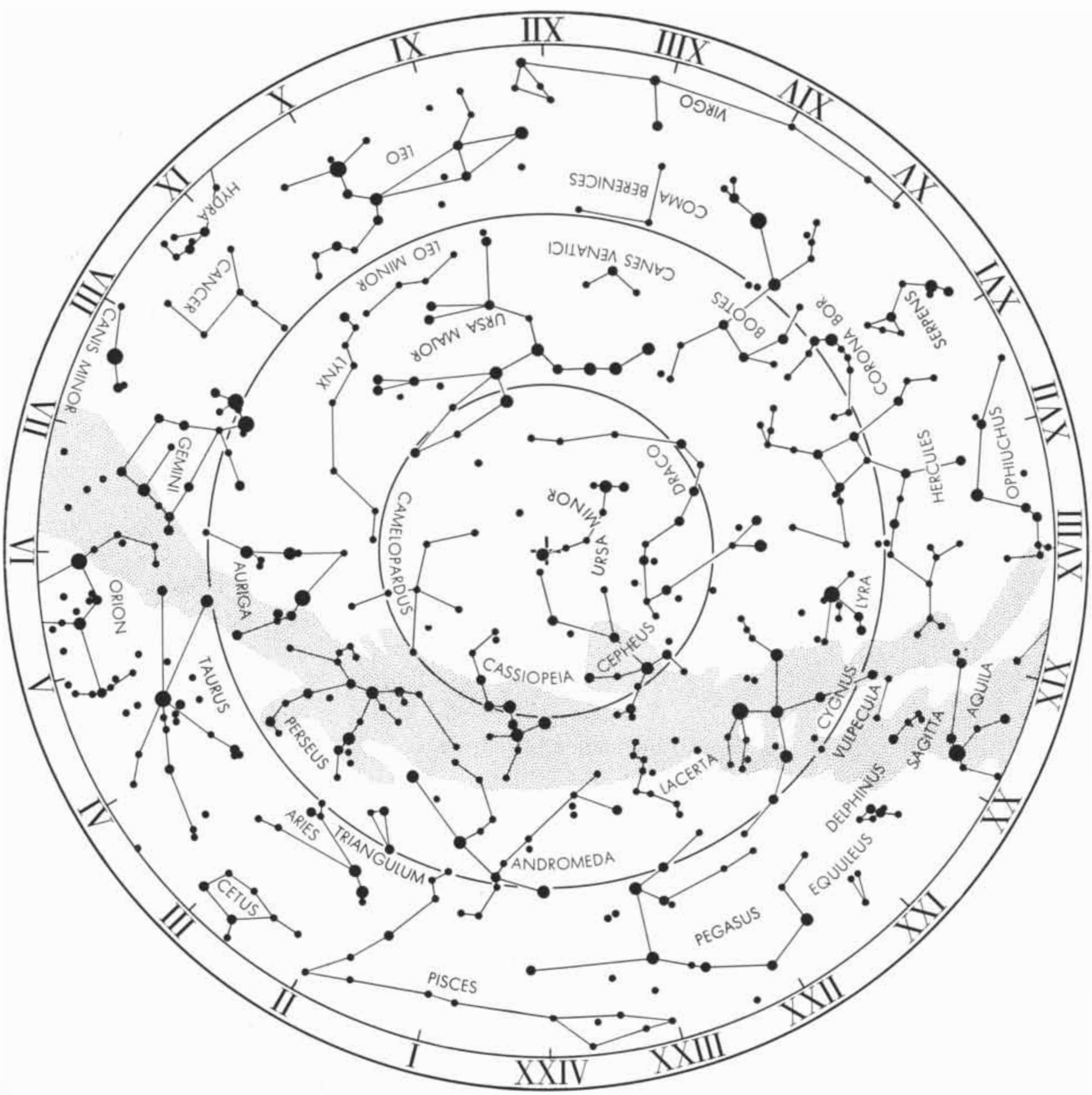
ON THE NEXT TWO PAGES is a photograph of a huge cluster of galaxies in the constellation of Coma Berenices (*see star chart on page 76*). The photograph was made with the 48-inch Schmidt telescope on Palomar Mountain. The reproduction is made from a negative print which increases contrast and makes faint objects more visible. The galaxies are the small fuzzy objects. They may be further distinguished from nearby stars by the fact that the images of the stars are either small and round or larger and surrounded by four spikes. The spikes are caused by the diffraction of starlight around the four structural members which support the photographic plateholder within the tube of the Schmidt telescope.





cal universe was surrounded by nothing, not even space.

Ingenious as this system was, it was simply not capable of accounting for some of the motions and other phenomena actually observed. To "save the phenomena" the later Greeks fell back upon a purely mathematical representation of motions intended to account for observed irregularities. Its most characteristic device was to allow each of the seven wanderers (including the sun and moon) to move uniformly in a circle (the epicycle) whose center itself moved uniformly on another circle (the deferent) about the earth. Since the whole purpose of the exercise was to account for the motions as viewed from the earth, this was quite naturally taken as at rest, and the firmament of stars allowed to rotate daily about it. In the form elaborated by Ptolemy in the second century, this geometrical scheme was capable of giving a tolerably accurate account of the naked-eye observations amassed over the preceding centuries. It was, however, truly a scheme rather than a system, for it embodied no physical principle accounting for the relations between the orbits of the various bodies. Ptolemy's value for the mean distance of the moon from the earth was accurate to within 2 per cent, but his estimate of the distance of the sun was only a twentieth of the true value. The root of the trouble lay in the

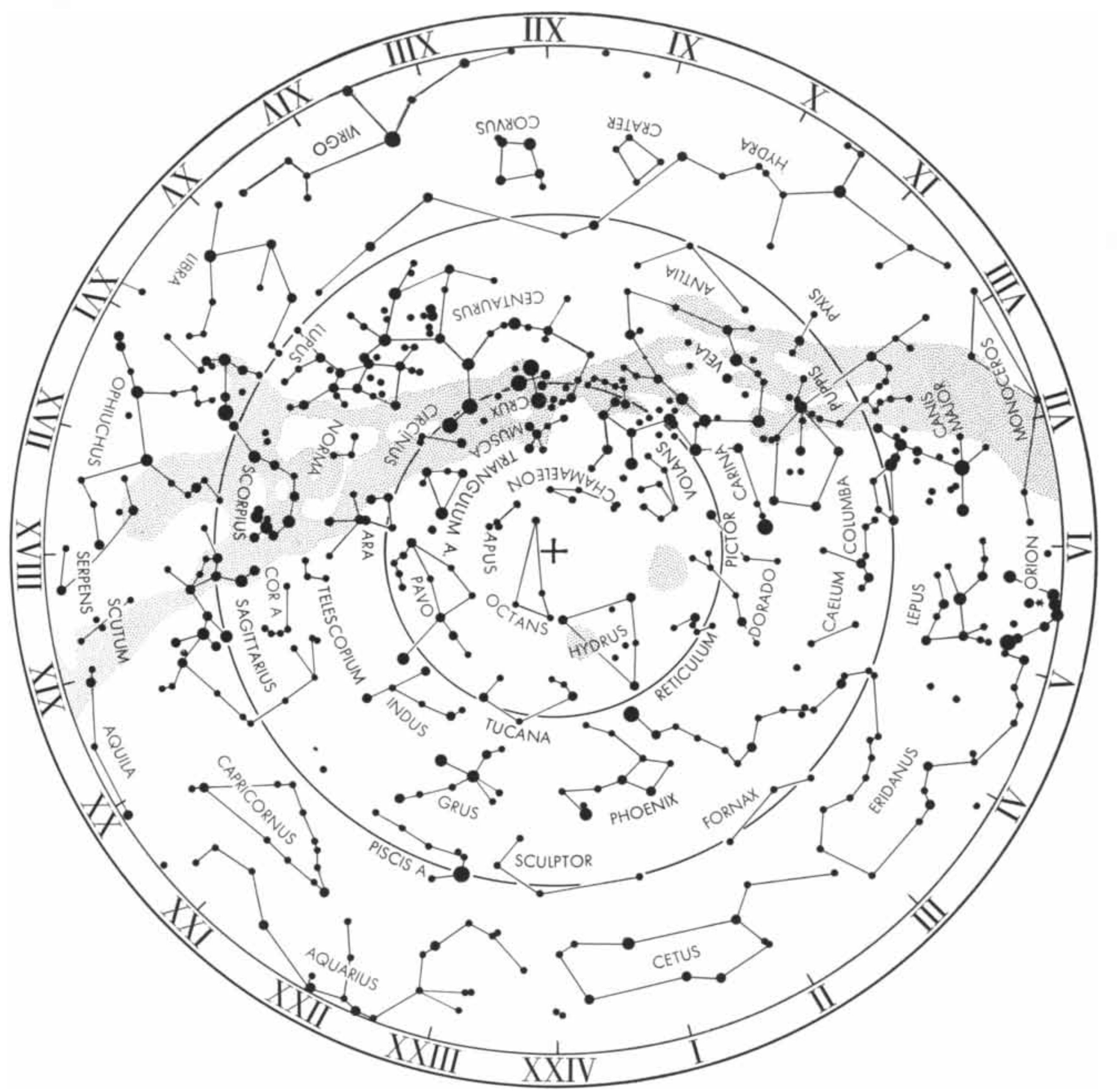


STAR CHARTS display the constellations as a guide to the location of astronomical objects which are reproduced elsewhere in this issue. The chart of all the constellations visible from the Northern Hemisphere is shown at the left. The earth's North Pole points to the Pole Star in the center. The chart of the constellations that are visible from the Southern Hemisphere is on

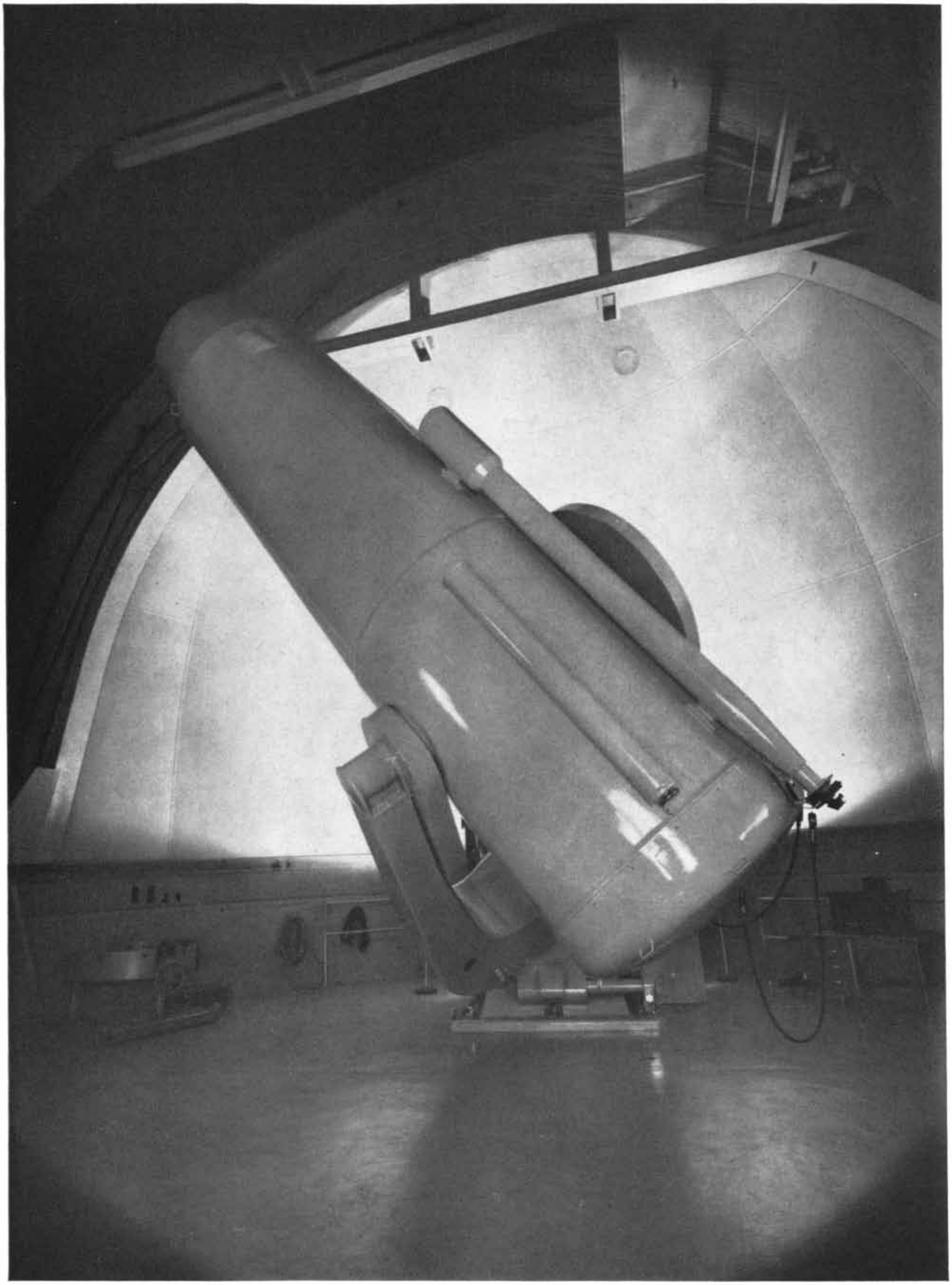
fact that Greek physics was woefully inadequate to the tasks put upon it.

The extrication of cosmology from this welter of philosophy and astronomy began when Nicolaus Copernicus early in the 16th century transferred the central reference point from the earth to the sun. Copernicus retained the epicyclic motions to save the phenomena, but by allowing the earth to rotate he stopped the dizzy motion of the stars, and by allowing the earth to revolve about the sun he did away with the complications Ptolemy had had to introduce in the planetary motions to offset the assumed motion of the sun around the earth. The sphere of the fixed stars was now at rest, and taken large enough so that the earth's pilgrimage about the sun would result in no noticeable displacement of the stars in the sky from opposite points in its orbit. (It was not until the 19th century that meticulous measurements made it possible to observe such parallactic displacements for nearby stars.)

Toward the end of the 16th century Thomas Digges, the first to present the essentials of Copernicus' *De revolutionibus orbium coelestium* in English, introduced a change in the Copernican scheme which at first sight seemed so slight that even Digges failed to appreciate its basic significance. In his *Perfit Description of the Coelestiall Orbes*, Digges replaced the sphere of fixed stars with an infinity of stars extending uni-



the right. Between the center and the edge of each chart are two large concentric circles; these mark 30 degrees of declination, or latitude, on the celestial sphere. The Roman numerals indicate the right ascension, or longitude on the sphere. The stippled band is the Milky Way. The two small stippled areas near the center of the Southern Hemisphere chart are the Clouds of Magellan.



THE 48-INCH SCHMIDT complements the 200-inch telescope. Although it does not penetrate so deeply into space, its field of view is much larger. A photograph made with it covers 44 square degrees; a 200-inch photograph, about a 20th of a square degree.

formly throughout an infinite universe. This change made inevitable the eventual dethronement of the sun, which, in Digges's own words, "like a king in the middest of al raigneth and geeveth lawes of motion to ye rest." But the time was not yet ripe for such a reorientation: its full fruition would require the inventive genius and skill of the great observers from Galileo Galilei to George Ellery Hale, and the unifying genius and thought of the host of theorists from Isaac Newton to Albert Einstein.

Three of the elements needed for the breakthrough to the Newtonian conception of the world were furnished around the turn of the 17th century by Galileo and by Johannes Kepler. Galileo's service was twofold, both in the observational domain and in furthering the breach with the impotent Aristotelian dynamics by recognizing clearly that only change of motion—and not motion itself—was impelled by the force applied. His development of the telescope into a practical instrument enabled him, by discovering the satellites of Jupiter, to strip the earth forever of its claim to being the only center of rotation in the universe. At the same time he resolved portions of the Milky Way into great collections of stars, paving the way for the dethronement of the sun from the central position assigned it by Copernicus. Curiously enough Galileo held to the doomed epicycles. It was Kepler who, in order to save the phenomena as observed by Tycho Brahe, the last great naked-eye astronomer, threw off at last the restricting dogma of uniform motion in circles. His three laws describing the motions of the planets, traveling in elliptical orbits, supplied the cornerstone for a rational structure of the solar system, though Kepler himself failed in his lifelong attempt to put the pieces together.

What was needed was a unifying principle to bring order into the disjointed parts, to tie them together into a physical model which would satisfy the philosophers in their quest for truth and the astronomers in their requirement of accuracy. This Newton supplied in his theory of universal gravitation. He subjected not only the solar system but also the ethereal stars to one reign of law. Gravitation was the force that held objects on the earth, that bound the moon to it, that steered the planets in their elliptical orbits about the sun and adjusted their periodic times in accordance with their distances from it. For the first time it was possible to measure accurately the dimensions of the solar system. Along with his gift of gravitation, Newton invented the tools required for the construction of a universal system by completing the science of dynamics and perfecting the infinitesimal calculus.

The first crude steps could now be taken toward a cosmology describing the world at large, and toward a cosmogony accounting for the evolution of its parts. Newton himself speculated that "if the matter were evenly distributed throughout an infinite space . . . some of it would convene into one mass and some into another, so as to make an infinite number of great masses, scattered great distances from one another throughout all that infinite space. And thus might the sun and fixed stars be formed. . . ." This bold leap into the distant reaches of time and space blazed a path for Immanuel Kant, Pierre Simon de Laplace and other cosmogonists to follow. But the vastness and complexity of the system that would have to be explained was not yet even suspected: there was still little idea of the organization of stars in loose associations and tight clusters or of the various types of nebulae, to say nothing of the clustering of tens of thousands of these island universes into supersystems so vast that it takes light tens of millions of years to traverse them.

By the first quarter of the present century the ever-quickening accumulation of research had set the stage for spectacular developments. The telescope, increasing in power from the early reflectors of Sir William Herschel and of the Earl of Rosse to the great instruments of America, had shown the Milky Way system to be a lens-shaped collection of some 100 billion stars, with the sun out toward the rim. The spectroscope, analyzing the light of the stars, had identified family traits among them. Studies of their color shifts, assumed to be a Doppler effect, had told something of the stars' motions away from us. The distances of stars had been measured by the methods of parallactic displacement and comparison of apparent brightness. Henrietta Leavitt at the Harvard College Observatory and Harlow Shapley at Mount Wilson had discovered that the pulsating stars called Cepheid variables provided a scale for measuring distances in our own galaxy, the Milky Way, and for estimating the distances of other galaxies in which these variables could be resolved. With this new tool it was found that the sun's distance from the center of our galaxy was some 26,000 light-years—a far cry indeed from the little world of Johannes Kepler, which light could have traversed in less than one tenth of a year! And the galaxy was found to be spinning about that distant center at a rate which would swing the sun around it in 200 million years.

The galaxy itself had been measured, and many of the objects seen in the heavens had been identified as members of it. But what of the multitude of nebulae, now numbering thousands, that could not be placed in our system? Immanuel Kant had in 1755 put forward the notion that such nebulae were themselves distant island universes—peers in every way of our own galaxy. The proof had to await the development of methods of measuring the titanic distances involved. The break came in 1917, when G. W. Ritchey at Mount Wilson identified a nova in the Great Spiral Nebula in Andromeda [*see page 92*]. By 1924 Cepheid variable stars had been found in this and other nearby nebulae, and on the heels of this came the development of other brightness criteria of distance—supergiant stars, supernovae, nebulae themselves and finally even the brightest nebulae in clusters. This break initiated the modern era in cosmology.

One of the first tasks was to identify the galaxies by type. Edwin P. Hubble at Mount Wilson established a system which starts with elliptical nebulae, of increasing degrees of flatness, and branches off into normal spirals on the one hand and barred spirals on the other, with a sprinkling of irregular nebulae falling outside the sequence. The question immediately arose: Where does our own galaxy fit into the scheme? The unevenness of its texture, its great star clouds and murky patches, indicate that it does not belong in the class of elliptical nebulae, which are almost structureless. On the other hand, its rotation and rudimentary symmetry suggest that our galaxy is not to be classed with the irregular nebulae, such as our closest companions, the Clouds of Magellan [*see page 100*]. Hubble tentatively placed the Milky Way well toward the end of the branch of normal spirals, a counterpart of the very open spiral in Triangulum [*see page 103*]. It is indeed easy to imagine that an observer looking out at that galaxy from a point near its rim would see a ragged veil of stars very like our own Milky Way; its nucleus would be obscured, like ours, by dark clouds of dust, and the structure of its arms would be unclear, again like ours, because the observer would be looking at them along the plane in which they lie.

But science will not rest with satisfying the imagination; the imagined picture is a challenge driving the astronomer on to find means of mapping the elusive nucleus and the spiral arms, if such there be. And such means are being found, making the problems of galactic structure one of the most active and exciting in the whole cosmological field. Closer study of the spiral in Andromeda has brought out certain characteristics of spirals—red giant stars and cluster-type variables in the nucleus, blue supergiants surrounded by hydrogen gas in the arms. These features serve as clues for exploring our own galaxy. A marvelous new tool, radio astronomy, has enabled us to detect hydrogen gas lining its spiral arms, and to hear significant radio "noises" from its central regions. The evidence indicates more and more that we are residents in a normal spiral galaxy, very similar in size, structure and composition to the Andromeda Nebula.

Having found a way to identify and classify galaxies, the next task was to map their distribution. Surveys showed that nebulae tend to cluster in groups, containing up to a thousand or more. The exploration has in fact suggested to some that our own galaxy may be an outrider in a supergalaxy, just as the sun was earlier found to be an outrider of the galaxy.

Are the clusters themselves distributed irregularly or are they scattered at random more or less uniformly through space? The evidence is conflicting, but inspection of selected regions indicates that by and large the fainter—and therefore presumably more distant—nebulae are indeed fairly uniformly distributed, aside from their apparent tendency to cluster. Here again is a field of research which is being explored vigorously, both from observational and theoretical points of view.

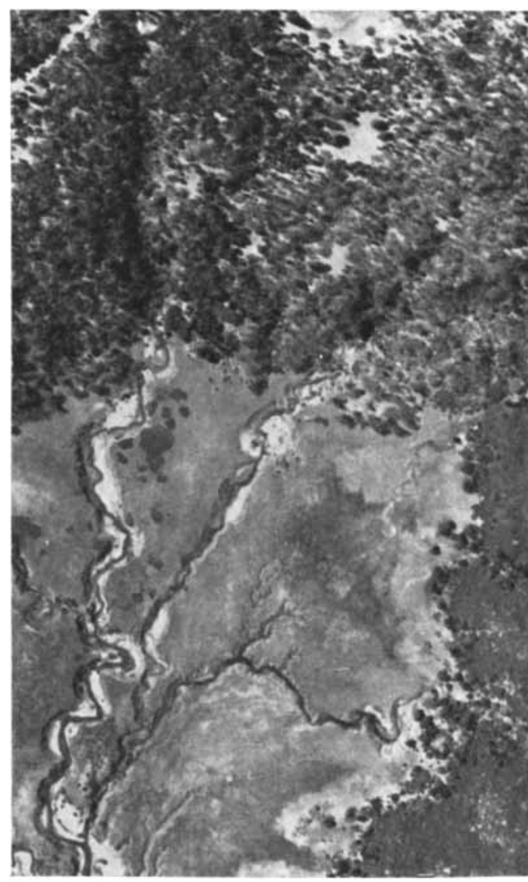
The question of the distribution of nebulae in depth—that is, with increasing distance from us—is a crucial one for deducing the structure of the universe as a whole. According to our recently recalibrated distance scale [see "A Larger and Older Universe," by George W. Gray; SCIENTIFIC AMERICAN, June, 1953] the 200-inch telescope on Palomar Mountain reaches out to more than two billion light-years, and new radio telescopes may take us even farther. If the concentration of nebulae is found to change with distance, we may obtain a measure of the curvature of space postulated by certain interpretations of Einstein's general theory of relativity. If nebulae at great distances are found to differ physically from those nearby, we may have clues to the evolution of galaxies, for we are seeing the distant galaxies as they were billions of years ago, when their light began its enormous journey to us.

These possibilities raise the question of the time scale of the universe. Did the universe originate at some finite time in the past, or has it existed forever? The question may not be one for science alone to answer, but there can be no doubt that it is one to which the findings of science are relevant. Many of the older cosmologies assumed that the universe was created full-blown in very much the state in which we find it now; more recent theories, in rationalistic reaction, tacitly assumed that the universe had no beginning. If the first of these assumptions were correct, it would be hard to account for the observed existence of one-way processes in nature; the second fails to account for the continued existence of radioactivity. The nebulae themselves, by their motions, offer an answer to this question of time—if not a complete answer, then at least a time scale which must prove significant for any cosmological theory. For the nebulae appear to be rushing away from us; if these motions are real, and if they have been going on continuously in the past, then all the matter we now see spread throughout the universe must a few billion years ago have been compressed into a very small compass indeed. It is as if, at that time in the dim past, there was a mighty explosion which catapulted fragments out to form the nebular universe as we now see it.

The evidence for this view is, of course, the well-known red-shift in the light we receive from distant nebulae. By the end of the first quarter of this century V. M. Slipher at the Lowell Observatory at Flagstaff, Ariz., had compiled a list of some two-score nebulae that showed red-shifts, and Hubble compiled a corresponding list of their distances. Developments in the general theory of relativity suggested that distant objects should in fact be moving away from us at a speed proportional to their distance, and in 1927 we found such a correlation—ragged, it is true, but showing a distinct increase of velocity with increasing distance. Hubble and Milton L. Humason at the Mount Wilson and Palomar observatories extended this correlation to vastly greater distances; the most distant nebulae observed so far seem to be traveling at one fifth the speed of light and more.

Knowing the distances and velocities of the nebulae, it should be easy, by extrapolating backward in time, to tell when they were all together. And so it would, if we could be sure that these velocities have been the same from the beginning, or even if we knew the law by which they have changed, if they have. But assuming for the moment that the velocities have kept the same, and adopting the new distance scale proposed last year by Walter Baade of Mount Wilson and Palomar, the answer is that the "origin" of all this motion lies five and a half billion years in the past. Is this time enough for the chemical elements to have evolved, in the proportions we now observe, from elementary particles? Is it long enough for stars and nebulae to have been built from primordial matter? For the creation of the solar system in all its parts? Such are the questions that cosmology asks of its sister science cosmogony.

But are we justified in assuming that the relative velocities have not changed during all these celestial eons? Probably not, for we should expect the various



PALOMAR MOUNTAIN is seen in this aerial photograph from the direction in

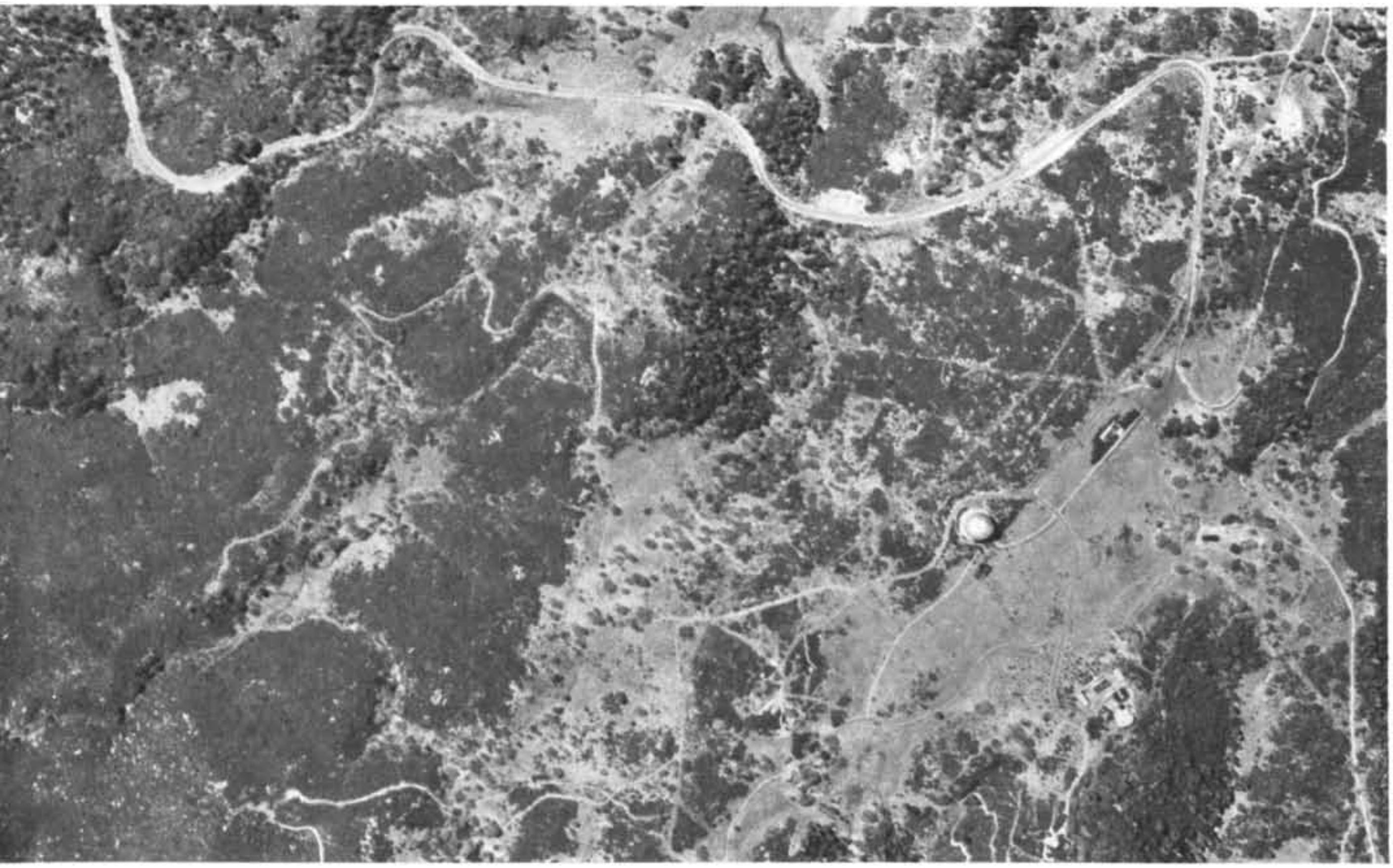
nebulae to interact, and such interaction could very well lead to changes in relative velocity. Specifically, the retarding pull of gravitation should slow the nebulae down. If gravitation is the only force effective between nebulae, then we should expect that the time scale inferred from the present slowed rate of expansion must be shortened—but by how much? At this point we have need of a theory, of some hypothesis on the dynamics of the universe, to point to further observational tests.

A theory opportunely presented itself, in the form of Einstein's general relativistic theory of gravitation. Hardly had this revolutionary extension of Newton's laws been formulated when it was applied, by Einstein himself and by the Dutch astronomer Willem de Sitter, to the cosmological problem. Within a decade research leads converged from various directions upon an idealized model, or rather a series of models. The general theory of relativity sets out with few *a priori* prejudices concerning the geometry of space, holding the geometry to be in large measure contingent on the material content. This results in the intriguing possibility that physical space may be curved into a non-Euclidean form—a closed but unbounded universe of finite volume if the curvature is positive, an infinite open one if the curvature is zero or negative. Observation should be able, in principle, to determine which obtains, and how great is the curvature. Thus if matter is distributed at random, the total number of nebulae seen out to a given astronomical distance should increase faster with distance in a closed space than in the flat Euclidean model, and the discrepancy should lead to an estimate of the amount of curvature.

Besides the models arising from Einstein's theory of gravitation, other relativistic models are possible, and several have been advanced as better suited to the facts. Among them is one in which the universe is stationary in time, but which yet allows for the general expansion. This it can do only by breaking with the postulate of conservation of matter and replacing it with the hypothesis of continuous creation of matter—the theory espoused by Fred Hoyle and his University of Cambridge colleagues.

As of the present no one model can lay exclusive claim to being the best representation of the actual universe. The choice sways from one to another as we choose to emphasize now one, now another set of partial observations, or as new horizons bring new knowledge. But the faith of science in the rule of law and the uniformity of nature bids us continue the search, confident that if we ask the right questions, and as we produce the means to answer them, all the parts of the puzzle will fall together into a consistent picture of the universe which portrays truth in the only sense in which science can sanction the word.

So history has shown. The world of ancient man was closed within a cramped sphere to which the stars were attached. The giants of the age of Newton pushed back this puny sphere to make room for the sun and its entourage, and their followers made of the stars a galaxy of majestic size and structure. And now in our day man leaps from it into the dim reaches of a universe of galaxies, groping with the problem of its structure, of whence it came, and of whither it goes. Truly one can say with Hubble: "The history of astronomy is a history of receding horizons!"



which its telescopes look out into the realm of the nebulae. The bulbous object at lower right is the dome of the 200-inch. Almost directly below it at the edge of the photograph is the dome of the 48-inch Schmidt. The domelike object between them is a water tank.

THE ORIGIN OF THE ELEMENTS

The relative abundance of the various kinds of atoms is a powerful clue to the history of the universe. The author discusses the recent theory that the heavier ones were built up from hydrogen in stars

by William A. Fowler

In investigating the nature and history of the universe we can hardly do better than to begin by examining what it is made of. The universe we see and measure is composed of an orderly yet diverse system of elements, from hydrogen to uranium. How did these elements come into being; from what primordial stuff were they made? As rare Ben Jonson shrewdly observed more than 300 years ago in *The Alchemist* (in a quotation to which the physicists Ralph A. Alpher and Robert C. Herman have previously called attention):

Ay, for 'twere absurd
To think that nature in the earth bred gold
Perfect i' the instant: something went before.
There must be remote matter.

Research into "remote matter" and the origin of the elements is going forward today along many paths, and of these none has been more fruitful than the study of the relative abundance of the various elements in the universe. The present abundances of the elements offer one of our most powerful clues to the history of the earth, the stars and the galaxies, for the abundance curve is the product of that history and was shaped by cosmic events. From this curve we can learn much about the evolution of stars, about cosmology and about all the grand-scale subjects of modern science.

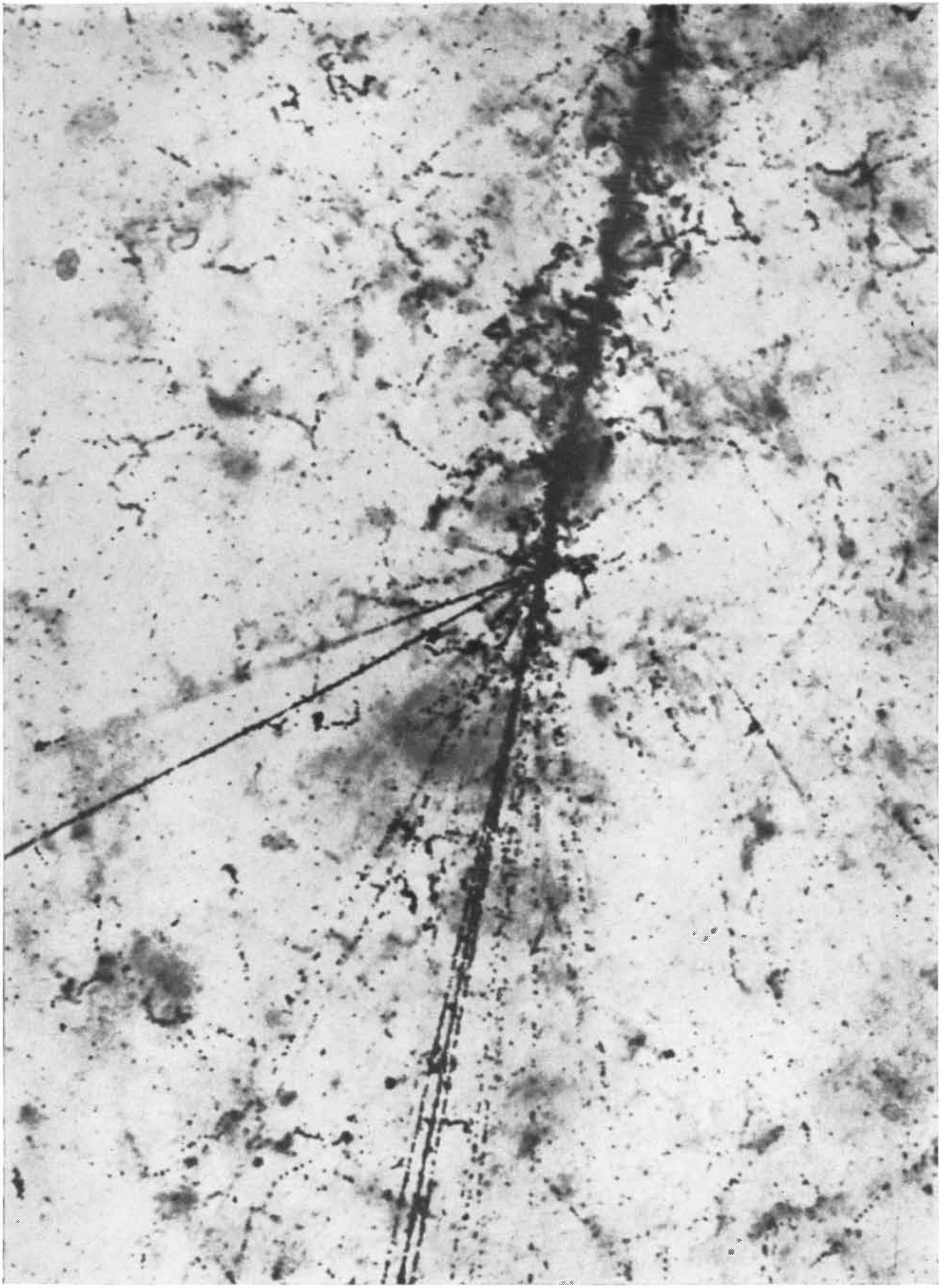
Our inquiries into the composition of the universe are severely handicapped, to be sure, by the fact that gravitation, which acts alike on heavenly bodies, apples and human beings, has so far chained mankind to his native planet. But notwithstanding this handicap, an imposing range of information on the universal abundance of elements is available to us today. There is, first of all, our own planet, where we can analyze at first hand the composition of the crust, oceans and atmosphere, and, allowing for losses of matter to space and redistribution of matter to the interior, can compute the proportions of the elements in the earth when it was formed. Secondly, there are the meteorites plucked by the earth from outer space; we attach considerable weight to these samples, because the matter in meteorites is assumed to have undergone less change than that in the earth's crust. Thirdly, the light from a star, when analyzed with the spectroscope, identifies the elements on its visible surface. Every element emits or absorbs a characteristic spectrum of light (bright or dark lines at certain wavelengths) when its atoms are excited to high temperature; the elements have been "fingerprinted" in this way in laboratories, and their prints can be matched to the spectral light from stars. The abundance of each element can be estimated from the intensity of its radiation or from the amount of radiation the surface atoms absorb from the star's background radiation. Fourthly, from galaxies and from interstellar space we can hear a song of hydrogen, in the form of radio waves at the 21-centimeter wavelength; as radio astronomy develops it may tell us much more about the abundance of the elements in space. Finally, the cosmic ray particles that continually bombard the earth also supply us with samples of matter from the universe outside our planet.

All these clues are beset with complications that may mislead us. Nor can we be confident that we have a true sample of the whole universe, for the information comes mainly from our own galaxy, indeed, largely from our own solar system. But it has been gratifying to find that every one of our methods of observation, when carefully carried out and corrected for complicating factors, yields much the same story. They produce a reasonable and consistent picture of the average abundance of the elements in the universe as far as we can observe it. This picture—a curve showing the proportions of the various elements in the cosmos as a whole—is well represented by the curve constructed by Harrison Brown of the California Institute of Technology on the basis of his analysis of meteorites and other evidence [*see upper chart on page 85*].

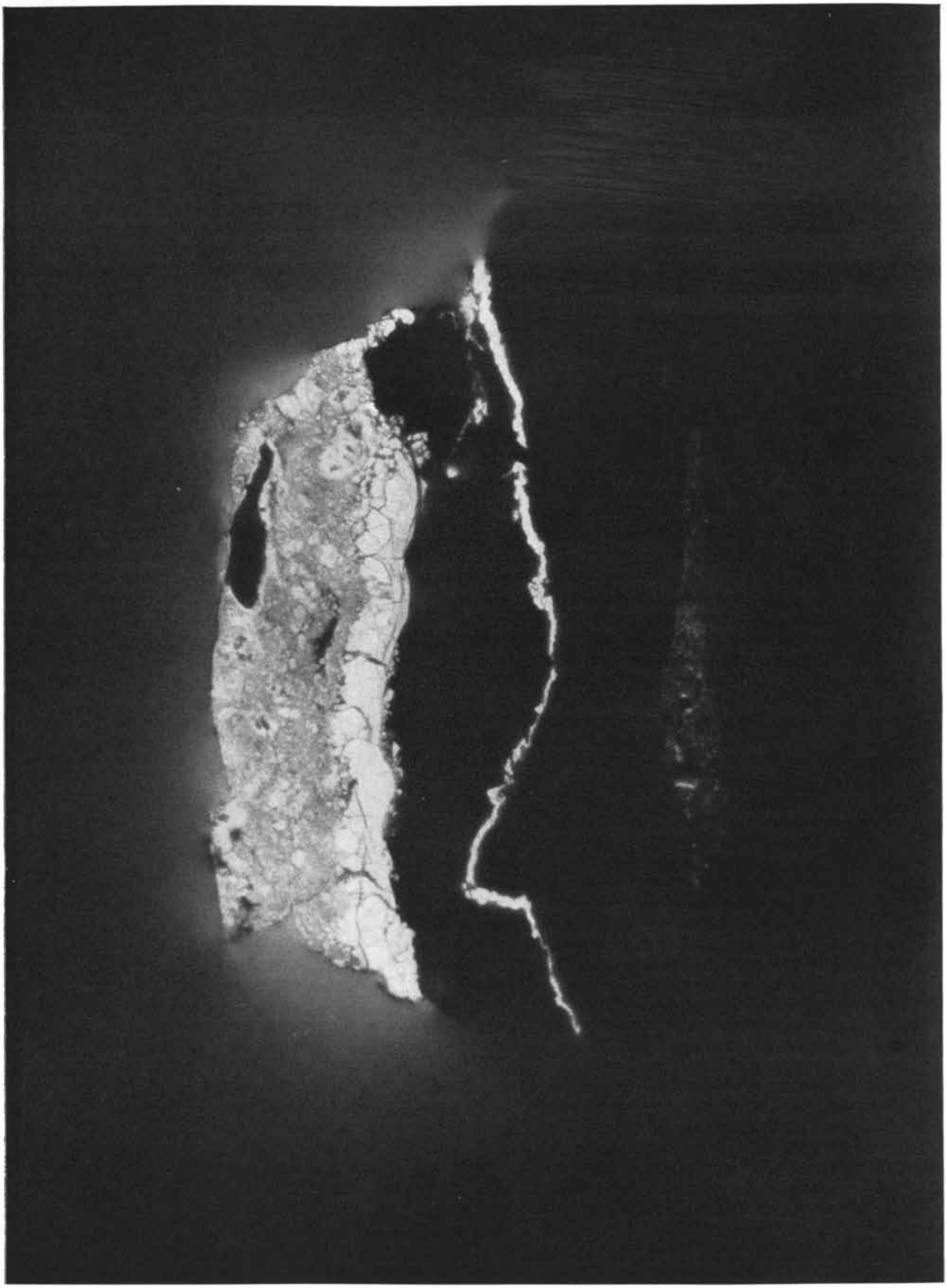
By far the most abundant element is hydrogen: it accounts for 93 per cent of the total number of atoms and 76 per cent of the weight of the universe's matter. Helium is next: about 7 per cent by number of atoms and 23 per cent by weight. In general the abundance of the elements drops off with increasing atomic weight. The fall in the curve has one sharp interruption when we come to the elements of the iron group: these are about 10,000 times more abundant than their neighbors in the atomic-weight sequence. But except for this anomaly there is a general decline, and the heaviest elements add up to only a hundred millionth of all matter by number of atoms and a millionth by weight. It is a striking fact that all the elements beyond helium together amount to only a little more than 1 per cent of the mass of the universe.

If we take this picture to be correct, we have, then, a universal pudding composed of certain known ingredients mixed in certain proportions. Our task is to determine what recipe could have brewed this mixture.

We begin with the fact that, to the best of our knowledge, all the elements



COSMIC RAY smashes a nucleus in a photographic emulsion. The character of the original track indicates that it was made by a nucleus of iron. The distribution of elements in cosmic rays provides evidence on the relative abundance of elements in the universe.



URANIUM-BEARING ROCK, when cut so that it can be placed in close contact with a glass photographic negative, records its radioactivity in the emulsion. The relative abundance of the isotopes in such rocks provides evidence as to the age of the earth.

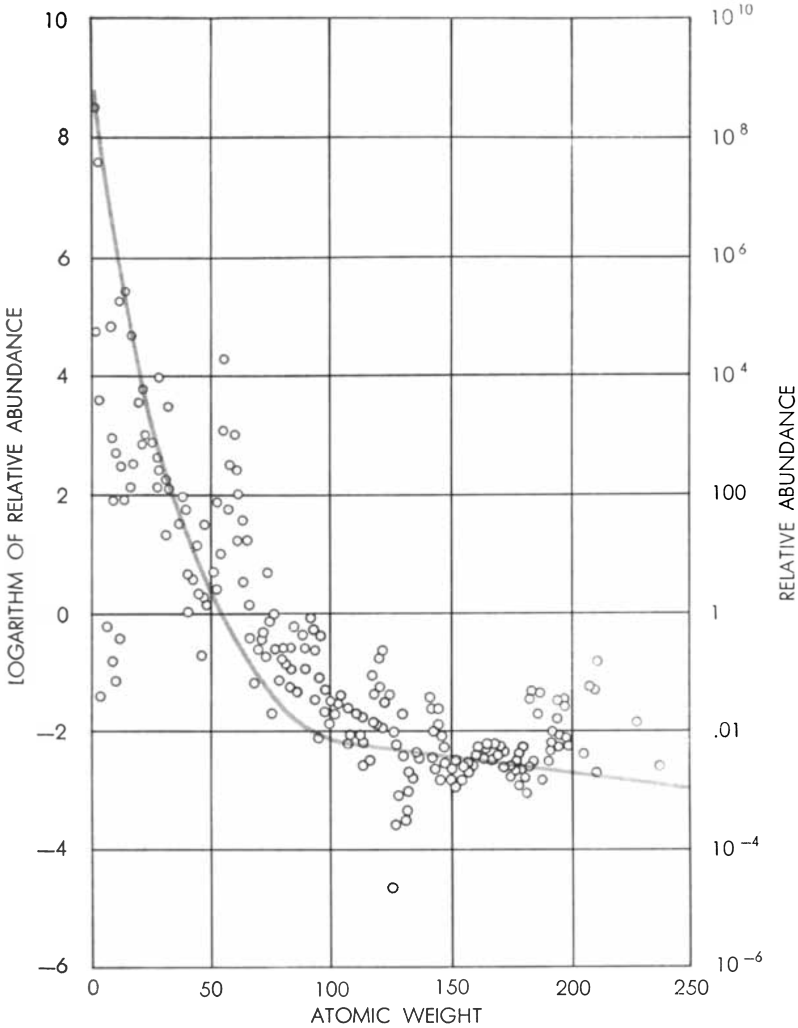
are made up of just two nuclear building blocks—protons and neutrons. (How the protons and neutrons themselves were created is a question outside the province of this article: only men of strong convictions, religious or scientific, have the courage to deal with the problem of the creation.) In a sense protons and neutrons are merely different versions of a nucleon: a free neutron may decay into a proton by shedding a negative electron, and the positively charged proton may become a neutron by combining with an electron or by emitting a positron.

The nucleus of the simplest element, hydrogen, is a single proton. Nearly a century and a half ago the Englishman William Prout suggested that all the elements consisted of combinations of hydrogen atoms. We have learned that the situation is vastly more complicated, but essentially most of the modern theories make a similar approach. It is natural to start with the working hypothesis that the elements were built up from protons or neutrons or both as the units.

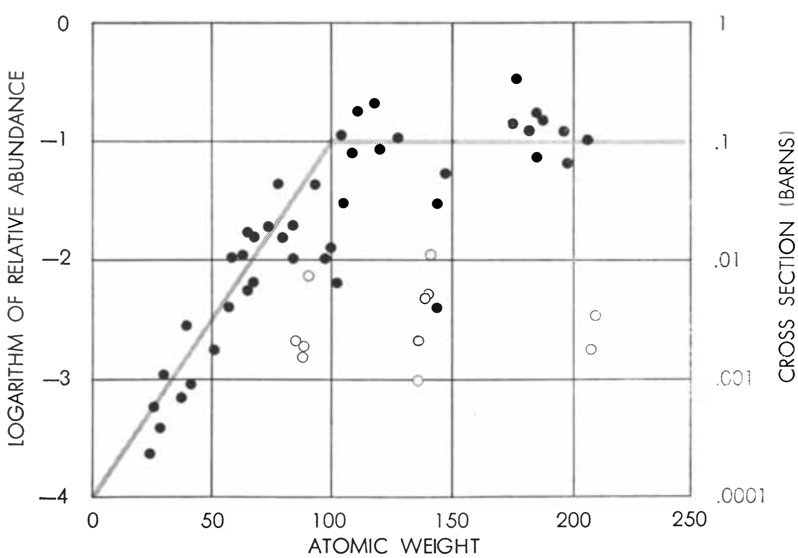
The difficulty lies in trying to picture how this build-up took place and how it could have proceeded through the whole sequence to produce all the elements in the periodic table. The positively charged protons repel each other, and it takes a large amount of energy to overcome this repulsion and force them close enough together to combine. Some combinations are highly unstable or nonexistent. Other combinations in the sequence are so stable and so strongly bound that it is difficult to see how they can be transmuted or built up to larger atoms by natural processes.

There are several current theories about the origin of the elements, but we shall consider only the two that have been worked out in fairly comprehensive fashion and are taken most seriously.

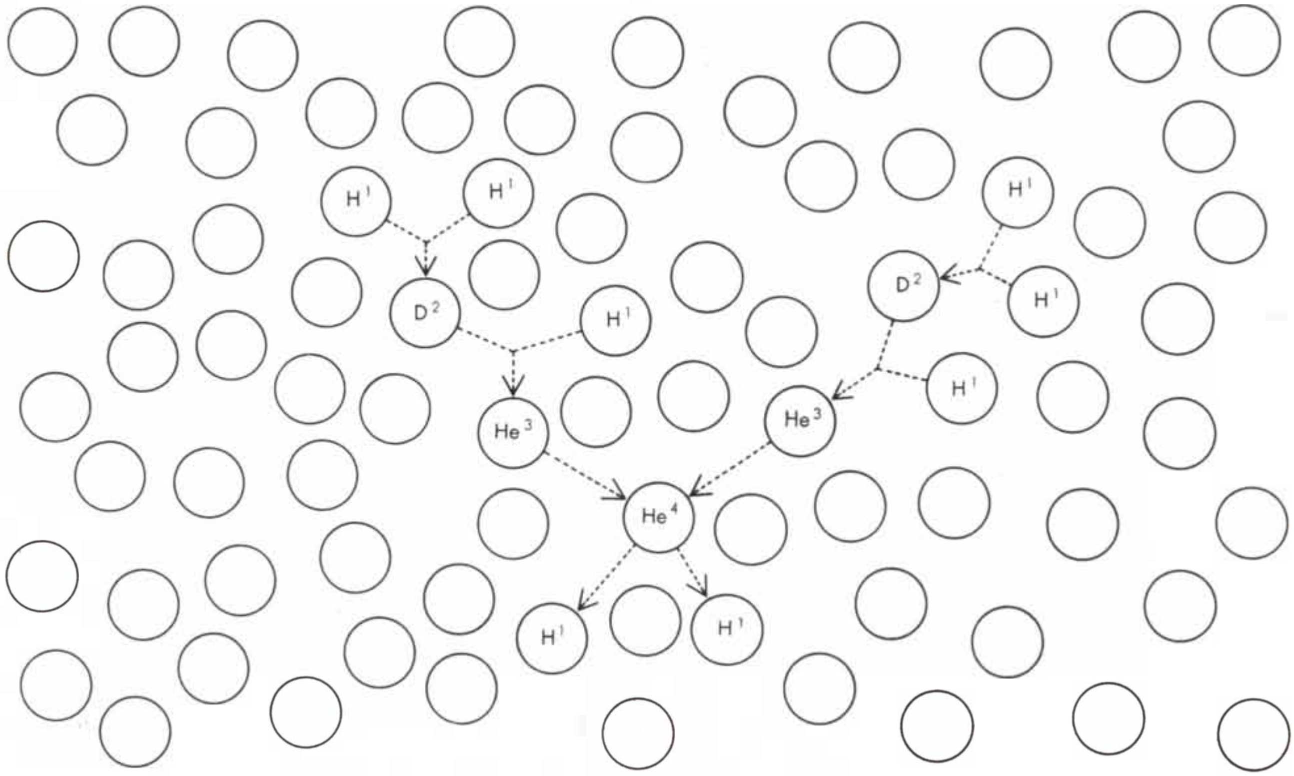
The more popular of the two is the one advanced by George Gamow and his collaborators. This theory holds that the elements were formed by a step-by-step build-up from neutrons. Gamow starts from the postulate, based on the apparent expansion of the universe, that the cosmos started from a core which exploded in a primordial "big bang" some five billion years ago. This exceedingly dense core, he believes, was made up primarily of neutrons, for under the great pressure electrons would be compressed into the protons. As the great neutron ball began to expand, some of the neutrons decayed to protons. Each proton promptly captured a neutron, the



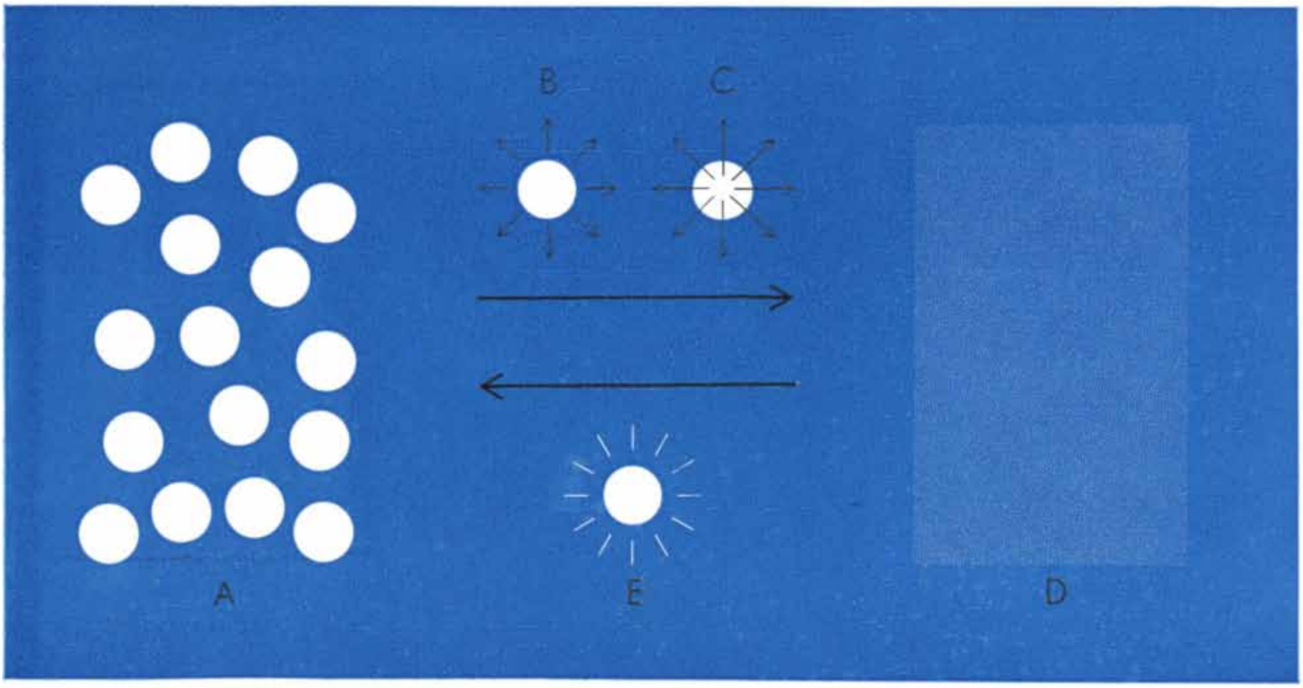
RELATIVE ABUNDANCE of the elements is plotted. The solid curve itself is based on theoretical abundance expected from neutron-capture cross sections (*see below*). Anomalies near atomic weight 56 are the iron group; near 10, rare lithium, beryllium and boron.



CROSS SECTIONS of nuclei for neutron capture are plotted according to Donald J. Hughes and his collaborators. The heavier nuclei capture neutrons more readily. The exceptionally stable nuclei are indicated by open circles. A barn (*type at right*) is 10^{-24} square centimeters.



SYNTHESIS OF ELEMENTS from hydrogen begins with the steps depicted here. The circles represent nuclei in the interior of a star. Two nuclei of hydrogen 1 (H^1) fuse to form a nucleus of hydrogen 2, or deuterium (D^2). The deuterium then fuses with hydrogen 1 to form helium 3 (He^3). Two nuclei of helium 3 next combine to form helium 4 (He^4) and two nuclei of hydrogen 1.

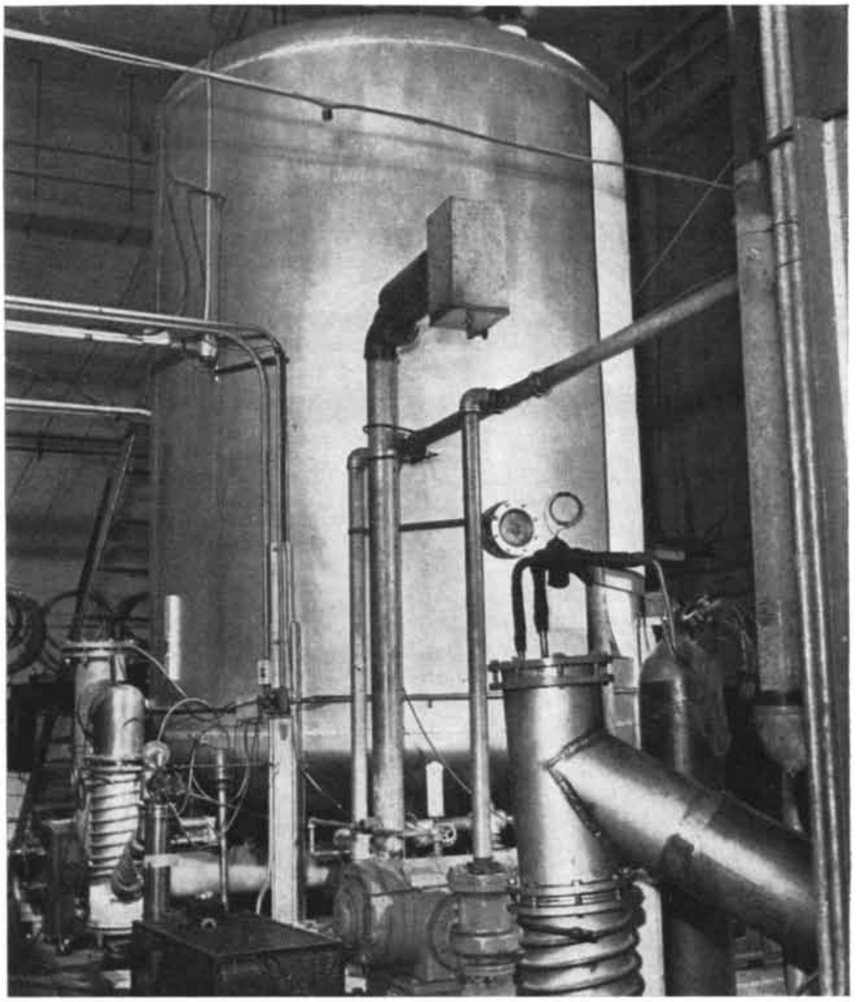


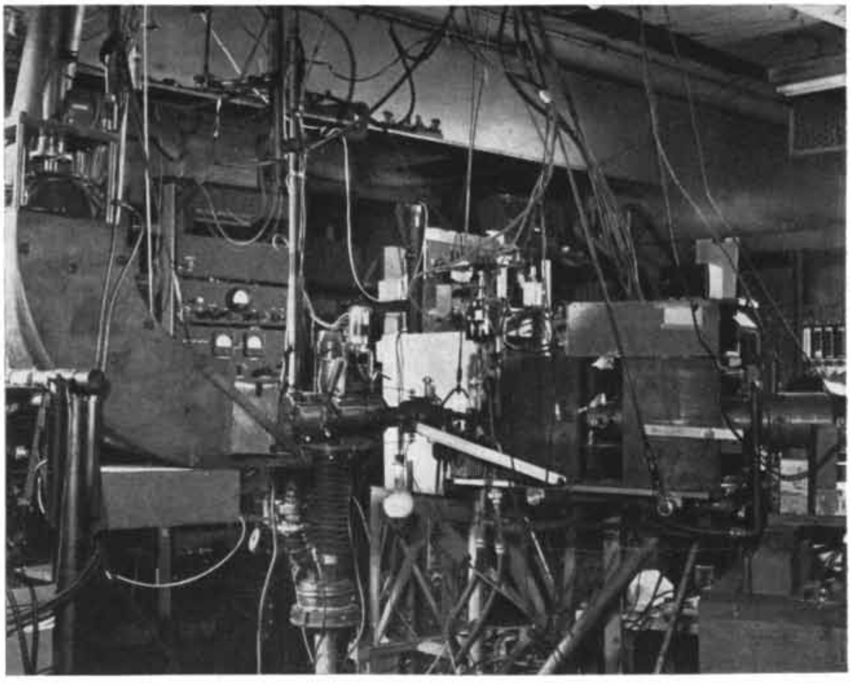
TRANSFER OF ELEMENTS between stars and the interstellar dust and gas is illustrated. Elements are synthesized in stars (A) by processes of the kind depicted at the top of the page. The stellar material is ejected slowly by stars such as the sun (B), or explosively by novae or supernovae (C). The material is mixed in the dust and gas (D). It condenses into young, bright stars (E).

pair forming a deuteron, the nucleus of the hydrogen isotope of mass 2. Some deuterons then captured another neutron and became nuclei of tritium, or hydrogen 3. This nucleus soon decays by emitting a negative electron and thus is transmuted to helium 3. And so, by a rapid succession of neutron captures and electron decays, all the elements were built in the first burst of the universe's expansion. Gamow believes that the whole process of formation of the elements as we know them took place in a matter of a few minutes. The fleeing matter thereafter formed stars, planets and galaxies.

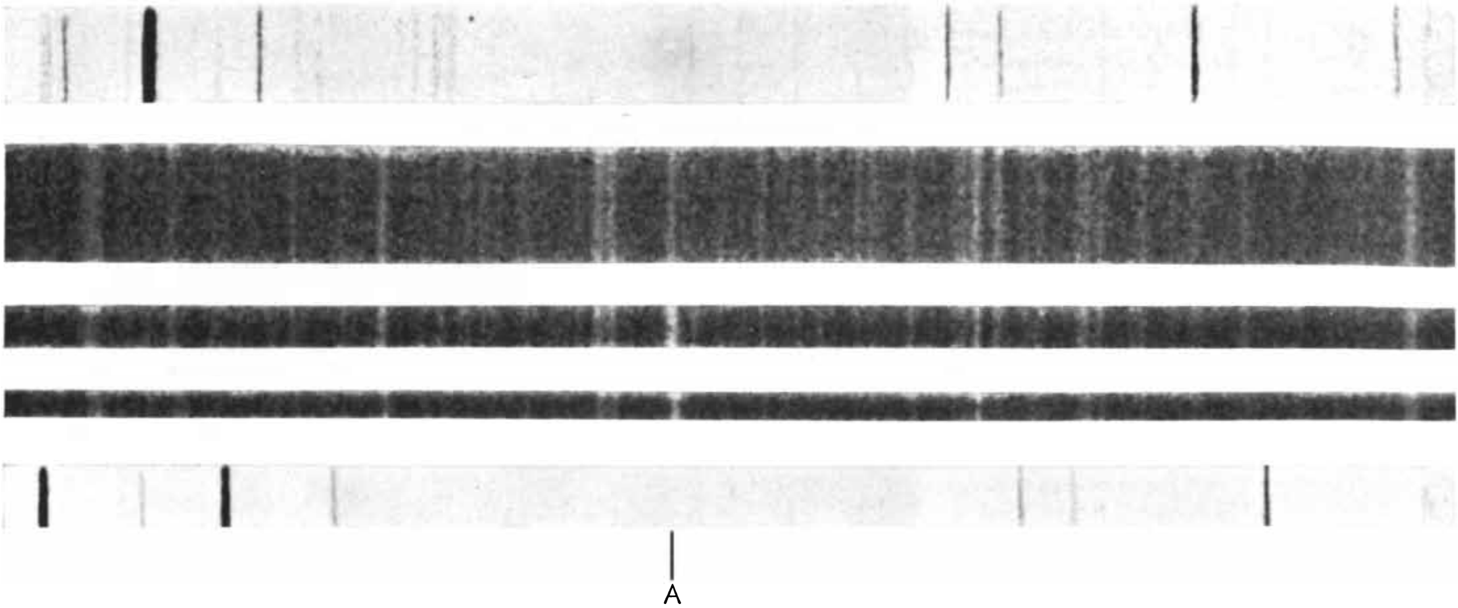
Two lines of evidence from laboratory experiments with particles give impressive support to Gamow's theory. First, it is well established that nearly all nuclei do in fact capture neutrons readily. Secondly, the neutron-capture cross sections of the various nuclei predict a pattern of element abundances which agrees remarkably well with the one actually observed. We should expect a simple relation between the neutron cross section of a given nucleus (*i.e.*, the rate at which it captures neutrons) and the relative abundance of its production. Nuclei that capture neutrons rapidly should be comparatively rare when the sequence of element formation is completed, because most of them are quickly converted by such capture to other nuclei; conversely, nuclei that are slow to capture neutrons should accumulate to relatively high abundance. The curve of element abundances does in fact closely follow the curve of neutron-capture cross sections, in an inverse sense: that is to say, just as the curve of abundance falls sharply from hydrogen to the nucleus of atomic weight 100 and then flattens out, so the curve of neutron cross sections rises sharply from hydrogen to 100 and similarly flattens out beyond this atomic weight [*compare charts on page* 85]. There are even some correlations between fluctuations of elements from the two curves, notably at the neutron numbers 50, 82 and 126.

But there are important difficulties with Gamow's theory—difficulties to which his collaborators Ralph A. Alpher and Robert C. Herman have themselves called attention. The most serious is the fact that in the sequence of atomic weights numbers 5 and 8 are vacant. That is, there is no stable atom of mass 5 or of mass 8. We can produce helium 5 in the laboratory by bombarding helium 4 with neutrons, but it immediately breaks down to helium 4 again. Likewise we can produce momentarily an





ELECTROSTATIC PARTICLE ACCELERATOR is used at the California Institute of Technology to study nuclear reactions of the kind that occur in stars. In the photograph at the top is the vacuum tank which encloses the generator. In the photograph at the bottom is the apparatus on the floor below. The beam of particles is bent by curved magnet at left.



STELLAR SPECTRA studied by G. R. and E. Margaret Burbidge show an intensification of the absorption lines due to the elements barium, lanthanum, praseodymium and samarium in two "peculiar" stars. Reproduced here are five spectra. At the top and bottom, for comparison purposes, are the spectra of an iron arc. Second from the top is the spectrum of the normal star Kappa

isotope of beryllium of mass 8, but it too instantly breaks down (by fission into two helium 4 atoms). The question then is: How can the build-up of elements by neutron capture get by these gaps? The process could not go beyond helium 4, and even if it spanned this gap it would be stopped again at mass 8. In short, if neutron capture were the only process by which elements could be built, starting with hydrogen, the build-up would get no farther than helium.

This basic objection to Gamow's theory is a great disappointment, in view of the promise and philosophical attractiveness of the idea. The other major current hypothesis is less simple and less elegant; it complicates the picture by invoking other processes, in addition to neutron capture, to account for the build-up of the elements. But it seems to surmount the difficulties encountered by the Gamow hypothesis.

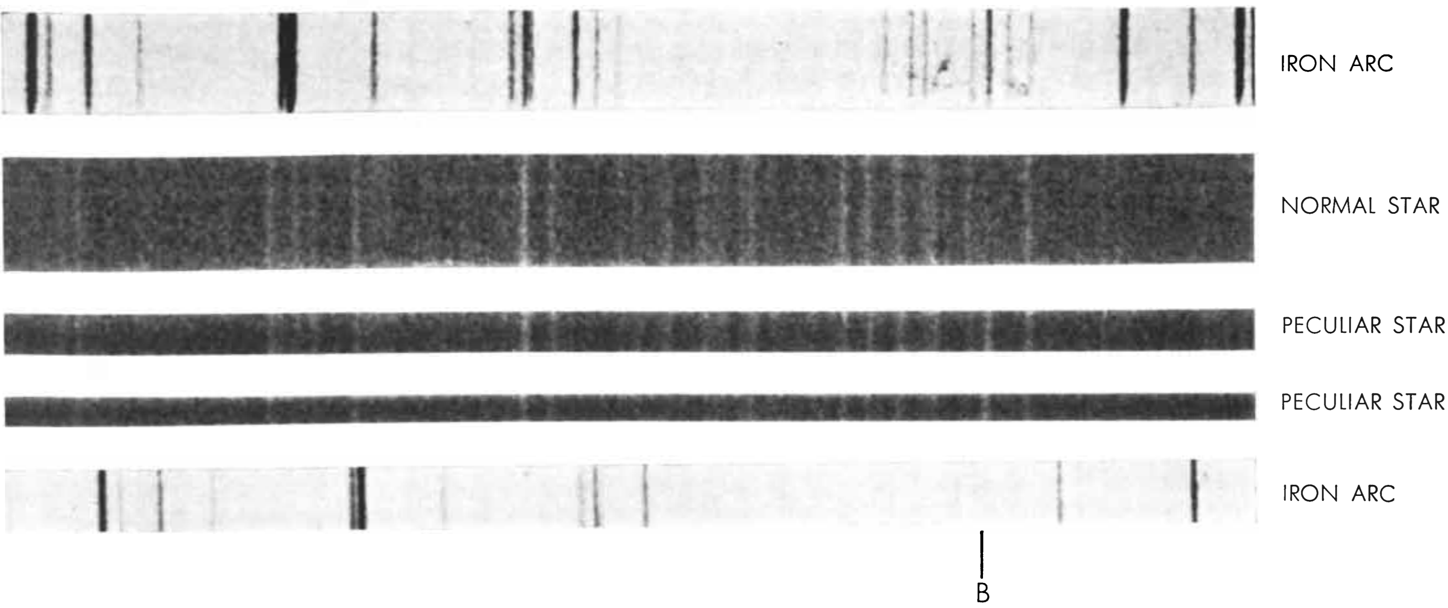
The theory argues that the elements were built not in a primordial explosion but in the hot interiors of stars. It starts from our knowledge that nuclear reactions and transformations must be going on constantly in the stars. As Sir Arthur Eddington presciently remarked in 1920, after Lord Rutherford had transmuted nuclei by bombardment in his laboratory: "What is possible in the Cavendish Laboratory may not be too difficult in the sun." Eddington's informed guess was certainly correct, but not until 1938 was it translated into terms of specific processes. Hans A. Bethe, seeking to account for the enormous and enduring energy of the sun and other stars, conceived two chains of nuclear reactions that would explain their tremendous release of energy and would build new nuclei. The processes have been known ever since as proton-proton fusion and the carbon-nitrogen cycle. The new theory of synthesis of the elements, which has been championed most extensively by Fred Hoyle of the University of Cambridge, assigns key roles to these processes.

We start with a universe consisting of a cold, dilute and turbulent gas of hydrogen atoms. By gravitational attraction part of the gas condenses into stars. As a star contracts under gravitational force, its interior grows very dense and hot. When the central temperature reaches about five million degrees, the protons are moving with enough energy to fuse on colliding and form deuterons. Deuterons in turn combine with protons to form helium 3. Helium 3 does not interact with protons, but laboratory experiments have shown that two helium 3 nuclei can fuse and produce helium 4, ejecting the two surplus protons. The net result of this proton-proton chain is the conversion of four atoms of hydrogen into one atom of helium.

In this way a core of helium develops in the center of the star and gradually grows in size. After a time, as the hydrogen fuel in the interior is used up, the core begins to cool. It then contracts, because gravitational forces gain the upper hand. As a result the temperature of the core rises again. The sudden rise of the internal temperature heats up the star's outer envelope of hydrogen; the mantle expands enormously; its extended surface then radiates cooler (*i.e.*, redder) light, and the star becomes a "red giant."

We have now a star with a hot core of helium, at a computed temperature of more than 100 million degrees. What happens next? We have come to the Gordian knot of the speculations on the build-up of the elements. Two helium nuclei may combine to form a nucleus of mass 8, but as we have seen, any nucleus of mass 8 must be extremely unstable, for none is found in nature. However, beryllium 8 *has* been produced momentarily in the laboratory, and will certainly materialize in the very hot and dense interior of a star. In fact, in that environment beryllium 8 will be produced at as fast a rate as it breaks down, so that a small amount of it is always present. If so, an occasional beryllium 8 nucleus may during its very brief lifetime fuse with a helium 4 nucleus. The combination should result in a nucleus of carbon 12.

Hoyle has pointed out that, in view of the extreme rarity of the beryllium 8 nuclei (about one part in 10 billion in a



Geminorum. Third from the top is the spectrum of the peculiar star HD 46407; fourth from the top, the spectrum of the peculiar star HD 26. At A is an absorption line for ionized barium; at B, an absorption line for ionized lanthanum. The intensity of these lines in the spectra of the peculiar stars shows that their atmospheres contain more barium and lanthanum than that of Kappa Geminorum.

100-million-degree star), the beryllium 8 nucleus had better have a big cross section for capturing helium nuclei if this scheme is to work. Naturally the question cannot be put to a direct test by bombarding a beryllium 8 target in the laboratory, for the nucleus is too ephemeral. But in the W. K. Kellogg Radiation Laboratory at Cal Tech we have been able to obtain indirect evidence that this capture does have a high probability, or, in the parlance of nuclear physics, that it is a "resonant" reaction. Hoyle reasoned that if the reaction is indeed a resonant one, the product, carbon 12, must go through an excited state with certain specified properties. We have found that the carbon 12 nucleus can in fact take this excited form, with almost exactly the properties Hoyle predicted. We produced excited carbon by bombarding boron with high-energy deuterons. The excited carbon 12 nucleus resulting from this reaction promptly disintegrated into three helium nuclei. On the basis of very general physical principles we can argue that in the hot core of helium in a star the reverse process can take place: that is, three helium nuclei may combine to form excited carbon 12, which may then discharge its energy of excitation and become stable carbon.

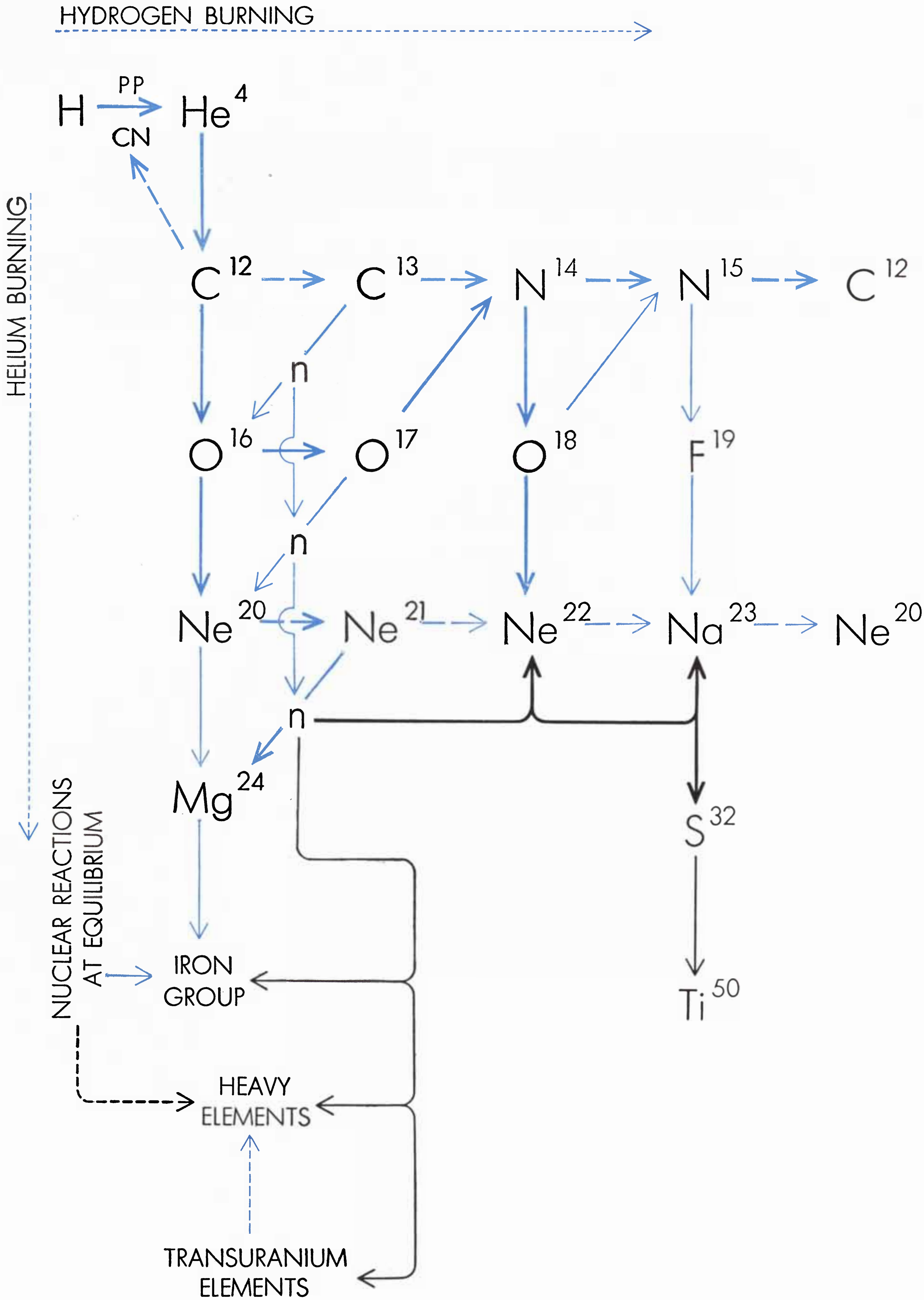
The jump from helium to carbon of course skips the elements lithium, beryllium (whose stable form is beryllium 9) and boron. There is good reason to suppose that these elements are not produced in the main line of build-up of the elements. They are comparatively rare, and may be made by secondary processes. It is known, for instance, that bombardment of heavy elements with hydrogen nuclei sometimes chips off fragments which are identifiable as nuclei of lithium, beryllium and boron. Possibly this process goes on in spots ("sunspots") on the surfaces of stars or occurs in stellar explosions.

Once carbon 12 has been synthesized in the helium core of a star, it may build up by successive captures of helium nuclei to oxygen 16, neon 20 and perhaps magnesium 24. When the helium has been largely used up, so that there can no longer be much release of energy from these fusion reactions, the core cools and contracts. The contraction again raises the temperature of the core, this time perhaps to an energy high enough to trigger interactions among the nuclei of carbon, oxygen and neon. Such reactions would produce the silicon group of elements (around atomic weight 28). The temperature of the core may continue to rise until, at about five billion degrees, the build-up of elements by fusion reaches a dead end. At this stage the build-up would form the most stable of all the elements, namely iron and its neighbors (around atomic weight 56). Any nuclear reaction involving the iron group must absorb energy rather than release it; hence these nuclei cannot serve as fuel to continue the chain of fusions.

Hoyle has suggested that this impasse may account for the anomalous abundance of the iron group of elements in the universe. As the primeval stars grow older, they accumulate iron as the end product. If they reach the stage where they have burned up all their internal fuel and then explode (perhaps as a result of a sudden disturbance of the hot core material and its reaction with unburned material in the envelope of the star), they will fling a considerable amount of iron into interstellar space.

We must now pause to relate the element-building processes to the evolution of stars. Clearly in the early stages of a star's evolution the only, or at least dominant, process is the build-up of hydrogen to helium. The fusion of hydrogen to helium is, in fact, the main source of energy of most stars (which fall in what is called the "main sequence" on the familiar chart of star classifications). Recall that most of the matter in the universe is hydrogen and helium: we can assign the building of all the other elements to comparatively minor or rare processes in the life of stars.

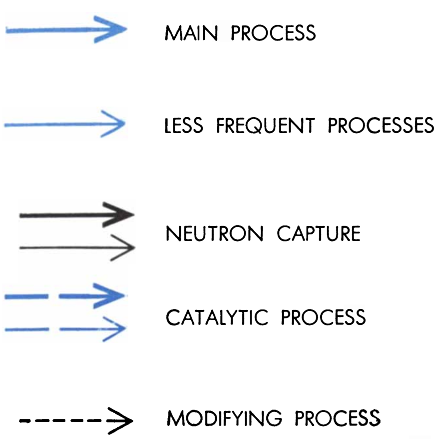
It is in the old "red giants" that the fusion of helium into carbon and successively heavier elements takes over the dominant role. But, as we have just seen, we have reached an impasse at iron, and


HYDROGEN BURNING
HELIUM BURNING
H
PP
CN
He4
C12
C13
N14
N15
C12
n
O16
O17
O18
F19
n
Ne20
Ne21
Ne22
Na23
Ne20
n
Mg24
S32
Ti50
NUCLEAR REACTIONS AT EQUILIBRIUM
IRON GROUP
HEAVY ELEMENTS
TRANSURANIUM ELEMENTS

we must now find some way to construct the elements beyond the iron group. Here Gamow's concept of build-up by neutron capture, and what we know of certain cataclysmic events in the history of stars, comes to our aid.

Stars, like human beings, are subject to accidents and disorders: not all of them live to a ripe old age. They occasionally boil up to a state of instability that results in their exploding as a nova or supernova. This may happen in a star of any age, young or old. When a young star explodes, it discharges hydrogen and helium into interstellar space. An old star will spew forth not only these nuclei but also other elements from carbon up to iron. Besides this, even stable stars, including our sun, are known to be constantly ejecting corpuscles of matter into space.

ENTIRE SCHEME of the synthesis of elements in stars is presented on the opposite page. Elements synthesized by interactions with protons (hydrogen burning) are listed horizontally. Elements synthesized by interactions with alpha particles (helium burning) and more complicated processes are listed vertically. The letters "pp" stand for the proton-proton reaction; the letters "CN," for the carbon-nitrogen cycle. The letter "n" stands for neutrons liberated in nuclear reactions and thus available for neutron-capture processes. The production of carbon (C), nitrogen (N), oxygen (O), fluorine (F), neon (Ne) and sodium (Na) are given in detail. Described in less detail are the neutron-capture processes responsible for magnesium (Mg), sulfur (S), titanium (Ti), the iron group, the heavy elements and the transuranium elements. The colored dotted line between the transuranium elements and the heavy elements represents alpha decay or fission.



Thus a debris of matter from living and dying stars pours into space, and its elements mix with the interstellar gas. From this material new stars are born: astronomy today has strong evidence of the existence of young or infant stars in the heavens. So we can postulate two kinds of stars: primeval or "first generation" stars, and "second generation" stars, which start with a legacy of the elements up to iron from the parents of their matter.

Let us now consider a second generation star which has condensed from hydrogen mixed with some carbon, oxygen, neon and even a little iron. In these stars hydrogen in the core will again be converted to helium, but now, because carbon is present, the conversion will take the route of the second process described by Bethe, the carbon-nitrogen cycle. In this cycle carbon 12 captures hydrogen nuclei in a series of steps which converts it successively to carbon 13, nitrogen 14 and nitrogen 15: in the end nitrogen 15 takes on another proton, breaks down to carbon 12 again, and in so doing emits a nucleus of helium. Thus the chain of reactions produces helium and all the isotopes of carbon and nitrogen. It can be calculated that this process, rather than the direct fusion of protons, is the source of energy in second-generation main-sequence stars which are large enough to have internal temperatures over 15 million degrees.

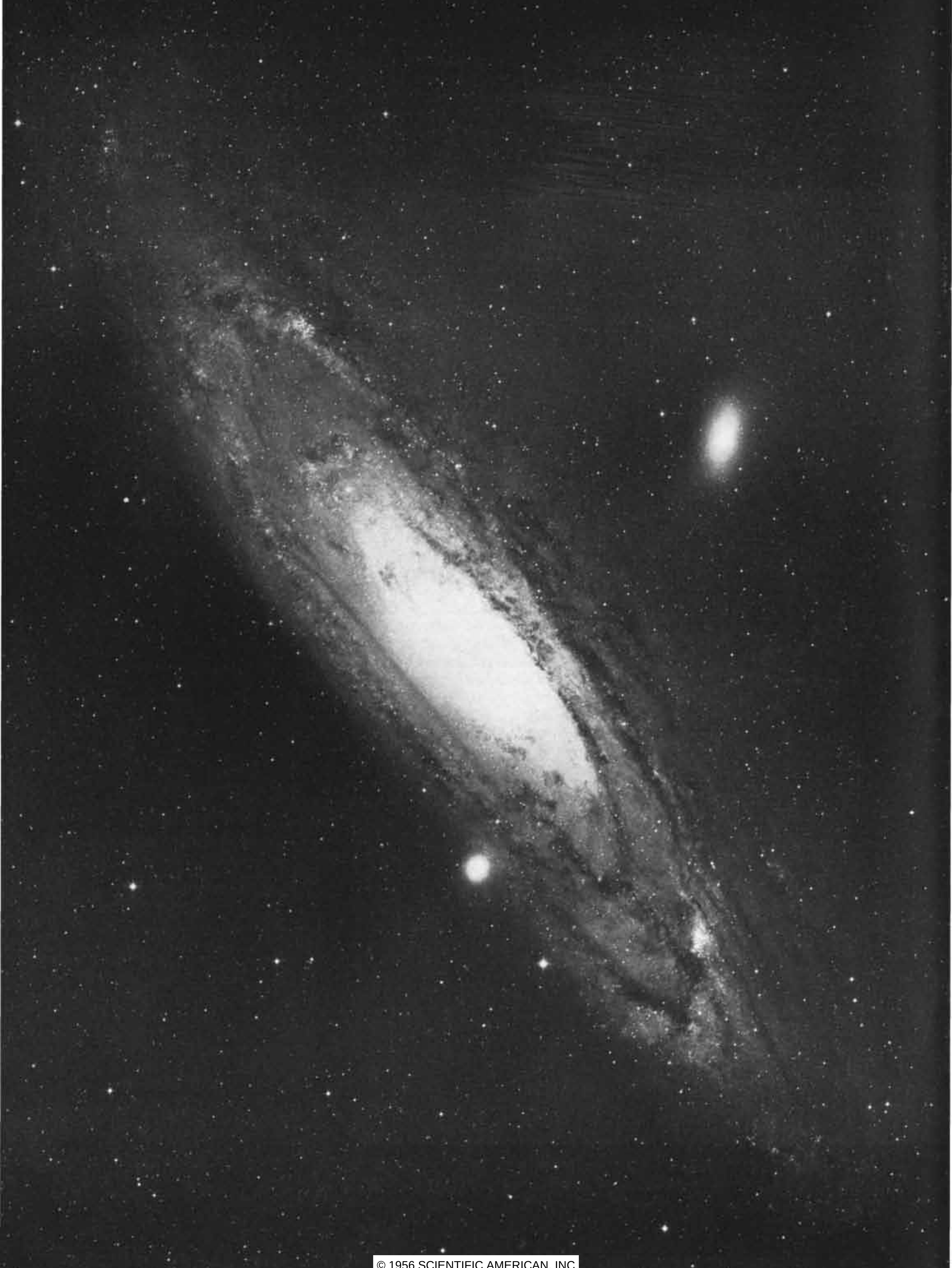
The oxygen in the star's core mixture is converted by proton capture to the isotope oxygen 17, and neon similarly to neon 21. Now these isotopes, and carbon 13, come to play a crucial role when the star arrives at the red giant stage and its core consists mainly of hot helium. The three isotopes, on reacting with helium, produce unstable nuclei which emit neutrons; so laboratory experiments have shown. Consequently they furnish a steady supply of neutrons within the core. We have seen that all nuclei, even iron, readily capture neutrons. Here, then, is the mechanism that breaks the iron bottleneck. By successive captures of neutrons, nuclei can be built up from the iron group to elements as heavy as lead and bismuth. The slow neutron-capture process in the core of a star cannot carry the build-up beyond bismuth, because the heavier elements decay too rapidly (by emitting alpha particles, or helium nuclei). However, the heavy elements *can* capture neutrons at a sufficiently rapid rate to continue the chain during an explosion of a star.

That the stars do in fact synthesize heavy elements has been confirmed by considerable evidence, some of it spectacular. The most dramatic was the discovery of the element technetium in certain giant stars (through its spectral fingerprints). Technetium is an unstable element whose longest-lived known isotope has a half-life of only 216,000 years—far less than the age of the stars in which it is found. It must therefore have been made in the star long after the star's birth. As for the synthesis of the heaviest elements, an isotope of the element californium was found in the debris from a thermonuclear explosion in the Bikini tests of 1952, and we have seen an intriguing suggestion of its presence in certain supernovae. After their original flare-up, these exploding stars decline in brightness at a rate which corresponds to a half-life (decline to half the intensity) of 55 days, and this is just the half-life of spontaneous fission of californium 254!

Research in our own and other laboratories has now established possible processes for synthesis of all the elements [*see opposite page*]. Of course this scheme is still highly tentative. It is disconcerting that so many different processes have to be invoked; it would be much more satisfying to see a single process that could build all the elements. The picture may, however, become simpler as more research is done. What particularly gratifies workers in this field is that speculation about the origin of the elements has been reduced to questions specific enough to be tested both by nuclear physicists in the laboratory and by astrophysicists studying the stars.

There is food for philosophical thought in what has been learned so far. The heavy elements, of which our solar system has its full share, took a long time to produce—probably one to two billion years. Thus the particular part of the universe we inhabit is not the oldest thing in it; many cosmic events preceded the formation of the earth. The oldest stars in our galaxy are estimated to have an age of 6.5 billion years, while analyses of meteorites indicate that the solar system is no more than 4.5 billion years old.

Copernicus displaced the center of the universe from the earth to the sun; later cosmologists dethroned the solar system as the center; now we see that our system was not even in existence at the beginning of the galaxy. So dies the last vestige of mankind's geocentric conception of the universe.



The Content of Galaxies

The discovery that there are two populations of stars illuminates the history of galaxies. Population II stars are old; Population I stars are still being born in the dusty arms of spiral galaxies

by Walter Baade

During the last 30 years, ever since the discovery of the apparent expansion of the universe, studies of our cosmos have been dominated by the cosmological approach: the attempt to understand the structure of the universe in terms of the geometry of space and to estimate its age from its expansion. But as William A. Fowler has made clear in the preceding article, we can also explore these questions by studying the matter the universe contains. After all, the long history of the universe must have left its marks on the material we now observe, and we should be able to obtain information about this history—specifically the formation of stars and galaxies—by examining the composition of these systems. Within the past 10 years we have come to realize that there is an intimate relation between the structure of a galaxy and the character of its population of stars, a relationship which gives a clue to the origin of stars and to the evolution of galaxies.

In order to appreciate the significance of this relationship we must first have a brief look at the forms of galaxies and their classification. This classification was established by the late Edwin P. Hubble of the Mount Wilson and Palomar Observatories. Hubble showed that the galaxies can be divided into three broad groups. The first comprises systems which are spherical or nearly spherical in shape and are filled with stars, apparently packed densely at the center of the galaxy and gradually thinning out to the edge of the system. These galaxies range in shape from truly spherical to ellipsoidal forms. Because their projection on a photographic plate usually has an elliptical outline, Hubble called this group the "elliptical" galaxies. About 17 per cent of all the brighter galaxies observed fall in this class.

The second class, comprising the majority of the galaxies studied (about 80 per cent), have a spheroidal body at the center, but in them a flat disk surrounds the central body. Spectroscopic observations show clearly that the disk rotates rapidly around the axis of the system. Because the disk usually contains spiral arms, this group are called spiral galaxies. Hubble distinguished three subclasses among the spiral galaxies: the so-called Sa spirals, in which the spheroidal body is so large that it almost envelops the outer disk; the Sb spirals, in which the central system is considerably smaller than the disk; and the Sc spirals, in which the central body has shrunk to a bright kernel of almost insignificant size. A peculiar type among the spiral galaxies are the so-called "barred" spirals, in which the disk has degenerated into a broad bar running through the center, the spiral arms emanating from the two ends of the bar.

The third class are the irregular galaxies, which show no recognizable form or order, except that most of them seem to be flattened. The Clouds of Magellan are typical examples of this class. Only 2 to 3 per cent of the galaxies belong to the irregular group.

Hubble made an extensive photographic survey of all the galaxies in the Northern Hemisphere above a certain brightness, and two important internal differences between spiral and elliptical galaxies emerged. One was the fact that the spiral galaxies as a rule contain large quantities of dust, whereas the elliptical systems rarely do. We shall consider the significance of this observation later. The second observation, which became the starting point for a long and fruitful investigation, was that while the spiral galaxies were easily identifiable as collections of stars, not a single elliptical galaxy could be resolved into individual stars!

Intensive studies were made of the galaxies closest to our own. The Milky Way system is a member of a cluster of 17 galaxies concentrated within a radius of about one million light-years; outside this cluster we have to travel eight million years before we encounter the next spiral galaxy. Nearly all types of galaxies are represented in our local group. For illustration let us consider a set of examples of different types which are all at nearly the same distance from us. An irregular galaxy (IC 1613) and an open, Sc spiral (NGC 598) proved to be easily resolvable into stars throughout their extent; in fact, even a 20-inch telescope resolved the brightest stars in these galaxies. The case of the Great Nebula in Andromeda, a spiral of the Sb type (with a large central spheroid), was quite different. Only the spiral arms of this galaxy were resolvable: in the central body and the regions between the spiral arms no individual objects could be distinguished. Finally, the galaxies of the elliptical type, the two companions of the Andromeda Nebula, were not resolvable at all, in spite of repeated attempts to force their resolution.

What did these findings mean? Evidently, if the unresolved systems were made up of stars, these stars were too

GREAT NEBULA in Andromeda is a spiral galaxy of much the same size and type as our own. The spiral is viewed at a shallow angle to its central plane. Above and below the galaxy in this 48-inch Schmidt-telescope photograph are two much smaller satellite galaxies of the elliptical type (see article on the evolution of galaxies, page 100).

STELLAR POPULATIONS are contrasted in these two photographs of the spiral galaxy NGC 4594, which we see edge on. The photograph at top, made with a red filter, suppresses the bright blue stars in the disk of the galaxy and brings out the red Population II stars which are concentrated around and in the roughly spherical nucleus. The photograph below, made with a blue filter, reduces the brightness of the nucleus and brings out the light of the blue stars formed in the dust and gas that obscure the edge of the disk.

faint to be distinguishable individually by our most powerful telescope at that time—the 100-inch on Mount Wilson. This meant that any stars in the unresolved parts of the Andromeda Nebula, for example, must be at least 100 times fainter than the brightest stars in its spiral arms. Now there were a number of good reasons to believe that the central part of the Andromeda Nebula was made up of stars. One of them was the fact that novae, known to signal the explosion of stars, occur in the central region of that galaxy. What kind of stars might be hidden there? The only clue at the time was that they are at least 100 times fainter than the brightest stars in the spiral arms of the Andromeda Nebula. It was possible to determine the intrinsic, or absolute, brightness of those stars, because the Nebula's distance from us was known. It turned out that the Andromeda Nebula's brightest stars are of the same luminosity as the brightest stars in the surroundings of our sun. Like the brightest stars in the neighborhood of the sun, they are very blue stars. In short, the stellar population of the spiral arms of the Andromeda Nebula is very similar to the population of stars around us.

All this was well known by the early 1940s. It left the stellar populations of the elliptical galaxies and of the central bodies of the spiral galaxies as mysterious as ever. Only this much was clear: the stars were fainter than the faintest objects the 100-inch telescope was then capable of recording. Obviously the problem had to wait until the 200-inch telescope came into operation.

When the outbreak of the Second World War postponed the completion of the 200-inch telescope indefinitely, I decided to try once more at the 100-inch. I knew it would call for every trick of the game. But wartime conditions brought certain advantages: I could get all the time at the telescope I wanted and could thus wait for good observing conditions, and the blackout of the Los Angeles valley restored the dark night sky of the early Mount Wilson days and made it possible to utilize the high sensitivity of modern photographic plates.

The new attempts to resolve the central region of the Andromeda Nebula began in the fall of 1943 on blue-sensitive plates of high speed. In the very last plate of this trial run we found unmistakable signs of a beginning of resolution. No stars had yet emerged, but the formerly smooth appearance of the unresolved area had broken up into a curious patchiness. (As we learned later, this reflected small-scale fluctuations of the underlying star field.)

No further gains could be expected from blue plates, because they had already been exploited to the limit of their sensitivity. The only alternative was to use red-sensitive plates, whose speed had been improved, and long exposures. No marked gain could be expected from the red plates unless the brightest stars in the unresolved systems were red, but luckily one could predict that they must be red indeed. Photoelectric measures had shown that the elliptical galaxies and the central systems of spirals are distinctly reddish in color.

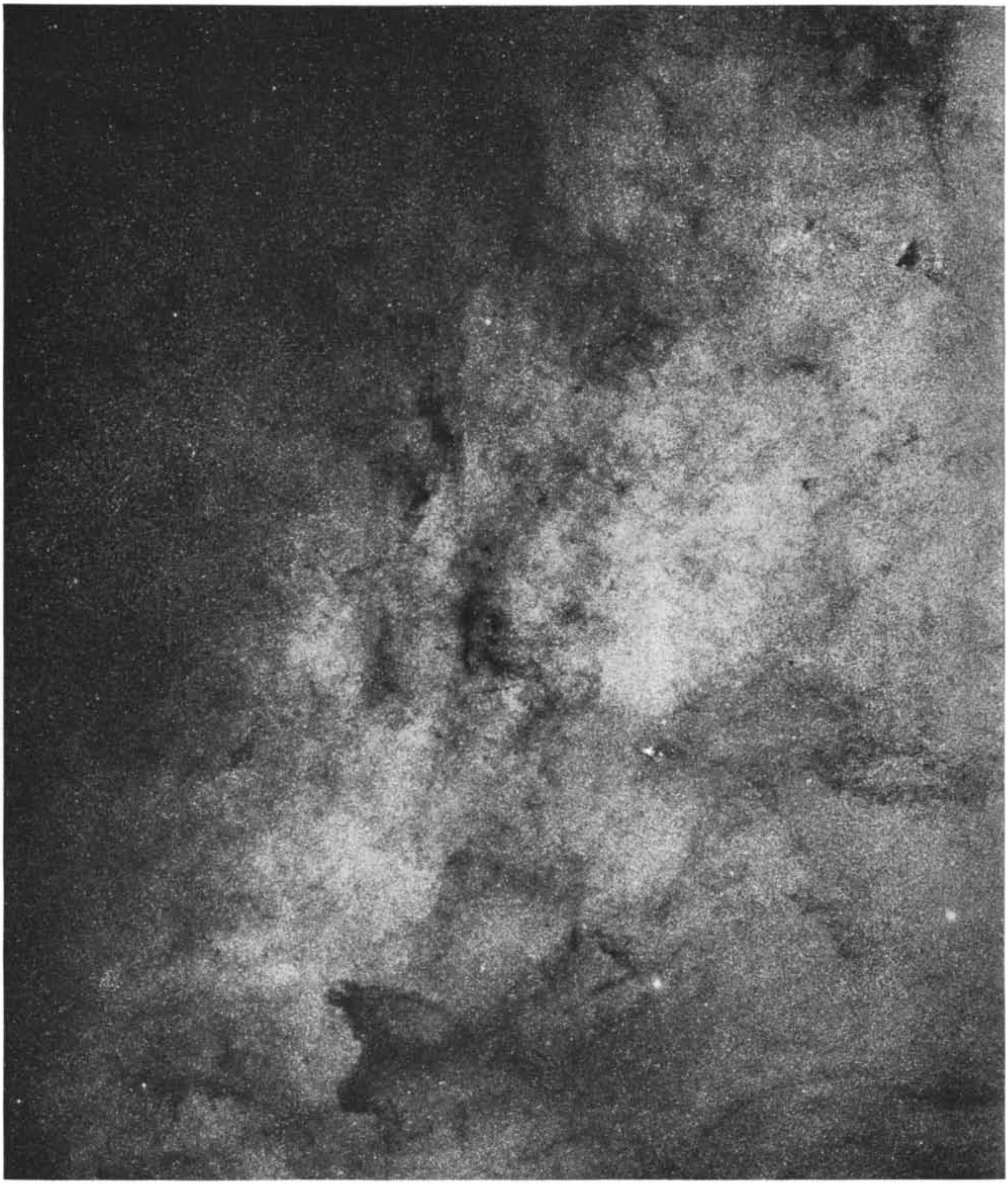
The exposure time necessary to force the resolution of our systems turned out to be four hours. At this point a new difficulty arose. In four hours the focus of the 100-inch telescope may change by a millimeter or more because of the cooling of the secondary mirror, which is exposed to the cold night air. But it was absolutely essential to stay within one tenth of a millimeter of the actual focus, because the star images were certain to be extremely close together. Therefore a method had to be devised to adjust to the focus changes with the prescribed accuracy. Such a method was perfected, and in the fall of 1944 everything was ready for the final attack.

The new campaign was a complete

GREAT GLOBULAR CLUSTER Omega Centauri was photographed with the 33-inch Baker-Schmidt telescope at the Boyden Station near Bloemfontein, South Africa. Globular clusters contain Population II stars and are spherically distributed around center of galaxy.

success. It led in rapid succession to the resolution of the Andromeda Nebula, of its two companions (the elliptical systems M 32 and NGC 205) and of the elliptical galaxies NGC 147 and NGC 185. There could not be the slightest doubt that real resolution into stars had been achieved. Comparison of different plates of the same system showed that for each star present on one plate there was a corresponding stellar image on the other. And indeed, in the elliptical galaxy NGC 205 we actually identified some variable stars (later confirmed with the 200-inch).

What kind of star population emerged on the plates? The brightest stars in the newly resolved systems turned out to be red giants of the same kind as the brightest stars in globular clusters in our galaxy. Exhaustive analysis of several



POPULATION II STARS IN OUR GALAXY are shown in this 48-inch Schmidt photograph of the Milky Way in Sagittarius. The picture indicates the density of stars in the central plain of our galaxy and suggests the difficulty of resolving them in other galaxies.

kinds of evidence made this certain. Furthermore, the elliptical galaxies were found to share another distinctive feature of the globular clusters: they contain many short-period Cepheid variable stars.

Thus it was clear that elliptical galaxies and the central bodies of spiral systems have the same general stellar make-up as globular clusters. Their stars are quite different from those in the neighborhood of our sun and in spiral arms. The latter form a sequence whose brightest stars are blue supergiants; the stars of the globular clusters and elliptical systems are of a class whose brightest members are red giants. The stars making up the contrasting systems could therefore be distinguished into two different populations. They were named Population I (as in spiral arms) and

POPULATION II STARS IN ANDROMEDA NEBULA are resolved in this 200-inch telescope photograph. The brighter round objects and those surrounded by four spikes are stars within our own galaxy. Nucleus of the Andromeda Nebula is toward the left.

EMISSION NEBULOSITY Eta Carinae was photographed with the 33-inch Baker-Schmidt at Boyden Station. Within this object in our own galaxy is a bright star of Population I.

Population II (as in globular clusters).

Obviously all elliptical galaxies are pure Population II systems. In spirals with central spheroidal systems, both populations are present—Population I in the spiral arms, Population II in the central body. In spirals without a large central core and in irregular systems the splash of Population I is so overwhelming that the much less conspicuous Population II is easily obliterated. For a while it was believed, indeed, that the irregular Clouds of Magellan were pure type I systems, but short-period Cepheid variable stars and novae (both Population II types) were found in them. There is strong evidence that all galaxies have at least some Population II.

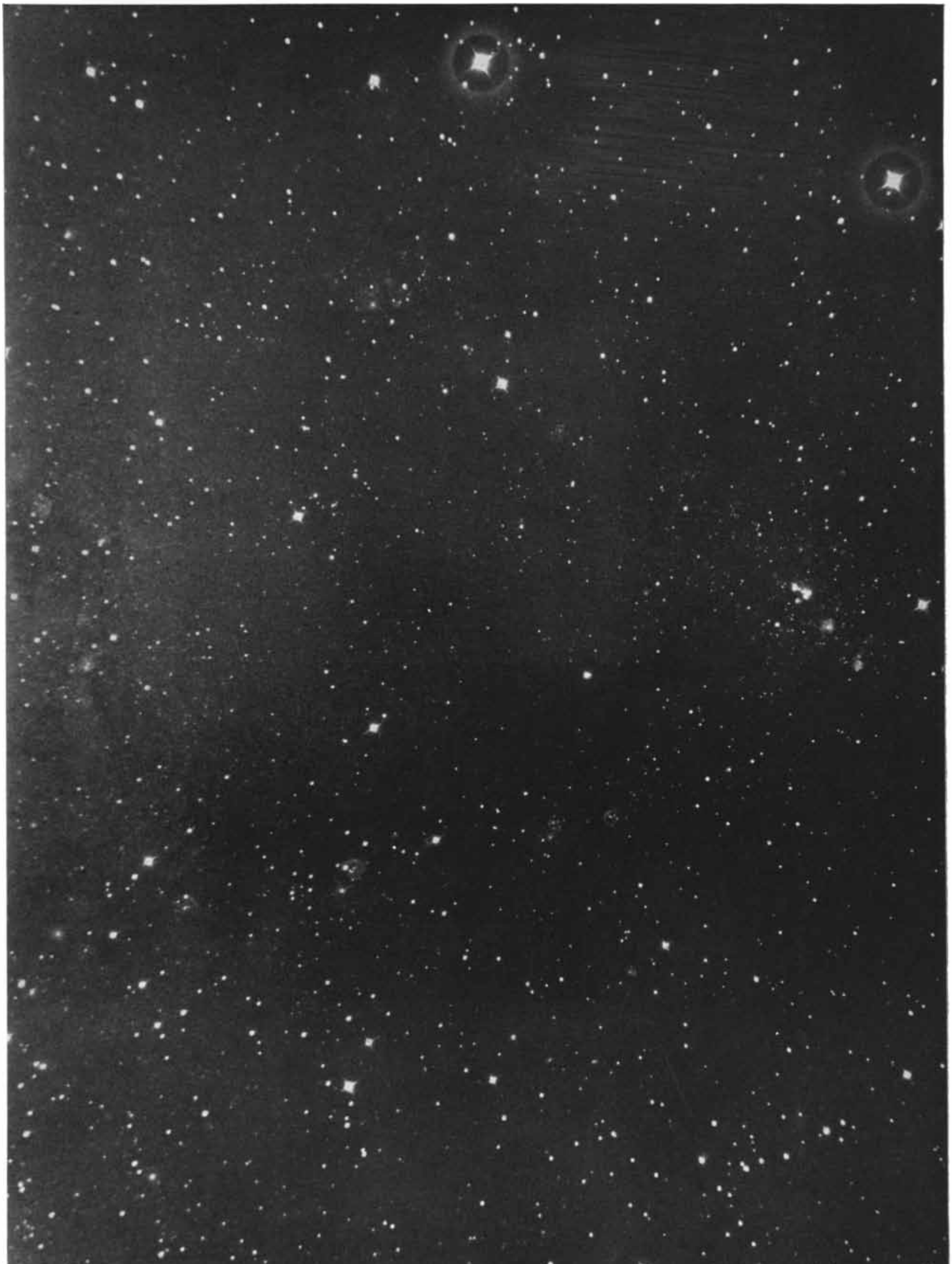
What is this rather inconspicuous but obviously ever-present Population II? The answer is: a population of very old stars, in fact the very oldest of which we have any knowledge so far. They are known to be about five billion years old.

When I examined the first red exposure of the Andromeda Nebula that resolved the central region, I was very surprised to discover two large clouds of luminous gas in a spiral arm which happened to cross the field. I had previously photographed the same region on blue-sensitive plates, and those plates had not shown the clouds. Moreover, Hubble, in his earlier survey with blue-sensitive plates, had been unable to find a single luminous nebulosity in the whole Andromeda Nebula! Obviously blue plates simply fail to detect these objects (called "emission nebulosities"), while red-sensitive plates do. To get a clearer picture of the situation I made a new survey of the Andromeda Nebula on both red and blue plates. The result was the discovery of nearly 700 emission nebulosities on the red-sensitive plates. They show a most striking arrangement—strung out like pearls along the spiral arms. This restriction to the arms is not surprising, because such a nebulosity must be excited by a hot star of the Population I type, and these stars occur, as we know, only in the spiral arms.

The survey confirmed that blue plates register these luminous clouds only faintly if at all. At the same time N. U. Mayall of the Lick Observatory showed by analysis of the clouds' spectra that they emit exactly the same kind of light as do luminous clouds in our own galaxy. There was only one explanation: namely, that the blue part of the light from these clouds in the Andromeda Nebula was heavily absorbed by dust in the Nebula. Dark lanes along its spiral arms confirm the high density of dust in the arms. On the other hand, there is good evidence that outside the arms the density of the dust is much lower. The Andromeda Nebula is surrounded by more than 200 globular clusters. If it were filled with dust throughout, light coming to us from clusters on the farther side of the Nebula would be heavily reddened. No reddening comparable to that in the emission nebulosities has been found in these clusters. The few heavily reddened globular clusters found in the Andromeda Nebula are located in the spiral arms.

Altogether there are good reasons to believe that the most basic feature of the structure of spiral galaxies is the dust and gas in their arms, and that the Population I stars represent a secondary phenomenon. To put it differently: it is the dust that makes the stars, and not *vice versa*. The nuclear processes responsible for the energy of stars offer a very cogent argument in favor of this conclusion. The hot stars of the spiral arms burn their fuel so fast that their lifetime hardly can exceed 50 to 100 million years. The continued presence of such stars in spirals wherever we look means that burned-out stars must be continuously replaced by new ones. During the last few years investigation of the so-called "stellar associations" of our own galaxy has made us acquainted with whole groups of young stars barely older than a few tens of millions of years. All are typical Population I stars. There cannot be the slightest doubt that all Population I stars are young stars, cosmically speaking.

We are now able to outline in bold strokes at least a part of the history of the galaxies. Some five billion years ago there was a big burst of star formation in all galaxies. In the spheroidal galaxies, which rotate slowly, apparently all the available dust and gas were formed into stars at that time, for we find in them today only old (Population II) stars. (That their supply of dust and gas is largely exhausted is documented by Hubble's finding that cosmic dust is exceedingly rare in elliptical galaxies.) In all rapidly rotating systems, which had flattened into disks, only part of the dust and gas was converted into stars. The remaining part formed the spiral structure of the disk and has produced stars ever since.



EMISSION NEBULOSITIES in the Andromeda Nebula appear in this photograph made with the 100-inch telescope on Mount Wilson. The nebulosities are fuzzy objects about an eighth of an inch across. Three are near the right edge of the picture halfway from the top.

IRREGULAR GALAXY is represented by the Large Cloud of Magellan. This galaxy is one of the two nearest our own; the other is the Small Cloud of Magellan. The photograph was made with a wide-field 10-inch telescope at the Boyden Station in South Africa.

The Evolution of Galaxies

They have various forms: irregular, elliptical, spiral and barred spiral. The study of these structures, including that of our own galaxy, has led to a theory of their descent from a primordial gas

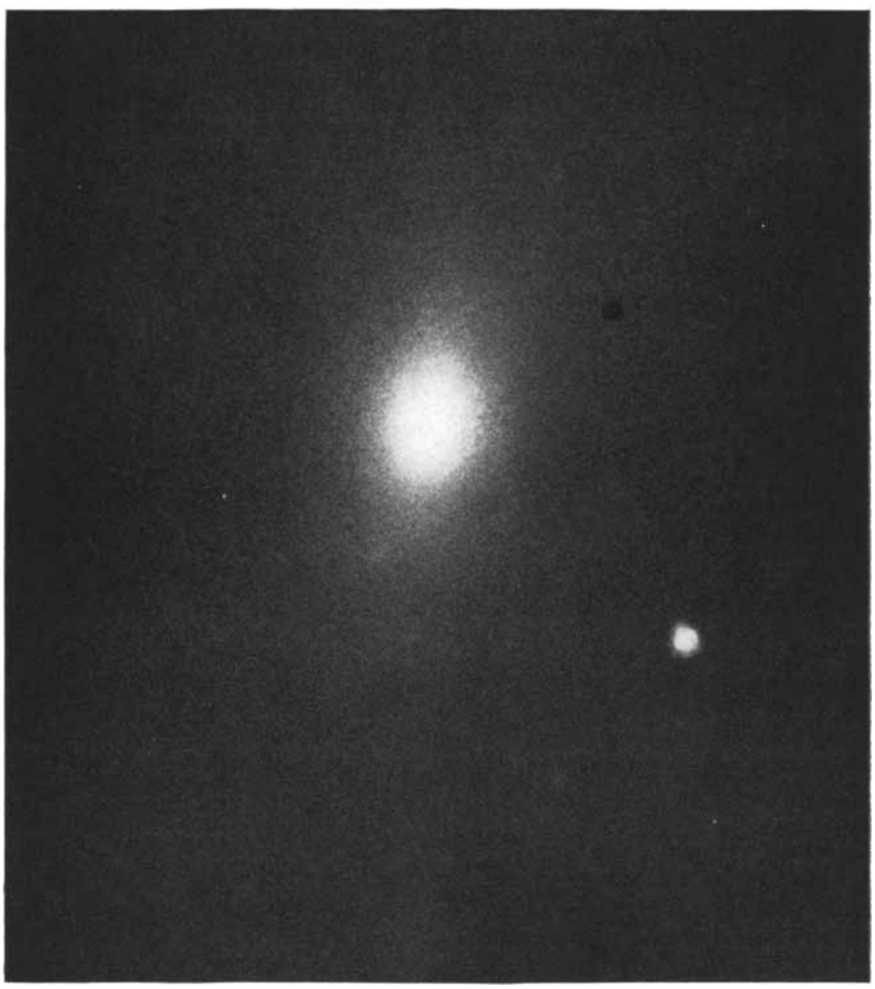
by Jan H. Oort

Surveying the galaxies in the heavens, astronomers in the past couple of centuries have been in a position like that of a lookout watching the approach of an armada of strange objects. The objects came into view first as dim, fuzzy forms ("nebulae"). As more powerful telescopes brought them closer and closer, they were identified as collections of stars, then distinguished into systems of varied shapes and types; today we can resolve the details of internal structure in many of them. With this clearer view of other galaxies, man has acquired a new perspective on the galaxy in which he lives—the Milky Way—and can begin to speculate intelligently about the origin and evolution of galaxies in general.

Several thousand galaxies (of the billion or so visible with present telescopes) are close enough to show details of their structure. They vary widely in shape and texture. At one extreme are chaotic, mottled-looking systems which have been named "irregular" galaxies; at the other are perfectly smooth, symmetrical systems called "elliptical galaxies." Between these extremes is a great variety of systems not entirely regular and yet not quite chaotic; most of them, including our own Milky Way, have a spiral structure with wide-flung arms encircling the central nucleus of the galaxy. The majority of galaxies examined are spirals. Elliptical systems make up roughly 20 per cent of the total and the irregular systems comprise some 2 or 3 per cent.

On its face, this general picture suggests that the evolution of galaxies may proceed from the irregular through the various spiral types to the smooth, elliptical form as the final stage. But when we look at the picture in detail it becomes difficult to see how the spiral systems could evolve to the regular, more or less globular shape of the elliptical galaxies. This article will present a theory attempting to explain the evolution of spiral and elliptical galaxies.

The spiral galaxies are particularly intriguing, for a number of reasons. We shall consider their structure in detail, with the help of the accompanying photographs illustrating their varying features and forms. Galaxies are usually identified by number, prefaced by initials for the source from which they got their names. The brightest have the ini-



ELLIPTICAL GALAXY NGC 4621 was photographed with the 200-inch telescope. Elliptical galaxies are characterized by their symmetrical mass of stars and lack of dust and gas.

SPIRAL GALAXIES are shown more or less face-on in the four photographs at the top of these two pages. At left is NGC 7217, a galaxy of Type Sa: spirals with tightly wound arms. Second from left is NGC 3031, a galaxy of Type Sb: spirals with less tightly

tial M (*e.g.*, M 51) for Charles Messier, the French astronomer who listed the 103 brightest nebulae in 1784; many of the fainter ones are designated by NGC, for the New General Catalogue of the Danish astronomer John L. E. Dreyer, which was based largely on discoveries of nebulae by the 18th- and 19th-century English observers William and John Herschel—father and son—who pioneered the study of galaxies.

The spirals take many forms. Some have two principal arms, stemming from opposite sides of the core of the galaxy [*see photographs above*]. Sometimes the galaxy has a large, smooth central mass, like an elliptical galaxy, with spiral arms wound tightly around it. About 30 per cent of the spiral systems are so-called "barred spirals"—formations of bars across the central region with spiral arms projecting from their ends in various circular or open forms.

Practically all the spiral galaxies possess an important feature in common: they have a flat, wheel-like shape

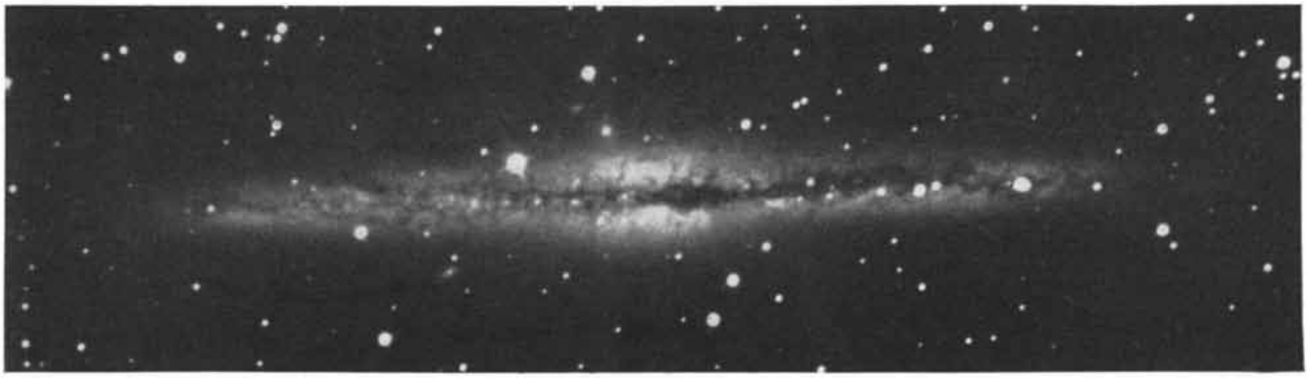
SPIRAL GALAXIES PHOTOGRAPHED EDGE ON reveal their characteristic thin cross-section and central disk of dust and gas. This obscuring material is responsible for the dark lane against the bright background of stars in the two galaxies at the bottom of

wound arms. Third is NGC 5194, a galaxy of Type Sc: spirals with still more loosely wound arms. The blob at the bottom of this picture is actually NGC 5195, a companion of the larger galaxy. Fourth is NGC 598, another galaxy of Type Sc with arms more open.

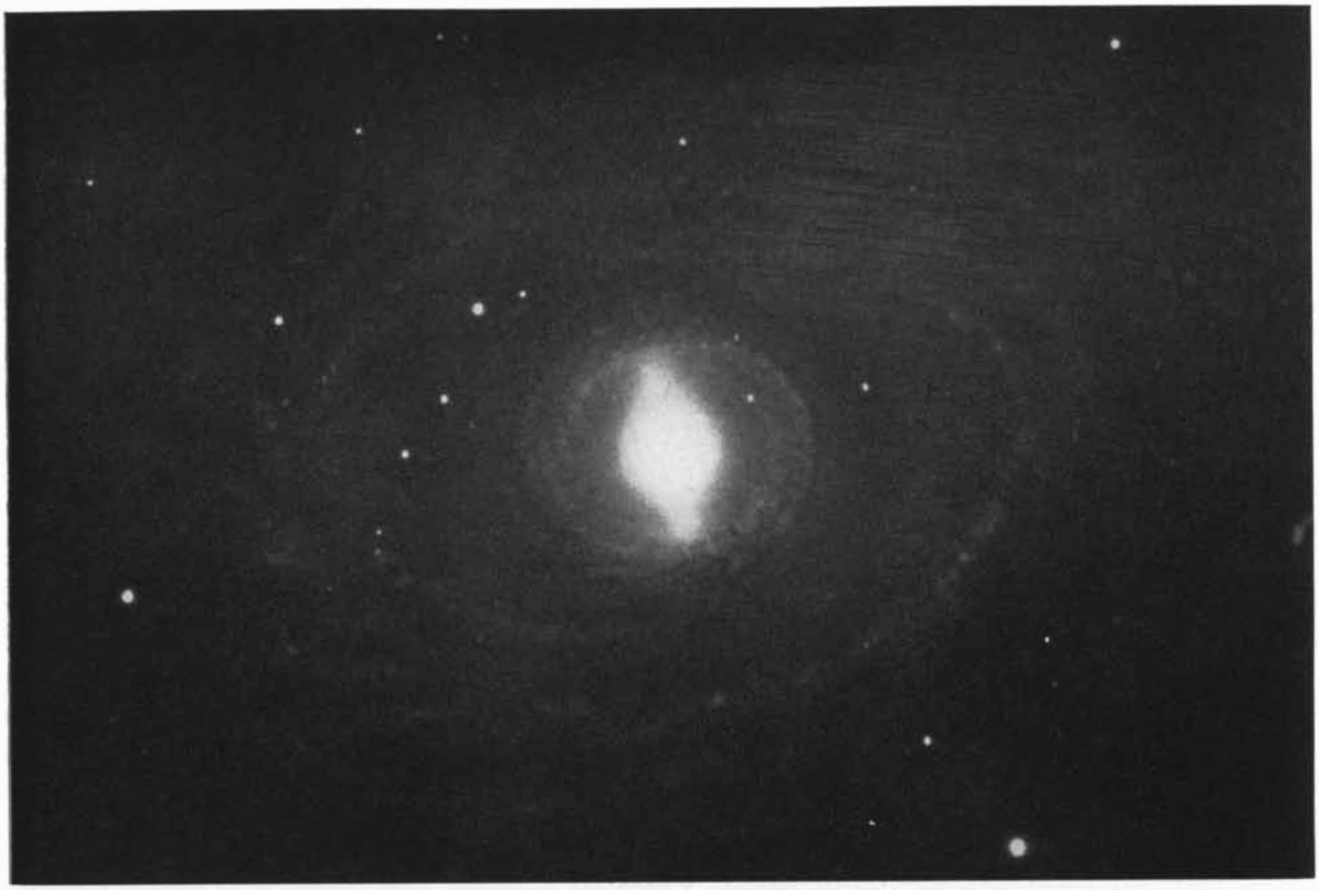
and the arms lie in this plane. This flatness is clearly evident in spiral systems that we see edge on [*see below*]. The most striking example of all is our own galaxy: it is a disk some 80,000 light-years in diameter from edge to edge but only about one hundredth of that distance in thickness.

The spiral galaxies have another common characteristic. Like the irregular galaxies (but unlike the elliptical ones) they all have great clouds of gas. Their spiral arms show bright patches that can be identified as luminous gas; besides this we can detect many clouds which, though cool and invisible, betray their presence because they contain dust and block light. Dark bands and streaks defining such clouds appear in spiral galaxies seen edge on and along the arms of spirals seen face on [*see photographs below and picture of the Milky Way on page 106*].

During the past four years the clouds of gas in our own galaxy have been mapped from our station in the Netherlands by means of radio receivers trac-



these two pages. At left is NGC 4565, a galaxy of Type Sb (*see photographs at top of pages*). At right is NGC 891, a galaxy of Type Sc. In the latter type the disk is less regular. All the photographs on these two pages were made with the 200-inch telescope.



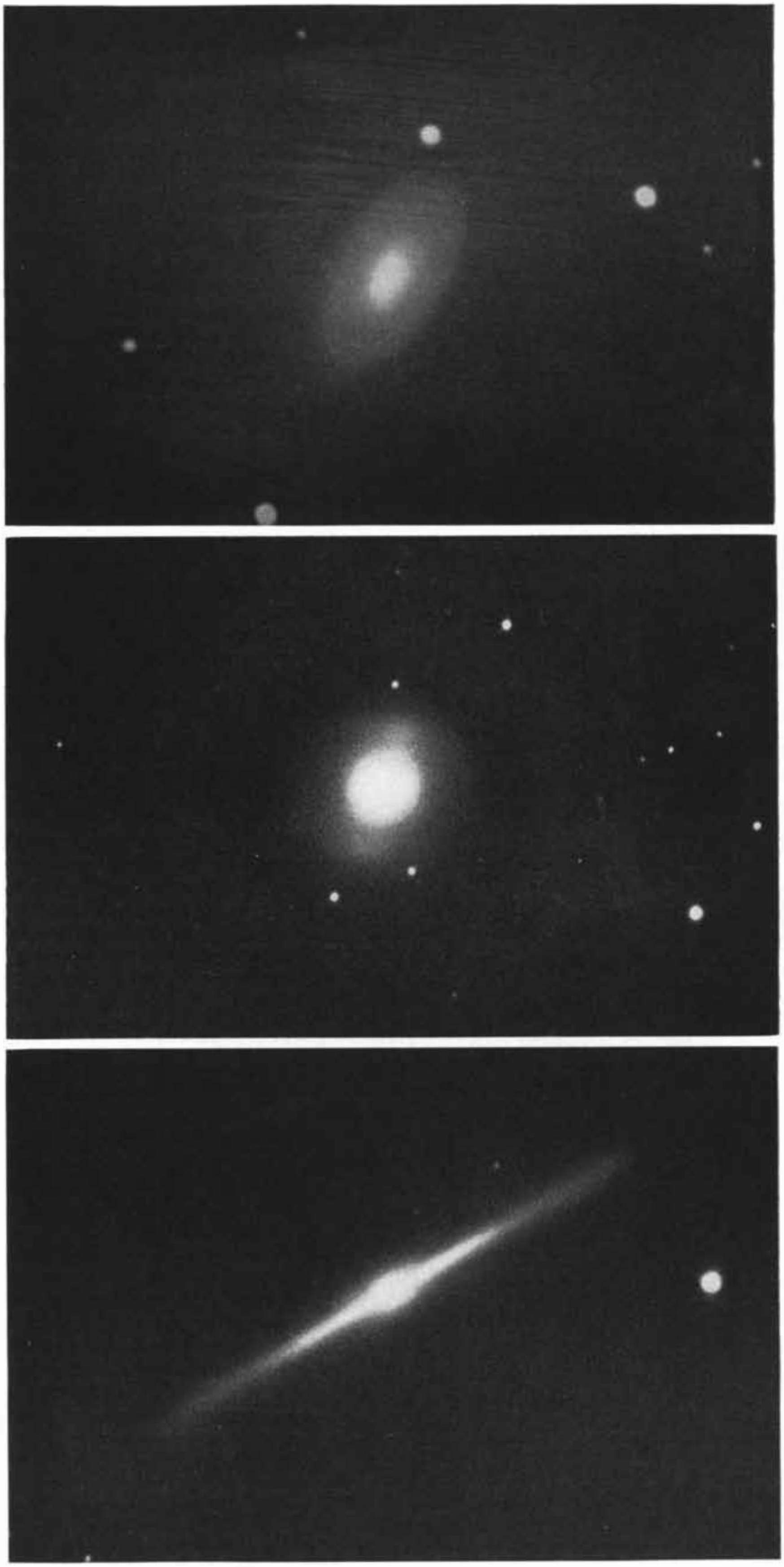
BARRED-SPIRAL GALAXIES were also photographed with the 200-inch. At the top is NGC 1398, a galaxy of Type SBa: a barred spiral with tightly wound arms. At the bottom is NGC 1300, a galaxy of Type SBb: a barred spiral with less tightly wound arms.

ing the 21-centimeter radiation from hydrogen gas in the clouds [*bottom of page 107*]. Most of the clouds are confined to a thin, flat section along the central plane of the Milky Way; in fact, the faint luminescence of the Milky Way comes from distant star clouds in this thin layer. As the map shows, the gas is not spread evenly throughout the plane but rather is concentrated in long lanes. There cannot be much doubt that these lanes define spiral arms, such as we see in other galaxies. The spacing between the lanes (roughly 6,000 light-years) is a measure of how tightly the spiral arms are wound around the core of the galaxy.

These observations confirm what studies of other galaxies have led us to suspect: namely, that the interstellar gas in spiral systems is largely concentrated in the arms. The radio measurements also tell us a good deal more. They prove that the galaxy is rotating around its center, and that the arms are trailing. And from the Doppler effect on the wavelength of the 21-centimeter radiation we can calculate the speed of rotation of different parts of our system. It turns out that the galaxy is not turning uniformly around the center. Our own solar system and its neighbors, for instance, take about 230 million years to make a complete revolution around the center of the galaxy, but the stars and clouds nearer the hub (at half the distance from us to the center) travel around it in only 120 million years.

The measurements of speeds of motion in the galaxy give us important information on the dynamics of the system, which in turn has a crucial bearing on the galaxy's origin and evolution. The velocity of rotation indicates the strength of the centrifugal forces acting on the spiral arms. Since the centrifugal force must be balanced by gravitational force in any system that holds together, the rotational velocity also gives us a means of estimating the mass of the galaxy as a whole and of its various parts. The total mass of our galaxy turns out to be 70 billion times that of the sun. Of this total about 94 per cent is accounted for by the stars and only about 6 per cent by the interstellar gas.

The arms of the spiral galaxies have always been a major enigma. How can they keep their form and structure as the galaxy whirls rapidly in space? One would suppose that the shearing effect due to the differing rates of rotation of different parts of the galaxy, as well as internal motions within the arms themselves, would wipe out the arms be-

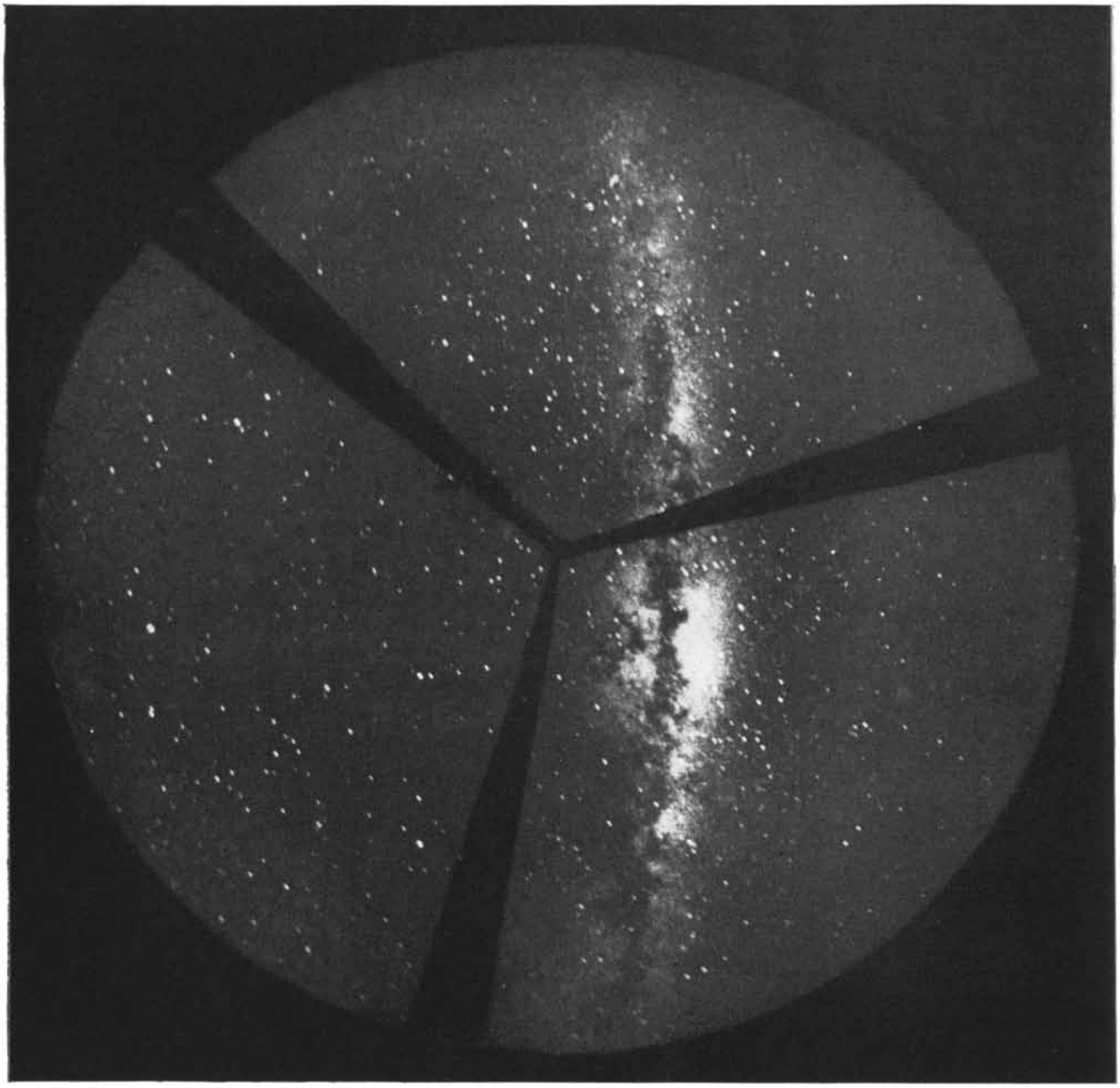


UNUSUAL GALAXIES of Type SO have the outline of spirals but no dust and gas. At the top is NGC 1553, photographed with the 74-inch reflecting telescope in Pretoria, South Africa. Second and third from top are NGC 2859 and 4762, photographed with the 200-inch.

fore the galaxy had made many revolutions.

It seems unlikely that gravitational attraction alone could form an immense, tenuous arm of this kind or hold it together. To explain the existence of the spiral arms we must look to other forces, and, as we shall see, these forces involve the clouds of gas in the arms.

There is another striking feature of the structure of spiral galaxies that must be explained by any theory of their origin and history. As Walter Baade has explained in the preceding article [*page* 92], spiral galaxies are made up of two types or "populations" of stars: Population I consists of supergiant blue stars and gas clouds; Population II is distinguished by red giant stars and contains little gas. Now these populations have very different distributions in the galaxy. Population I is concentrated within a thin, flat disk extending over the plane of the galaxy. Stars and clusters of the Population II type, on the other hand, have an almost spherical distribution in the galaxy and are strongly concentrated toward the center [*see page 103*]. There are classes of Population II stars which, like Population I, are



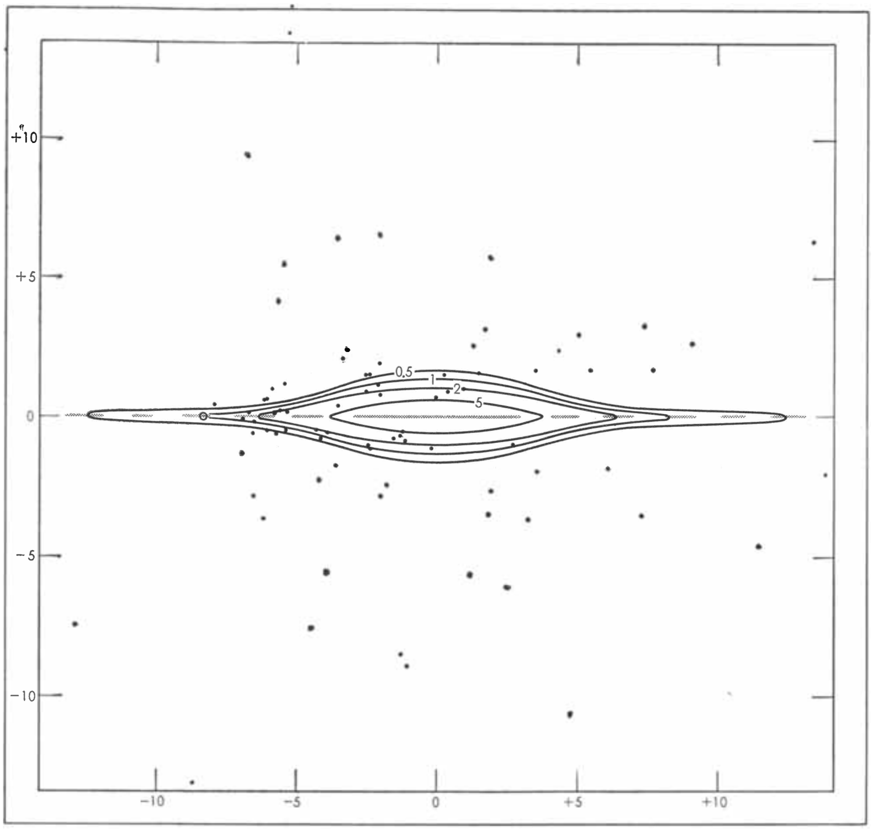
SOUTHERN MILKY WAY was photographed with a special Yerkes Observatory camera which covers 140 degrees of the sky in one exposure. The dark lane running down the middle of the bright area strikingly resembles those in the photographs of spiral galaxies at the bottom of pages 102 and 103. In short, the photograph shows our own spiral galaxy from the edge! Although the sun and the earth are about two thirds of the way from the center of the galaxy to the edge, a wide-angle camera pointed toward the center views it much as it might be seen from extragalactic space. This photograph was made with an emulsion sensitive to infrared radiation in order to penetrate nearby interstellar dust clouds. The dark spokes in the picture are the supports of a camera which photographs the image of the sky in a concave mirror. The photograph was made by A. D. Code and T. E. Houck of Washburn Observatory.

found only within a flat disk in the plane of the galaxy (we call them "disk Population II"), but these stars, unlike the irregular Population I, have a smooth distribution and are densely concentrated around the center.

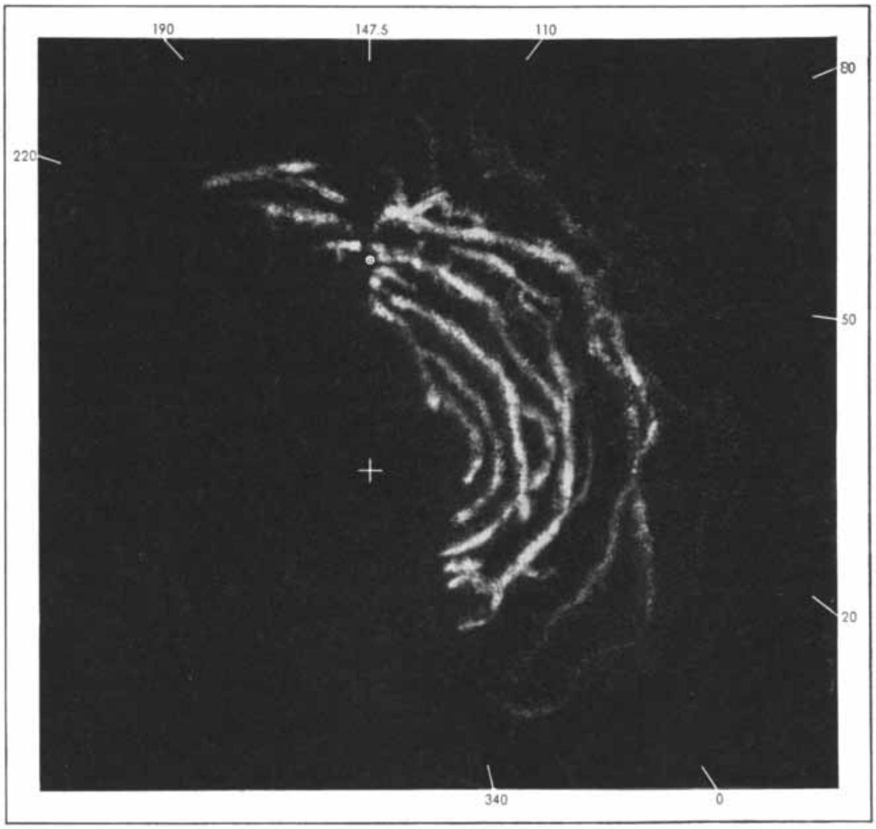
How are we to explain this curious coexistence of different populations, distributed in very different patterns, within a galaxy? This question, and the others we have already considered, can be answered if we postulate the following theory of the origin of the various types of galaxies.

Let us suppose that the universe consisted at first of a thin, expanding gas, denser in some places than in others. At a certain stage in the expansion of the universe the internal gravitational force in some of the denser regions apparently became sufficient to overcome the velocity of expansion with which all matter had been endowed from the beginning. These aggregations of matter detached themselves from the rest of the universe, began to develop as independent units ("protogalaxies") and thus set off on the road to becoming galaxies. The protogalaxy was an irregular mass with large-scale random internal motions (as well as smaller turbulences); but for our lump of universe to stay together, the gravitational pull of the whole lump on its separate parts had to be strong enough to overcome the original relative velocities. After a time the mass of gas started to contract under the influence of this gravitation. As the gas currents collided and intermingled, some of their energy of motion was converted to heat, which was radiated away. The slowing of the gas's motions made it possible for the system to contract further, and at the same time to even out its irregular shape.

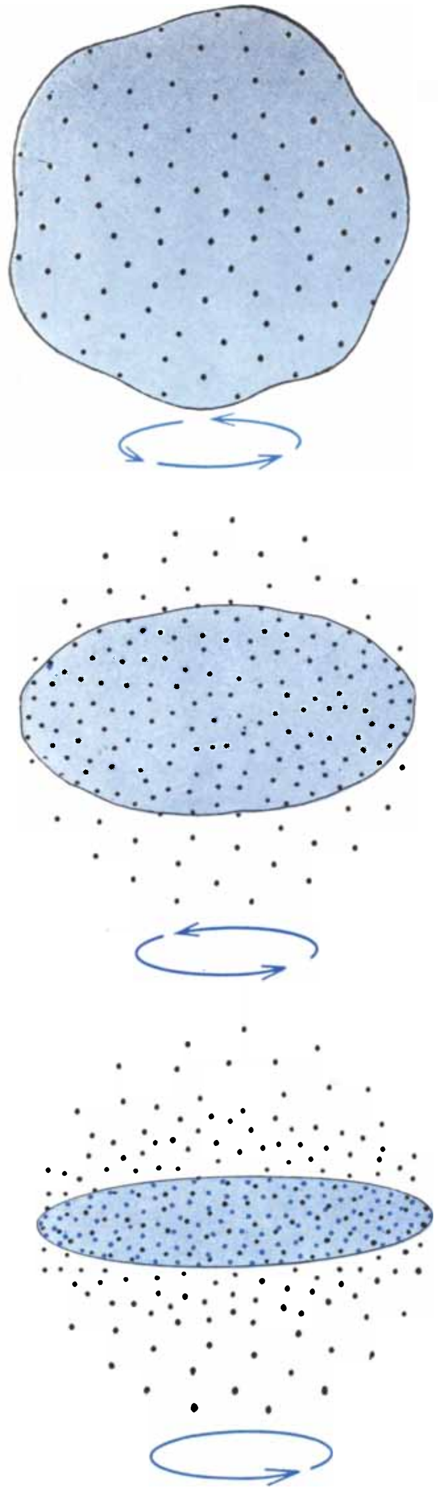
If these processes of contraction and loss of energy through radiation had continued indefinitely, our protogalaxy might have ended up as a small and very dense mass of gas. But two factors set a limit to the contraction. First, some of the denser lumps of matter within the mass contracted more rapidly than the rest and condensed into stars. The birth of stars put an end to contraction, because the stars, being much smaller than gas currents or clouds, no longer had much chance of colliding and losing energy of motion. The second limit on contraction would develop from rotation of the system. A system formed in the way we have described would inevitably start rotating as a result of the intermingling of currents in the original gas—



EDGE-ON DIAGRAM of our galaxy locates the sun in the small circle at left. The contours roughly indicate the space density of stars in terms of the density near the sun. The thin gray line represents dust and gas. The dots are globular clusters of old stars projected in the plane of the page. The scales are in kiloparsecs. One kiloparsec is 3,260 light-years.



PARTIAL FACE-ON DIAGRAM of the galaxy is based on 21-centimeter radio waves emitted by interstellar hydrogen. The light areas trace the hydrogen and thus the spiral arms.



SPIRAL GALAXY MAY EVOLVE according to this scheme. In the beginning was a thin, expanding gas. A protogalaxy broke away from it and began to rotate (*top*). A few stars (*black dots*) may have condensed out of the gas at this point. As the protogalaxy rotated faster, it flattened out, leaving the old stars behind (*middle*). It finally flattens into a thin disk (*bottom*), out of which hot new stars condense (*colored dots*). The old stars, notably red giants, are Population II. The new stars, many of which are blue giants, are Population I. The size of the stars is greatly exaggerated.

as an eddy forms when currents of water meet. Now as the system contracted, its rotation would speed up through the conservation of angular momentum (just as a whirling skater turns faster when he pulls in his arms). The increase in rotational velocity would increase the centrifugal force. Eventually, when the centrifugal force came to equal the gravitational attraction, the system would cease its contraction in the plane of rotation. However, in the plane perpendicular to this (*i.e.*, the plane through the poles of the spinning system) contraction would continue. Thus we would end up with a disk-shaped galaxy.

We can now see an explanation of the great differences between the disk-shaped spiral galaxies and the more globular elliptic galaxies. A protogalaxy which started with considerable rotation (high angular momentum) would spin out to a disk shape and, because its contraction in the plane of rotation was severely limited, would never become very dense and would be left with a great deal of uncondensed gas, especially in its outer parts. On the other hand, a system that started with little rotational momentum could contract far more in the plane of rotation; thus it could become extremely dense and ultimately might condense almost completely into stars, forming a smooth, dense ball—*i.e.*, an elliptical galaxy.

We can also understand the two-population structure of our own galaxy. The Population II stars and globular clusters of stars must have been born in the earliest stages of the protogalaxy's evolution; they may even have been in existence before the protogalaxy detached itself as a separate system. This swarm of stars could not contract to a disk. In the course of time the originally chaotic swarm became a regular, spherical group, concentrated toward the center. In the disk part of our galaxy, on the other hand, stars condensed only after the disk itself had been formed by the contraction and flattening of the gas clouds. The earliest stars formed in the disk are now so old that we identify them as of the Population II type (disk Population II). In the huge, more or less homogeneous disk of gas that remained, the younger Population I stars were formed as time went on and are still being born at the present time.

We are still left with the problem of accounting for the spiral arms. Some have suggested that the arms developed from close encounters between galaxies, which drew out the long arms by tidal force. However, such encounters are too rare now to account for all the spiral systems we see, and even if we assume that they occurred frequently in an early stage of the universe, there are serious objections to this theory. One thing is clear: the spiral structure depends on some property of the interstellar gas—without clouds of gas there can be no spiral arms. This has been interestingly confirmed by the observation of Baade and Lyman Spitzer, Jr., that spiral systems are rare in dense clusters of galaxies. Presumably the galaxies in such clusters interpenetrate one another occasionally, and in so doing remove the gas [*see following article, page 125*].

The answer to the enigma of the spirals probably will come from more thorough study of the spiral arms in our own galaxy, which have just begun to be explored. They have already presented us with some new and difficult questions. One of the most challenging has to do with the fact that at a point halfway between us and the center of the galaxy the arms are rotating around the center with about twice the speed of their rotation in our neighborhood, out near the galaxy's rim. This differential rotation should be winding the arms more and more tightly around the core, and it can be calculated that under such conditions spiral arms could not survive for more than a few hundred million years. In view of the fact that a majority of the galaxies we observe are spirals, the spiral structure must have a longer duration than this small fraction of the lifetime of a galaxy. We can only suppose that some compensating process is at work building up the arms while the rotation pulls them in. Perhaps one side of an arm collects material while the other side evaporates it, so that the arm holds a constant position. Calculations indicate that the arms may be maintained in this way by the same mechanism thought to be responsible for the internal motions in interstellar gas.

The new view of the origin of the galaxies gives us, among other things, a new perspective on the conditions existing in the universe when the galaxies were first formed. It should enable us to deduce, from the present nature and behavior of the galaxies, something about the density and motions of the matter in the universe at that far-off epoch.

Kodak reports to laboratories on:

how far we've come from camphor . . . a small chance of opening a tremendous door . . . a better chance of getting through to the besieged brain . . . coloring a mental image

Soft vinyl, soft arteries

At this year's National Plastics Exhibition we exhibited the latest triumph in the continuing effort to find something more elegant than burning to do to the hydrocarbon gases that issue from holes drilled in the ground. Perhaps an important new direction has been given to plasticizers, substances that make plastics plastic.

The new twist is a practical plasticizer that is itself a high polymer (molecular weight about 1200). To him who first cries "So what?" we retort that our new polyester of a dibasic acid with neopentyl glycol (a trivial name for 2,2-dimethylpentane-1,3-diol, made by condensing formaldehyde with isobutyraldehyde from our Texas petrochemical operations) resists hydrolysis and stays put in vinyl films, come weather, aggressive hydrocarbons, or soapy water; that with no auxiliary plasticizer it keeps vinyl sheet palely clear and softly flexible, even at low temperature; and that it "mills in" rapidly during compounding with vinyl resins.

Eastman Polymeric Plasticizer NP-10 *it is designated. Samples, data, and quotations are available from Eastman Chemical Products, Inc., Kingsport, Tenn. (Subsidiary of Eastman Kodak Company). To come up with something like this is a comfort because it suggests that a corporation can attain venerability in a field, unaccompanied by hardening of the arteries. More than 70 years ago, when we became involved in an attempt—successful—to extend photography from plates and paper to film, nitrocellulose was the only plastic and camphor was its plasticizer.*

Little black tracks

In an article, "The Tracks of Nuclear Particles," *Scientific American* a few months ago sketched the valiant attempts of the world's physicists to plumb the cosmic meaning of the microscopic tracks left in photographic emulsions by nucleons, leptons, mesons, and hyperons. The reader was assumed without background in the subject but blessed with a vigorous, inquiring mind. As parent or teacher, you may know some youngster for whom this article might open a tremendous door. Small as the chance is, we have thought it worth while to buy reprints to give away. One may be obtained from Eastman Kodak Company, Special Sensitized Goods Division, Rochester 4, N. Y.

Movies with comment

As between 55 pages of typescript to detail the progress on a certain project for last month and six minutes of Kodachrome movies to do the same, which has the better chance of getting through to the besieged brain?

Since you can't say everything without words and since you have to be quite rich to afford a full-dress sound movie that is looked at once or twice and filed for the record, you use a magnetically recorded commentary. At the time we process the film for your dealer (and you can, if you wish, specify us as your favorite processor of Kodachrome Film), we can lay down a *Kodak Sonotrack Coating* along the edge.

While the *Kodascope Magnetic-Optical Sound Projector* shows the picture, appropriate extending remarks are spoken into the microphone. Any remarks that seem less than appropriate when the projector plays them back with the picture have merely to be respoken. Automatically the boo-boo is wiped clean and replaced by wiser words.

This projector we have just brought out now. We hadn't thought it wise to take anybody's money for such a machine until enough organizations had used our design without trouble and had liked the way it sounds.

From Eastman Kodak Company, Cine-Kodak Equipment Sales, Rochester 4, N. Y., one may expect an honest attempt at collaboration on sensible procedures for using inexpensive sound movies in technical communication and documentation.

"I have a photo here"

You will find within the next couple of years that the mental image created by the word "photograph" will have altered. To think of a photograph as a piece of paper bearing a representation in tones of black, white, and grey will be like calling a man who flies an airplane an aviator or picturing a professor as bearded —perfectly proper but no longer general. The photographs that you file as records of work and observations and the photographs you pull out of your billfold at postprandial bull sessions will, in general, be in full color.

Here is what has been happening:

1) This year a new *Kodacolor Film* came out. It is as sensitive as the popular variety of black-and-white snapshooting film used to be not so long ago. It works equally well for daylight and clear flash without filters. It gives negatives from which can be made color prints and enlargements that you look *at*, not through.

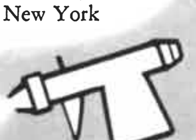
2) There is now a *Kodak Color Print Material, Type C.* Prints made on it from Kodacolor negatives have the same color quality as used to be obtained only through vastly more involved techniques.

3) Processing chemicals for both the film and the print material are available in kits from all Kodak dealers. Quality of results tends to run commensurate with the degrees of care, zeal, and skill generated by the worker's needs or the hobbyist's self-fulfillment urge.

4) The fellow who, during the Great Depression, had some "Films Developed, Printed, and Enlarged" signs printed and placed in drug stores around town no longer operates from his kitchen. For the convenience of those who would just as soon not do it themselves, he has gone into color. To compete on both quality and price he finds it wise to own *Kodak Color Densitometers* and the like. His plant manager comes to Rochester for brush-up courses. He has met and mastered a complex technology, and he is determined to convince you that its product has it all over the monochromatic view of things.

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

Kodak
TRADEMARK



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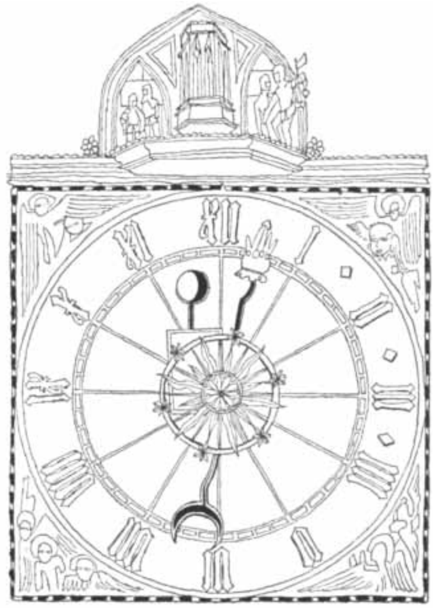


Nuclear Training Facilities

A major problem in the development of atomic energy is a lack of properly trained scientists and engineers. Full-fledged curriculums in nuclear engineering are extremely scarce; schools have neither qualified teachers nor adequate laboratory equipment. Citing the "critical shortage" of personnel, the Atomic Energy Commission has asked that Congress authorize it to arrange for the conduct or support of educational activities.

Only two universities now have operating reactors, the Commission said. Very few have such other equipment as subcritical assemblies (simulated reactors which contain too little fissionable material to sustain a chain reaction), heat-transfer loops, metallurgical equipment suitable for working with uranium and thorium or "hot labs" for handling highly radioactive materials. "None have the complete facilities which we believe to be necessary adequately to train engineers in the atomic energy industry," the AEC concluded.

The two universities that already have reactors are Pennsylvania State and North Carolina State. Before the end of this year, according to a recent survey by *Chemical and Engineering News*, there will also be reactors for research and training at the University of Michigan, Battelle Memorial Institute and the Armour Research Foundation. Next year two more will be finished at the University of Buffalo and the Massachusetts Institute of Technology. The cost of these devices ranges from $300,000 to $2.4 million. At least half a dozen other universities have already announced plans to acquire reactors. Some of them may install an inexpensive unit developed at the Argonne National Laboratory. Called the "Argonaut" (Argonne Nuclear Assembly for University Training), it will cost less than $100,000.

A much more modest installation is represented by the $5,000 "pickle barrel" at New York University. It is simply a three-foot tank containing two tons of natural uranium rods. This represents less than a critical amount of fissionable material. When supplied with neutrons from the outside, the device operates at a power level of one 300th of a watt.

Also available are simulated reactor controls. Leeds & Northrup makes a trainer which will mimic several types of reactors. Virginia Polytechnic Institute has bought the first one for $12,600.

To encourage the expansion of nuclear engineering education, the AEC has invited representatives of 150 colleges and universities to a conference at Gatlinburg, Tenn., early this month. The presidents and deans of engineering of these schools will discuss recent developments in the field and will hear about the Commission's educational and training program.

British View of Radiation

The British Medical Research Council released its own summary of radiation hazards simultaneously with the report of the National Academy of Sciences (see "Science and the Citizen," August). Although the two reports agreed in most details and reached virtually the same conclusions, public reaction in the two countries has differed considerably.

Most U. S. commentators seemed reassured by the Academy's estimate that the fallout of strontium 90 from weapons tests had added only a negligible amount of radioactivity to the atmosphere. The British press, on the other hand, was alarmed by the same figures. *New Statesman and Nation* declared this section of the report to be "the writing on the wall. Statesmen will ignore it at our peril." The publication said the report shows that persistent weapons testing will "raise to a danger point the amount of radiostrontium stored in the world's atmosphere."

The Times Weekly Review endorsed

the rationing of weapons testing but expressed doubt that nations could reach agreement on the subject. "The danger is that rationing will always be supported by the power that believes itself to be temporarily in the lead and opposed by those which hope by the next experiments to catch up."

The Economist took issue with Prime Minister Anthony Eden's decision to carry out next year's hydrogen bomb tests as scheduled. "Britain's aim seems to be to get its own series of tests over and done with before any rationing system enters into force. This sets a bad example to other countries and may well make it more difficult to reach an agreement."

Ph.D. Production

The National Research Council has ended a 10-year study with the publication of a 158-page book which tells where U. S. scientists earned bachelor's and doctor's degrees between 1936 and 1950. The survey was headed by M. H. Trytten, director of the Office of Scientific Personnel.

The study compares two intervals: from 1936 through 1945 and from 1946 through 1950. In the first period Cornell University led in the production of science doctorates with 851; the University of Wisconsin was second with 828. In the second period the two universities changed positions; Wisconsin awarded 689 Ph.D.'s in science; Cornell, 559. The Massachusetts Institute of Technology, which had ranked only tenth during 1936-1945, jumped to third in the period 1946-1950.

The University of California consistently retained the highest proportion of graduates from its own colleges as graduate students: 36.3 per cent of its Ph.D.'s during 1946-1950 had done their undergraduate work at the University.

Trytten is now preparing to publish similar figures on doctorates awarded since 1950.

Idle Isotopes

Some 700 of the known radioactive isotopes are at least potentially valuable for medical diagnosis and therapy. Yet up to now only four—phosphorus 32, cobalt 60, iodine 131 and gold 198—are in general medical use, Lee Edward Farr of Brookhaven National Laboratory told the American Chemical Society's Fifth National Medicinal Symposium in East Lansing, Mich.

It is not that physicians are unwilling to use radioactive isotopes, Farr believes, but just that they do not know how to use many of them and are uncertain about the therapeutic benefits of others. Physiological research, often based on radioactive-tracer techniques, is clarifying the behavior of many of these isotopes in the body. Among the relatively new medical applications that seem promising Farr mentioned four.

Chlorine 38 and sodium 24, which concentrate in body fluids outside cell structures, are tools for measuring the volume of this fluid in cases of edema. Chlorine 38 also appears to be good for treating cancer that has spread through the peritoneal cavity. Because this isotope has a half-life of only 37 minutes, it does its work and decays before it can spread to other parts of the body that might be damaged by radiation.

Manganese 56, a beta and gamma emitter with a half-life of less than two and a half hours, has an affinity for the liver. Within 15 minutes after being injected into the bloodstream, 40 per cent of this isotope is concentrated in the liver. And virtually 100 per cent of certain compounds of manganese 56 are deposited in the liver within 10 minutes. This isotope can thus be aimed precisely at cancers in the liver.

Boron 10 is particularly suited for brain tumor therapy. Approximately 10 minutes after injection, the isotope reaches a high concentration in the tumor. Then, when it is irradiated with neutrons, it disintegrates almost instantly into highly radioactive lithium 7 and alpha particles. Since the range of these particles is equal to only about the diameter of one cell, they bombard tumor tissue effectively while surrounding cells escape strong radiations.

Case Closed

With the recent announcement that he and six associates at Cornell Medical College have synthesized the pituitary hormone vasopressin, Vincent du Vigneaud completed the work that won him last year's Nobel prize in chemistry. The research is a biochemical epic stretching over a decade.

It started with the isolation of small amounts of vasopressin and oxytocin, the first hormones ever isolated from the rear half of the pituitary gland. In this phase of the research the Cornell chemists used the glands of 100,000 cattle. After ascertaining that both hormones are polypeptides, or long chains of amino acids, du Vigneaud proceeded to determine their molecular structure. Then he succeeded in synthesizing first oxytocin and now vasopressin, the first polypeptide hormones to be produced artificially.

Oxytocin plays a part in birth by causing contraction of the uterus; it also starts the flow of milk. Vasopressin, which raises blood pressure and reduces urine production, is given in the treatment of one form of diabetes. It is hoped that the use of synthetic vasopressin will eliminate the allergic reactions which some people develop toward the natural hormone.

Du Vigneaud's collaborators in the final stage of the investigation were M. Frederick Bartlett, Albert Johl, Roger Roeske, R. J. Stedman, F. H. C. Stewart and Darrell N. Ward. They reported the synthesis of vasopressin in *Journal of the American Chemical Society.*

Appeal for Information

The Federation of American Scientists appealed last month to President Eisenhower to revoke regulations that obstruct the international exchange of basic scientific and technical information. The FAS endorsed three recommendations of the House Government Operations Subcommittee: that unclassified scientific information should be exempted from Commerce Department export controls; that the Office of Strategic Information should be eliminated; and that the State Department should resume its scientific attaché program. The number of such attachés assigned to U. S. embassies and consulates dropped from 10 in 1952 to zero by this year.

The FAS statement concluded: "Peacetime attempts to extend voluntary controls to unclassified information are unrealistic and fraught with dangers far greater than the presumed benefits."

Comet Chemistry

As comets are tracked across the sky, they are occasionally seen to erupt and throw out a mass of luminous material. The cause of these outbursts has been a mystery. Now Bertram Donn and Harold C. Urey of the University of Chicago suggest that they are caused by chemical explosions of free radicals in the bodies.

According to a theory originated by Fred Whipple of Harvard University, comets consist largely of an icy conglomerate of solid methane, ammonia and water. Donn and Urey believe that some of the ice is made of solidified free radicals such as CH, OH and NH. These materials have been found in the laboratory to be stable at very low temperatures but to become explosively reactive when heated a few tens of degrees above absolute zero.

In an article in *The Astrophysical Journal* Donn and Urey propose a mechanism that would account for intermittent explosions of free radicals in comets. Normally the radicals are so diluted by stable molecules as to be unreactive. As a comet approaches the sun, some of the stable material evaporates and the concentration of unstable materials increases. Eventually an outside energy source, such as a corpuscle from the sun, can trigger a chain-reacting explosion. The reaction will continue until it runs into a large concentration of stable molecules or of meteoritic material in the ice. Then the comet subsides.

If the hypothesis is correct, an outburst should begin with the flash of bright light typical of violent explosions. The authors suggest that astronomers be on the lookout for such flashes.

DNA Synthesis

Desoxyribonucleic acid, the substance that governs the special characteristics of genes and animal viruses, has for the first time been made artificially. Arthur Kornberg of the Washington University School of Medicine in St. Louis announced the DNA synthesis at a conference on chemical genetics at the Johns Hopkins University. Less than a year earlier Severo Ochoa at New York University Medical School had synthesized ribonucleic acid (RNA), a kindred genetic material which is found also in plant viruses.

Biochemists who had followed this work noted important differences between the two syntheses. Ochoa makes RNA by treating certain triphosphates with enzymes. He can use one, two, three or any combination of the four phosphate bases that occur in natural RNA. The result of the reaction is "nonsense RNA"—that is to say, a long-chain molecule which does not necessarily correspond to any of the forms of RNA found in nature.

Kornberg and his collaborators, on the other hand, find they have to use all four phosphate bases and also must prime their reaction with a little natural DNA. It is likely that the DNA they create is identical with whatever nucleic acid they use as a primer.

So far the St. Louis biochemists have

initiated their reaction with a complex mixture of enzymes, which they refer to as a "choline extract." They are now trying to find which enzyme or enzymes in this mixture actually join the phosphate bases into DNA molecules.

Primeval Palms

A recent discovery of fossilized imprints of palm leaves in southwestern Colorado indicates that flowering plants arrived on the earth many millions of years earlier than paleontologists have supposed. Roland W. Brown of the U. S. Geological Survey and the Smithsonian Institution, who found the leaves, estimates they date from the Triassic Period, about 160 million years ago. He believes that they were preceded by still more primitive flowering plants.

The fossils of that area seem to have accumulated when southwestern Colorado was a sparsely vegetated plain a few hundred feet above sea level. Near the palm-leaf imprints Brown found teeth of phytosaurs—ancient reptiles which resembled crocodiles. Not until 100 million years later, when insects capable of pollinating blossoms became abundant, did flowering plants become common.

Sterile Stallions

A fresh complexity in the study of male sterility has been turned up by experiments of J. W. Goldzieher of the Southwest Foundation for Research and Education. He has found that semen from some infertile stallions contains apparently normal sperm cells. Further investigation showed that the sperm cells' ability to fertilize ova depends to a large extent on the nature of the seminal plasma in which the cells are suspended. In fact, Goldzieher was able to fertilize mares with sperm cells taken from infertile stallions and mixed with seminal plasma from fertile stallions.

Following these experiments with a biochemical study of seminal plasma, Goldzieher found that sulfydryl compounds in the plasma seem to interfere with fertilization. He reported his work at a recent meeting of the Society for the Study of Fertility in London.

Early Man in the Negev

The remains of a rich stone-age civilization, dating back almost 4,000 years, have been found in the northern Negev desert of Israel. Nelson Glueck, the U. S. archaeologist who made the discovery, called it "the largest flint tool

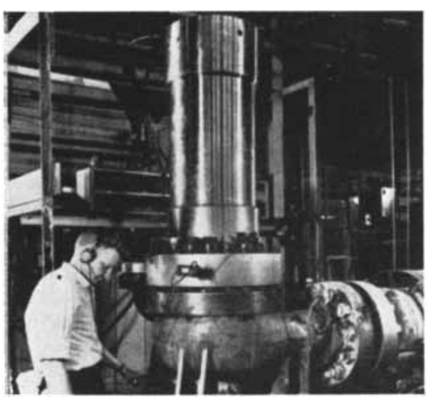
DOW CORNING

SILICONE NEWS

How Designers Plan for Tomorrow

- Silicone insulated motor-pump handles radio-active coolants
- Industry eyes liquid springs made more efficient with Silicone fluids
- New auto transmission seals of Silicone rubber are "boiled in oil"

HEART OF THE USS NAUTILUS— Heat energy of radioactive water from the nuclear reactor is circulated under pressure through the steam generators by canned motor-pumps. Water at temperatures up to 675°F circulates through the motor bearings, between the separately canned stator and rotor assemblies and around the stator. Silicone insulated stator windings are protected from the hot liquid by a stainless steel jacket; the rotor by a leak-tight cylinder of nickel alloy. **Canned motor-pumps** with capacities ranging from 5 to 17,000 gallons per minute are made by Westinghouse. Skillful engineering with silicone insulation enables these pumps to handle liquids at system pressures up to 2500 psi. Special units will even handle liquid metal at temperatures



up to 1000°F. Other applications: steam systems involving controlled or forced circulation and some process applications in the chemical and petroleum industries. No. 29

METHUSELAH AMONG MOTORS is a silicone insulated 10 hp motor in Dow Corning's motor test lab. It's still going after more than 58,000 hours at an average copper temperature of 465° F. That's equivalent to over 350 years' operation at regular Class H motor temperatures.

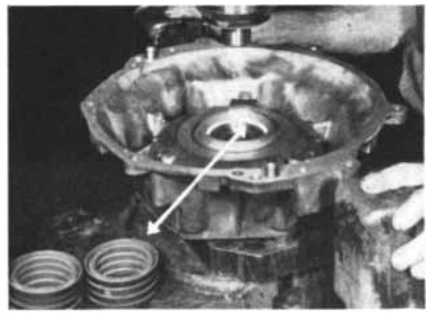
MIGHTY MITES — Liquid filled "Hydra Springs" by Wales Strippit Corporation provide forces 3 to 6 times greater than coil springs of the same size. Dow Corning silicone fluid is specified as the compressible medium for these springs because its compressibility is 9 to 10% at 20,000 psi compared to 6 or 6½% for mineral base oils.

Heat stability was another important consideration leading to the use of Dow Corning silicone fluid. Semi-inorganic, it retains nearly constant viscosity and does not break down despite high operating temperatures. Hydra Springs have already proved highly successful in metal working dies, perforating equipment, testing equipment, ordnance devices and specialized machinery. Other applications are in the offing. No. 30

SILICONE SURFACE — gives glass containers better "slip", reduces jam-ups on filling line, increases filling rates as much as 80%. Also imparts greater resistance to bruising and scratching—cuts line breakage as much as 50%. Leading glass makers now offer containers coated with Dow Corning Silicones at little or no extra cost. No. 31

BOILED IN OIL—Most advanced design in automatic transmissions for automobiles requires greater activity of the oil within the unit. This means more heat. Where old designs operated in the range of 150°F to 250°F, new models average 250°F with frequent highs of 325°F. Seals molded of Silastic*, Dow Corning's silicone rubber, prevent leakage of the hot oil and assure long maintenance-free service.

Amazing as it may seem, this sealing assignment is actually duck soup for a material that stays rubbery and



keeps its shape at temperatures far above and far below the limits of organic rubber. Silastic's range is from −130°F to 500°F. No. 32

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

GOOD-BYE HEADACHES — Mold cleaning, a costly problem in the rubber industry, has been virtually eliminated by Dow Corning silicone mold lubricants. Here's a typical report from a leading rubber company: "With silicone mold lubricants we never have to clean molds except when we take them out for change or repair." No. 33

TOMORROW'S PRODUCTS — will come from imaginative use of new materials. That's why design, production and maintenance men need the new Reference Guide to Dow Corning Silicone Products. No. 34

Dow Corning Silicones Mean Business!

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site I have ever seen. One could cart away trainloads of implements which were made, used and abandoned."

The discovery proves that this now-desolate area, populated by only a few Bedouins, was settled long before the time of the Nabataeans, who cultivated the desert until the Romans conquered them [see "Masters of the Desert," by Michael Evenari and Dov Koller; SCIENTIFIC AMERICAN, April]. "At these sites," Glueck said, "prehistoric generations of men gathered, grazed their flocks, utilized their advanced skills in making flint tools and left many thousands of them behind." Fragments of pottery found on a gentle slope belonged "unmistakably" to the Abrahamitic period of about 2,000 B.C. Abrahamitic people are known to have lived in permanent villages of stone houses, but as yet Glueck has found nothing on the surface except flint implements and pottery.

Glueck, who worked close to the Egyptian frontier, was accompanied by a heavily armed escort of Israeli soldiers.

Part-time Graduate Study

Assistant Secretary of Defense Clifford C. Furnas has proposed that the U. S. finance graduate study for young scientists employed in laboratories that do government research. The research contracts could be changed to make the cost of part-time advanced training an allowable expense item, he told a meeting of the National Committee for the Development of Scientists and Engineers. If this practice were adopted, he said, the nation would within five years harvest a crop of Ph.D.'s who would otherwise have stopped their education at the bachelor's level.

Furnas suggested also that government research grants ought to permit a more liberal charge for overhead. The present allowances range from only 8 per cent on some Public Health Service contracts to 48 per cent on some Navy grants. At this rate, according to Furnas, universities lose money on every government research project, with the result that they have to raise student fees and reduce faculty salaries.

No Smoking

A standing rule of the British Medical Association prohibits smoking during lectures at its meetings. But it is a time-honored custom to suspend this rule by voice vote as soon as a meeting begins. This year a BMA conference at Brighton broke with tradition. The vote


CRUSADER 1956
Crusader.....1956 A.D.
His weapon—Chance Vought's supersonic interceptor—while infinitely more complex, it must be just as reliable as his forebearer's sword.
Sub-systems such as this Servomechanisms, Inc., Angle of Attack and Mach computer do their part in assuring that American Military Aircraft maintain their leadership in performance and reliability.
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MECHATROL DIVISION
Westbury, L. I., New York
MECHAPONENTS DIVISION
El Segundo, California

in favor of smoking (173 to 154) fell short of the three-quarters majority necessary to suspend the rule.

In the U. S. a new analysis of tobacco and cancer was reported by the National Cancer Institute. William Haenszel, head of the biometry section, and Michael B. Shimkin, chief of biometry and epidemiology, collaborated in the first attempt to compare all the information collected in the several cancer-smoking studies on the smoking habits of Americans and the general distribution of lung cancer in the U. S. Their conclusion is that cigarette smoking and lung cancer follow similar patterns.

Haenszel and Shimkin observed that five men for every one woman die of lung cancer. This represents the highest sex ratio known for any major disease. If smoking is a cause of lung cancer, they predict, the ratio of women dying of lung cancer will have risen by 1965.

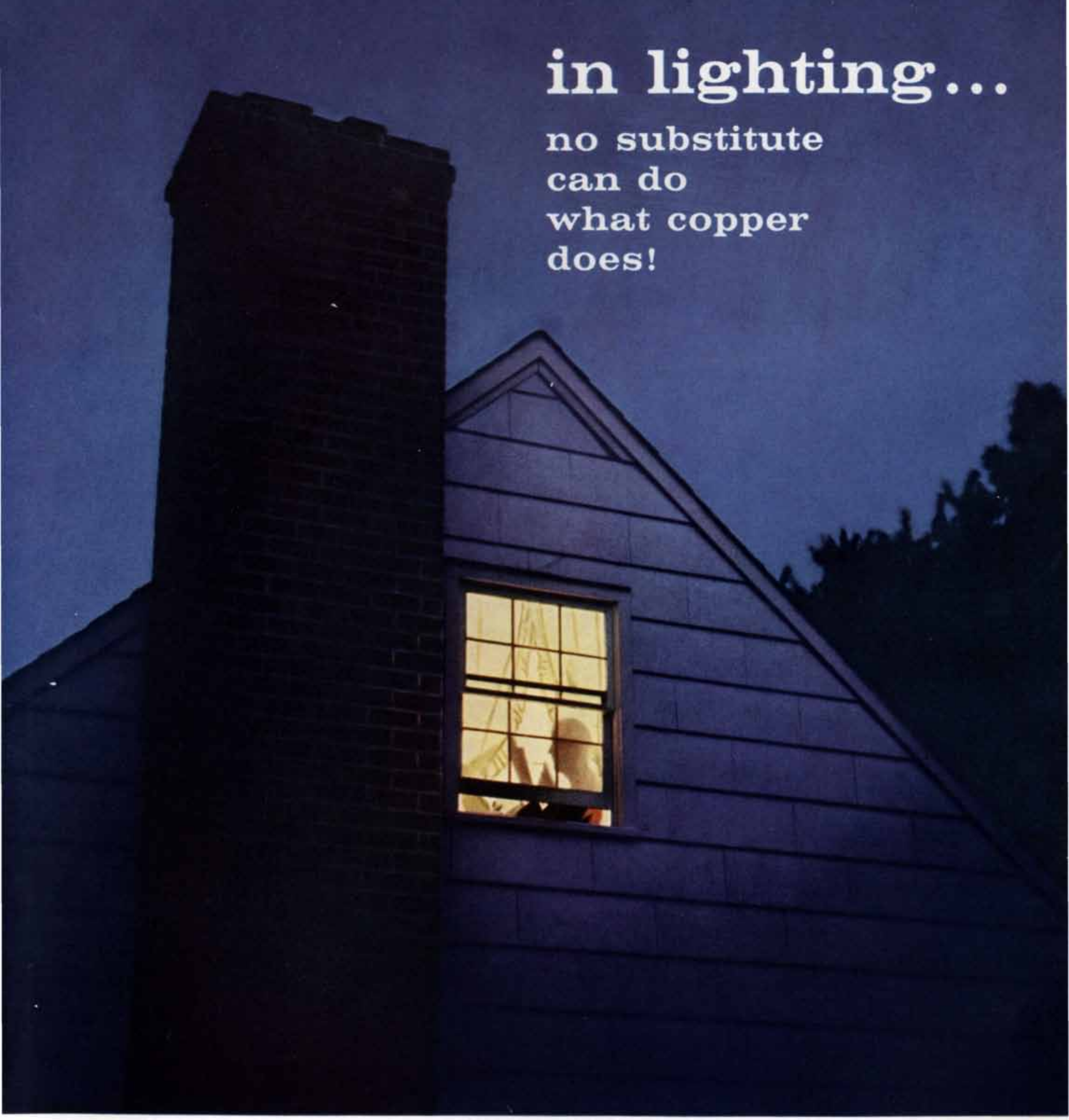
Tin Pan Computer

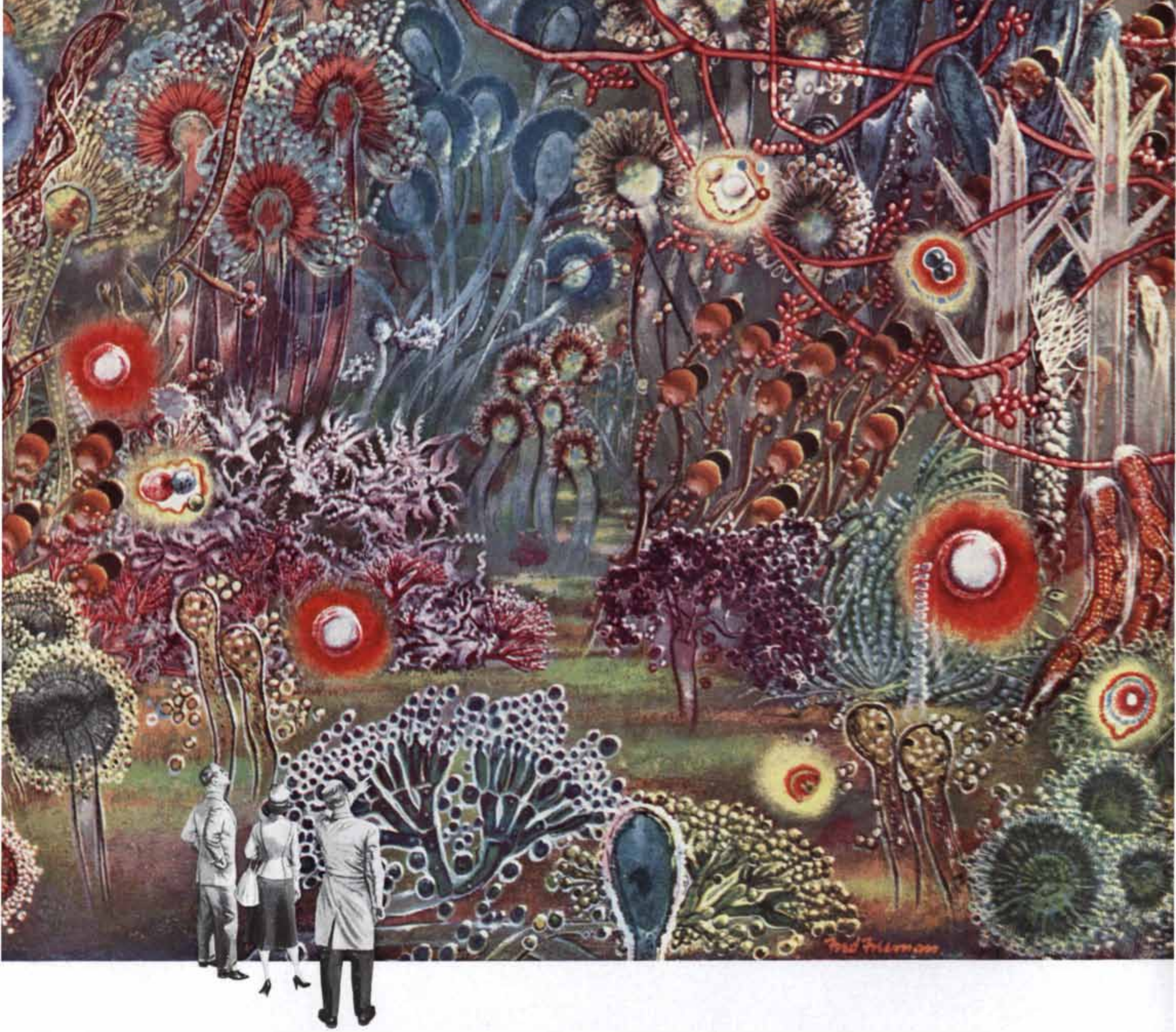
It has often been suggested that a digital computer, fed proper instructions, could grind out music in the style of Bach, Mozart or any other composer. Two California mathematicians have now actually rigged a computer so that it will compose in one of the most rigid styles in musical history: the American popular song. They broadcast one of the machine's early efforts—a ditty entitled *Pushbutton Bertha*—on a Los Angeles television program last month.

Mathematicians Douglas Bolitho and Martin Klein of the ElectroData Corporation estimate that the computer, the Datatron, can create songs at the rate of 1,000 per hour and can write more than 10 billion different tunes without further instructions.

For each new composition the computer selects a 10-digit random number and then from this number generates 1,000 additional one-digit random numbers. From this string of numbers, each representing a musical tone in the diatonic scale starting with middle C, plus two accidentals, the machine selects successive notes. The program prepared in advance limits each choice. The second note, for example, may not be a minor second, a fourth, a flatted fifth or a ninth. The melody is never allowed to jump more than six tones, a restriction which makes all Datatron tunes easy to sing.

Bolitho and Klein are now elaborating their instructions so the computer will be able to choose from a variety of rhythm patterns. The next step will be to program the machine so that it can orchestrate its works.


in lighting...
no substitute can do what copper does!



Mastery over Molds

In the jungle of microscopic life around us science captures unique servants of mankind. A new kind of engineer puts these living creatures to work through fermentation chemistry.

LOOK through a microscope at a single pinch of rich, moist earth, and you see a lush jungle of molds, yeasts, bacteria and other microorganisms—like the authentic types the artist has grouped together in the illustration above.

It is a world of spectacle and motion. Here, microbial colonies grow in patterns of wild beauty. Their laws of survival are as violent as those in any jungle. They work endlessly at breaking down their environment into its basic chemical elements...and war unremittingly for the nourishment these elements provide. It is a world of perpetual struggle and perpetual change. It is, literally, a world in ferment.

This process of fermentation occurs everywhere in nature—above the earth as well as beneath it. Each mold spore, each subdividing bacterium cell struggles to survive — wherever the wind blows it or another agent carries it. When microorganisms win this struggle they change their environment, whatever it is... a loaf of bread, the leaf of a tree, the blood of a man.

Ancient man used the powers of those tiny living organisms without even knowing they existed. He aged meats, brewed drinks, made cheese out of milk—all by means of fermentation.

Is This an Advertisement?

You may call the message on these pages an advertisement if you wish . . . but it's really something more. It's an attempt to share some important scientific knowledge with the many magazine and newspaper readers who may wish to know more about a subject that merits wide attention.

If you're interested, an absorbing and unusual book, "Our Smallest Servants", is yours for the asking. (See coupon next page). It will give you in illustrated story-form the history and science of fermentation chemistry — as viewed by leaders in this field. You'll learn how and why it plays such a vital role in medicine, industry, agriculture . . . and in your daily life. Teachers and students may find this free book a helpful adjunct in science study.

Today, with fermentation chemistry no longer a mystery, a new kind of engineer can breed microorganisms as efficiently as cattle or prize roses. This is the biochemical engineer. When a useful mold is discovered, his skill can control every phase of its life and growth in order to mass produce an important new drug or chemical.

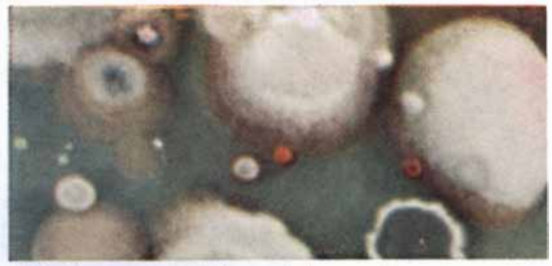
How did this modern technology of fermentation chemistry grow? Its beginning was only possible toward the end of the last century when the French scientists Thenard and Pasteur had convinced the world that fermentation was the work of microscopic living organisms.

The inheritors of Pasteur's knowledge sought to use microbes as production workers in industry. If a yeast could change grape juice to wine, it was reasonable to suppose that some similar creature might provide a short cut in the manufacture of valuable chemicals or other products.

Of all the resultant research and experimentation, the most significant took place in the United States, where after ten years' work chemists of Chas. Pfizer & Co., Inc. succeeded in producing by fermentation an important chemical used in many industries. They perfected a process by which the mold *Aspergillus niger* transformed ordinary sugar into citric acid. Now, vast quantities were readily available. The world price of citric acid dropped more than two-thirds. And the new technology of biochemical engineering became a factor of highest importance to industry. *(Continued on next page)*

2750-2665 B.C.— Egyptian brewer straining mash . . . an ancient example of the employment of fermentation.

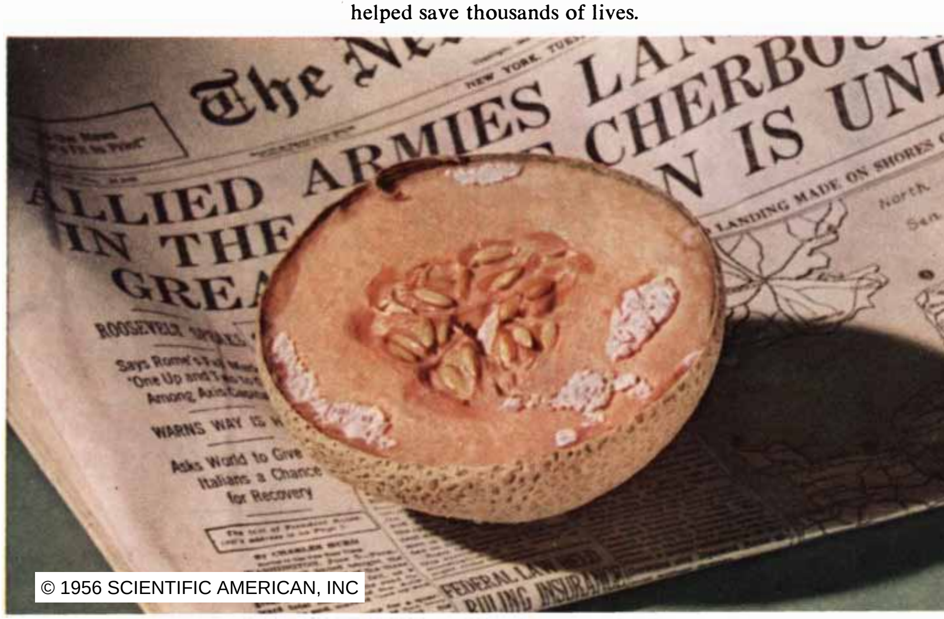
FROM THE METROPOLITAN MUSEUM OF ART

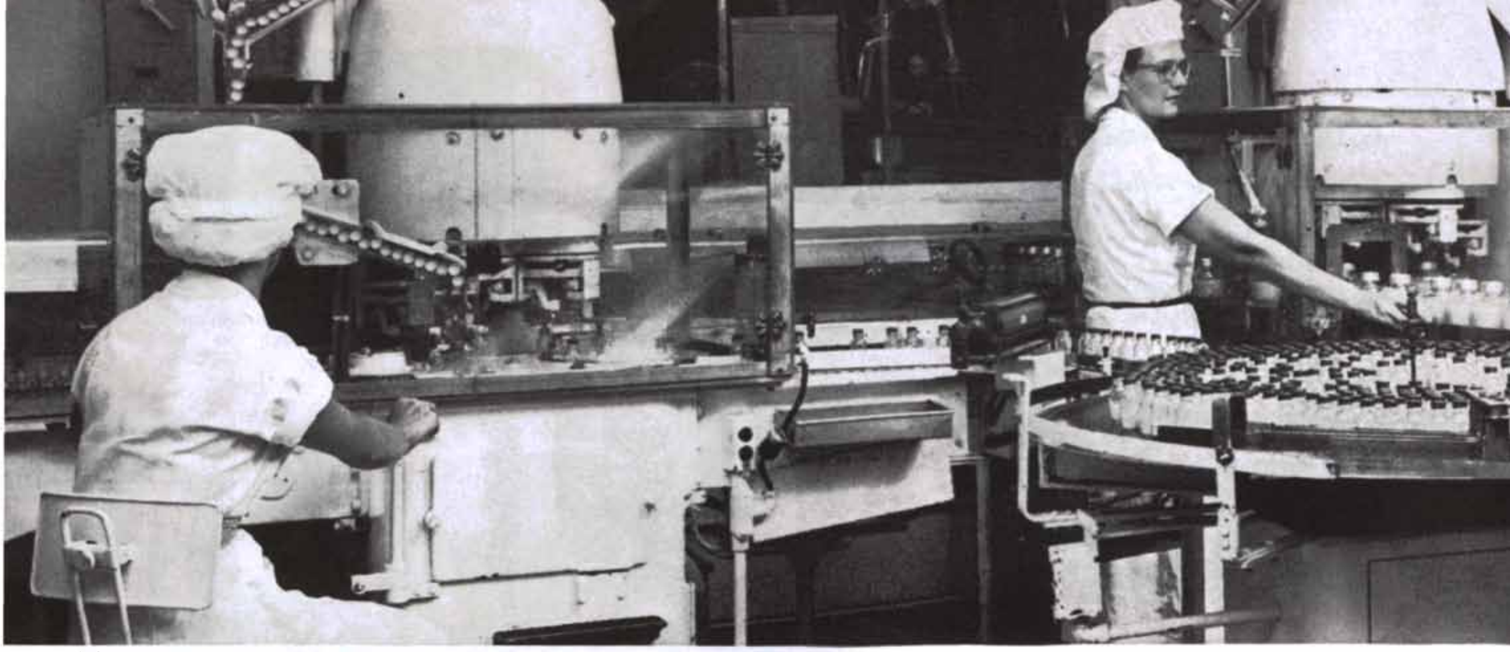


Primitive man used fermentation molds without knowing they existed.

15th Century experimenters learned to improve wine taste. But only with Louis Pasteur's research in **1857** did man learn that living organisms produced fermentation.

World War II—a moldy cantaloupe found in a Peoria market helped save thousands of lives.





Modern production of life-saving antibiotics like Terramycin requires elimination of all chance and error—from cultivation of the mold to final packaging.

The greatest test of this new technology was to come during World War II. Alexander Fleming and other British scientists who followed his lead had found remarkable disease-fighting potentials in an ordinary mold called *Penicillium notatum*. But producing significant quantities of the antibiotic penicillin seemed nearly impossible, for at first the yield was no more than one part of penicillin to *one million* parts of fermentation broth!

Three American companies—Pfizer, Merck and Squibb—led the way in applying biochemical engineering to the problem. A special strain of *Penicillium* discovered on a cantaloupe was pampered, coddled and nurtured. Disciplined at last, the mold produced tons of the antibiotic in time to save thousands of lives—beginning on D-day in Normandy.

Since World War II scientists have tested thousands of soil samples for organisms which the biochemical engineer might train to serve man, organisms which could produce better antibiotics and other useful chemicals.

From a bit of earth spooned up near one of Pfizer's own middle western plants came the actinomycete which was made to yield the yellow crystals of another vital antibiotic—life-saving Terramycin. Where penicillin combatted some twenty-five diseases and streptomycin fifteen, Terramycin was found effective against one hundred!

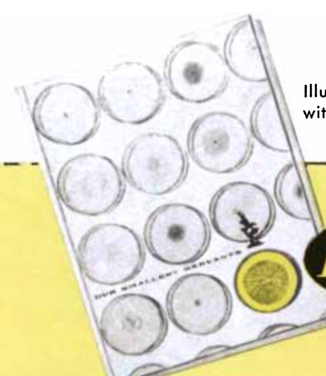
The continuing development of biochemical engineering put Terramycin in the hands of physicians many years earlier than had been the case with penicillin. And even for penicillin production, the basic molds in use today are far more efficient than the one found on the Peoria cantaloupe. The superprecision of biochemical engineering controls the mold's diet, its environment and its production.

Without this mastery over microorganisms that is biochemical engineering, life-saving antibiotics would still be a scientific curiosity. Many important vitamins, hormones, industrial and agricultural chemicals produced by fermentation chemistry would be virtually beyond reach.

What lies ahead? In the United States alone there are 2,974,726 square miles of land. Any pinch of that nearly limitless soil may offer the new organism whose life activity can be harnessed to conquer cancer, or the common cold, or to produce new materials that answer human needs. These challenges will be met. With biochemical engineering and man's expanding capacity for daring research, the future of humanity is one of better health, better food, and a longer, richer life.

* * * *

If you would like to read more about the fascinating story of molds and fermentation, then mail the coupon on this page for a free copy of the handsome book *"Our Smallest Servants"*.



Illustrated book with dimensional mold reproduction.

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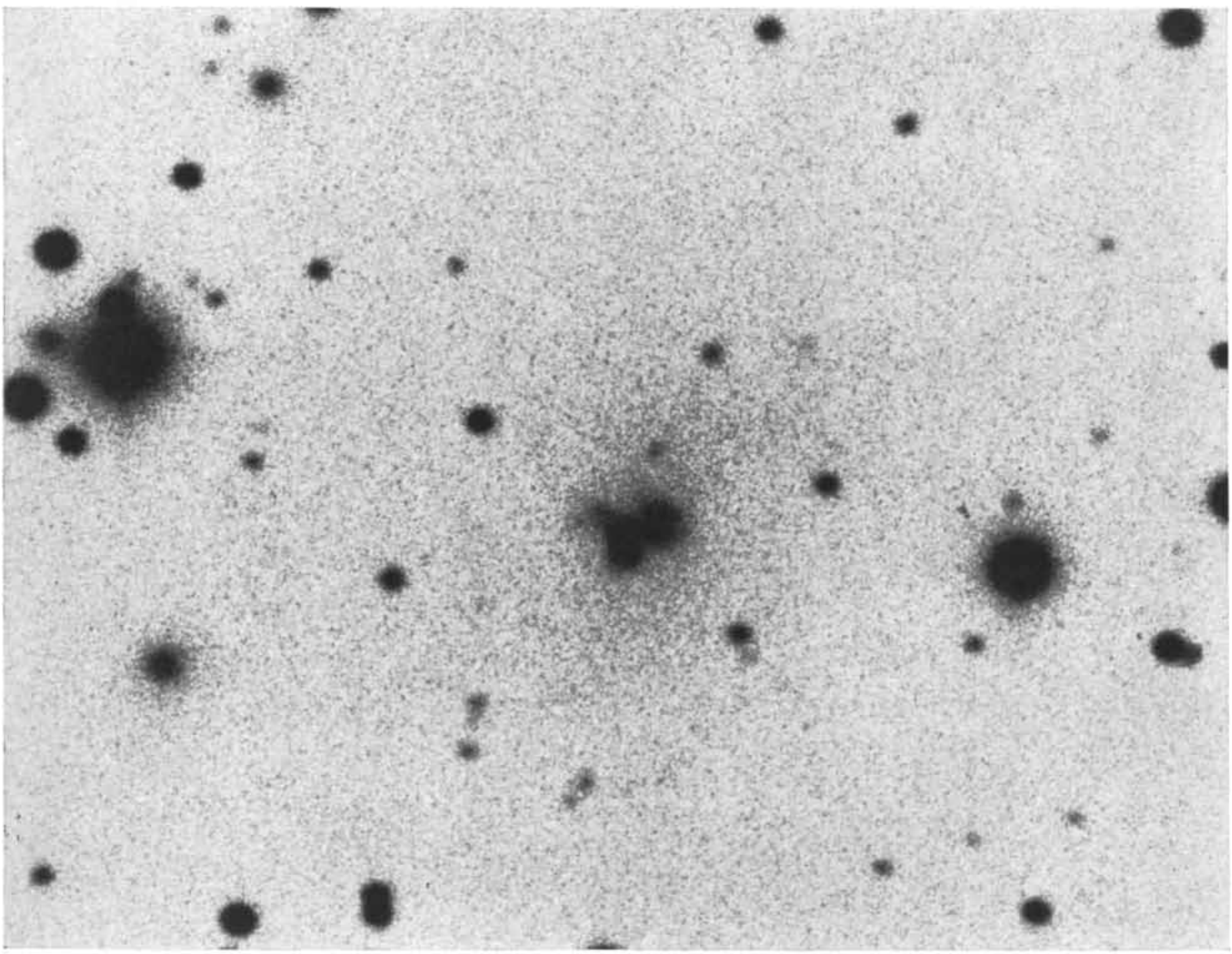
Colliding Galaxies

Many galaxies occur in clusters, the density of which is such that their members may be expected to collide occasionally. The results are discussed here and in the article on radio galaxies (page 204)

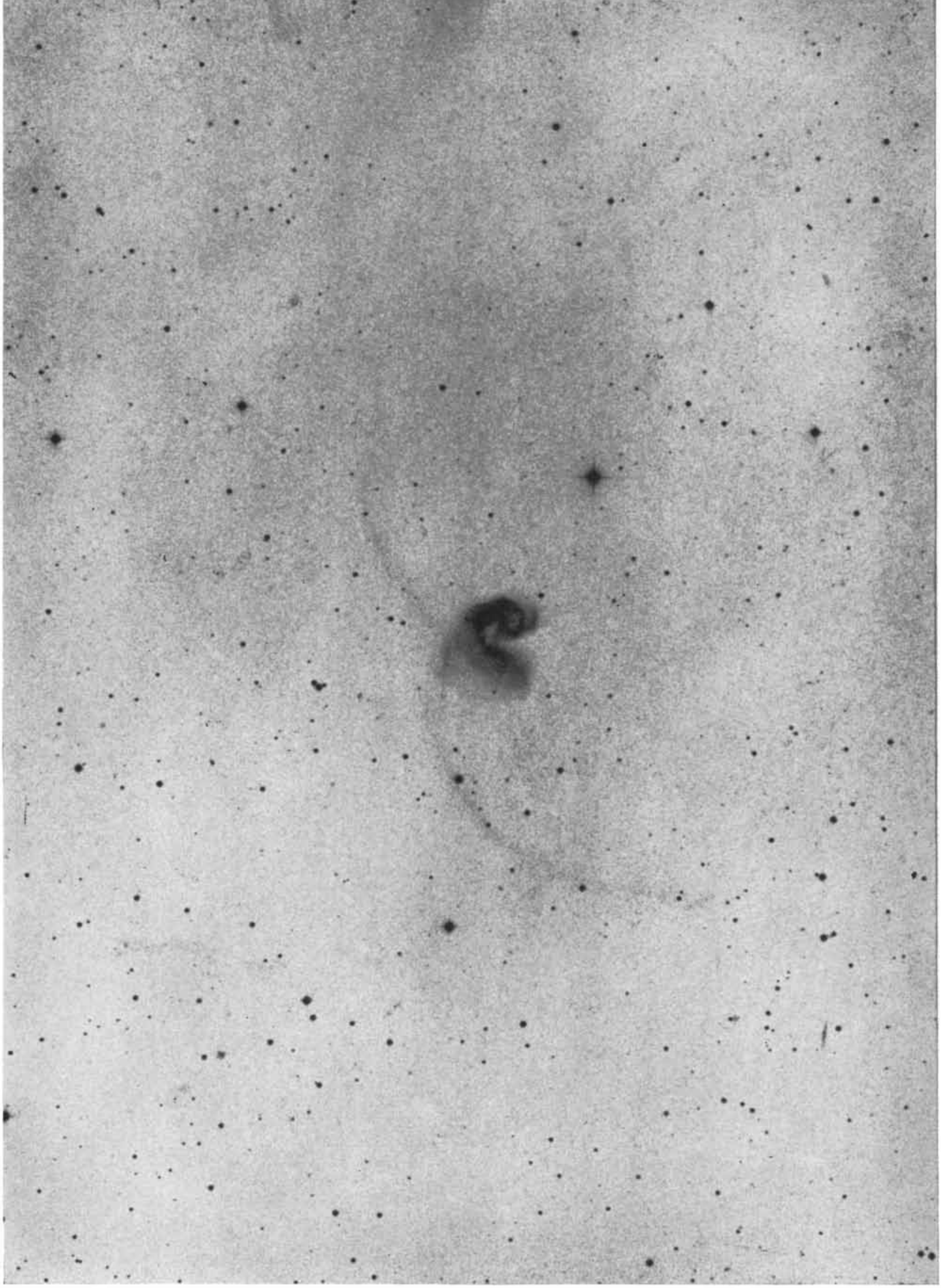
by Rudolph Minkowski

During the past 10 years radio astronomers have discovered a new kind of object in the sky. These objects are distinct sources of radio energy, just as stars or galaxies are discrete sources of light. Some of the radio sources can be identified with well-known visible objects, such as the spectacular Crab Nebula, which marks the location of an exploded star in our galaxy. But curiously the two most powerful radio sources are located at points in the sky where no conspicuous objects appear.

One of these lies in the constellation Cygnus. As the resolving power of radio telescopes was improved, the search for the radio source narrowed down to an area containing a faint object far out beyond the stars of our own galaxy. In 1951 F. G. Smith of the University of



GALACTIC COLLISION in Cygnus is represented by the irregular spot in the center of this photograph made with the 200-inch telescope. Although the galaxies are 270 million light-years away, they comprise the second strongest radio source in the sky. This contrasty negative print shows only the distorted central masses of the galaxies. Their total visible diameter is about six times greater.



ANOTHER PAIR OF COLLIDING GALAXIES is NGC 4038 and 4039. This negative print from a photograph made with the 200-inch telescope shows long tidal filaments above and below the central masses of the galaxies. The radio emission of this system is weak.

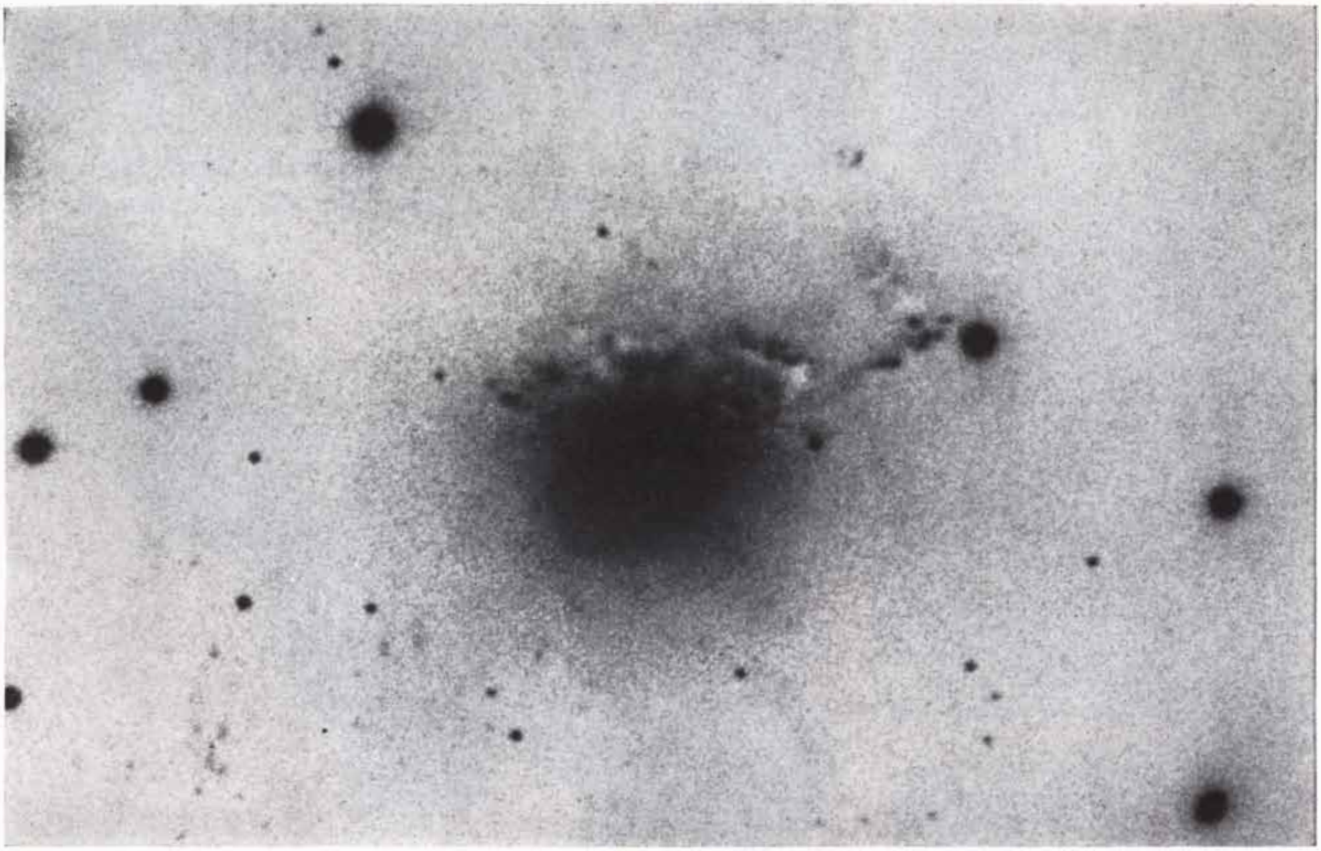
Cambridge, using a British radio interferometer of high resolving power [*see article on page 204*], boxed the source of the strong radio emission, called Cygnus A, within an area of less than one square minute of arc.

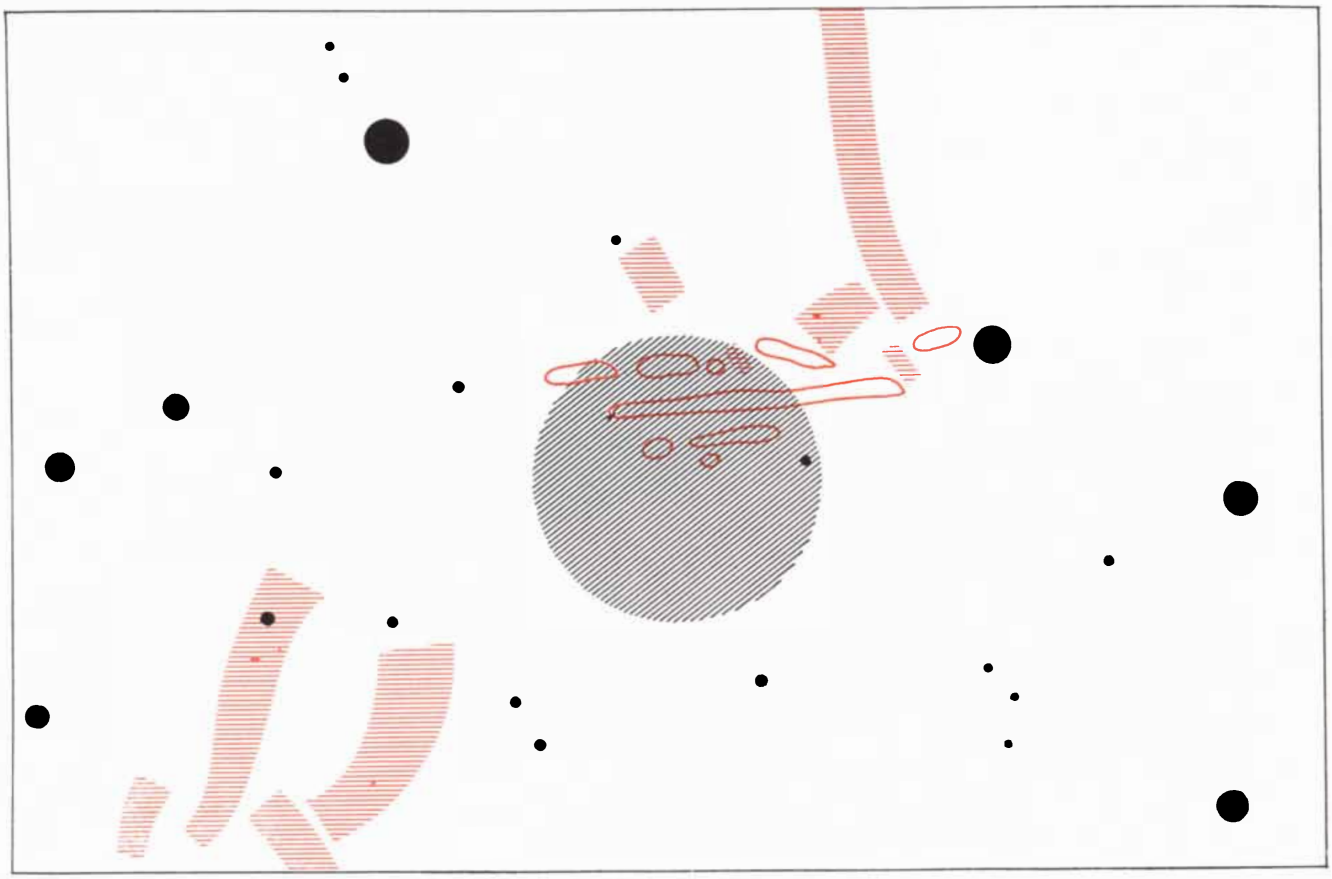
Walter Baade thereupon took a picture of the object with the 200-inch telescope on Palomar Mountain, and made a surprising discovery. What had appeared in plates made with smaller telescopes as a single galaxy turned out to be an unusual system composed of two galaxies, one superposed on the other. Furthermore, it became plain that the two are not separate galaxies in the same line of sight but are actually in close contact, for their nuclei are strongly distorted by gravitational interaction. The centers of the two systems are only about two seconds of arc apart; evidently the galaxies have penetrated far into each other. In short, there was every indication that in Cygnus A we are beholding a close collision between two galaxies.

This was soon confirmed by a beautiful proof. What should we expect to see when galaxies collide? It is altogether unlikely that their individual stars will collide, because the average distance between stars in a galaxy is immense. In an encounter between two galaxies the gravitational attraction of their stars will perturb the stars' motions and distort the structure of the galaxies, but the stars themselves would not be expected to undergo any observable change. We should, however, expect to see an important effect on clouds of dust and gas in the galaxies. The gas and dust particles *will* collide. At velocities in the range of hundreds to thousands of miles per second such collisions should heat the gas to temperatures of one million to 100 million degrees.

Assuming that Cygnus A is a galactic collision, then, its gas should be very hot, and the atoms should be in a highly excited state. There is a way to test whether this is so: namely, examine the spectrum of light from the hot material. We can read the degree of excitation of atoms in a glowing gas from the character of the lines in its spectrum. Studies of spectra of Cygnus A made with the 100-inch and 200-inch telescopes fully confirmed the reality of the collision. Almost half of the light of the system is in broadened lines of hydrogen and in "forbidden" lines of emission by oxygen, neon, sulfur and iron in highly ionized states.

The strong emission lines of this spectrum, incidentally, made it possible to measure the red-shift of Cygnus A, and thereby its distance from us, with great





SEPARATION OF COLLIDING GALAXIES in the photograph at the top, made with the 200-inch telescope, was achieved by spectroscopic observations. The results are given in the schematic drawing at the bottom. The galaxies are jointly known as NGC 1275. One of them is a spiral with tightly wound arms which are not visible in the photograph. The other is a loose galaxy with highly distorted arms. The compact galaxy is roughly outlined by the black crosshatching. Parts of the loose galaxy are indicated by the areas enclosed by a colored line. The colored crosshatched areas probably belong to the same galaxy. This object is a radio source.

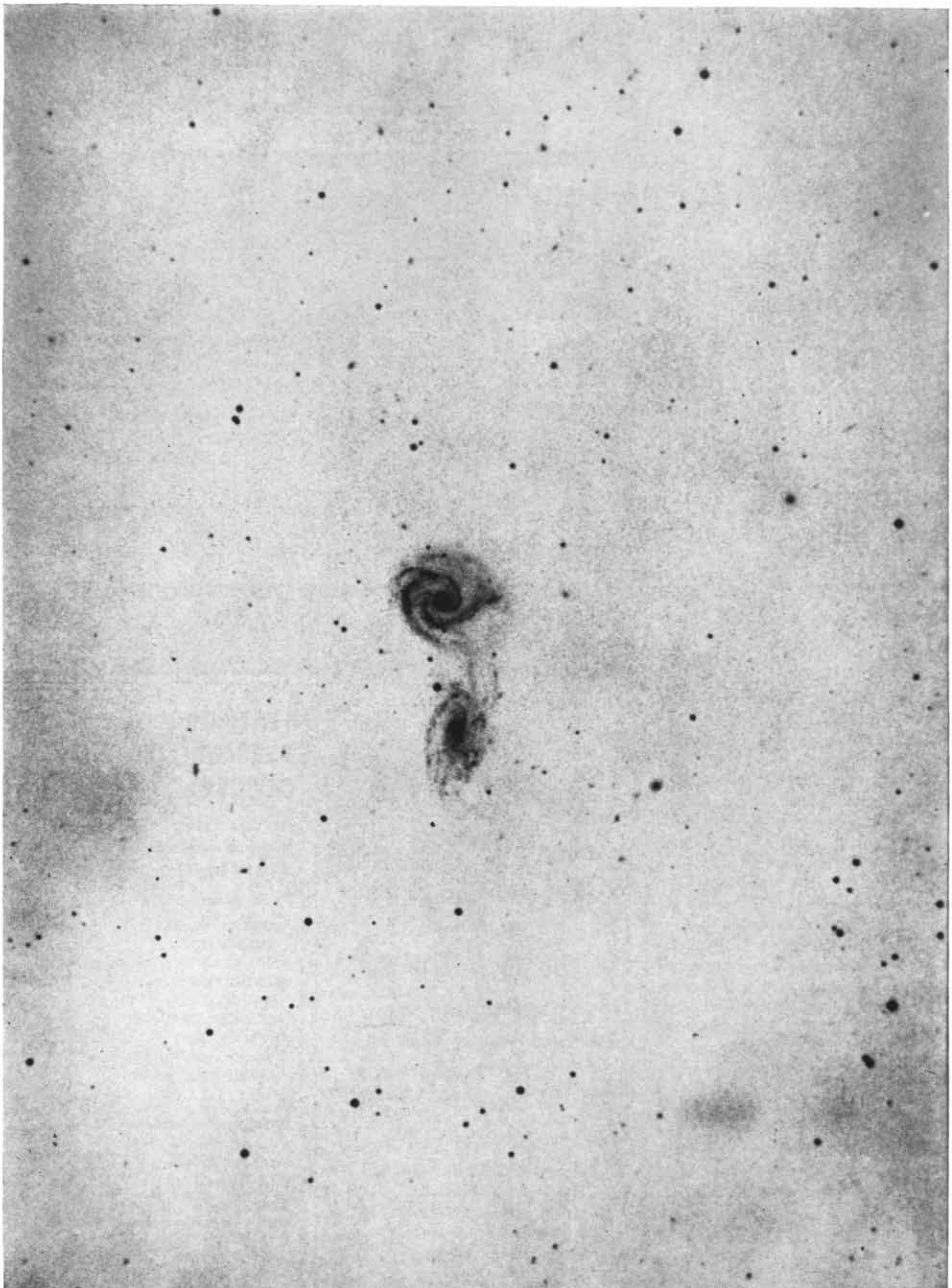
accuracy. The pair of colliding galaxies is 270 million light-years away.

The case of the colliding galaxies in Cygnus has great interest in itself, but it has even more interest for cosmology. It has already yielded a discovery of first importance. A. E. Lilley and E. F. McClain of the Naval Research Laboratory found that the 21-centimeter radio line of hydrogen in Cygnus A shows a Doppler shift precisely in accord with the red-shift of its light. This seems to verify that the red-shift is a Doppler effect and therefore a measure of the velocity and distance of galaxies.

The measurement of a radio "red-shift" is particularly exciting because radio astronomy promises a long extension of our reach into space. The radio signal from Cygnus A could be detected by our present radio telescopes even if it were only one 3,000th as intense as it is; thus we could detect such collisions at vastly greater distances—distances far beyond the range of the 200-inch optical telescope. All in all, there is solid ground for expecting that radio observation of colliding galaxies will answer many cosmological questions which optical astronomy cannot.

How frequent are collisions between galaxies? That depends in part on how we define a "collision." In the case of Cygnus A the two galaxies have penetrated far into each other: their central bodies, or nuclei, are only about 3,000 light-years apart. Such an event must be exceedingly rare. If we take a collision to mean any encounter in which the galaxies approach close enough to touch at the outer boundaries of their thin reaches of matter, the probability (*i.e.*, estimated frequency) of collisions becomes much greater. Assuming that the radius of a typical galaxy is 15,000 light-years, two such galaxies will be in collision, by our definition, whenever their centers are no more than 30,000 light-years apart. In the average region of space the average distance between galaxies is about three million light-years. On the basis of these figures and of what we know about the motions of galaxies, we can calculate that in the volume of space out to 250 million light-years from us, which is estimated to contain about two billion galaxies, some 10 collisions would be in progress at the present time if the galaxies were evenly distributed in space.

Of course this theoretical average must be adjusted to take account of the actual sizes and distributions of galaxies. Our own Milky Way has a radius of about 40,000 light-years; some spiral



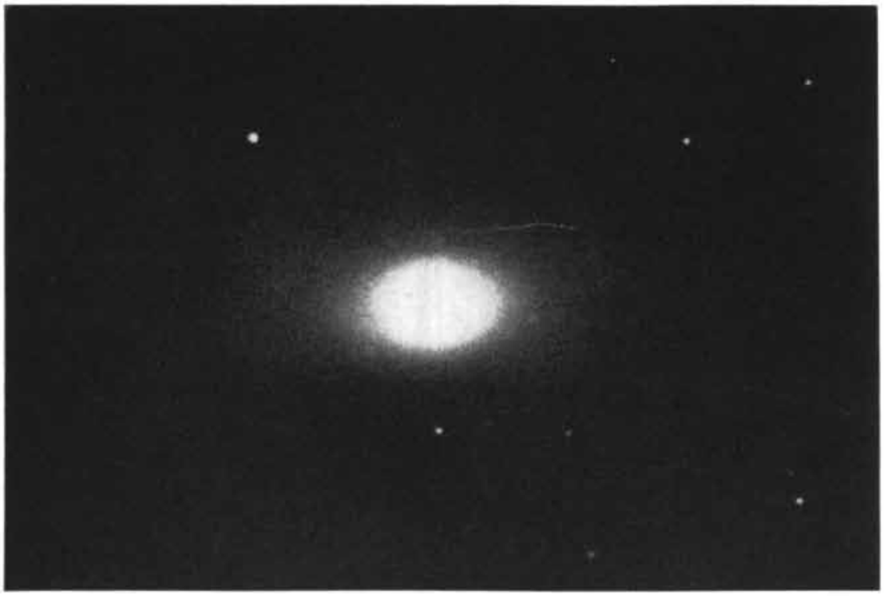
NEAR-COLLISION of two spiral galaxies is also photographed with the 200-inch telescope. The galaxies are NGC 5426 and 5427. Tidal interactions between the two are faintly visible in the photograph. This system is not, however, a collisional radio source.

galaxies have arms extending out to 60,000 light-years. What is much more important, many galaxies are grouped in clusters, where the average distance of separation is much less than three million light-years. For example, the central part of the Coma cluster of galaxies has some 500 galaxies concentrated within a space about 2.6 million light-years across. Here, we can estimate, at least two collisions should be in progress at this moment; the number is probably higher because the cluster increases in density toward its center. Cygnus A lies in another fairly rich cluster of galaxies. Collisions of its type, however, must still be rare, for the calculations indicate that a collision as close as this one is 1,000 times less frequent than the slightly overlapping contacts we have been discussing. Thus we should not expect to find more than a few clusters containing objects like Cygnus A.

Even before an actual instance of collision was found, Baade and Lyman Spitzer, Jr., of Princeton University had calculated the high probability of collisions in clusters and had assigned to the process an important function in the evolution of galaxies. Most of the galaxies in a condensed cluster such as Coma have a general form characteristic of the spiral type of galaxy (notably a flattened disk shape) but lack the arms and clouds of gas typical of the spiral systems. Spitzer and Baade proposed that these cluster galaxies were originally spirals and that successive collisions had swept them clear of their clouds of gas and dust, in which the hot stars characteristic of spiral arms are formed.

A galaxy would have to undergo a fairly large number of collisions to lose all its interstellar matter. It can be shown, however, that a sufficient number of collisions is likely to occur in a dense cluster. In the Coma cluster, for example, a galaxy moving roughly along the radius of the system and through the region of its center would have suffered between five and 30 collisions (the number depending on the size of the galaxy) during the five-billion-year lifetime of the universe. This order of probability is adequate to account for the removal of interstellar matter from most of the members of the Coma cluster. Clouds of material removed from a spiral galaxy may assist in sweeping dust and gas out of other spirals in the cluster. David S. Heeschen of the Harvard College Observatory has in fact found evidence—21-centimeter radiation—that the Coma cluster contains a large amount of hydrogen gas.

In a loose cluster, where collisions are

THREE GALAXIES are compared. At the top is the Type Sb spiral galaxy NGC 2481. In the middle is the Type E5 elliptical galaxy NGC 4697. At the bottom is the Type SO galaxy NGC 1201. SO galaxies are similar to elliptical galaxies in that they lack spiral arms, but otherwise they resemble spirals. Their dust and gas may have been swept away by collisions.

less frequent, we should expect to find that many of the galaxies still possess spiral arms and gas clouds. There is a loose cluster in Virgo which actually shows such a picture.

The discovery of the Cygnus A collision naturally inspired astronomers to an intensive search for collisions in other radio "stars." A few have been found, though none as intense as Cygnus A. It has been possible to study one in considerable detail. The object is known as NGC 1275, the brightest member of a cluster of visible galaxies in the constellation Perseus [*see photograph and diagram on page 128*]. The light spectrum of this object has long been known to be peculiar, with the emission lines that indicate high excitation. Now a detailed spectroscopic study of the object has shown clearly that it consists of two galaxies, colliding with a relative velocity of about 2,000 miles per second. One of the pair is a tightly wound spiral; the other, a very loose spiral with grossly distorted arms. The two galaxies are inclined at a small angle to each other, and we see both almost face on. The loose system is tilted to our line of sight in a direction such that the top or northerly part of the galaxy is nearer to us and the southerly part is away. In the upper portion of the overlapping image of the two galaxies we can see two distinct spectra of relatively low excitation. These evidently come from separate masses of gas lying respectively in the loose spiral and in the compact spiral behind it. This must mean that these sections of the two galaxies have not yet collided. But at a line just above the nucleus of the compact galaxy there is an abrupt change in the spectrum: here we get only one spectrum of emission, from gas in a very excited state. The line apparently marks the section where the loose spiral galaxy has entered the compact one and is slicing through it. Below this line we see but a single spectrum, which indicates that the forward edge of the loose galaxy has passed through the lower part of the compact system and left it in an agitated state. As the loose galaxy continues to move through, the line of collision should gradually shift upward, or northward.

We now have a fair picture of the sequence of conditions that leads to radio emission in collisions. In general it is clear that strong radio emission occurs only when the galaxies actually penetrate each other. But we still have little idea as to the mechanism responsible for generating radio energy of such strength. Astrophysicists have been hunting for

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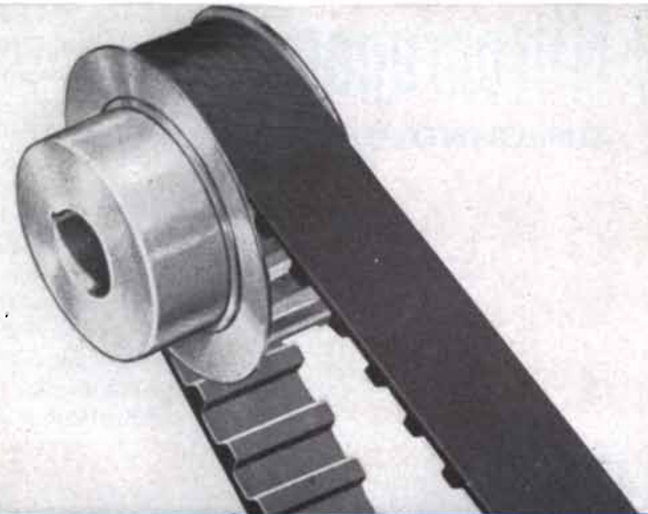

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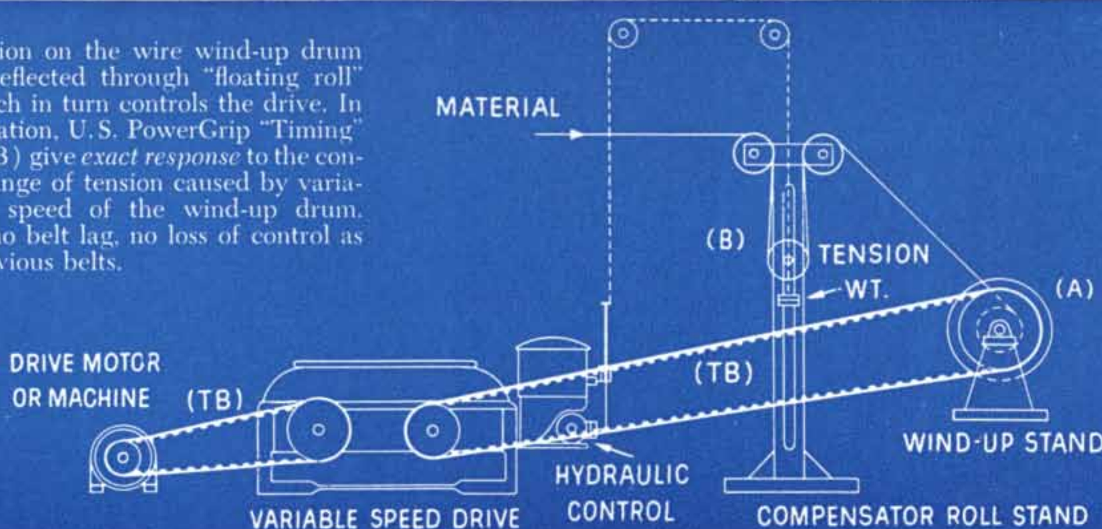

The schematic drawing illustrates a "floating roll," one of the most sensitive and precise methods of controlling tension in a web of material—whether it be wire, paper, cotton, threads, plastic or strips of metal. It is one more example of U. S. PowerGrip "Timing"® Belt's ability to simplify and improve a power transmission unit . . . one of the reasons why the invention of this belt was recently awarded the Franklin Institute's Edward Longstreth Medal for "Invention of High Order."

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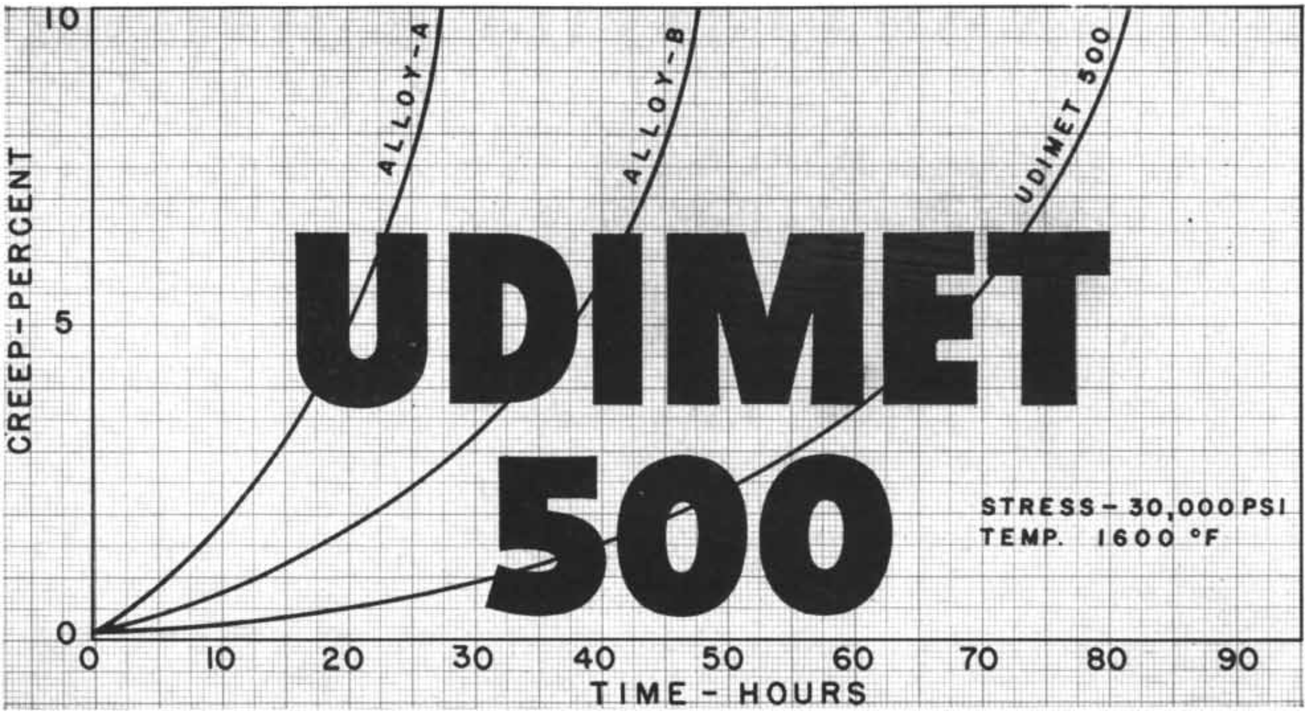
such a mechanism, but so far with little success. The intensity and the spectrum of the radio emission show that the radio energy cannot arise merely from the heating of the gas that occurs as a result of the collision.

In Cygnus A the strong radio signals seem to be coming from two outlying parts of the system separated by about 120,000 light-years, almost three times the visible extent of the system. We know that galaxies extend far into space beyond their bright central masses, and we know that a collision may scatter their gas clouds widely. But we cannot explain how the faint outer regions can emit radio energy at the huge rate of 10^{44} ergs per second—10 times the output of light by the colliding galaxies. Energy of this order can be provided by the relative kinetic energy of the colliding systems, but this energy is concentrated in their central masses.

It is tempting to suppose that at least part of the radio energy in collisions may be produced by a process already observed in the Crab Nebula, whose radio emission is generated by the motion of high-energy electrons in a magnetic field. We cannot, however, exclude the possibility of other processes. We know, for instance, that our sun generates radio energy by a mechanism different from that of the Crab Nebula.

The colliding galaxies thus offer many interesting problems: how galaxies interact and generate radio energy during collisions, how frequently collisions occur, and so on. The answers to these questions should lead to a far better understanding of our universe.

DRAMATIC OBJECT known as NGC 5128 appears to be a giant SO galaxy in collision with a spiral galaxy. The spiral is seen edge on. Its central disk of dust and gas is distorted.



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THE EVOLUTIONARY UNIVERSE

Most cosmologists believe that the universe began as a dense kernel of matter and radiant energy which started to expand about five billion years ago and later coalesced into galaxies

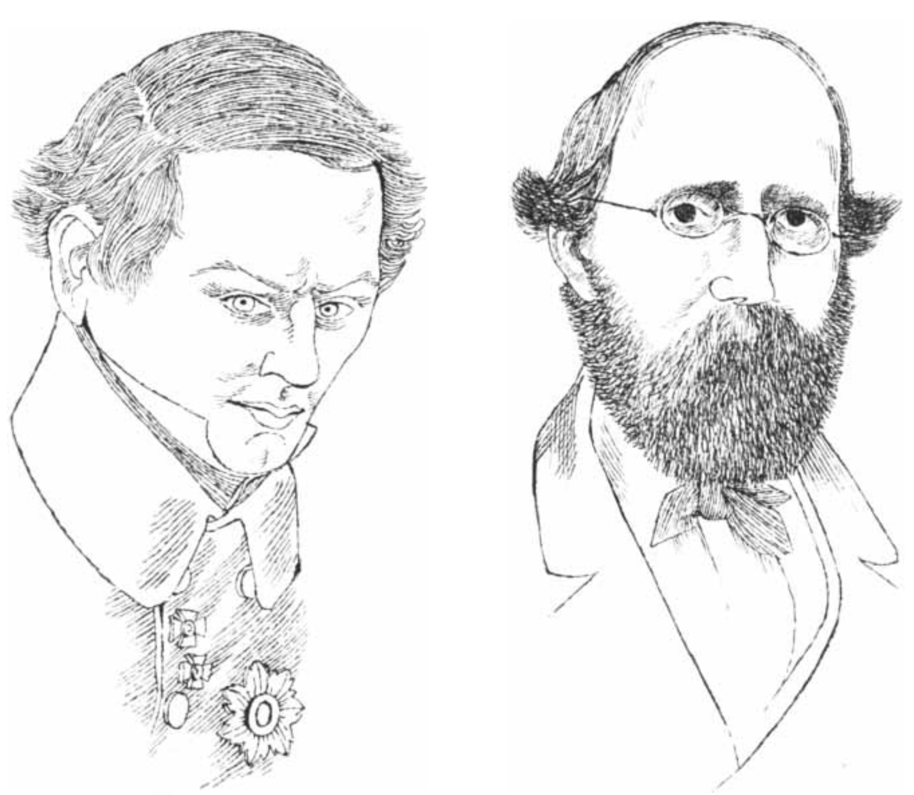
by George Gamow

Cosmology is the study of the general nature of the universe in space and in time—what it is now, what it was in the past and what it is likely to be in the future. Since the only forces at work between the galaxies that make up the material universe are the forces of gravity, the cosmological problem is closely connected with the theory of gravitation, in particular with its modern version as comprised in Albert Einstein's general theory of relativity. In the frame of this theory the properties of space, time and gravitation are merged into one harmonious and elegant picture.

The basic cosmological notion of general relativity grew out of the work of great mathematicians of the 19th century. In the middle of the last century two inquisitive mathematical minds—a Russian named Nikolai Lobachevski and a Hungarian named János Bolyai—discovered that the classical geometry of Euclid was not the only possible geometry: in fact, they succeeded in constructing a geometry which was fully as logical and self-consistent as the Euclidean. They began by overthrowing Euclid's axiom about parallel lines: namely, that only one parallel to a given straight line can be drawn through a point not on that line. Lobachevski and Bolyai both conceived a system of geometry in which a great number of lines parallel to a given line could be drawn through a point outside the line.

To illustrate the differences between Euclidean geometry and their non-Euclidean system it is simplest to consider just two dimensions—that is, the geometry of surfaces. In our schoolbooks this is known as "plane geometry," because the Euclidean surface is a flat surface. Suppose, now, we examine the properties of a two-dimensional geometry constructed not on a plane surface but on a curved surface. For the system of Lobachevski and Bolyai we must take the curvature of the surface to be "negative," which means that the curvature is not like that of the surface of a sphere but like that of a saddle [*see illustrations on page 138*]. Now if we are to draw parallel lines or any figure (*e.g.*, a triangle) on this surface, we must decide first of all how we shall define a "straight line," equivalent to the straight line of plane geometry. The most reasonable definition of a straight line in Euclidean geometry is that it is the path of the shortest distance between two points. On a curved surface the line, so defined, becomes a curved line known as a "geodesic" [see "The Straight Line," by Morris Kline; SCIENTIFIC AMERICAN, March].

Considering a surface curved like a saddle, we find that, given a "straight" line or geodesic, we can draw through a point outside that line a great many geodesics which will never intersect the given line, no matter how far they are extended. They are therefore parallel to it, by the definition of parallel. The possible parallels to the line fall within certain limits, indicated by the intersecting



Five contributors to modern cosmology are depicted in these drawings by Bernarda Bryson.

lines in the drawing at the left in the middle of the next page.

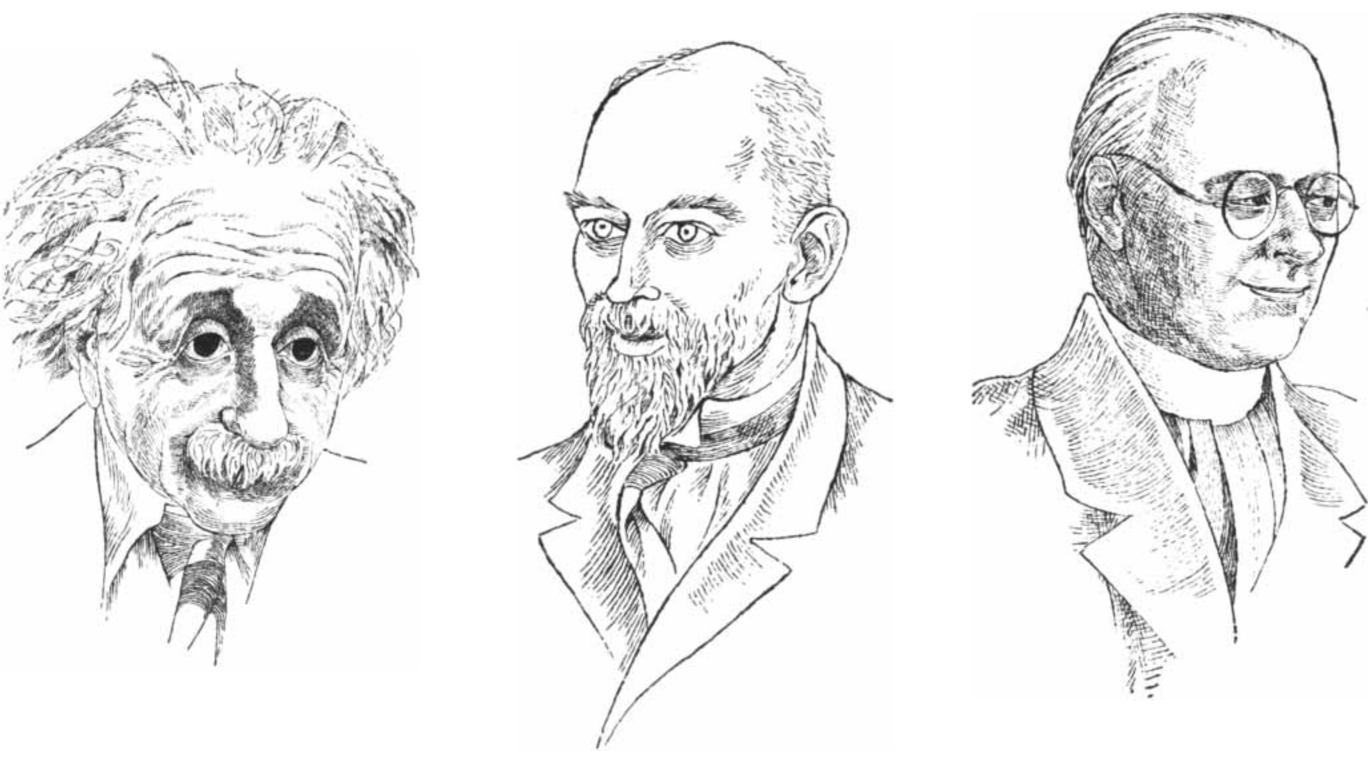
As a consequence of the overthrow of Euclid's axiom on parallel lines, many of his theorems are demolished in the new geometry. For example, the Euclidean theorem that the sum of the three angles of a triangle is 180 degrees no longer holds on a curved surface. On the saddle-shaped surface the angles of a triangle formed by three geodesics always add up to less than 180 degrees, the actual sum depending on the size of the triangle. Further, a circle on the saddle surface does not have the same properties as a circle in plane geometry. On a flat surface the circumference of a circle increases in proportion to the increase in diameter, and the area of a circle increases in proportion to the square of the increase in diameter. But on a saddle surface both the circumference and the area of a circle increase at *faster* rates than on a flat surface with increasing diameter.

After Lobachevski and Bolyai, the German mathematician Bernhard Riemann constructed another non-Euclidean geometry whose two-dimensional model is a surface of positive, rather than negative, curvature—that is, the surface of a sphere. In this case a geodesic line is simply a great circle around the sphere or a segment of such a circle, and since any two great circles must intersect at two points (the poles), there are no parallel lines at all in this geometry. Again the sum of the three angles of a triangle is not 180 degrees: in this case it is always *more* than 180. The circumference of a circle now increases at a rate *slower* than in proportion to its increase in diameter, and its area increases more slowly than the square of the diameter.

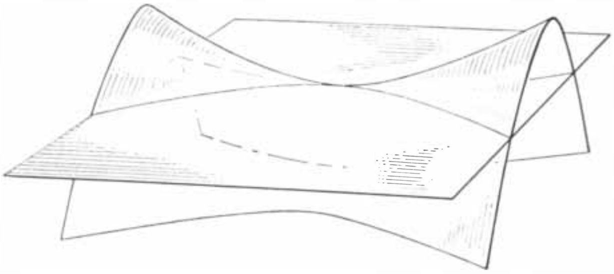
Now all this is not merely an exercise in abstract reasoning but bears directly on the geometry of the universe in which we live. Is the space of our universe "flat," as Euclid assumed, or is it curved negatively (per Lobachevski and Bolyai) or curved positively (Riemann)? If we were two-dimensional creatures living in a two-dimensional universe, we could tell whether we were living on a flat or a curved surface by studying the properties of triangles and circles drawn on that surface. Similarly as three-dimensional beings living in three-dimensional space we should be able, by studying geometrical properties of that space, to decide what the curvature of our space is. Riemann in fact developed mathematical formulas describing the properties of various kinds of curved space in three and more dimensions. In the early years of this century Einstein conceived the idea of the universe as a curved system in four dimensions, embodying time as the fourth dimension, and he proceeded to apply Riemann's formulas to test his idea.

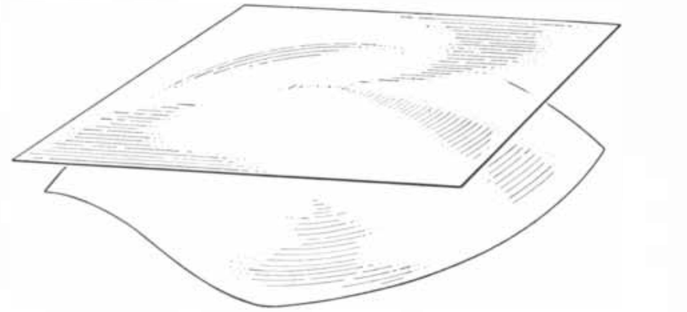
Einstein showed that time can be considered a fourth coordinate supplementing the three coordinates of space. He connected space and time, thus establishing a "space-time continuum," by means of the speed of light as a link between time and space dimensions. However, recognizing that space and time are physically different entities, he employed the imaginary number $\sqrt{-1}$, or i, to express the unit of time mathematically and make the time coordinate formally equivalent to the three coordinates of space.

In his special theory of relativity Einstein made the geometry of the time-space continuum strictly Euclidean, that is, flat. The great idea that he introduced later in his general theory was that gravitation, whose effects had been neglected in the special theory, must make it curved. He saw that the gravitational effect of the masses distributed in space and moving in time was equivalent to curvature of the four-dimensional space-time continuum. In place of the classical Newtonian statement that "the sun produces a field of forces which impels the earth to deviate from straight-line mo-

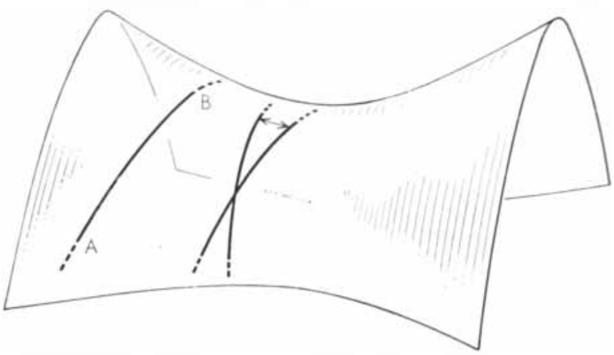


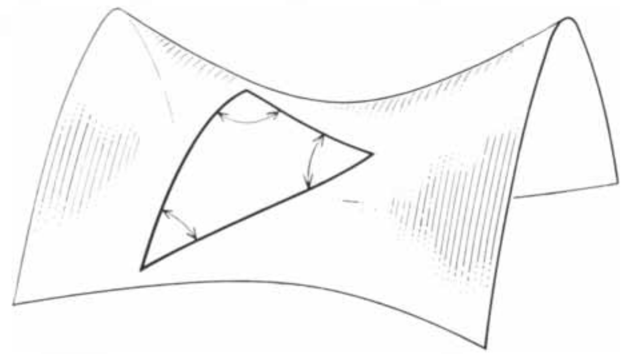
From left to right they are: Nikolai Lobachevski, Bernhard Riemann, Albert Einstein, Willem de Sitter and Georges Lemaître



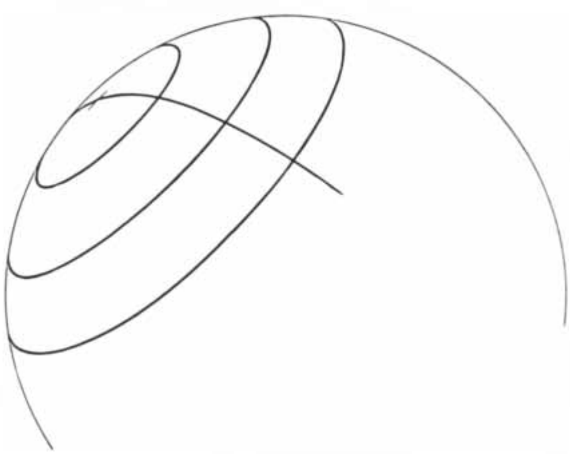


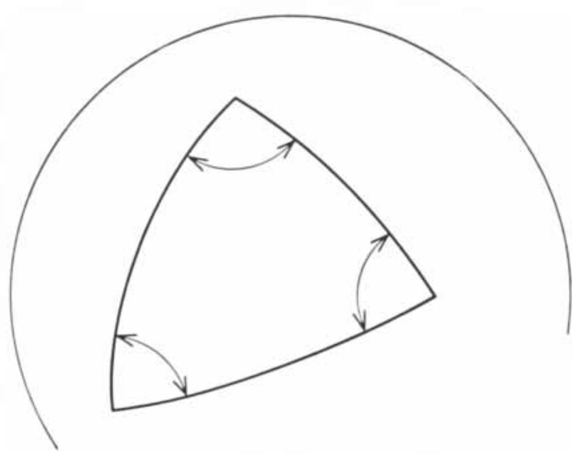
NEGATIVE AND POSITIVE CURVATURE of space is suggested by this two-dimensional analogy. The saddle-shaped surface at left, which lies on both sides of a tangential plane. is negatively curved. The spherical surface at right, which lies on one side of a tangential plane, is positively curved. If space is negatively curved, the universe is infinite; if it is positively curved, the universe is finite.





ON A NEGATIVELY CURVED SURFACE the shortest distance between two points is not a straight line but a curved "geodesic," such as the line AB at the left. On a plane surface only one parallel to a given straight line can be drawn through a point not on that line; on a negatively curved surface many geodesics can be drawn through a point not on a given geodesic without ever intersecting it. These "parallel" lines will fall within the limits indicated by the arrow between the intersecting lines at left. On a plane surface the angles of a triangle add up to 180 degrees; on the negatively curved surface at the right, they add up to less than 180 degrees.





ON A POSITIVELY CURVED SURFACE the shortest distance between two points follows a great circle, a closed line passing through opposite points on the surface (*single curved line at left*). In this geometry there are no "parallel" lines because any two great circles must intersect. The circumference of a circle increases more slowly with diameter than on a flat surface, and the area similarly increases more slowly (*concentric circles at left*). The angles of a triangle on the surface (*right*) add up to more than 180 degrees.

tion and to move in a circle around the sun," Einstein substituted a statement to the effect that "the presence of the sun causes a curvature of the space-time continuum in its neighborhood."

The motion of an object in the space-time continuum can be represented by a curve called the object's "world line." For example, the world line of the earth's travel around the sun in time is pictured in the drawing on the next page. (Space must be represented here in only two dimensions; it would be impossible for a three-dimensional artist to draw the fourth dimension in this scheme, but since the orbit of the earth around the sun lies in a single plane, the omission is unimportant.) Einstein declared, in effect: "The world line of the earth is a geodesic in the curved four-dimensional space around the sun." In other words, the line ABCD in the drawing corresponds to the shortest *four-dimensional* distance between the position of the earth in January (at A) and its position in October (at D).

Einstein's idea of the gravitational curvature of space-time was, of course, triumphantly affirmed by the discovery of perturbations in the motion of Mercury at its closest approach to the sun and of the deflection of light rays by the sun's gravitational field. Einstein next attempted to apply the idea to the universe as a whole. Does it have a general curvature, similar to the local curvature in the sun's gravitational field? He now had to consider not a single center of gravitational force but countless centers of attraction in a universe full of matter concentrated in galaxies whose distribution fluctuates considerably from region to region in space. However, in the large-scale view the galaxies are spread fairly uniformly throughout space as far out as our biggest telescopes can see, and we can justifiably "smooth out" its matter to a general average (which comes to about one hydrogen atom per cubic meter). On this assumption the universe as a whole has a smooth general curvature.

But if the space of the universe is curved, what is the sign of this curvature? Is it positive, as in our two-dimensional analogy of the surface of a sphere, or is it negative, as in the case of a saddle surface? And, since we cannot consider space alone, how is this space curvature related to time?

Analyzing the pertinent mathematical equations, Einstein came to the conclusion that the curvature of space must be independent of time, *i.e.*, that the universe as a whole must be unchanging (though it changes internally). However, he found to his surprise that there was no solution of the equations that would permit a static cosmos. To repair the situation, Einstein was forced to introduce an additional hypothesis which amounted to the assumption that a new kind of force was acting among the galaxies. This hypothetical force had to be independent of mass (being the same for an apple, the moon and the sun!) and to gain in strength with increasing distance between the interacting objects (as no other forces ever do in physics!).

Einstein's new force, called "cosmic repulsion," allowed two mathematical models of a static universe. One solution, which was worked out by Einstein himself and became known as "Einstein's spherical universe," gave the space of the cosmos a positive curvature. Like a sphere, this universe was closed and thus had a finite volume. The space coordinates in Einstein's spherical universe were curved in the same way as the latitude or longitude coordinates on the surface of the earth. However, the time axis of the space-time continuum ran quite straight, as in the good old classical physics. This means that no cosmic event would ever recur. The two-dimensional analogy of Einstein's space-time continuum is the surface of a cylinder, with the time axis running parallel to the axis of the cylinder and the space axis perpendicular to it [*see drawing at left on page 145*].

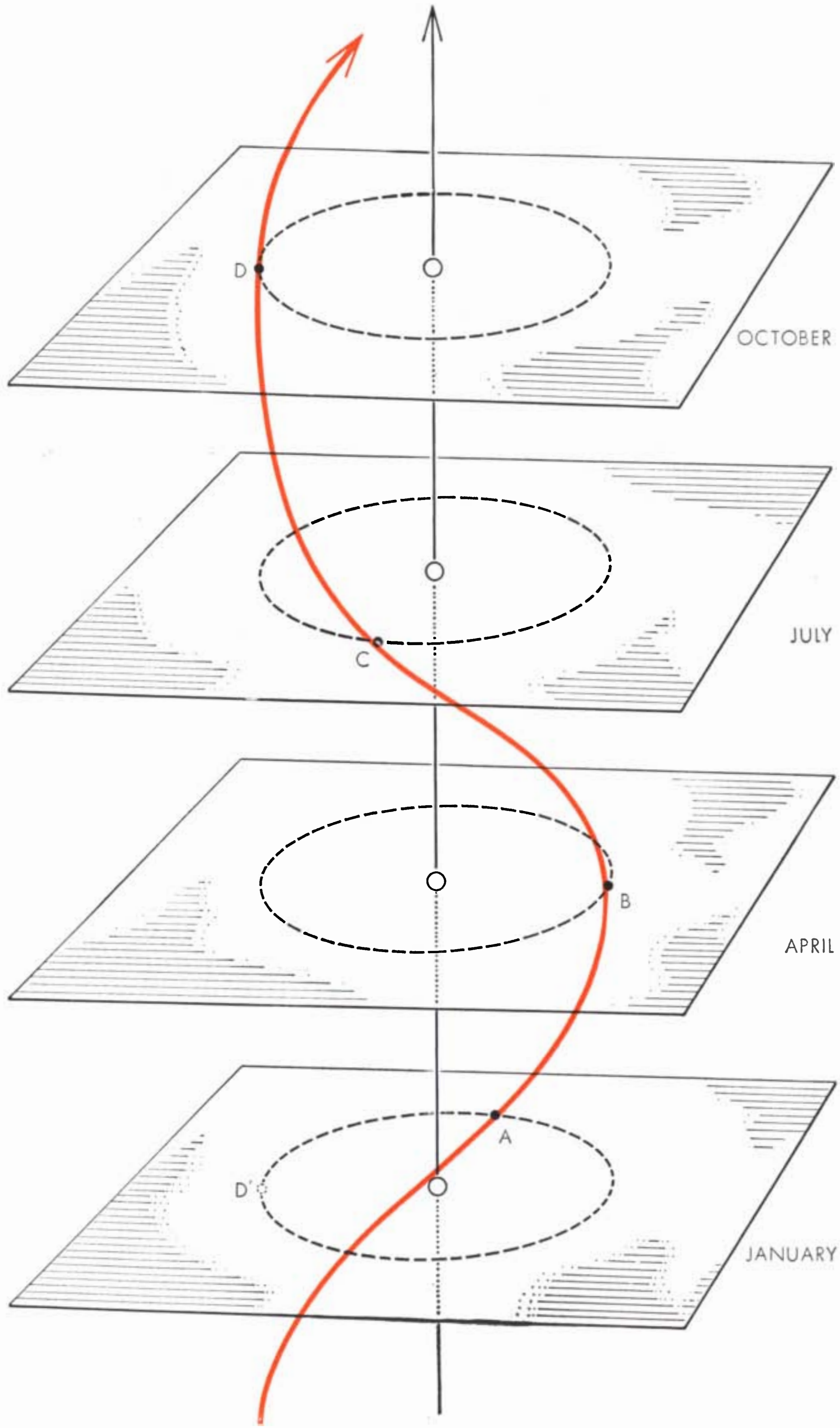
The other static solution based on the mysterious repulsion forces was discovered by the Dutch mathematician Willem de Sitter. In his model of the universe both space and time were curved. Its geometry was similar to that of a globe, with longitude serving as the space coordinate and latitude as time [*drawing at right on page 145*].

Unhappily astronomical observations contradicted both Einstein's and de Sitter's static models of the universe, and they were soon abandoned.

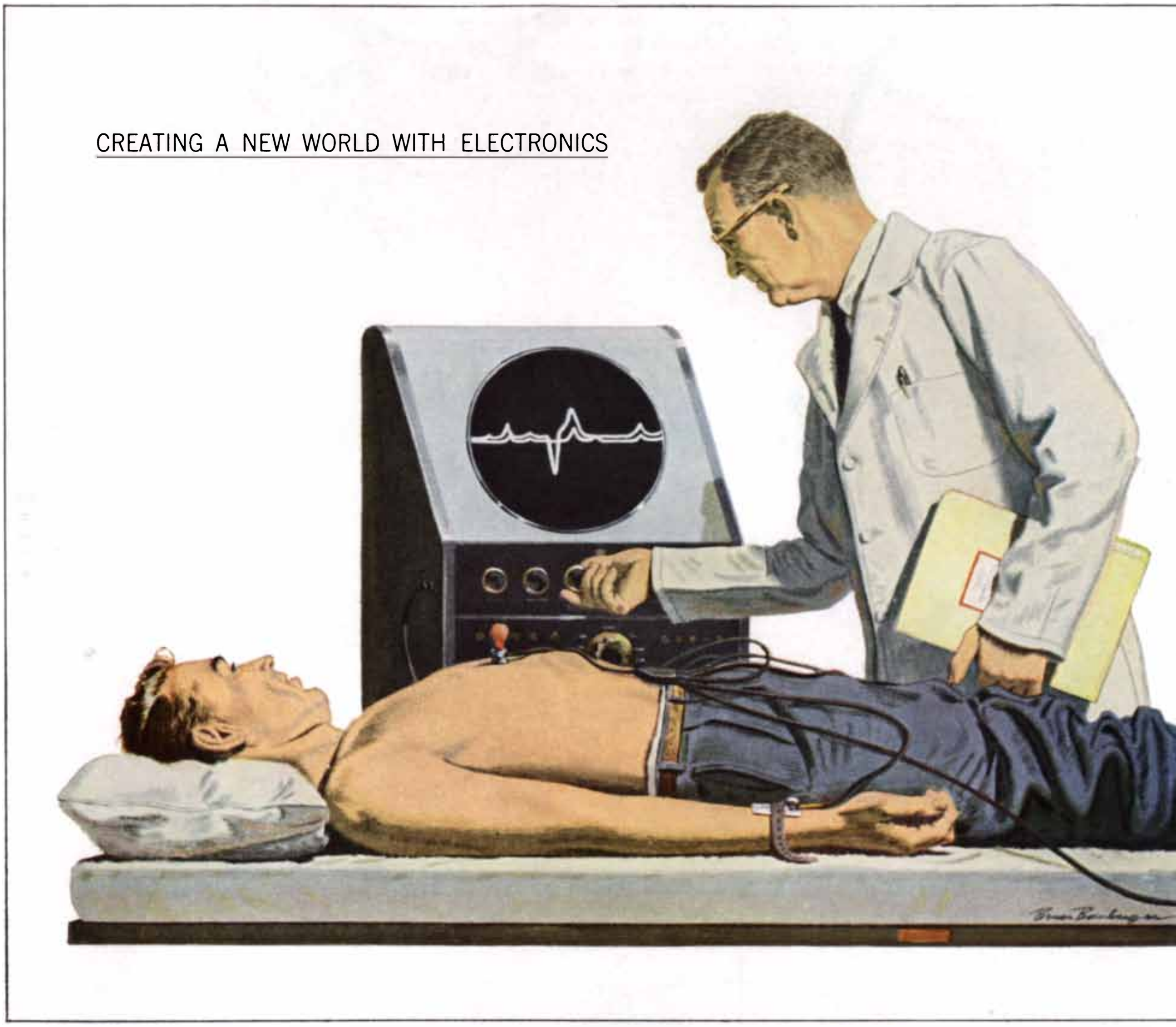
In the year 1922 a major turning point came in the cosmological problem. A Russian mathematician, Alexander A. Friedman (from whom the author of this article learned his relativity), discovered an error in Einstein's proof for a static universe. In carrying out his proof Einstein had divided both sides of an equation by a quantity which, Friedman found, could become zero under certain circumstances. Since division by zero is not permitted in algebraic computations, the possibility of a nonstatic universe could not be excluded under the circumstances in question. Friedman showed that two nonstatic models were possible. One pictured the universe as expanding with time; the other, contracting.

Einstein quickly recognized the importance of this discovery. In the last edition of his book *The Meaning of Relativity* he wrote: "The mathematician Friedman found a way out of this dilemma. He showed that it is possible, according to the field equations, to have a finite density in the whole (three-dimensional) space, without enlarging these field equations ad hoc." Einstein remarked to me many years ago that the cosmic repulsion idea was the biggest blunder he had made in his entire life.

Almost at the very moment that Friedman was discovering the possibility



MOTION OF BODY in the curved "space-time continuum" of Albert Einstein is represented by the "world line" of the earth's motion around the sun. Here the sun is the small open circle in each of the four planes. The earth is the black dot on the elliptical orbit. Each plane shows the position of the earth at a month of the year. The world line is in color.



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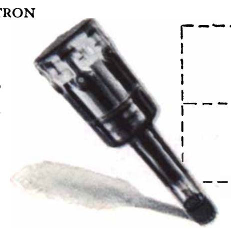

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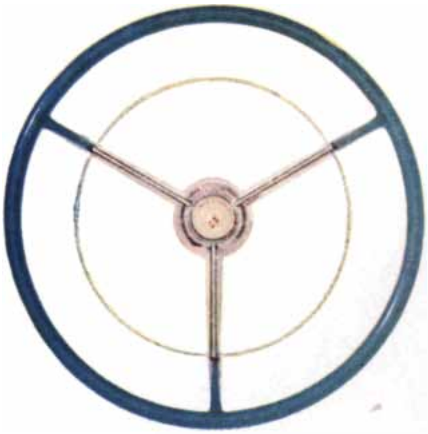

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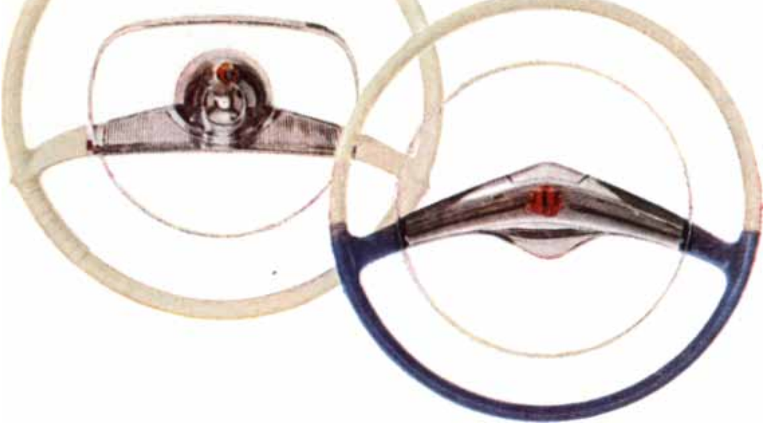

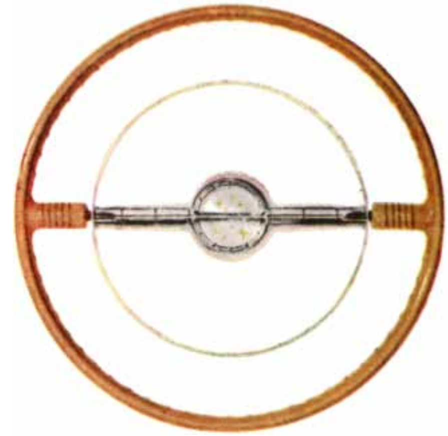

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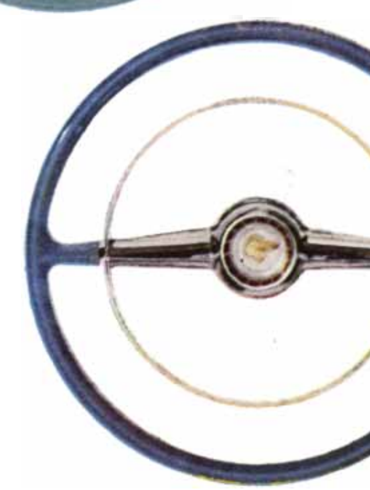

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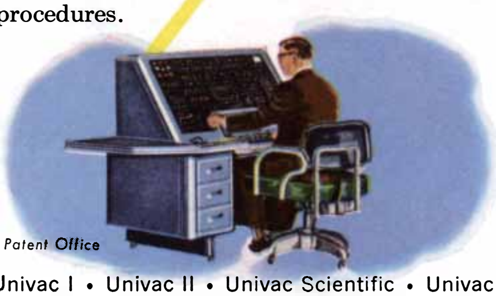

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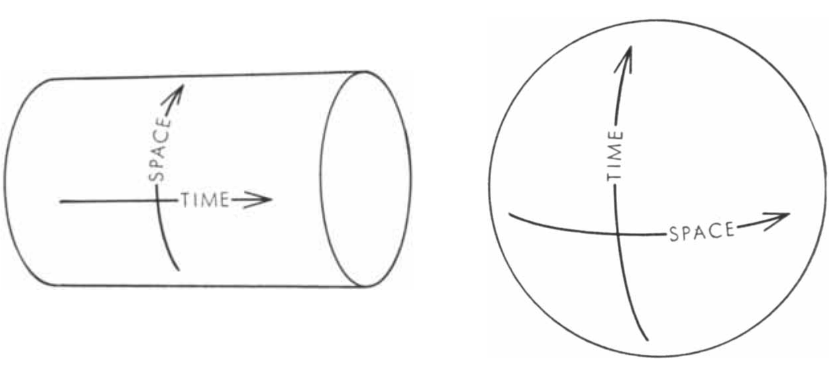
Makers of: Univac I • Univac II • Univac Scientific • Univac File-Computer • Univac 60 • Univac 120 • Univac High-Speed Printer of an expanding universe by mathematical reasoning, Edwin P. Hubble at the Mount Wilson Observatory on the other side of the world found the first evidence of actual physical expansion through his telescope. He made a compilation of the distances of a number of far galaxies, whose light was shifted toward the red end of the spectrum, and it was soon found that the extent of the shift was in direct proportion to a galaxy's distance from us, as estimated by its faintness. Hubble and others interpreted the red-shift as the Doppler effect—the well-known phenomenon of lengthening of wavelengths from any radiating source that is moving rapidly away (a train whistle, a source of light or whatever). To date there has been no other reasonable explanation of the galaxies' red-shift. If the explanation is correct, it means that the galaxies are all moving away from one another with increasing velocity as they move farther apart.

Thus Friedman and Hubble laid the foundation for the theory of the expanding universe. The theory was soon developed further by a Belgian theoretical astronomer, Georges Lemaître. He proposed that our universe started from a highly compressed and extremely hot state which he called the "primeval atom." (Modern physicists would prefer the term "primeval nucleus.") As this matter expanded, it gradually thinned out, cooled down and reaggregated in stars and galaxies, giving rise to the highly complex structure of the universe as we know it today.

Until a few years ago the theory of the expanding universe lay under the cloud of a very serious contradiction. The measurements of the speed of flight of the galaxies and their distances from us indicated that the expansion had started about 1.8 billion years ago. On the other hand, measurements of the age of ancient rocks in the earth by the clock of radioactivity (*i.e.*, the decay of uranium to lead) showed that some of the rocks were at least three billion years old; more recent estimates based on other radioactive elements raise the age of the earth's crust to almost five billion years. Clearly a universe 1.8 billion years old could not contain five-billion-year-old rocks! Happily the contradiction has now been disposed of by Walter Baade's recent discovery that the distance yardstick (based on the periods of variable stars) was faulty and that the distances between galaxies are more than twice as great as they were thought to be. This change in distances raises the age of the universe to five billion years or more.

Friedman's solution of Einstein's cosmological equation, as I mentioned, permits two kinds of universe. We can call one the "pulsating" universe. This model says that when the universe has reached a certain maximum permissible expansion, it will begin to contract; that it will shrink until its matter has been compressed to a certain maximum density, possibly that of atomic nuclear material, which is a hundred million million times denser than water; that it will then begin to expand again—and so on through the cycle *ad infinitum*. The other model is a "hyperbolic" one: it suggests that from an infinitely thin state an eternity ago the universe contracted until it reached the maximum density, from which it rebounded to an unlimited expansion which will go on indefinitely in the future.

The question whether our universe is actually "pulsating" or "hyperbolic" should be decidable from the present rate of its expansion. The situation is analogous to the case of a rocket shot from the surface of the earth. If the velocity of the rocket is less than seven miles per second—the "escape velocity"—the rocket will climb only to a certain



SPHERICAL UNIVERSE of Einstein may be represented in two dimensions by a cylinder (*left*). Its space coordinates were positively curved but its time coordinate was straight. The spherical universe of Willem de Sitter had positively curved coordinates (*right*).

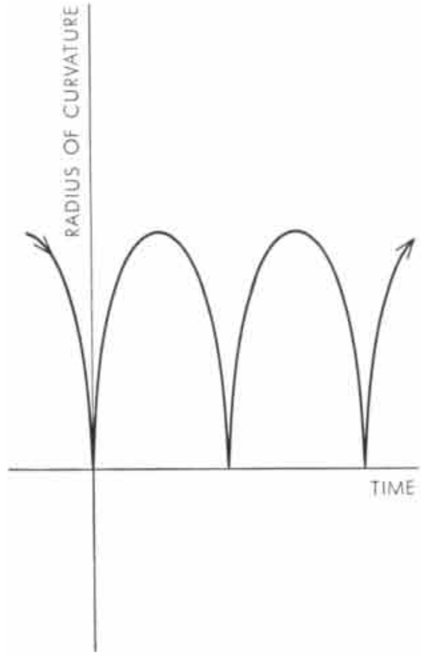
height and then fall back to the earth. (If it were completely elastic, it would bounce up again, etc., etc.) On the other hand, a rocket shot with a velocity of more than seven miles per second will escape from the earth's gravitational field and disappear in space. The case of the receding system of galaxies is very similar to that of an escape rocket, except that instead of just two interacting bodies (the rocket and the earth) we have an unlimited number of them escaping from one another. We find that the galaxies are fleeing from one another at seven times the velocity necessary for mutual escape.

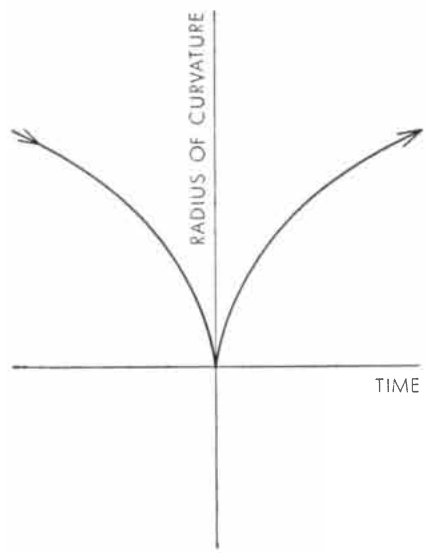
Thus we may conclude that our universe corresponds to the "hyperbolic" model, so that its present expansion will never stop. We must make one reservation. The estimate of the necessary escape velocity is based on the assumption that practically all the mass of the universe is concentrated in galaxies. If intergalactic space contained matter whose total mass was more than seven times that in the galaxies, we would have to reverse our conclusion and decide that the universe is pulsating. There has been no indication so far, however, that any matter exists in intergalactic space, and it could have escaped detection only if it were in the form of pure hydrogen gas, without other gases or dust.

Is the universe finite or infinite? This resolves itself into the question: Is the curvature of space positive or negative—closed like that of a sphere, or open like that of a saddle? We can look for the answer by studying the geometrical properties of its three-dimensional space, just as we examined the properties of figures on two-dimensional surfaces. The most convenient property to investigate astronomically is the relation between the volume of a sphere and its radius.

We saw that, in the two-dimensional case, the area of a circle increases with increasing radius at a faster rate on a negatively curved surface than on a Euclidean or flat surface; and that on a positively curved surface the relative rate of increase is slower. Similarly the increase of volume is faster in negatively curved space, slower in positively curved space. In Euclidean space the volume of a sphere would increase in proportion to the cube, or third power, of the increase in radius. In negatively curved space the volume would increase faster than this; in positively curved space, slower. Thus if we look into space and find that the volume of successively larger spheres, as measured by a count of the galaxies within them, increases faster than the cube of the distance to the limit of the sphere (the radius), we can conclude that the space of our universe has negative curvature, and therefore is open and infinite. By the same token, if the number of galaxies increases at a rate slower than the cube of the distance, we live in a universe of positive curvature—closed and finite.

Following this idea, Hubble undertook to study the increase in number of





PULSATING AND HYPERBOLIC universes are represented by curves. The pulsating universe at the top repeatedly expands to a maximum permissible density and contracts to a minimum permissible density. The hyperbolic universe at the bottom contracts and then expands indefinitely.

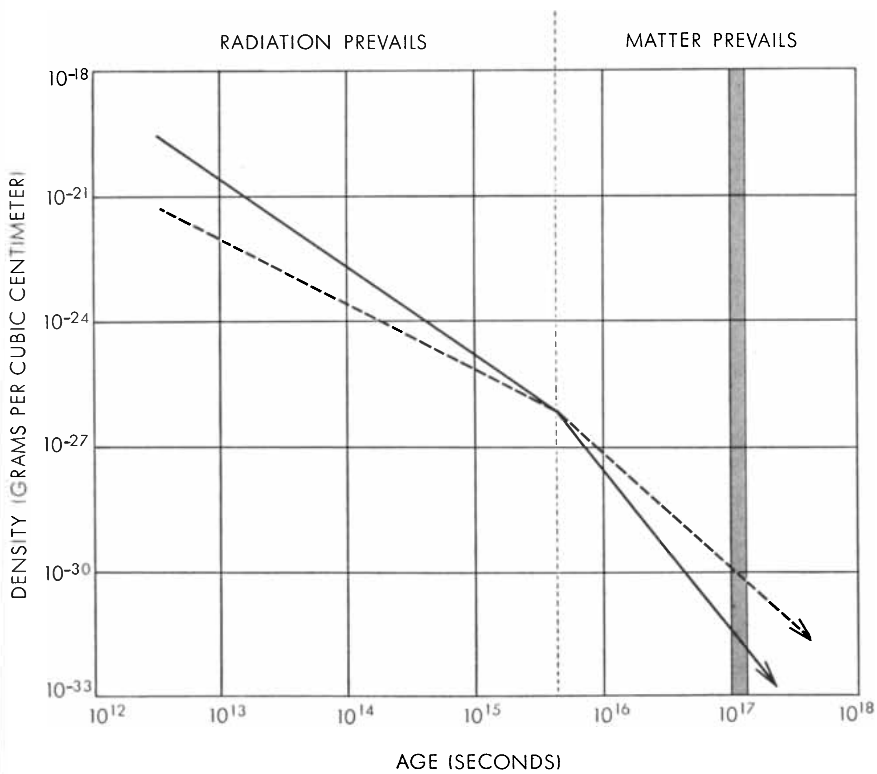
galaxies with distance. He estimated the distances of the remote galaxies by their relative faintness: galaxies vary considerably in intrinsic brightness, but over a very large number of galaxies these variations are expected to average out. Hubble's calculations produced the conclusion that the universe is a closed system—a small universe only a few billion light-years in radius!

We know now that the scale he was using was wrong: with the new yardstick the universe would be more than twice as large as he calculated. But there is a more fundamental doubt about his result. The whole method is based on the assumption that the intrinsic brightness of a galaxy remains constant. What if it changes with time? We are seeing the light of the distant galaxies as it was emitted at widely different times in the past—500 million, a billion, two billion years ago. If the stars in the galaxies are burning out, the galaxies must dim as they grow older. A galaxy two billion light-years away cannot be put on the same distance scale with a galaxy 500 million light-years away unless we take into account the fact that we are seeing the nearer galaxy at an older, and less bright, age. The remote galaxy is farther away than a mere comparison of the luminosity of the two would suggest.

When a correction is made for the assumed decline in brightness with age, the more distant galaxies are spread out to farther distances than Hubble assumed. In fact, the calculations of volume are changed so drastically that we may have to reverse the conclusion about the curvature of space. We are not sure, because we do not yet know enough about the evolution of galaxies. But if we find that galaxies wane in intrinsic brightness by only a few per cent in a billion years, we shall have to conclude that space is curved negatively and the universe is infinite.

Actually there is another line of reasoning which supports the side of infinity. Our universe seems to be hyperbolic and ever-expanding. Mathematical solutions of fundamental cosmological equations indicate that such a universe is open and infinite.

We have reviewed the questions that dominated the thinking of cosmologists during the first half of this century: the conception of a four-dimensional space-time continuum, of curved space, of an expanding universe and of a cosmos which is either finite or infinite. Now we must consider the major present issue in cosmology: Is the universe in truth evolving, or is it in a steady state of equilibri-



RELATIVE DENSITY OF MATTER AND RADIATION is reversed during the history of an evolutionary universe. Up to 250 million years (*broken vertical line*) the mass density of radiation (*solid curve*) is greater than that of matter (*broken curve*). After that the density of matter is greater, permitting the formation of huge gas clouds. The gray line is the present.

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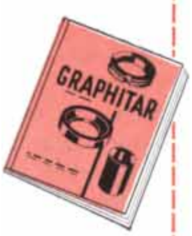

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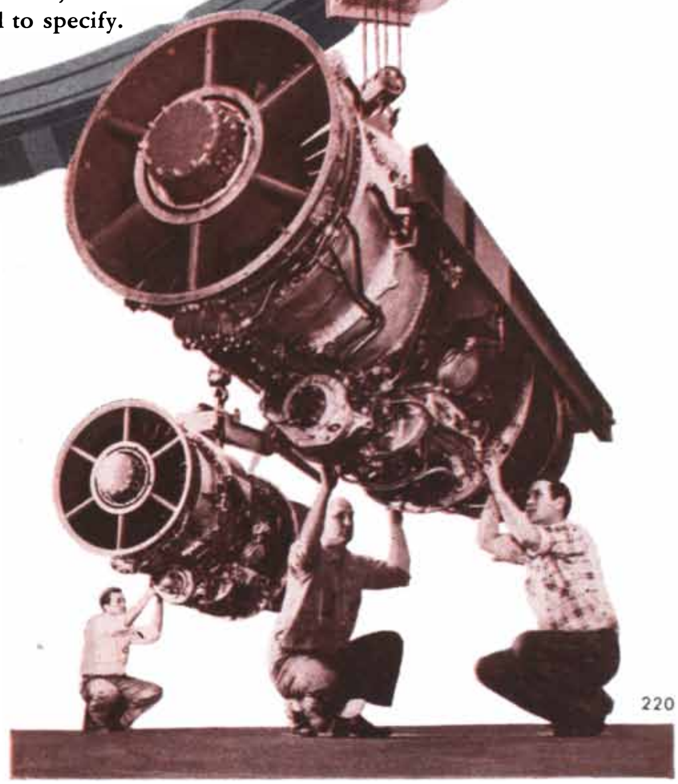

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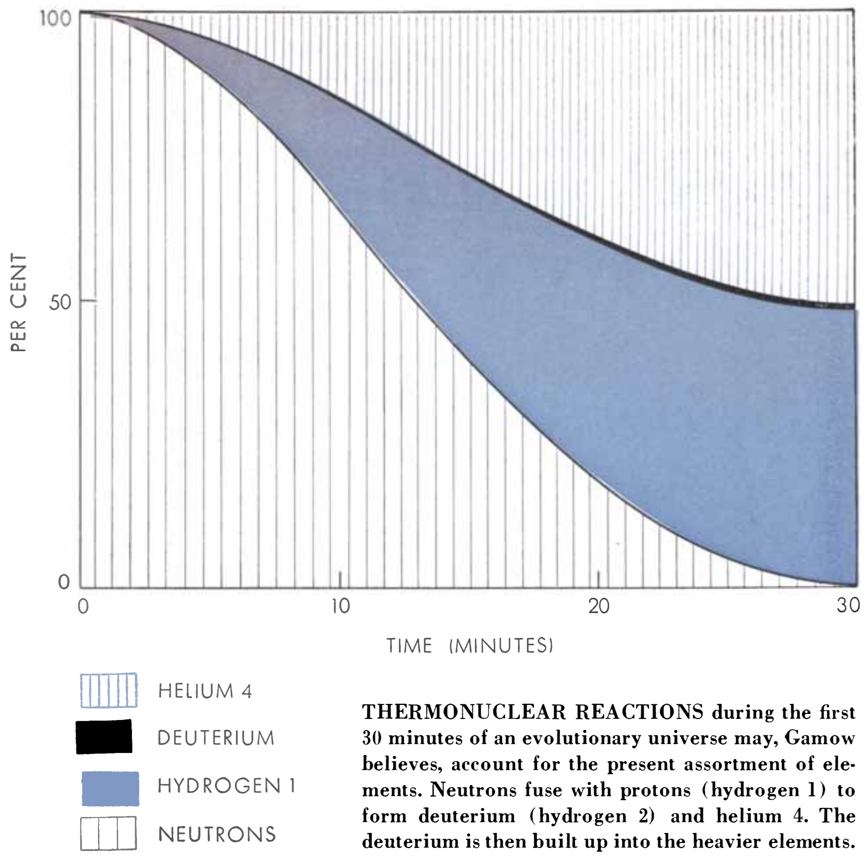

THERMONUCLEAR REACTIONS during the first 30 minutes of an evolutionary universe may, Gamow believes, account for the present assortment of elements. Neutrons fuse with protons (hydrogen 1) to form deuterium (hydrogen 2) and helium 4. The deuterium is then built up into the heavier elements.

um which has always existed and will go on through eternity? Most cosmologists take the evolutionary view. But in 1951 a group at the University of Cambridge, whose chief spokesman has been Fred Hoyle, advanced the steady-state idea. Essentially their theory is that the universe is infinite in space and time, that it has neither a beginning nor an end, that the density of its matter remains constant, that new matter is steadily being created in space at a rate which exactly compensates for the thinning of matter by expansion, that as a consequence new galaxies are continually being born, and that the galaxies of the universe therefore range in age from mere youngsters to veterans of 5, 10, 20 and more billions of years. In my opinion this theory must be considered very questionable because of the simple fact (apart from other reasons) that the galaxies in our neighborhood all seem to be of the same age as our own Milky Way. But the issue is many-sided and fundamental, and can be settled only by extended study of the universe as far as we can observe it. Hoyle presents the steady-state view in the following article [*page 157*]. Here I shall summarize the evolutionary theory.

We assume that the universe started from a very dense state of matter. In the early stages of its expansion, radiant energy was dominant over the mass of matter. We can measure energy and matter on a common scale by means of the well-known equation $E=mc^2$, which says that the energy equivalent of matter is the mass of the matter multiplied by the square of the velocity of light. Energy can be translated into mass, conversely, by dividing the energy quantity by c^2. Thus we can speak of the "mass density" of energy. Now at the beginning the mass density of the radiant energy was incomparably greater than the density of the matter in the universe. But in an expanding system the density of radiant energy decreases faster than does the density of matter. The former thins out as the fourth power of the distance of expansion: as the radius of the system doubles, the density of radiant energy drops to one sixteenth. The density of matter declines as the third power; a doubling of the radius means an eightfold increase in volume, or eightfold decrease in density.

Assuming that the universe at the beginning was under absolute rule by radiant energy, we can calculate that the temperature of the universe was 250 million degrees when it was one hour old, dropped to 6,000 degrees (the present temperature of our sun's surface) when it was 200,000 years old and had fallen

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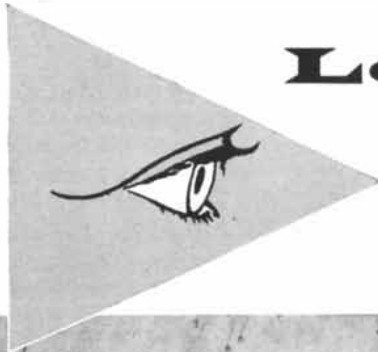

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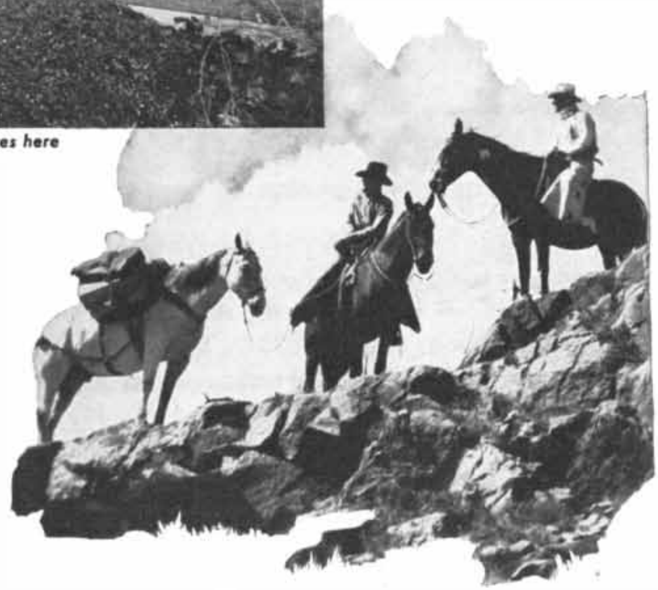

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to about 100 degrees below the freezing point of water when the universe reached its 250-millionth birthday.

This particular birthday was a crucial one in the life of the universe. It was the point at which the density of ordinary matter became greater than the mass density of radiant energy, because of the more rapid fall of the latter [*see chart on page 148*]. The switch from the reign of radiation to the reign of matter profoundly changed matter's behavior. During the eons of its subjugation to the will of radiant energy (*i.e.*, light), it must have been spread uniformly through space in the form of thin gas. But as soon as matter became gravitationally more important than the radiant energy, it began to acquire a more interesting character. James Jeans, in his classic studies of the physics of such a situation, proved half a century ago that a gravitating gas filling a very large volume is bound to break up into individual "gas balls," the size of which is determined by the density and the temperature of the gas. Thus in the year 250,000,000 A. B. E. (after the beginning of expansion), when matter was freed from the dictatorship of radiant energy, the gas broke up into giant gas clouds, slowly drifting apart as the universe continued to expand. Applying Jeans's mathematical formula for the process to the gas filling the universe at that time, I have found that these primordial balls of gas would have had just about the mass that the galaxies of stars possess today. They were then only "protogalaxies"—cold, dark and chaotic. But their gas soon condensed into stars and formed the galaxies as we see them now.

A central question in this picture of the evolutionary universe is the problem of accounting for the formation of the varied kinds of matter composing it—*i.e.*, the chemical elements. The question is discussed in detail in another article in this issue [*see page 82*]. My belief is that at the start matter was composed simply of protons, neutrons and electrons. After five minutes the universe must have cooled enough to permit the aggregation of protons and neutrons into larger units, from deuterons (one neutron and one proton) up to the heaviest elements. This process must have ended after about 30 minutes, for by that time the temperature of the expanding universe must have dropped below the threshold of thermonuclear reactions among light elements, and the neutrons must have been used up in element-building or been converted to protons.

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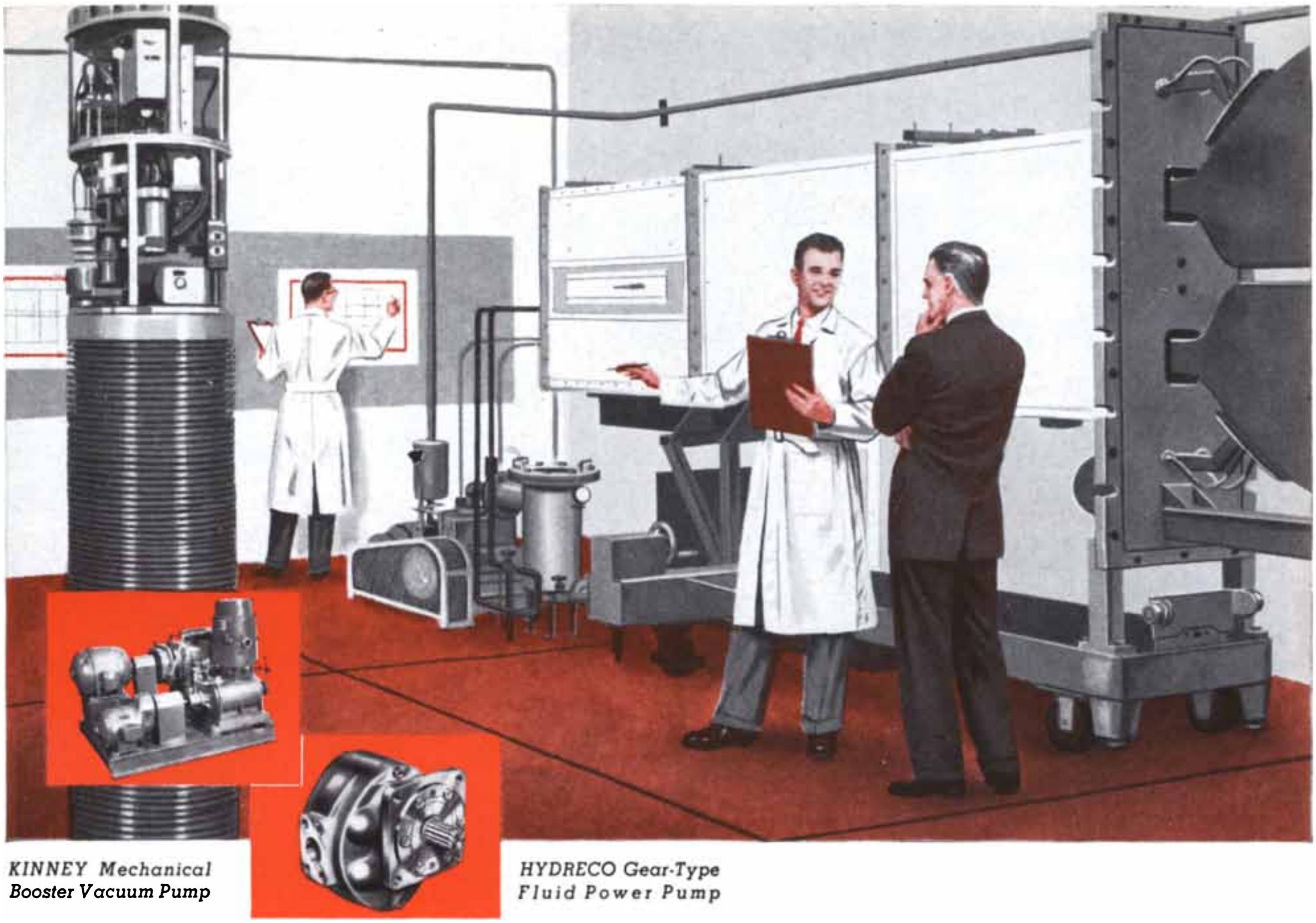
the present chemical constitution of our universe was decided in half an hour five billion years ago will sound nonsensical. But consider a spot of ground on the atomic proving ground in Nevada where an atomic bomb was exploded three years ago. Within one microsecond the nuclear reactions generated by the bomb produced a variety of fission products. Today, 100 million million microseconds later, the site is still "hot" with the surviving fission products. The ratio of one microsecond to three years is the same as the ratio of half an hour to five billion years! If we can accept a time ratio of this order in the one case, why not in the other?

The late Enrico Fermi and Anthony L. Turkevich at the Institute for Nuclear Studies of the University of Chicago undertook a detailed study of thermonuclear reactions such as must have taken place during the first half hour of the universe's expansion. They concluded that the reactions would have produced about equal amounts of hydrogen and helium, making up 99 per cent of the total material, and about 1 per cent of deuterium. We know that hydrogen and helium do in fact make up about 99 per cent of the matter of the universe. This leaves us with the problem of building the heavier elements. I hold to the opinion that some of them were built by capture of neutrons. However, since the absence of any stable nucleus of atomic weight 5 makes it improbable that the heavier elements could have been produced in the first half hour in the abundances now observed, I would agree that the lion's share of the heavy elements may well have been formed later in the hot interiors of stars.

All the theories—of the origin, age, extent, composition and nature of the universe—are becoming more and more subject to test by new instruments and new techniques, which are described in later articles in this issue. In the article on the red-shift investigations, Allan Sandage reports a tentative finding that the expansion of the universe may be slowing down. If this is confirmed, it may indicate that we live in a pulsating universe. But we must not forget that the estimate of distances of the galaxies is still founded on the debatable assumption that the brightness of galaxies does not change with time. If galaxies actually diminish in brightness as they age, the calculations cannot be depended upon. Thus the question whether evolution is or is not taking place in the galaxies is of crucial importance at the present stage of our outlook on the universe.



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THE STEADY-STATE UNIVERSE

Some cosmologists dissent from the evolutionary view, holding that the large-scale features of the expanding universe do not change, and that its density has been maintained by the creation of matter

by Fred Hoyle

The theory of a steady-state universe leads to many startling conclusions: that the universe had no beginning and will have no end, that space as well as time is infinite, that matter is continually being created throughout space—to mention a few. Human nature being what it is, there has been a tendency to become involved in emotional attitudes toward these concepts, instead of confining the discussion to purely scientific criteria. If the writer, along with critics, has transgressed in this respect, he promises to give some redress in this article.

The steady-state theory holds that the large-scale features of the universe do not change with time. Only the galaxies and clusters of galaxies change; if we "smear out" their material uniformly through space and consider the general properties of the cosmos, it is unchanging. The expansion of the universe is a basic feature of the theory. The question arises: If the galaxies are moving apart from each other, why does space not become more and more empty? The answer of the theory is that new galaxies and clusters of galaxies are constantly being formed, their rate of formation just compensating for the separating effect of the expansion. So a stable situation is preserved.

Before we go on to consider the reasoning, predictions and tests of steady-state cosmology, the writer should point out that his own approach to the theory, and also that of William H. McCrea of the University of London, differs rather markedly from the approach of Hermann Bondi and Thomas Gold. The writer's approach is a mathematical one developed in the framework of the theory of relativity. Bondi's and Gold's is founded on an intuitive but powerful physical principle. To understand their outlook we must look into the nature of this postulate, which is called the "cosmological principle."

Cosmology differs from all other branches of physical science in a very important respect. Whereas other physical scientists deal always with isolated systems, whose "boundary conditions" can be defined, a cosmologist has to deal with a nonisolated system. To cope with this unhappy situation he is forced to adopt a "symmetry" postulate, which says that, local fluctuations apart, the universe will look the same from wherever one views it. That is to say, it assumes that observers attached to different galaxies anywhere in the cosmos would all obtain exactly the same large-scale picture of the universe. But if the universe changes with time, this implies that the different observers compare their pictures at the same time, which of course requires us to have a definition of what we mean by "at the same time." In order to make a definition of simultaneity possible, the mathematician Hermann Weyl advanced the additional postulate that the motions of the galaxies follow a regular type of pattern, whose exact nature need not be described here.

Instead of this additional postulate Bondi and Gold proposed a single all-embracing "cosmological principle": namely, that the large-scale features of the universe are the same not only from every point of view in space but also from every point of view in time. This symmetry hypothesis leads immediately to the conclusion that the universe is in a steady state. It is then immaterial whether the observers compare their pictures "at the same time" or not.

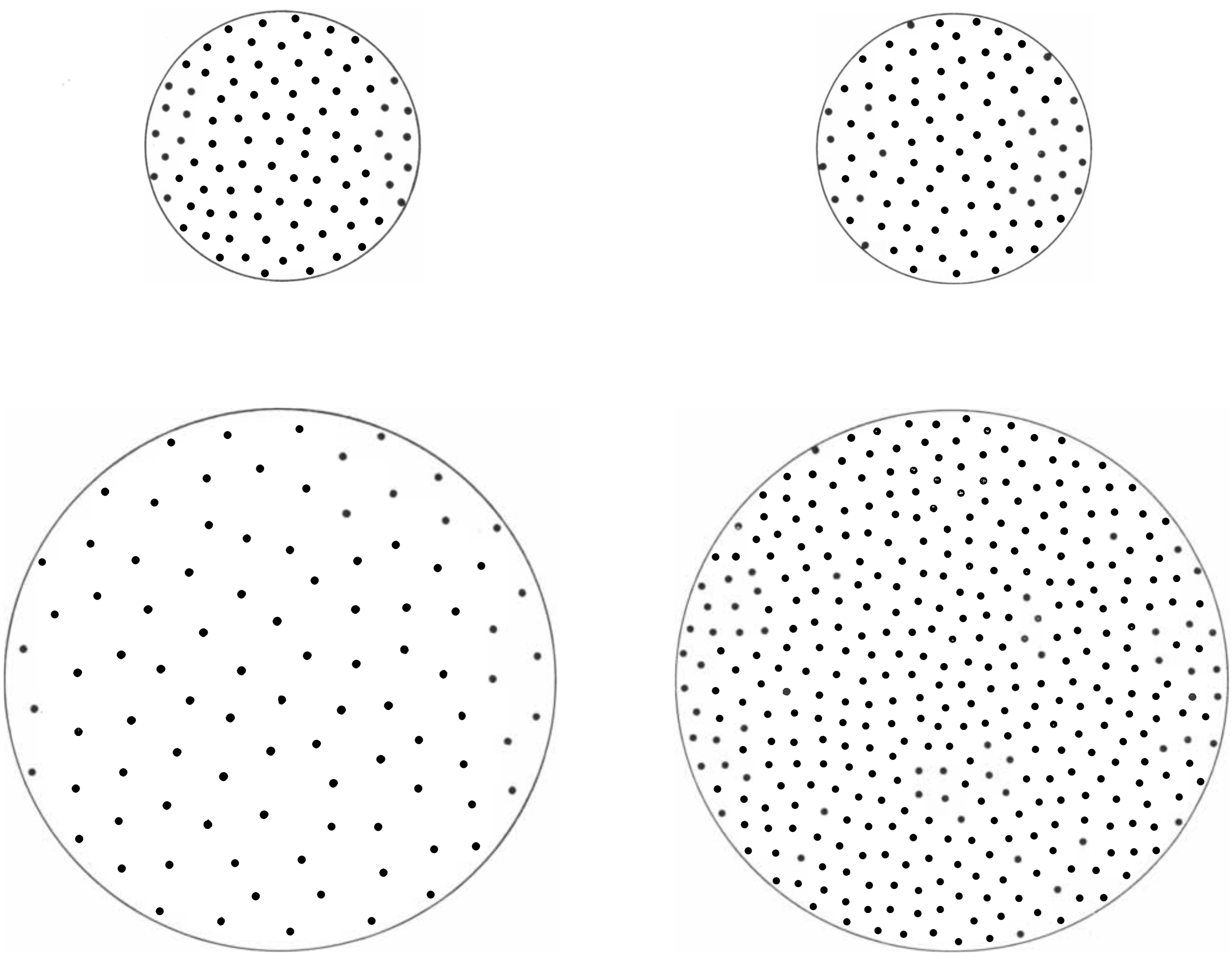
The outlook of Bondi and Gold has a compelling simplicity. Moreover, symmetry postulates have repeatedly demonstrated their power in theories of physics during the present century (*e.g.*, the positive and negative particles of nuclear physics). But to my own taste it is preferable to start with a mathematical definition of the continuous creation of matter within the framework of the relativity theory and then to derive the steady-state solution as a consequence of field equations.

At first sight the creation of matter may seem a queer concept to be invading scientific thought. But as other articles in this issue make abundantly clear, the origin of matter must enter all cosmologies. Nowadays we are coming more and more to realize that hydrogen is the original material—the material out of which the other elements have been produced by nuclear reactions inside stars. This transmutation of hydrogen is going on all the time.

Why is there any hydrogen remaining in the universe? Why was it not all used up in the production of heavy elements eons ago? If we assumed that the hydrogen of the universe has existed for an infinite time, there would be two conceivable answers. We might suppose that the hydrogen has not had sufficient time to become transmuted into other elements because the stars were born only recently, that is, within the last five billion years or so. But it would follow from this that the hydrogen remained stable for eons of time and then suddenly five billion years ago began to condense into stars and galaxies. This seems less than plausible. The other possibility, assuming the hydrogen is infinitely old, is that we still find it on hand because the higher elements formed from it break down to hydrogen again. The chief objection to this idea is the difficulty of explaining how the energy necessary for the breakdown would be supplied. Decomposition of the heavier elements into hydrogen requires absorption of energy—the reverse of the release of energy that occurs when hydrogen nuclei combine. To provide an amount of energy adequate to account for a sufficiently large-scale reconversion of the heavier elements, nothing less than an implosion of the whole universe (as opposed to an explosion) apparently would suffice.

We are thus led to the conclusion that the hydrogen we observe is not infinitely old: it has originated within some finite time and has not yet been converted to heavier elements. Both the evolutionary and the steady-state theories of the universe agree on this point. But there the similarity between them ends. The evolutionary theory argues that all the hydrogen was created in an explosive beginning some five and a half billion years ago [*see George Gamow's article beginning on page 136*].The steady-state hypothesis holds that hydrogen has been created at a steady rate throughout infinite time and is still being created at the same rate today.

If hydrogen has been present for an infinity of time, and has steadily been converted to heavier elements in stars, why don't we see galaxies made of very old matter? Why do we see only comparatively young galaxies, composed almost entirely of hydrogen? The answer of the steady-state theory is that the expansion of the universe spreads galaxies apart as they age, and the old material is rapidly diluted, in terms of its mean density in the universe as a whole. Meanwhile new hydrogen, and new galaxies, are just as rapidly being created. According to the mathematics of the theory, the expansion of the universe and the creation of new material go on at rates such that the mean density of 200-billion-year-old material, for example, is less than that of recently formed material by a factor of 10^{43} (1 followed by 43 zeros). It must be emphasized that this figure is a mean averaged over the universe as a whole: it does not apply to individual galaxies or clusters of galaxies. Expansion takes place in space *between* galactic systems: the individual galaxies and clusters do not themselves expand. The very old material of the universe is concentrated in very old galaxies. By virtue of the universal expansion these are now extremely far apart. Possibly there are some moderately old galaxies within the range of our telescopes. If a method could be worked out to identify distant galaxies



EVOLUTIONARY AND STEADY-STATE VIEWS are compared in these diagrams. At left is a schematic view of an evolutionary universe. At the top is a sample of the universe, with the galaxies represented by dots. At the bottom is a picture of the same galaxies after the passage of time. The galaxies have merely receded from one another. At right is the same kind of view of a steady-state universe. At the top is a sample of the universe. At the bottom is a picture of the volume occupied by the same galaxies after the passage of time. In that time, however, new galaxies have been created, maintaining the density of the galaxies as before.

composed of comparatively old matter, it would provide a test of the steady-state theory.

Approaching the steady-state theory from the mathematical point of view, our first step evidently must be to construct a mathematical law representing the origin of matter. We wish to formulate this law within the logical framework of the theory of relativity: like the evolutionary theory, steady-state cosmology makes use of the powerful equations devised by Albert Einstein to describe the four-dimensional space-time continuum [*see the preceding article*]. We can indicate briefly here some of the main principles involved, though the equations themselves are too complex to examine in detail.

The theory of relativity begins by generalizing the ordinary laws of motion in three-dimensional space to describe the properties and the non-Euclidean geometry of the four-dimensional space-time field. These laws can be set down in four equations: one equation for the law of conservation of energy and three for the conservation of momentum. Our problem is to frame the law of origin of matter in such a way that it can be introduced into these four conservation equations.

As a first step we must define energy and momentum, for the theory of relativity does not itself define them. It is most reasonable to choose definitions which will yield equations as closely analogous as possible to the ordinary equations describing the laws of conservation in our familiar (Euclidean) world. The evolutionary cosmologists seem at first sight to have done this, but it turns out that their conservation equations do not contain any generalized analogue of certain terms, known as "fluid stresses," which play a part in the ordinary equations. Now when we define energy and momentum in a way that yields such a generalization, the outcome of the equations is a steady-state universe, not an evolutionary one.

The equations, so generalized, imply a "feedback" relation between the expansion of the universe and the origin of matter. If the expansion rises above a certain critical rate (related to the rate of origin of matter), the feedback slows the expansion. If the universe's expansion slows down to less than the critical rate, the feedback speeds it up. Thus the interaction between the expansion and the creation of matter maintains a steady state in which the mean density of matter in the universe remains constant.

To many people the notion of continuous creation of new matter in space seems an outright violation of the conservation of energy. But this indicates a confusion between a closed system and the very different situation in an open system. The theory of relativity says that in an open, infinitely expanding universe, local concentrations of energy are related to the energy of expansion of the whole universe. The energy of expansion can take a form leading to a continuous creation of local matter.

The same question that is asked about the creation of matter might be asked about the red-shift of light from distant galaxies. The reddened light is weaker than when it started on its journey. Where does the lost radiant energy go to? It goes into a slight increase in the rate of expansion of the whole universe. The point is that for a total reckoning of the conservation of energy and matter in the cosmos we must take the expansion of the universe into account. We cannot balance the energy books strictly and completely within the confines of any locality, because no locality in the universe is entirely closed.

Before we drop this issue it is perhaps worth noting that we can consider the conservation question in purely operational rather than theoretical terms and come out with the same result. Suppose observers on the earth measured the energy content of a given portion of the universe, say that within the reach of the 200-inch telescope, and suppose this was done on several occasions at widely separated times. If the conservation of energy is to hold, the measured energy content must remain unchanged from one occasion to another. This would be true in a steady-state universe, but not in an evolving one. Furthermore, in a steady-state universe conservation in this operational sense holds good for an observer in any galaxy.

The two features of the steady-state theory that seem to cause the greatest general surprise are (1) that the theory possesses a clear-cut mathematical basis, and (2) that the theory is highly susceptible to test by observation. How can it be tested? Obviously we cannot test it in the laboratory—unless we were to find some way to speed up the creation of matter artificially—for the rate of creation, according to the theory, is negligible in terrestrial terms: in the space of the average physics laboratory one new hydrogen atom would materialize in about 1,000 years. But on the cosmological scale there are many possible tests.

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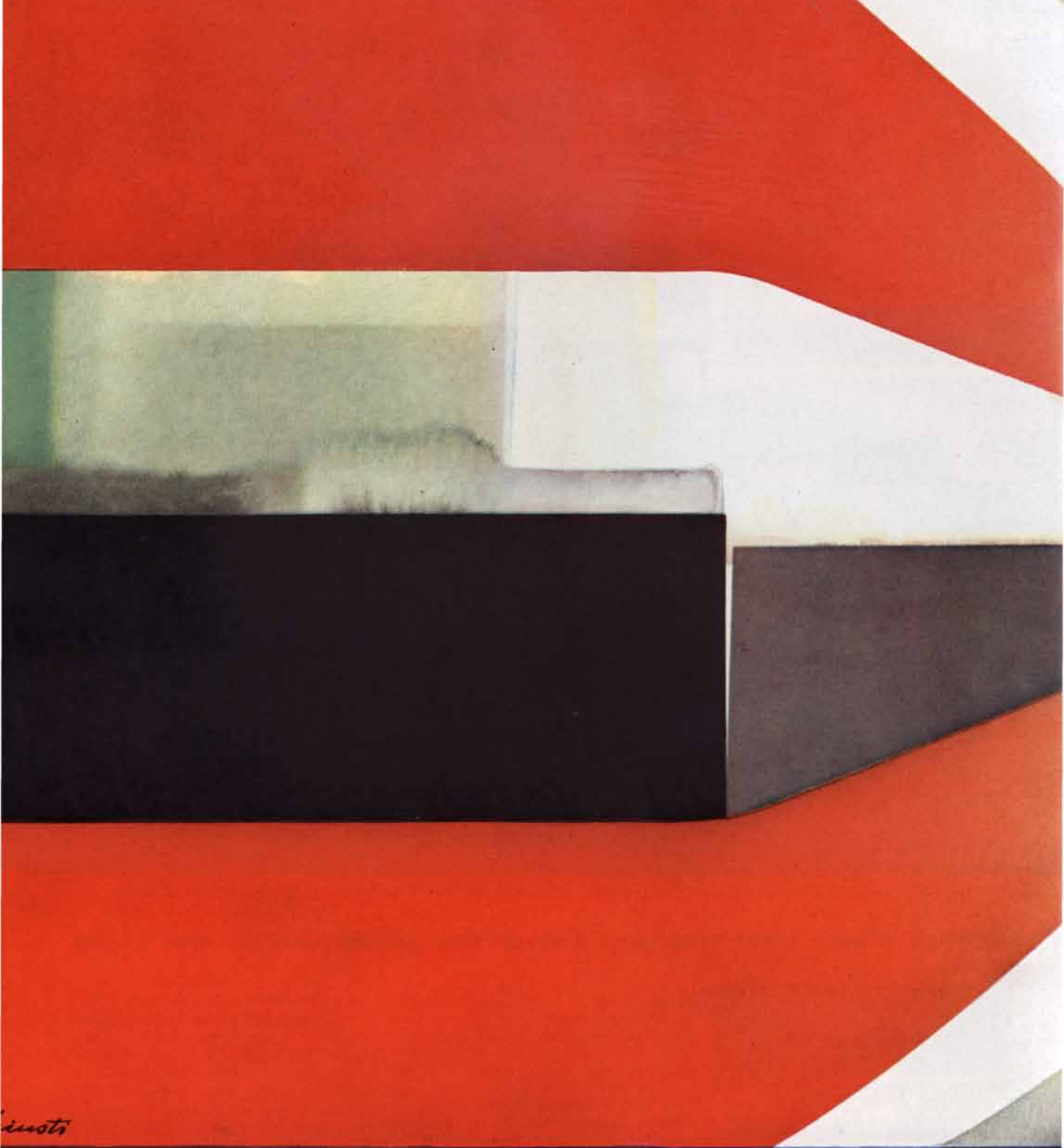

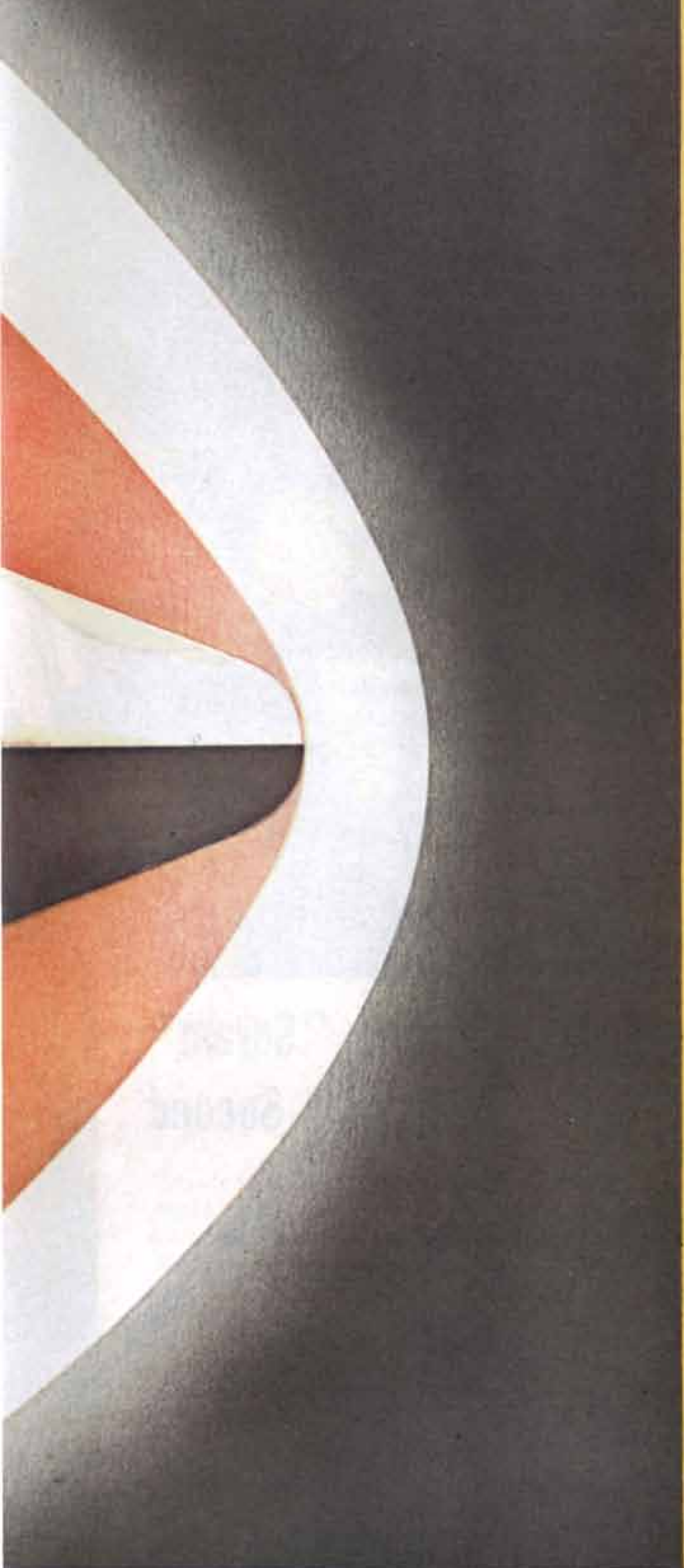


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telescopes we are seeing galactic systems as they were a billion or more years ago. Hence information can be obtained about how things used to be in the past, and this information can be compared with the cosmic scene close by us in space and time. Since the steady-state theory requires that there be no difference in large-scale properties between the past and the present, the theory is clearly exposed to check by this comparison. Large-scale properties can be estimated from many different clues: the density of the populations of galaxies, the magnitude and color of their light, the radio emissions signaling collisions and other significant events, the relation between the red-shift and distance of galaxies, and so forth.

Secondly, there are tests which can be made without looking so far away from home. We can think of the formation of new galaxies as equivalent to birth in the biological sense, and of their separation by expansion as equivalent to death. In terms of this analogy a new generation of galaxies is born, not every 30 years as in the case of human beings, but every few billion years. Now just as an animal population becomes extinct if it fails to reproduce its numbers from generation to generation, so large-scale properties of the systems of galaxies fail to survive unless they reproduce themselves in the same sense. If the universe is infinitely old, as the steady-state theory says, we should expect to see surviving only properties which have stabilized themselves so that they are reproduced at precisely the same level from generation to generation. In other words, according to the steady-state theory the galaxies are not a product of random fluctuations and condensations, as in the evolutionary theory, but represent a very strictly controlled system obeying a kind of cosmic ecology, with the origin of matter playing a critical role. This crucial difference between the two theories can form the basis of stringent tests. The tests can be applied to such properties as the density of galaxies in space and the distribution of sizes in masses of galaxies. That is, we can check whether the distribution follows a regular frequency curve or shows no regular pattern.

During the past five years it has twice been claimed that observations disproved the steady-state theory, but it now appears that in both cases the observations are open to serious doubt. The U. S. astronomers Joel Stebbins and A. E. Whitford thought that certain distant galaxies showed more reddening than could be attributed to the usual red-shift, and this was construed to support the evolutionary theory. But Whitford later found that certain data they had made use of were incorrect. Recently Martin Ryle in England reported a count of radio sources which indicated that the density of galaxies in space increases with distance from us—again an apparent support for the evolutionary hypothesis. However, Ryle's findings have been questioned by the radio astronomer B. Y. Mills in Australia.

In my view the most serious potential contradiction of the steady-state theory lies in the recent red-shift studies by the astronomers in California, which are reported in this issue by Allan Sandage [*see following article, page 170*]. As Sandage points out, however, the findings so far are highly uncertain.

George Gamow has offered against the steady-state theory the objection that elliptical galaxies (which are thought to consist only of old stars) apparently do not show the age variations that the theory predicts. In defense of the theory it can be said that the measurements cited (studies of the color of the galaxies, in two colors) are not a very sensitive index of the galaxies' ages. In the color test a galaxy six billion years old should look much like one three billion years old. More sensitive measurements are required.

The steady-state theory gains support, on the other hand, from recent studies indicating that the elements beyond hydrogen are formed in stars. These studies, reported in the article by William A. Fowler [*page 82*], make it appear more likely that the elements are constantly being "cooked" in the stars, as the steady-state cosmology suggests, than that they were created in a primeval explosion, as Gamow has urged.

Radio astronomy offers the exciting possibility of something close to a direct test of the creation of matter in space. The total amount of matter in the galaxies we can observe is estimated to come to about 10^{-30} of a gram per cubic centimeter if it were spread evenly all through space. The steady-state theory predicts that the average density of matter should be 10 or more times greater than this. The difference, according to the theory, is accounted for by hydrogen spread through intergalactic space. Up to now it has not been possible to detect intergalactic matter. But in the next few years new radio telescopes, tuned to the one-note "song of hydrogen," may be able to test whether such quantities of hydrogen do or do not exist in space.

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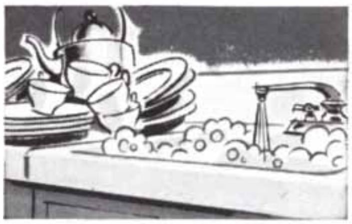

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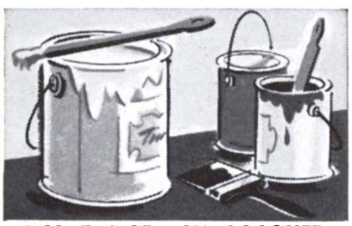

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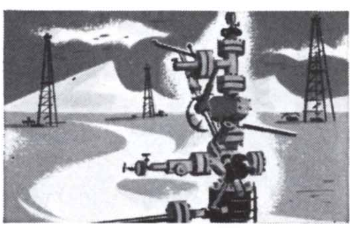

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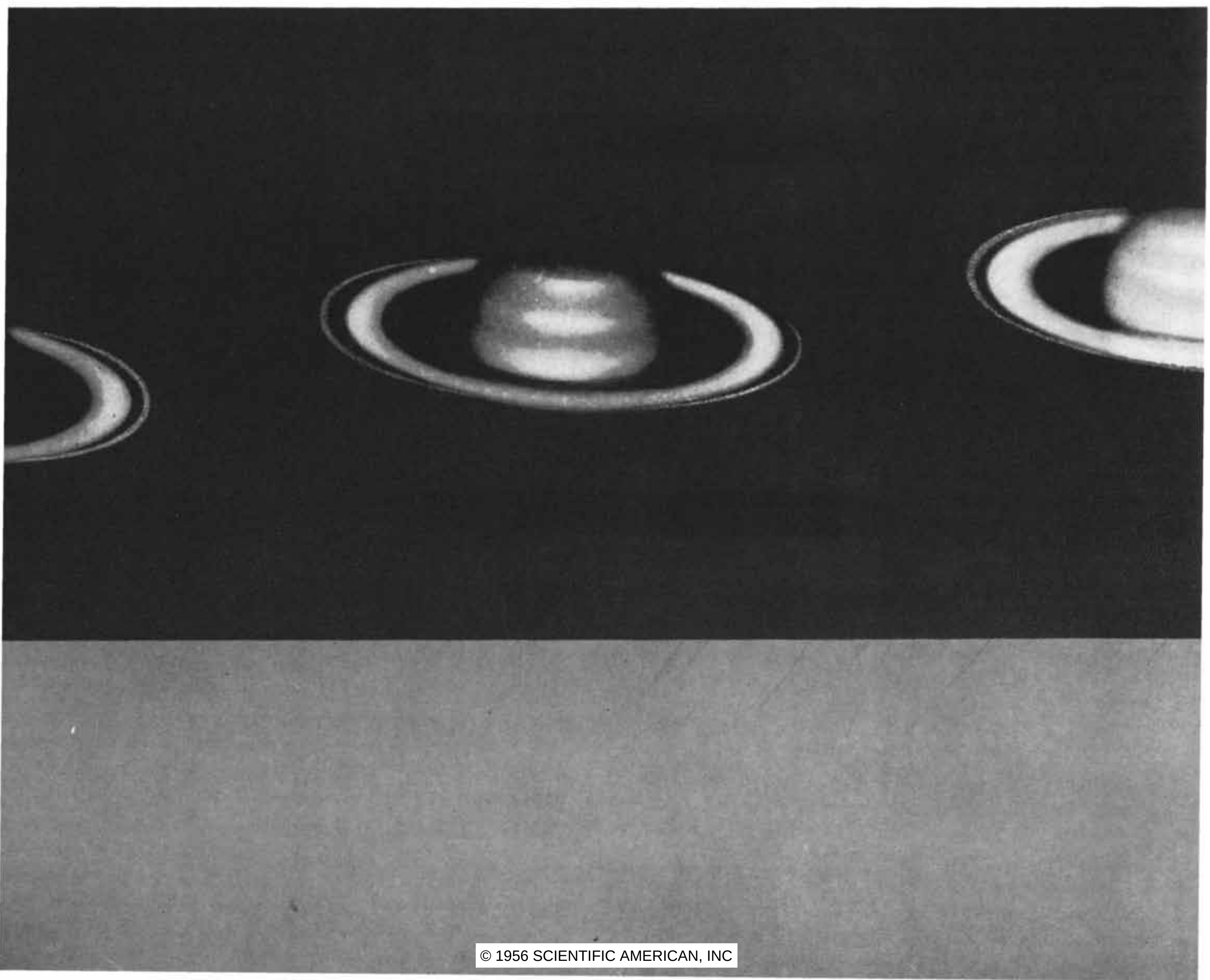

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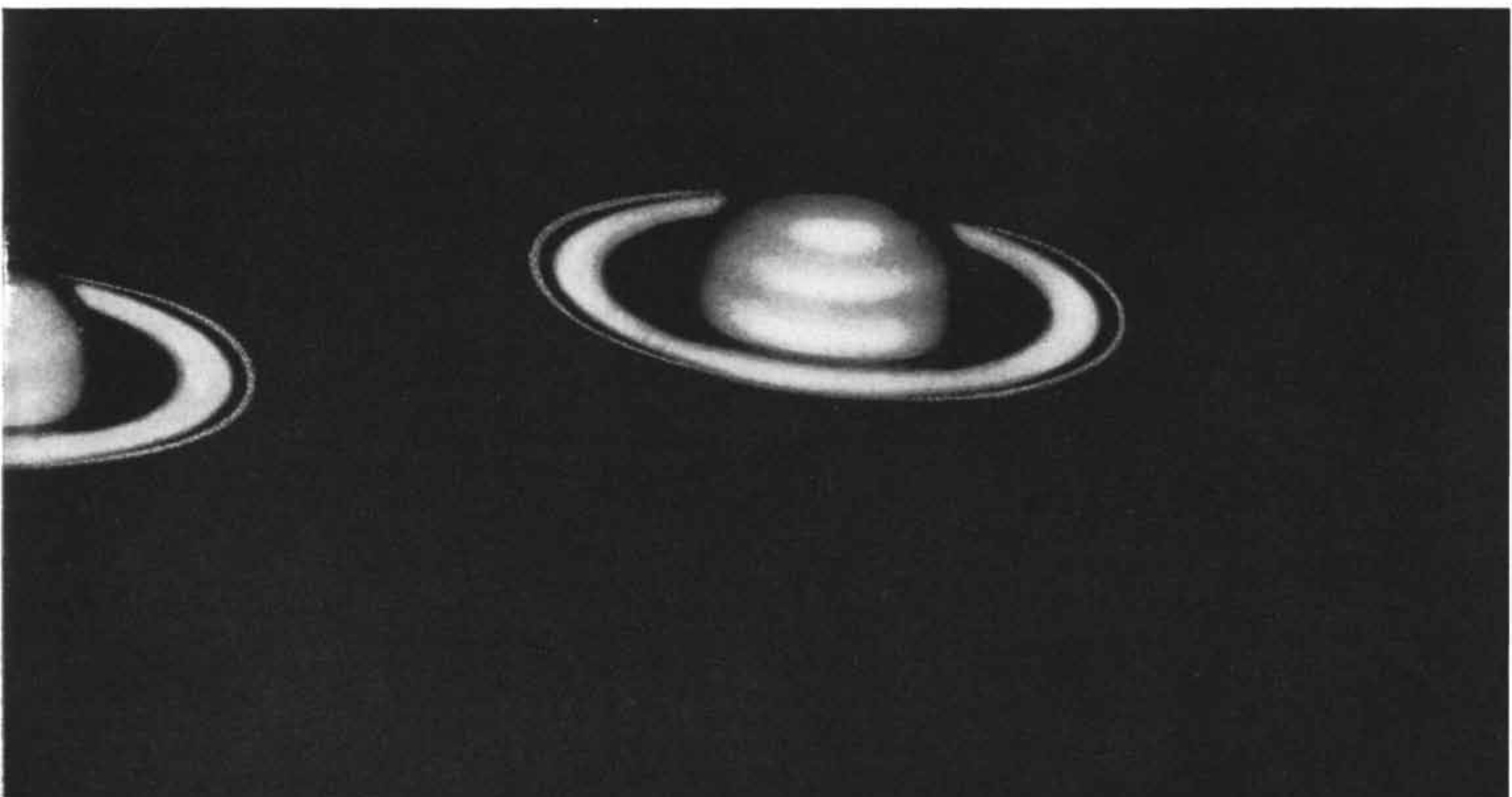

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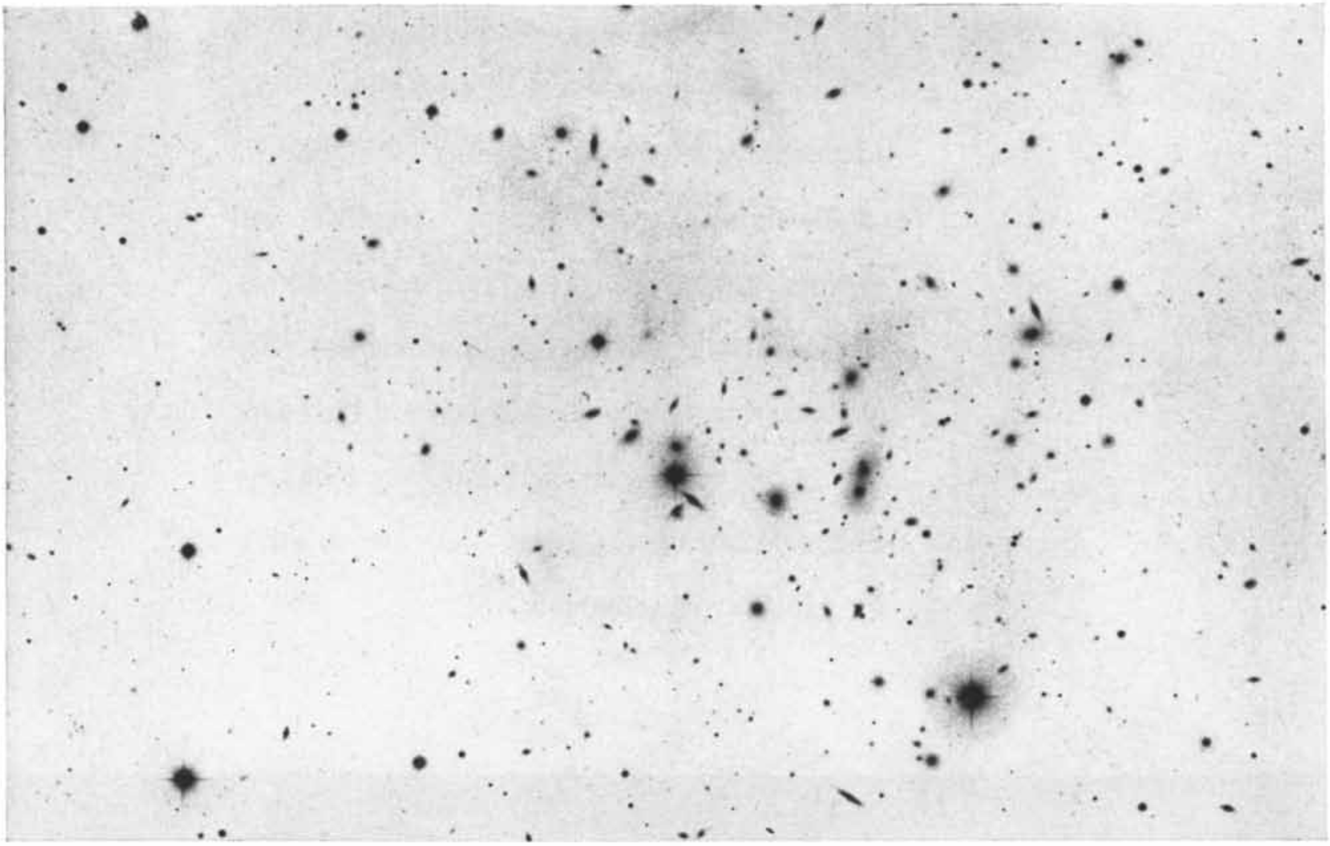
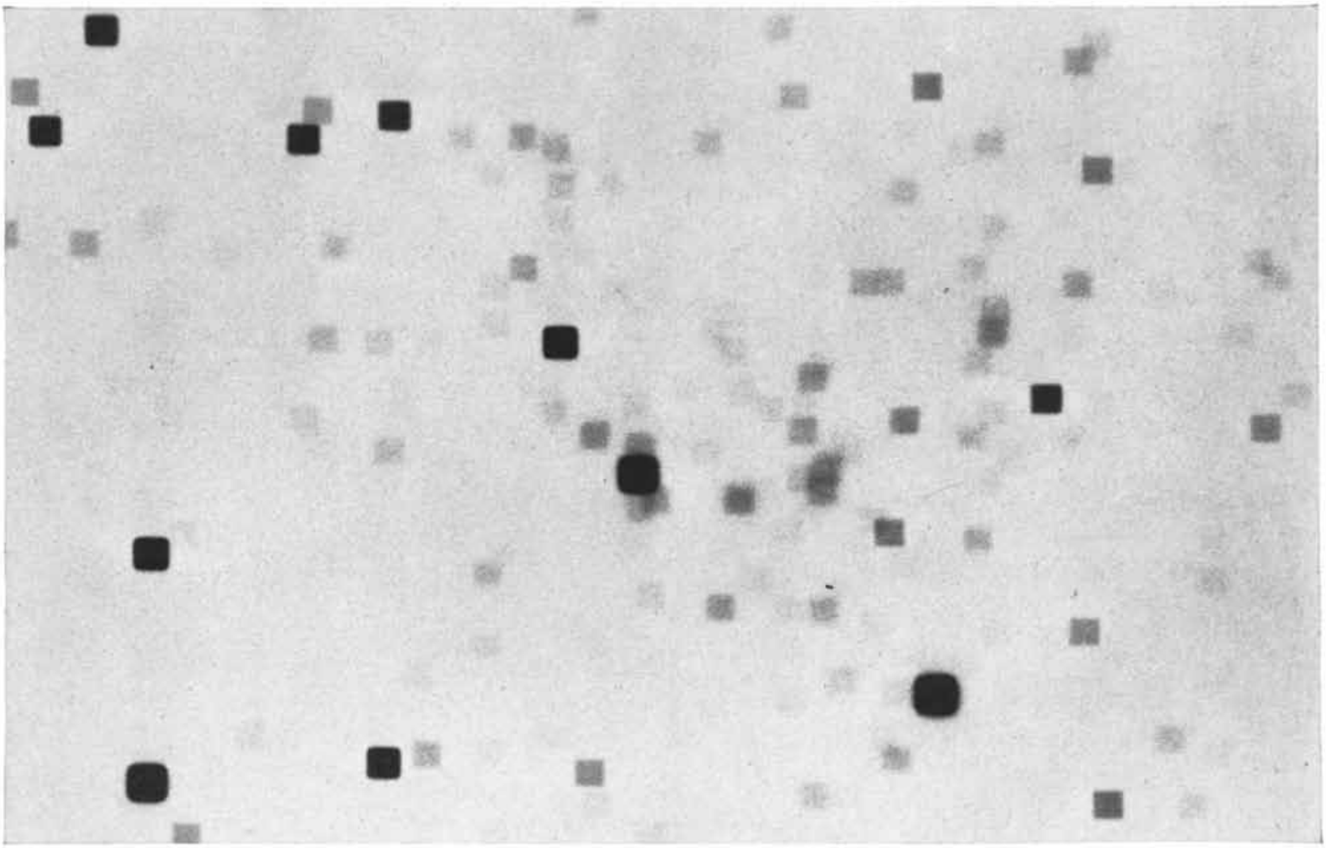




BRIGHTNESS OF GALAXIES may be measured with the help of the jiggle camera (*see photograph on the opposite page*). At the top is a negative print of a 200-inch telescope photograph showing nearby stars and a cluster of galaxies in Corona Borealis. Although the stars have made the brightest images in the photograph, they are essentially point sources of light. The galaxies, on the other hand, are extended sources of light. To measure the brightness of a galaxy by comparing it with the known brightness of a star, the two images must be made the same. This is done by smearing the images as shown at bottom in a jiggle-camera photograph of the same area.

THE RED-SHIFT

The redness, and presumably the speed of recession, of most galaxies increases regularly with distance. The most distant galaxies observed appear to depart from this law, a fact of deep meaning for cosmology

by Allan R. Sandage

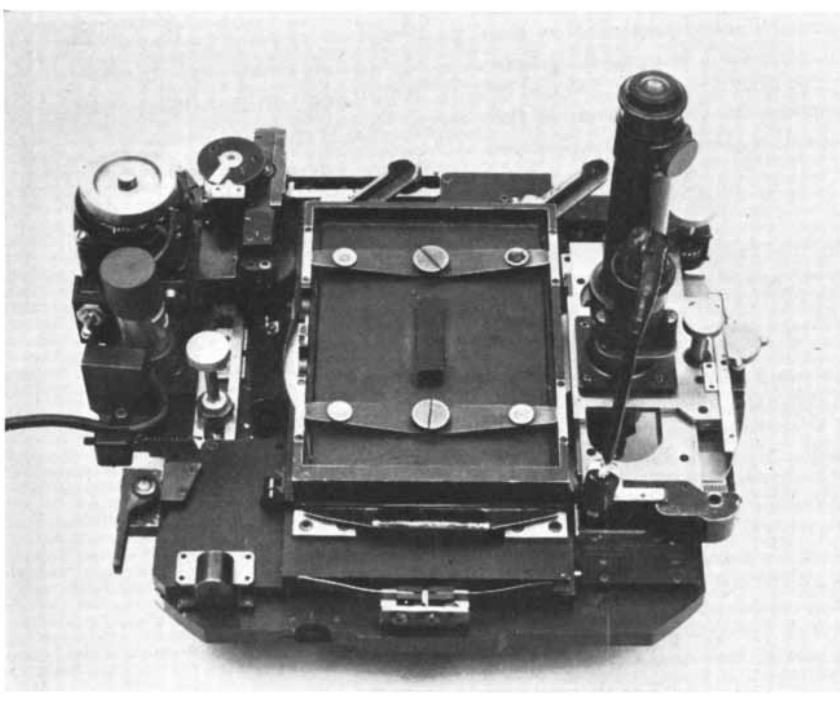
In the nature of things it is a delicate undertaking to try to discern the general structure and features of a universe which stretches out farther than we can see. For more than a quarter of a century both the theoreticians and the observers of the cosmos have been making exciting discoveries, but the points of contact between the discoveries have been few. The predictions of the theorists, deduced from the most general laws of physics, are not easy to test against the real world—or rather, the small portion of the real world that we can observe. There is, however, one solid meeting ground between the theories and the observations, and that is the apparent expansion of the universe. Other aspects of the universe may be interpreted in different ways to fit different theories, but concerning the expansion the rival theories make unambiguous predictions on which they will stand or fall. There is now hope that red-shift measurements of the universe's expansion with the 200-inch telescope on Palomar Mountain will soon make it possible to decide, among other things, whether we live in an evolving or a steady-state universe.

Let us begin by considering just what issue the measurements seek to decide, as between the theories expounded in the two preceding articles by George Gamow and Fred Hoyle. The steady-state theory says that the universe has been expanding at a constant rate throughout an infinity of time. The evolutionary theory, in contrast, implies that the expansion of the universe is steadily slowing down. If the universe began with an explosion from a superdense state, its rate of expansion was greatest at the beginning and has been slowing ever since because of the opposing gravitational attraction of its matter, which acts as a brake on the expansion—much as an anchored elastic string attached to a golf ball would act as a brake on the flight of the ball.

Now in principle we can decide whether the rate of expansion has changed or not simply by measuring the speed of expansion at different times in the universe's history. And the 200-inch telescope permits us to do this. It covers a range of about two billion years in time. We see the nearest galaxies as they were only a few million years ago, while the light from the most distant galaxies takes so long to reach us that we see them at a stage in the universe's history going back to one or two billion years ago. If the explosion theory is correct, the universe should have been expanding at an appreciably faster rate then than it is now. Since the light we are receiving from the distant galaxies is a flashback to that earlier time, its red-shift should show them receding from us faster than if the rate of expansion had remained constant.

The red-shift is so basic a tool for testing our notions about the universe that it is worthwhile to review how it was discovered and how it is used.

An astronomer cannot perform experi-



JIGGLE CAMERA smears the images by moving the photographic plate in a rectangle during exposure. It is mounted in the prime-focus cage at the upper end of the 200-inch.

ments on the objects of his study, or even examine them at first hand. All his information rides on beams of light from outer space. By sufficiently ingenious instruments and equally ingenious interpretation (we hope), he may translate this light into information about the temperatures, sizes, structures and motions of the celestial bodies. It was in 1888 that a German astronomer, H. C. Vogel, first demonstrated that the spectra of stars could give information about motions which could not otherwise be detected. He discovered the Doppler effect in starlight.

The Doppler effect, as every physics student knows, is a change in wavelength observable when the source of radiation (sound, light, etc.) is in motion. If it is moving toward the observer, the wavelength is shortened; if away, the waves are lengthened. In the case of a star moving away from us, the whole spectrum of its light is shifted toward the red, or long-wave, end.

This spectrum, made by means of a prism or diffraction grating which spreads the light out into a band of its component colors, is usually not continuous. Certain wavelengths of the light are absorbed by atoms in the star's atmosphere. For example, most stars show strong absorption, by calcium atoms, at the wavelengths of 3933.664 and 3968.-470 Angstrom units. (An Angstrom unit is a hundred-millionth of a centimeter.) The absorption is signaled by dark lines in the spectrum, known in this case as the K and H lines of calcium. Now if a star is moving away from us, these lines will be displaced toward the red end of the spectrum. In the spectrum of the star known as Delta Leporis, for in-

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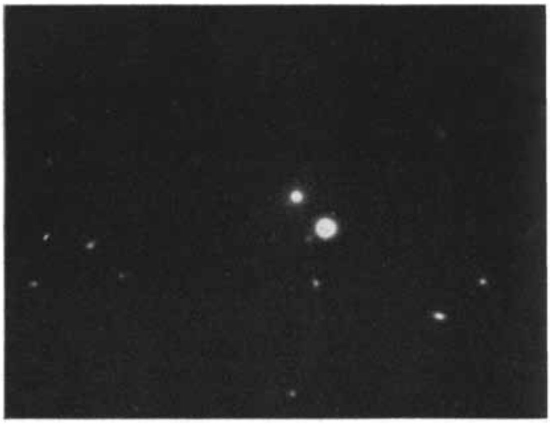

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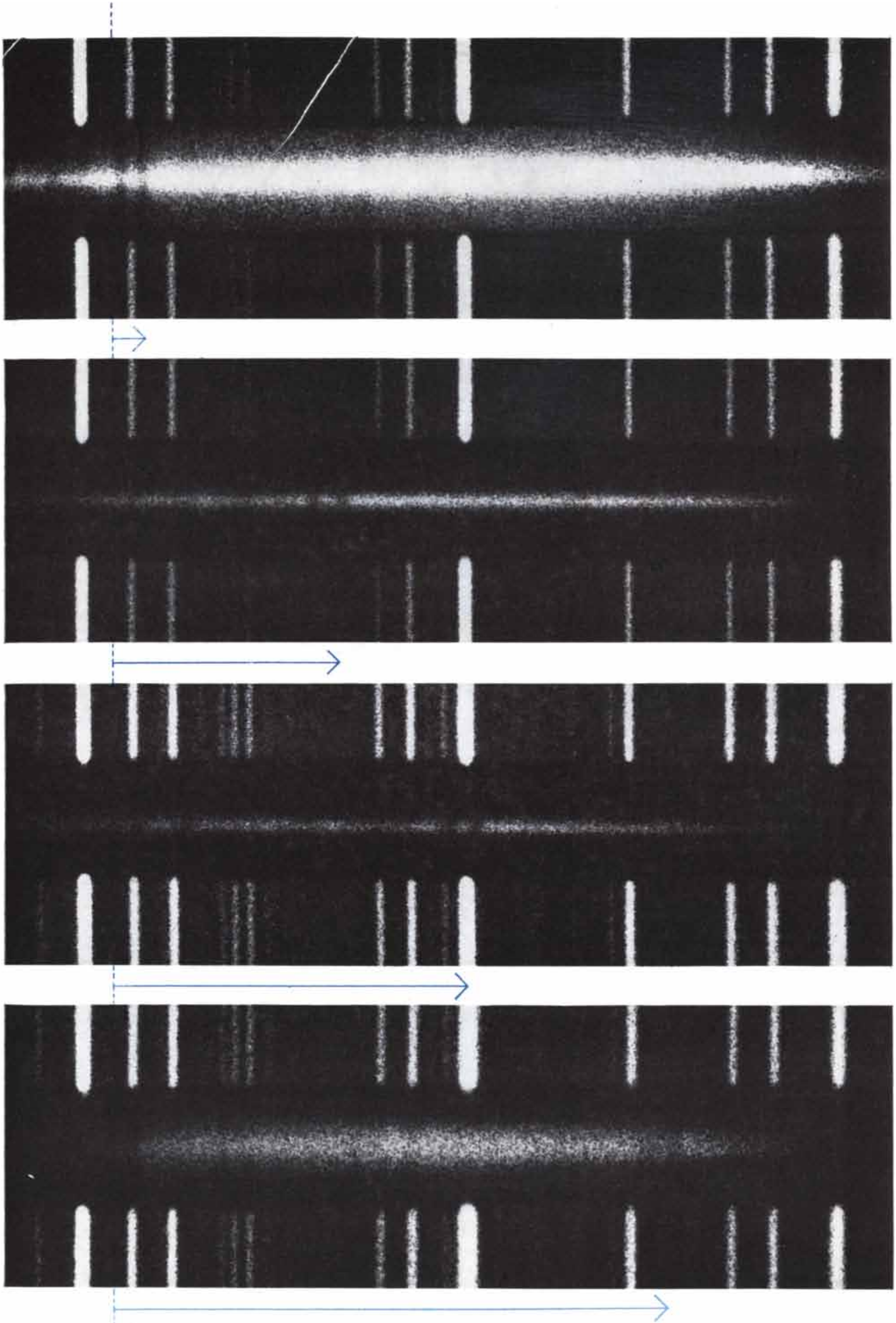
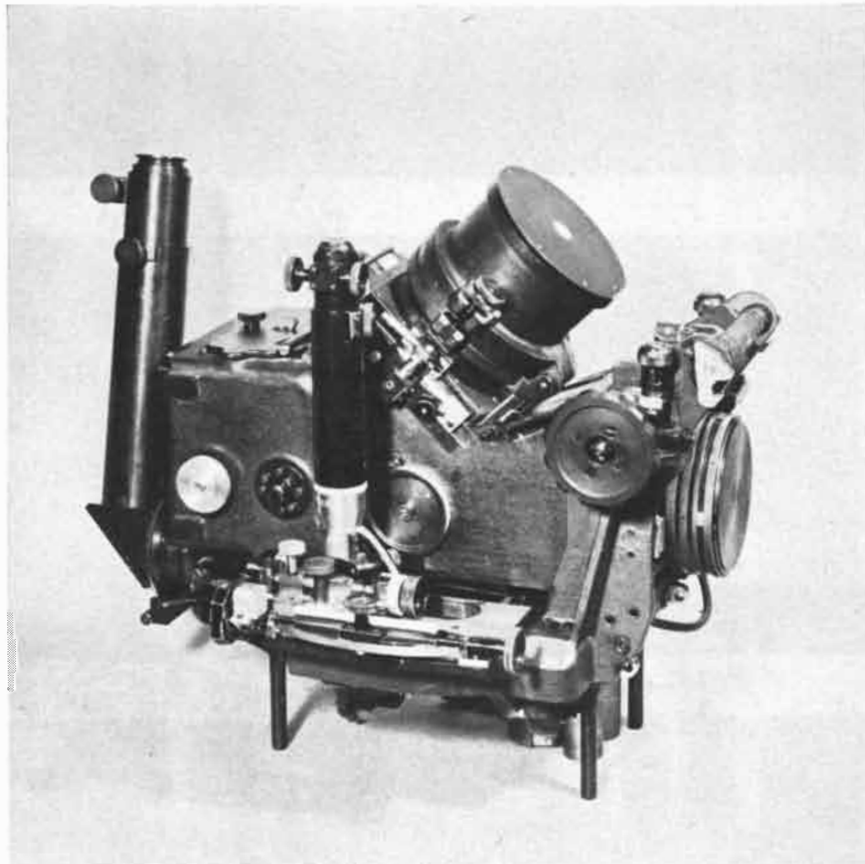
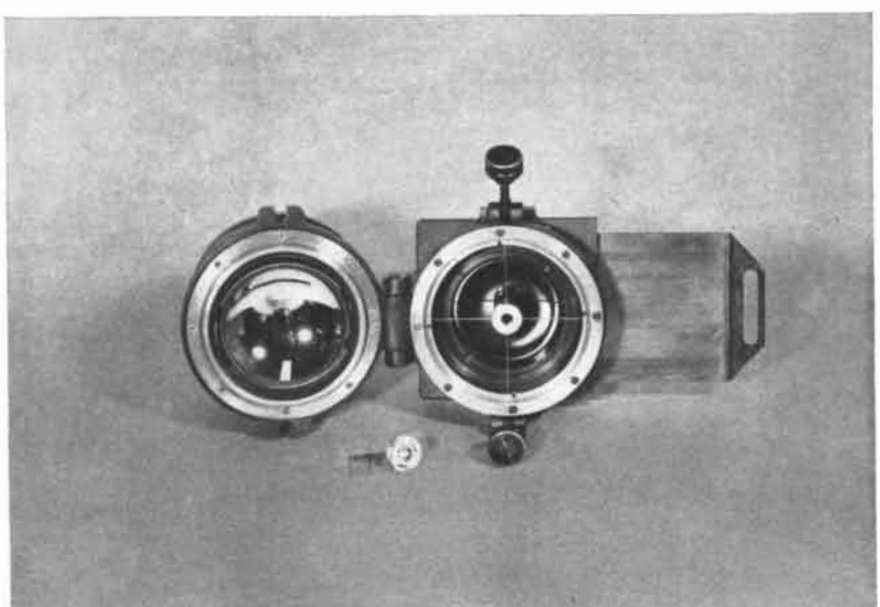
RED-SHIFT of four galaxies on this page is depicted in the spectra on the opposite page. The galaxies are centered in the photographs. The spectra are the bright horizontal streaks tapered to the left and right. Above and below each spectrum are comparison lines from the spectrum of iron. Near the left end of the spectrum at the top of the page are two dark vertical lines: the K and H lines of calcium. If the galaxy did not exhibit the red-shift, these lines would be in the position of the broken line running vertically down the page. The amount of their shift toward the red, or right, end of the spectrum is indicated by the short arrow to the right of the broken line. The larger shift of the K and H lines of the three fainter galaxies is indicated by the longer arrows below their spectra. The constellation, approximate distance and velocity of recession of each galaxy is at left of its photograph.



stance, the K line of calcium is displaced 1.298 Angstroms toward the red. Assuming the displacement is due to the Doppler effect, it is a simple matter to calculate the velocity of the star's receding motion. Dividing the amount of the displacement by the normal wavelength at rest, and multiplying by the speed of light (300,000 kilometers per second) we get the speed of the star—in this case 99 kilometers per second. The calculation on the basis of displacement of the H line gives the same figure.

Equipped with this powerful tool,

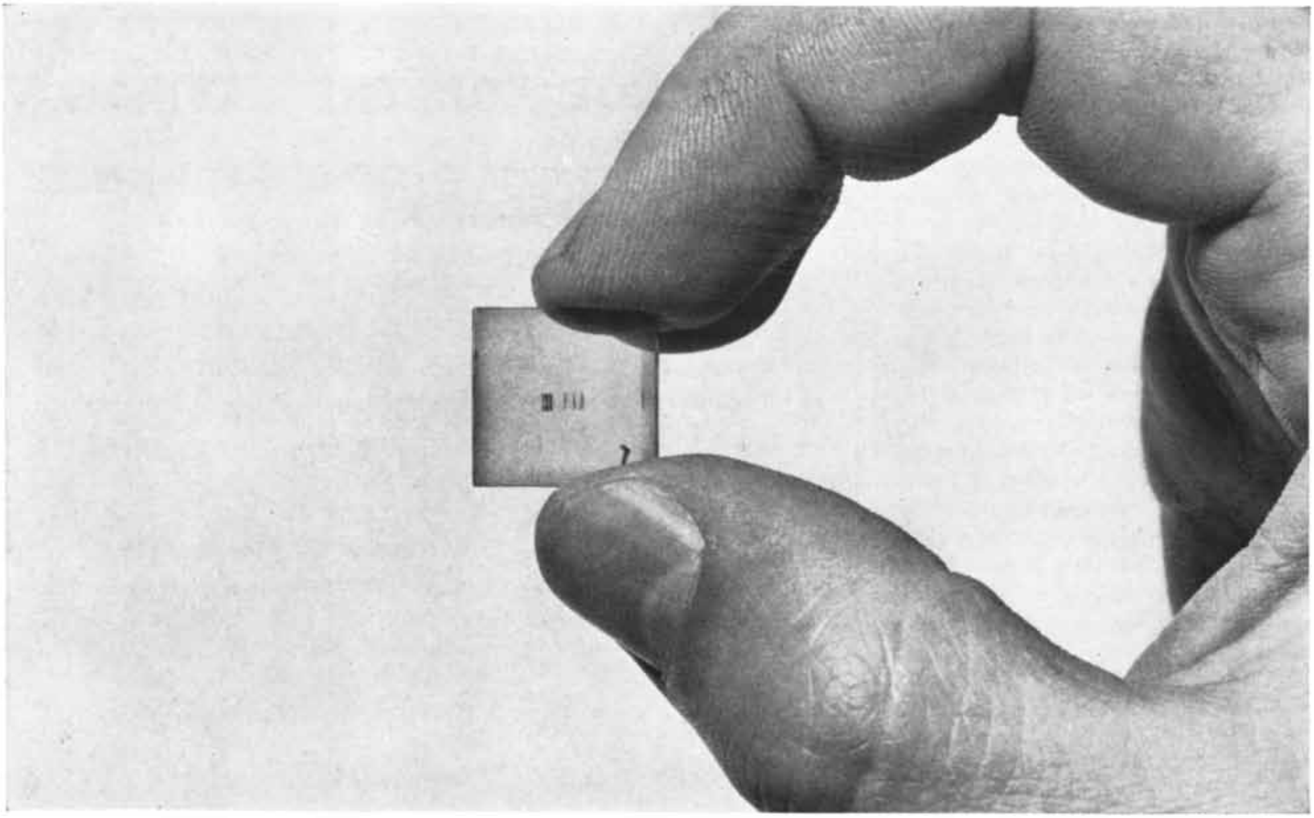




SPECTRA ARE MADE with the spectrograph at the top, which is mounted at the prime focus of the 200-inch telescope. Inside the spectrograph the converging rays of the 200-inch mirror are made parallel by a concave mirror. The light is then dispersed by a diffraction grating. At the bottom is a Schmidt camera used to photograph the spectrum. It has an optical path of solid glass and a speed of *f*/.48. The plateholder and plate are below the camera.

many of the large observatories in the world spent a major part of their time during the early part of this century measuring the velocities of receding and approaching stars in our galaxy. At first it was a work of pure curiosity, no one suspecting that it might have any bearing on cosmological theories. But in the 1920s V. M. Slipher of the Lowell Observatory made a discovery which was to lead to a completely new picture of the universe. His measurements of red-shifts of a number of "nebulae" then thought to lie in our galaxy showed that they were all receding from us at phenomenal speeds—up to 1,800 kilometers per second. Edwin P. Hubble at Mount Wilson soon established that the "nebulae" were systems of stars, and he went on to measure their distances. The method he used was the one developed by Harlow Shapley, employing Cepheid variable stars as the yardstick. Shapley had found a way to measure the intrinsic brightness of these stars, and therefore their distance could be estimated from their apparent brightness by means of the rule that the intensity of light falls off as the square of the distance. Hubble observed that the galaxies nearest our own system, including the Great Nebula in Andromeda, contained Cepheid variables, and when he computed their distances he came out with the then astounding figure of about one million light-years! He next tackled the problem of finding the distances of Slipher's nebulae. Since variable stars could not be detected in them, he used their brightest stars as distance indicators instead. He found that these nebulae were at distances ranging up to 20 million light-years from us, and what was more remarkable, their velocities increased in strict proportion to their distances!

Hubble made the daring conjecture that the universe as a whole was expanding. He predicted that more remote galaxies would show larger red-shifts, still in proportion to their distance. To test Hubble's speculation, Milton L. Humason began a long-range program of spectral analysis of more distant galaxies with the 100-inch telescope on Mount Wilson. In these faint galaxies it was no longer possible to distinguish even the bright stars, and so the relative brightness of the galaxy as a whole had to be taken as the measure of distance. That is, a galaxy one fourth as bright as another was assumed to be twice as far away. Hubble reasoned that while individual galaxies might deviate from this rule, statistically the population of galaxies as a whole would follow it. The prin-



ACTUAL SIZE of the red-shift spectrum is indicated by the photograph at the top of the page. The glass photographic plate is 15 millimeters on an edge. The spectrum is 5 mm. long. At bottom Milton L. Humason examines a spectrum with a low-power microscope.

ciple is still the basis of distance determinations today.

Humason laboriously photographed spectra of galaxies, and Hubble measured their apparent brightness, from 1928 to 1936, when they reached the limit of the 100-inch telescope. The history of the red-shift program in those years is a story of extreme skill and patience at the telescope and of steady improvement in instrumentation. It was a long and difficult task to photograph spectra then; the prisms used required long exposures, and it took 10 nights or more to obtain a spectrum which with modern equipment can be recorded in less than an hour today. The improvement in equipment includes not only the 200-inch telescope but also diffraction gratings, faster cameras and a vast improvement in the sensitivity of photographic plates, thanks to the Eastman Kodak Company. Astronomers the world over, and cosmology, owe a large debt to the Eastman research laboratories.

Humason's first really big red-shift came early in 1928, when he got a spectrum of a galaxy called NGC 7619. Hubble had predicted that its velocity should be slightly less than 4,000 kilometers per second: Humason found it to be 3,800. By 1936, at the limit of the 100-inch telescope's reach, they had arrived at a cluster of galaxies, called Ursa Major No. 2, which showed a velocity of 40,000 kilometers per second. All the way out to that range of more than half a billion light-years the velocity of galaxies increased in direct proportion to the distance. In a sense this was disappointing, because the various cosmological theories predicted that some change in this relation should begin to appear when the observations had been pushed far enough. Further exploration into the distances of space had to await the completion of the 200-inch Hale telescope on Palomar Mountain.

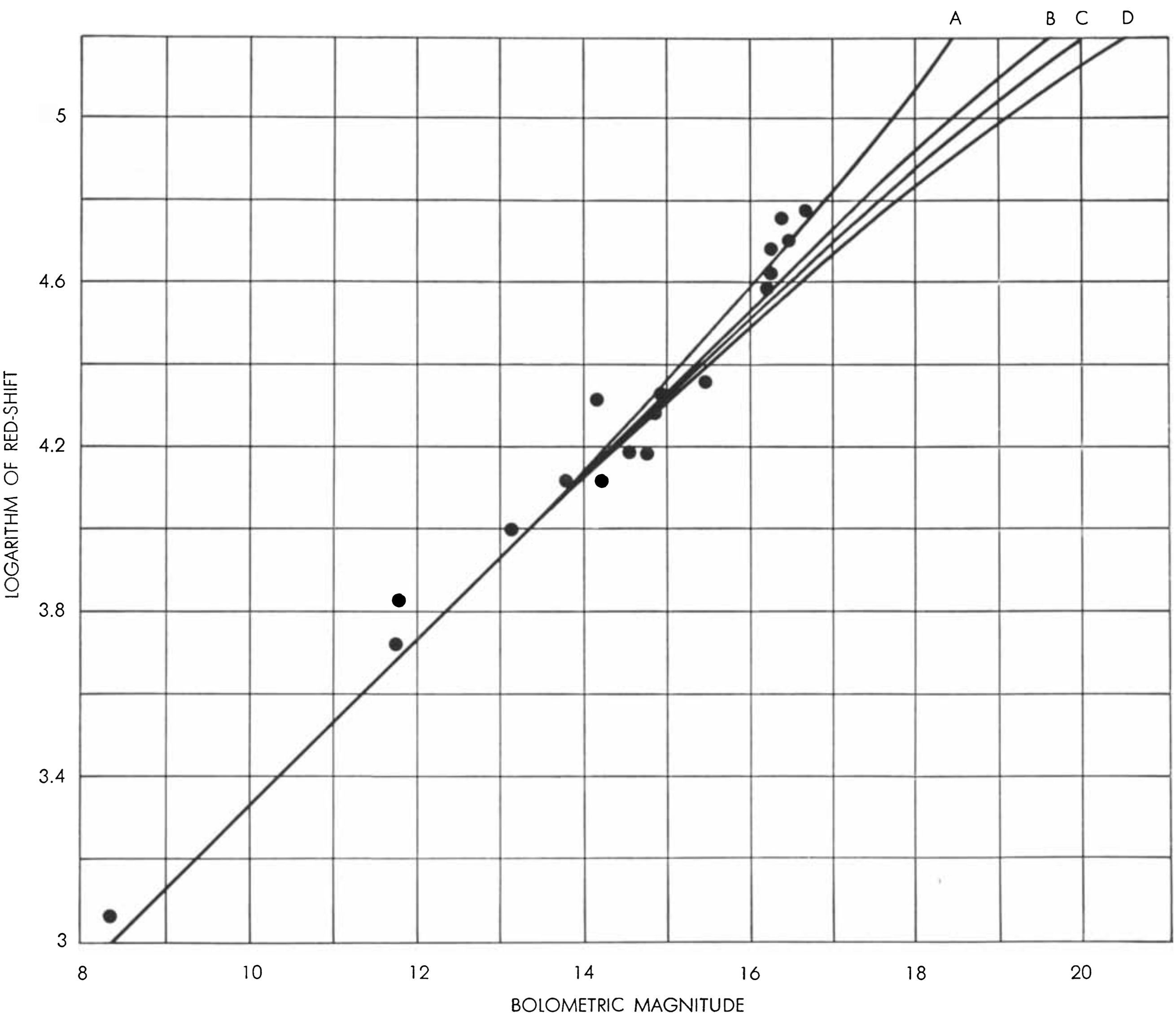
In 1951 the red-shift program was resumed, with a new spectrograph of great speed and versatility placed in the big telescope's prime focus cage, where the observer rides with his instruments. The spectrograph has to be of very compact design to fit into the cramped space of the cage. The photographic plate itself, mounted in the middle of a complex optical arrangement, is only 15 millimeters (about half an inch) on a side. The cutting and handling of such small pieces of glass in complete darkness (to avoid exposure of the plate) is a tricky business. The spectrum recorded on the plate is a tiny strip only a fifth of an inch long, but it is long enough to measure red-shifts to an accuracy of better than one half of 1 per cent.

The most distant photographable galaxies are so faint that they are not visible to the eye through the telescope: they can be recorded only by extended exposure of the plate. The observer guiding the telescope must position the slit of the spectrograph by reference to guide stars within the same field as the distant object. Another great difficulty in recording the red-shift of extremely distant galaxies arises from the magnitude of the shift. The displacement of the calcium dark lines toward the red is so large that the lines move clean off the sensitive range of blue photographic plates, which astronomers like to use because of their speed. So slow panchromatic plates must be used, and Humason has been forced to return to exposure times as long as 30 hours or more.

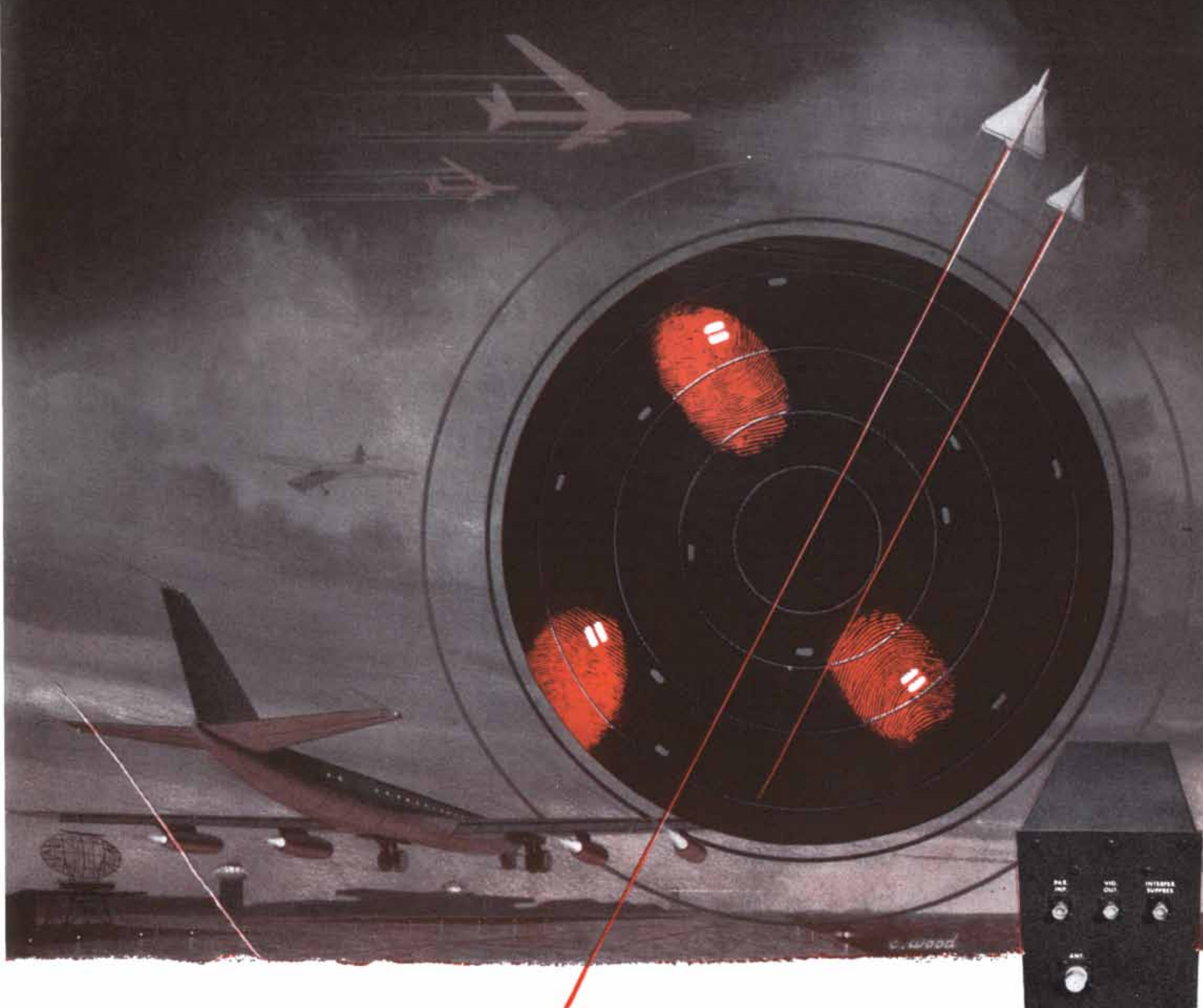
The other part of the program—measuring the distances of the galaxies—also has been helped by improvements in technique. For measurement of their brightness the Mount Wilson telescopes employ photomultiplier tubes, which amplify the light energy by electronic means. Such equipment was not available for the 200-inch telescope when the present program began. Instead the intensity of the light from very faint galaxies was measured by a tricky method which compares it with that of stars of known magnitude. No direct comparison can be made, of course, between the picture of a star and that of a galaxy or cluster of galaxies, because the star is a point source of light while a galactic system is a spread-out image. To make the images comparable, a region of the sky is photographed with a "jiggle" camera which moves the plate around so that the images of stars and of galaxies are smeared out in squares [*see photograph at bottom of page 170*]. They can then be compared as to brightness—just as one may use color cards to find a match to the color of a room.

Humason has now measured red-shifts of remote clusters of galaxies with recession velocities up to 60,000 kilometers per second. What do they show? Is the velocity still increasing in strict proportion to the distance?

The information about 18 of the faint-



EIGHTEEN FAINTEST CLUSTERS of galaxies yet measured are plotted for their red-shift (or speed of recession) and apparent magnitude (or distance). Line C is a universe expanding forever at the same rate. Line D is a steady-state universe. If the line falls to the left of C, the expansion must slow down. If it falls between C and B, the universe is open and infinite. If it falls to the left of B, the universe is closed and finite. If it falls on B, it is Euclidean and infinite. A is the trend suggested by the six faintest clusters.



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STEWART SW WARNER ELECTRONICS

a Division of Stewart-Warner Corporation est measured clusters is given in the accompanying chart [*see chart on page 178*]. Their velocities are plotted against their apparent brightness, or estimated distances. If velocity increases in direct proportion to the distance, the observed velocity-distance relation should be "linear" (*i.e.*, follow a straight line). But as the chart shows, the very faintest clusters have begun to depart from that line. These clusters, about a billion light-years away, are moving *faster* (by about 10,000 kilometers per second) than in direct proportion to their apparent distance. In other words, the data would be interpreted to mean that a billion years ago the universe was expanding faster than it is now. If the measurements and the interpretation are correct, this suggests that we live in an evolving rather than in a steady-state universe.

The observed change in the curve buys us much more information. To begin with, it tells us something about the mean density of matter in the universe. The rate at which the expansion of the universe is slowing down (if it is) depends on the mean density of its matter: the higher the density, the greater the braking effect. The amount of departure from linearity indicated by the measurements thus far calls for a mean density of about 3×10^{-28} grams of matter per cubic centimeter (about one hydrogen atom per five quarts of space). Now this amounts to about 300 times the total mass of the matter estimated to be contained in galaxies: that figure comes out to a mean density of only 10^{-30} grams per cubic centimeter. If our present tentative value for the slowdown of the expansion should be confirmed, we would have to conclude that either the current estimates of the masses of the galaxies are wrong or that there is a great deal of matter, so far undetected, in intergalactic space. Matter in the form of neutral hydrogen (*i.e.*, normal hydrogen atoms consisting of a proton and an electron) might be present in space and still have escaped detection until now because it is not luminous. The giant radio telescopes now under construction or on the drawing boards perhaps will detect the hydrogen, if it exists in the postulated quantities.

Once we know the rate at which expansion of the universe is slowing down, it becomes possible to determine not only the mean density of matter but also the geometry of space—that is, its curvature. As George Gamow points out in his article [*page 136*], models of the evolving universe take three forms: the Euclidean case, in which space is flat, open and in-

finite; a curved universe which is closed and finite, like the surface of a sphere; and a curved universe which is open and infinite, like the surface of a saddle. In the accompanying velocity-distance chart [*page* 178] curves to the left of C represent evolving models, and curve D represents the steady-state model. If the curve of the velocity-distance relation lies between C and B, the universe is open and infinite. Line B is the Euclidean case of flat space. If the curve is left of B, the universe is closed and finite, the radius of its curvature decreasing as we move farther to the left.

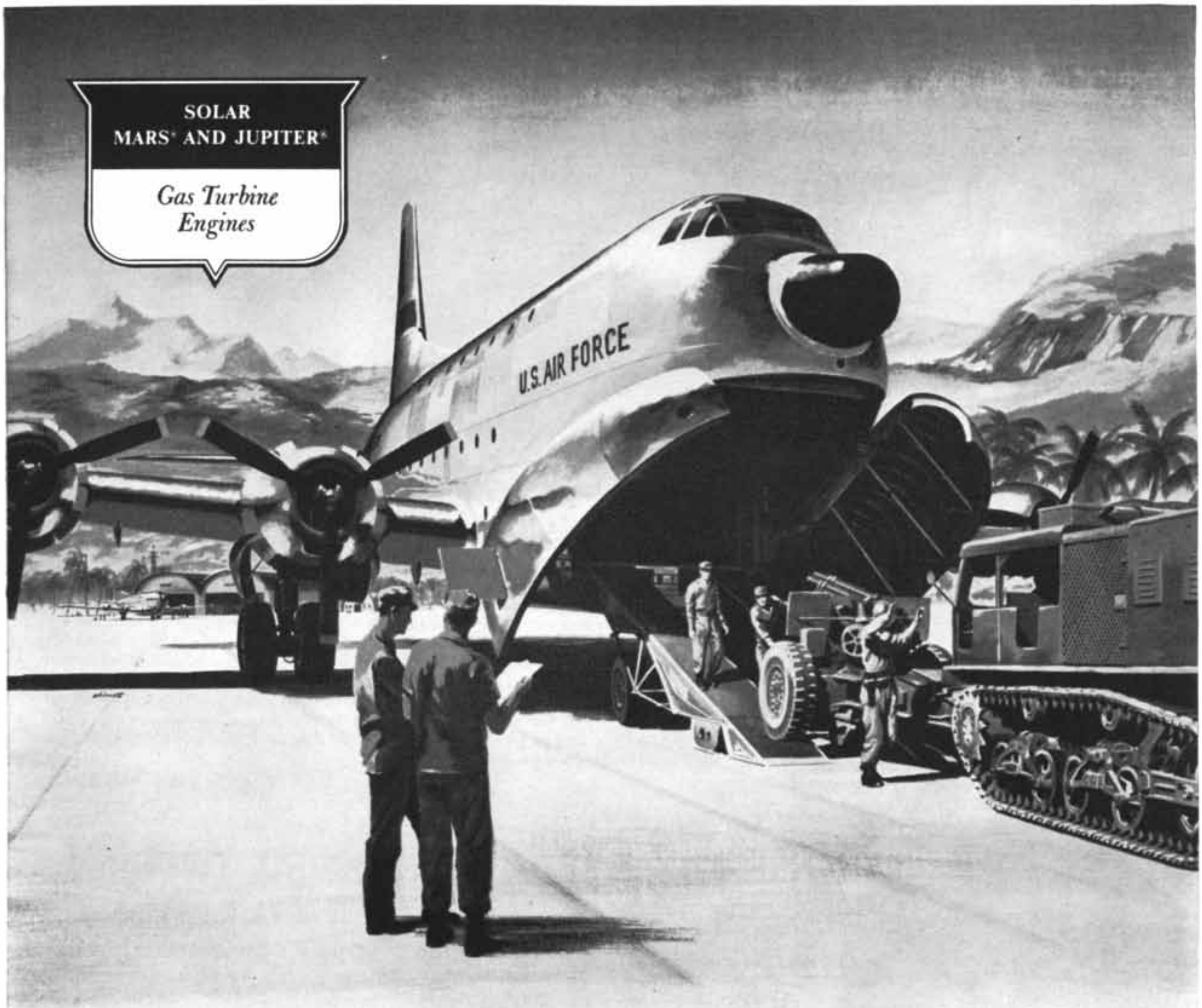
According to our present observations, the actual relation follows a curve left of B (curve A on the chart). Although our data are still crude and inconclusive, they do suggest that the steady-state model does not fit the real world, and that we live in a closed, evolving universe.

Humason has gone beyond 60,000 kilometers per second and attempted to measure the red-shifts of two faint clusters whose predicted velocity is more than 100,000 kilometers per second. So far these efforts have not yielded reliable results, but he is continuing them. These two remote clusters may well hold the key to the structure of the universe. We stand a chance of finding the answer to the cosmological problem. The red-shift program will continue toward this goal.

If the expansion of the universe is decelerating at the rate our present data suggest, the expansion will eventually stop and contraction will begin. If it returns to a superdense state and explodes again, then in the next cycle of oscillation, some 15 billion years hence, we may all find ourselves again pursuing our present tasks.

Although no final answers have yet emerged, big steps have been taken since 1928 toward the solution to the cosmological problem, and there is hope that it may now be within our grasp. The situation has nowhere been better expressed than in Hubble's last paper:

"For I can end as I began. From our home on the earth we look out into the distances and strive to imagine the sort of world into which we are born. Today we have reached far out into space. Our immediate neighborhood we know rather intimately. But with increasing distance our knowledge fades . . . until at the last dim horizon we search among ghostly errors of observations for landmarks that are scarcely more substantial. The search will continue. The urge is older than history. It is not satisfied and it will not be suppressed."



Tiny gas turbine provides vital power for giant air freighter

HUGE GLOBEMASTERS depend on Solar Mars gas turbines as a vital auxiliary power source. Built into an airborne generator, the Mars provides power to operate cargo winches, ramps, lights, engine starters and other equipment. Specified on the Douglas C-124C, the Mars unit is also used on the Lockheed C-121C, the Convair C-131B, and the Boeing KC-97.

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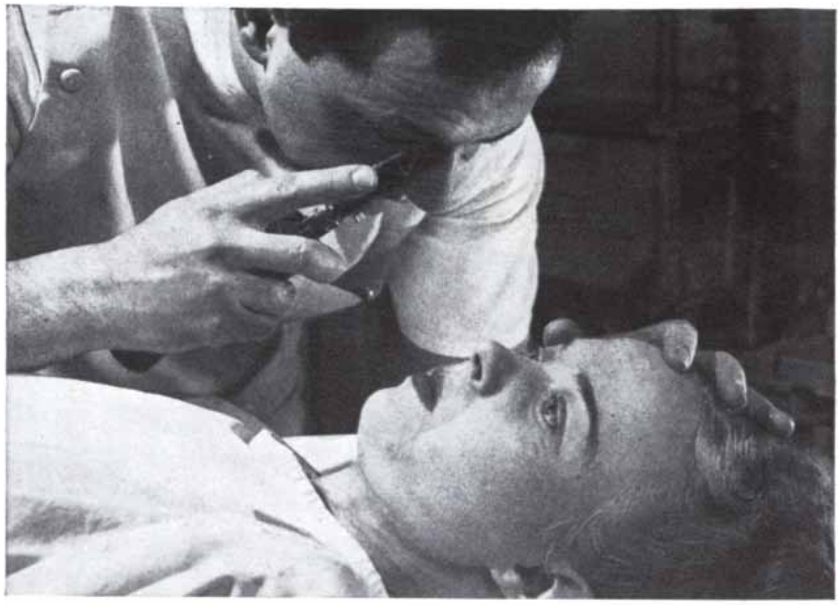
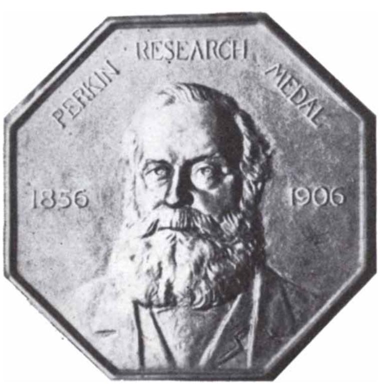
Life on the Chemical Newsfront



NEW ANILINE DERIVATIVE AIDS GLAUCOMA SUFFERERS. A common cause of blindness, glaucoma is a condition in which fluids accumulate within the eye, eventually damaging the optic nerve. DIAMOX* Acetazolamide, available only on a doctor's prescription, can be taken orally to reduce the watery secretion entering the eye and usually affords quick relief. Used in conjunction with other drugs, DIAMOX may provide adequate therapy, and in severe cases considerably increases the possibility of corrective surgery. DIAMOX is one of the latest in a long line of pharmaceuticals derived from Perkin's experimentation with aniline. (Lederle Laboratories Division) *Trademark



Fifty years ago, as recipient of the first Perkin Medal, William Henry Perkin told his American colleagues, ". . . that this industry which I was permitted to found should have led to this result is a source of pleasure to me because the final result of our work should be the benefit of mankind."

THE PERKIN CENTENNIAL 1856-1956

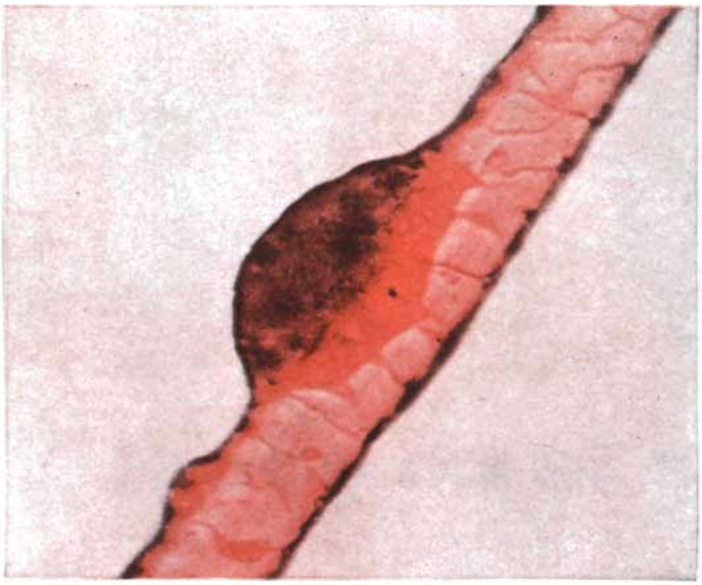
This month, the chemical industry commemorates the 100th anniversary of the discovery of the first synthetic organic dye by William Henry Perkin. The stature of today's chemical industry reflects the importance of Perkin's work. For not only was a new dye industry born that day in 1856, but also the branch of the chemical industry based on synthetic organic chemicals.

Until 1856, chemical science had been content to synthesize naturally occurring materials. After that date, the objective became the synthesis of products that improved on nature. The results are evident in the dyes, drugs, solvents, plastics, fibers, insecticides and fuels which so profoundly affect our lives today.

Cyanamid owes much to Perkin's early work. Many of our products today would be familiar to him. Others are derived through methods far beyond the limits of his day, yet are outgrowths of the work he initiated. Each product described on these pages is related to the coal-tar chemistry to which Perkin devoted his life.

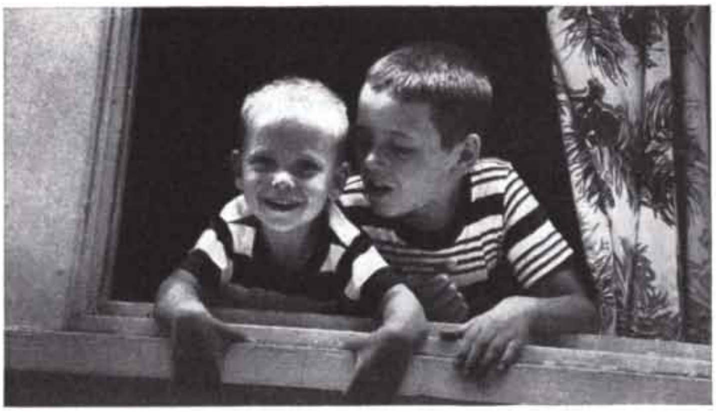
●

HELPING COLOR STAND UP TO SUNLIGHT has long been a major objective of chemistry. New protection now can be secured with Cyanamid's UV Absorber 9. Related to dyes which selectively absorb some wave lengths of light and reflect others, UV-9 absorbs strongly in the ultraviolet portion of the spectrum, thereby converting the color degrading rays into harmless heat. Colorless itself and highly stable, UV-9 is compatible with a wide range of formulation possibilities to protect clear or colored materials against discoloration, fading and deterioration in sunlight. Use in transparent films, waxes and surface coatings over light-sensitive materials is particularly recommended. (New Product Development Department A)



SEEN FOR THE FIRST TIME in dyeing history is the actual mechanism of fiber dyeing through the use of the Microdyeoscope, a development of Cyanamid's Organic Chemicals Division. A significant step in dye research, this instrument permits continuous microscopic observation of individual fibers through the complete cycle of dye-bath operation. Not only has the Microdyeoscope shed light on details of traditional dye techniques, but it is proving valuable in developing new dyes and dyeing processes for new fibers and fiber mixtures. Through such developments, one of the oldest of the commercial "arts" is fast becoming a well-understood science. **(Organic Chemicals Division)**

NEW COLOR STYLING EACH SEASON has been made more practical through steady reduction in dye costs. In 1856, Perkin's first commercial dye was worth its weight in platinum! An initial step in overcoming high raw material costs was the synthesis of anthraquinone from phthalic anhydride. Next, phthalic anhydride was produced by catalytic oxidation of naphthalene, and dye prices tumbled rapidly, making color available for every purpose. With bulk use growing, further savings in cost in many fields are made possible by the availability of Cyanamid phthalic anhydride in molten form. **(Industrial Chemicals Div., Dept. A)**



SPIC AND SPAN NOW—but there's a look in the eye that says it won't last! Even so, children's clothes today *can* stay colorful longer despite repeated soiling and washing. Of the many dyes developed since Perkin's time, none surpass the vats in colorfastness. Because of this property, they are superior for draperies, play clothes, slip covers, work clothes, bathing suits, shirts and many other fabrics made from cotton, viscose rayon and linen. The U.S. Army specifies vat-dyed fabrics for every possible use in government issue clothing. These goods can be expected to take rugged wear, heavy soiling, hard rubbing, frequent washings and still stay colorful when they are vat dyed. **(Organic Chemicals Division)**

COLOR INVADES THE KITCHEN, making mealtime chores more pleasant in lively and attractive surroundings. The modern trend in home decoration has created a demand for bright pastels and decorator colors in major appliances. Today, refrigerators, stoves and sinks, traditionally white, are available in many hues. Cyanamid pigments are contributing to this more pleasant way of life by providing test-proved color durability in architectural, household and appliance finishes, plastics, floor coverings and other materials found in today's modern kitchen. **(Pigments Division)**

Additional information may be obtained by writing on your letterhead to the Division of American Cyanamid Company indicated in the captions.

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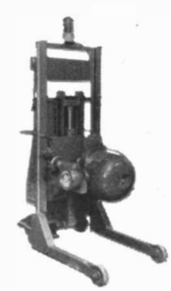

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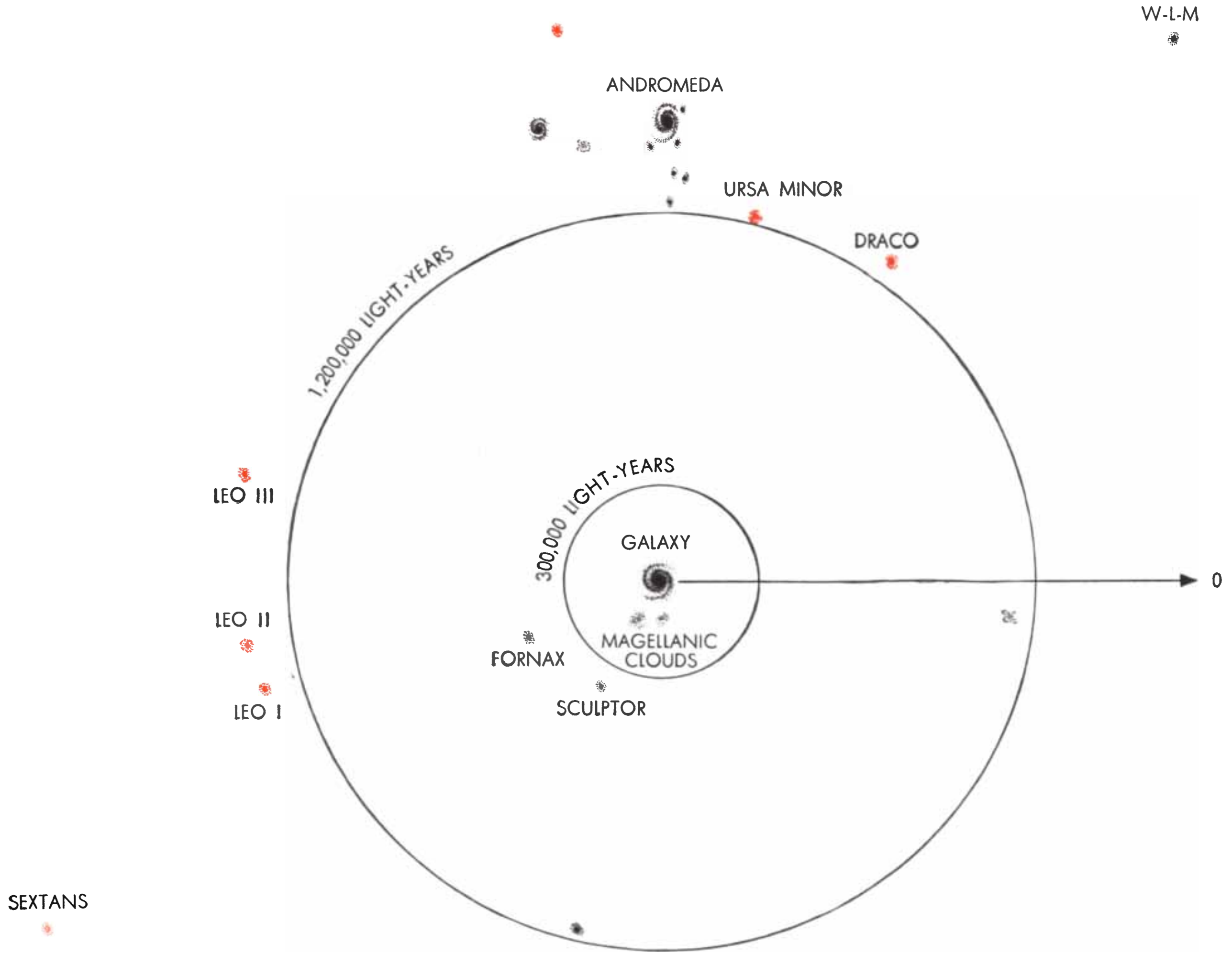
The Distribution of Galaxies

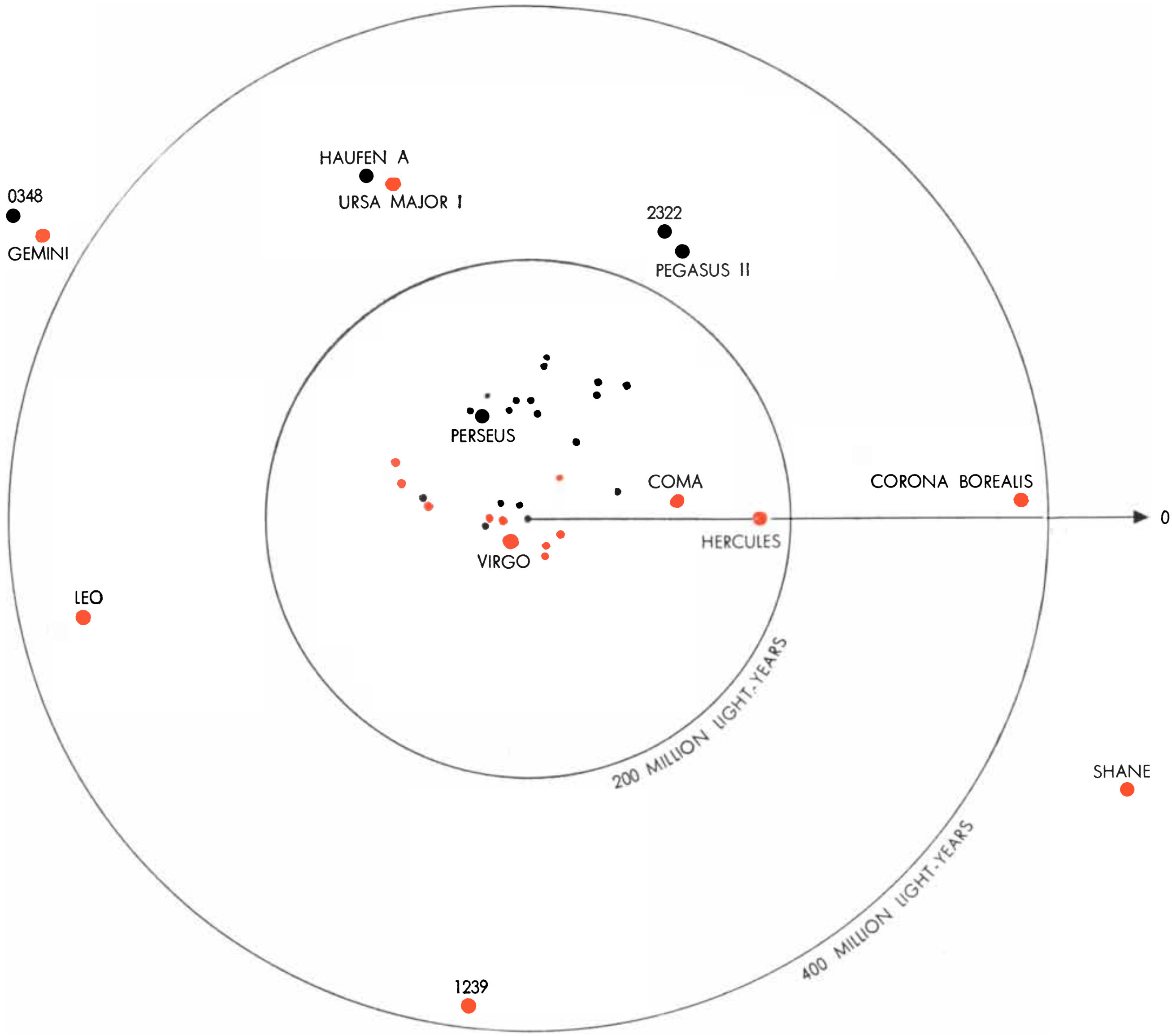
The light of galaxies takes so long to reach us that photographs of the deep sky map them both in space and time. Mathematicians now seek a chance mechanism that will account for their pattern

by Jerzy Neyman and Elizabeth L. Scott

In the effort to obtain a large-scale view of the universe, most cosmological studies are forced to reduce its observed make-up and behavior to averages—one atom to so many quarts of space, "average" galaxies set out uniformly in space like orange trees in a grove. This smoothing-out procedure is unavoidable in any attempt to describe the universe in terms of cause-and-effect relationships. The motion of a single planet may be predicted accurately by a few formulas, but to consider a whole universe of stars and galaxies in this way is completely out of the question. There are just too many bodies requiring separate equations, and the equations become far too complicated to handle. The formulas of the cosmologies are therefore applied to an averaged picture to see what general conclusions can be



LOCAL GROUP of galaxies is roughly projected in the plane of the page. Our galaxy is in the center; the arrow indicates 0 degrees on the Milky Way. The form of the galaxies is schematically shown, but their size is exaggerated. The objects to the north of the Milky Way are in color; those to the south of the Milky Way, in black. The galaxies are named according to various conventions.



ASSOCIATIONS OF GALAXIES far beyond the local group are similarly mapped. The smaller dots represent groups of 50 galaxies or less; the larger dots, clusters of more than 50 galaxies. On this scale the entire local group is in the small central dot. The objects in color are again those to the north of the Milky Way; the objects in black, those to the south of the Milky Way.

drawn. This approach, however, has obvious limitations. The conclusions can agree with the real universe only in terms of averages, and they leave unexplained many of the details of its structure and behavior.

There is another way of attacking the problem. We may give up the cause-and-effect approach and consider the universe as an outcome of a chance mechanism, subject to the laws of probability. A roulette wheel is a chance mechanism. The significant feature of such mechanisms is that they produce striking regularities "in the large" combined with a tremendous range of irregularities "in the small." Thus an appropriate mechanism might reproduce the large regularities and the pattern of local irregularities of the universe as we know it. In other words, we would seek to recreate the universe we see by the operation of some chance mechanism applied repeatedly inch by inch over all space and hour by hour over all time. Such a mechanism could not attempt to predict exactly what would happen at a given moment of time in a given region of space. But it would try to predict how frequently a given configuration of stars, galaxies or other systems will be found in different regions in space.

We have been working along these lines with our colleagues at the University of California and the Lick Observatory. C. D. Shane, astronomer at the Observatory, prompted our study. He was engaged in a survey of the distribution of galaxies in photographs of the sky, and he became curious to know whether their lumpy distribution (rather like handfuls of seed scattered in a field) might be described by some statistical law. Our efforts to answer his question developed into a long-range study. The results so far obtained include a plausible chance mechanism governing the distribution of galaxies in space and a novel method of testing certain cosmological models. The method is independent of the red-shift; indeed it offers an opportunity for a separate check on whether the universe is truly expanding. It also seems capable of deciding between the evolutionary and steady-state theories.

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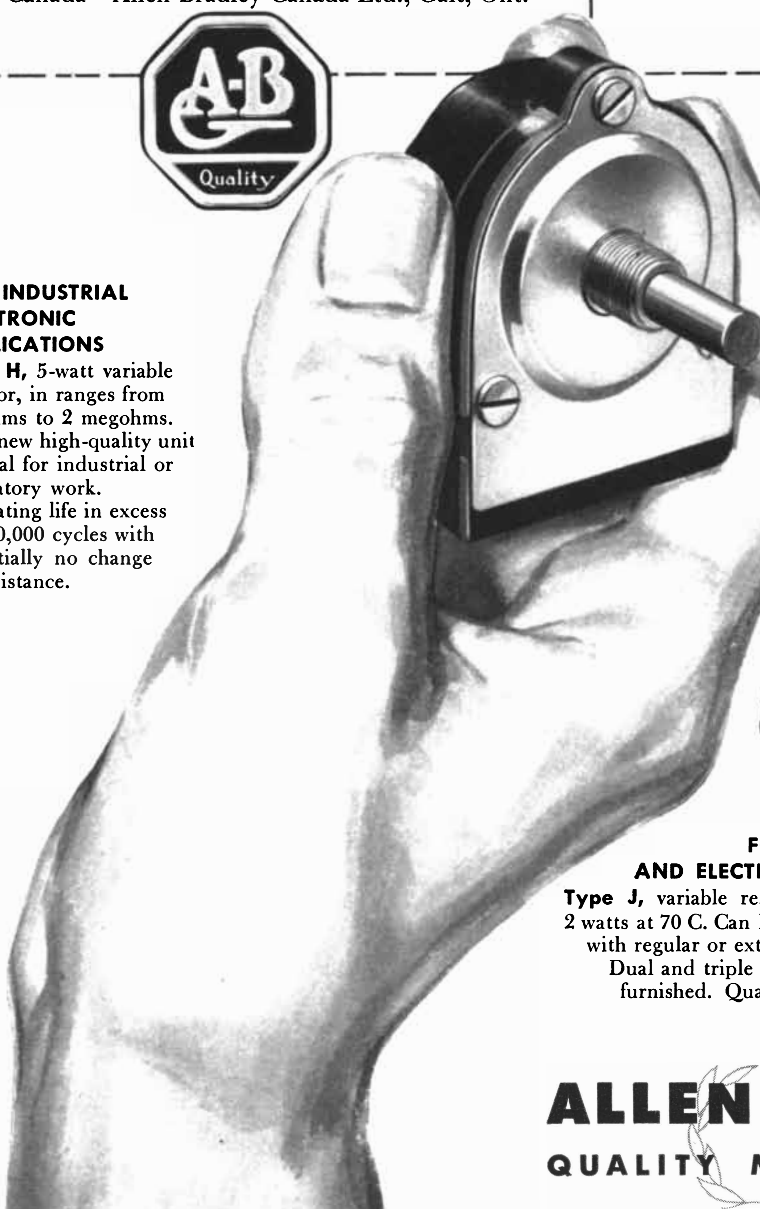

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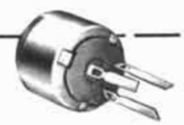

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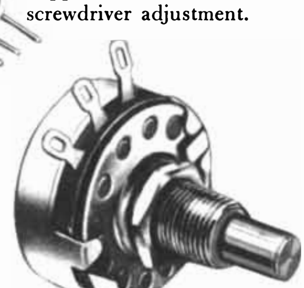

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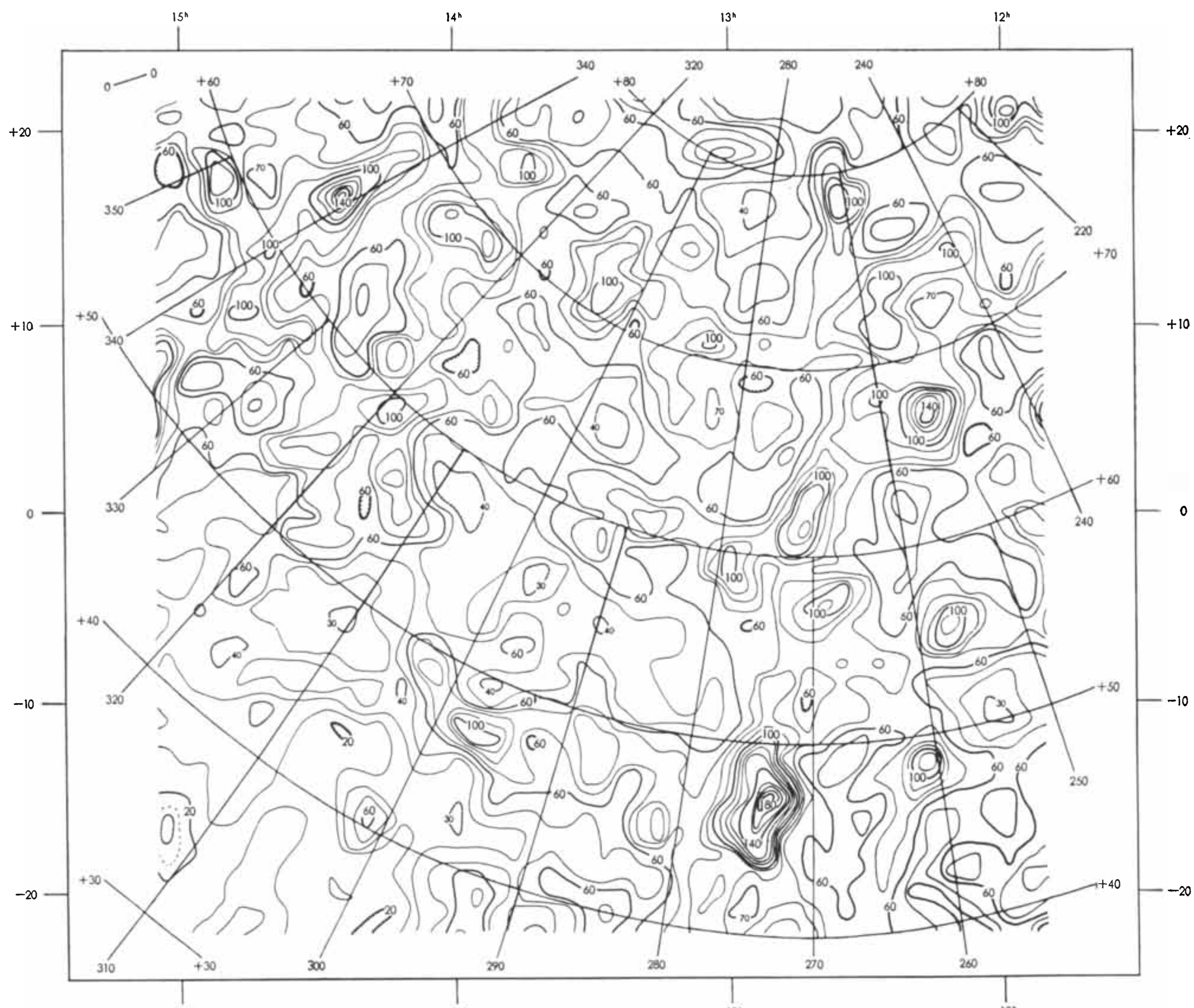
have been making systematic surveys of the distribution of galaxies in the sky: several are in progress just now. No general pattern of any kind has emerged. The galaxies are found in small groups, in large clusters, in clusters of clusters, and alone in wide space. A rough picture of the nature of their distribution is given in the two accompanying maps [*see pages 187 and 188*]. The first is a "close-up" view of the arrangement of galaxies in our own neighborhood, covering a span of about one million light-years. The second is a wider picture on a different scale which reduces all the galaxies in our local group to a dot in the center. It embraces a space of some 400 million light-years. On this scale no individual galaxies are shown but only clusters of them (which within the range of 150 million light-years can be distinguished into small "groups" and larger "clusters").

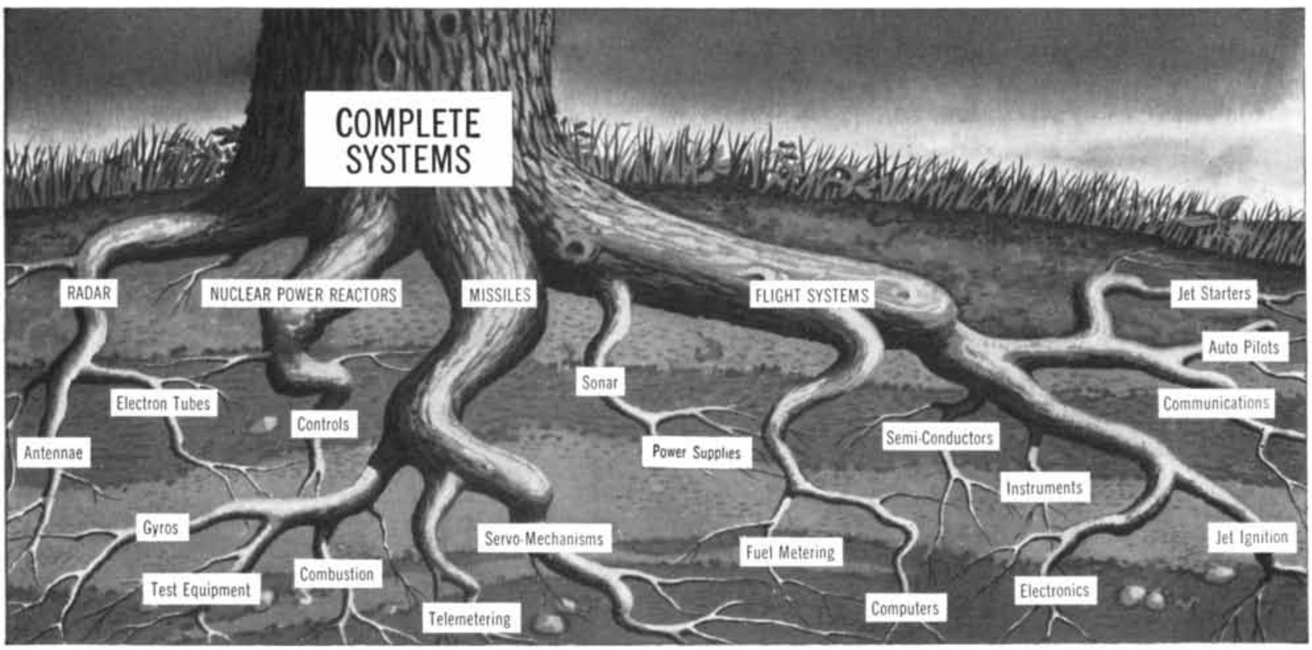
The maps illustrate the patchiness of the distribution of galaxies in space. It is this sort of picture that the chance mechanism procedure we have mentioned seeks to reproduce.

To explain our approach it may be helpful to consider as a rough analogy the problem of a life insurance actuary constructing a mortality table. His "universe" is a group of, say, one million policyholders, and his problem is to predict the state of this universe at various times in the future. Now the fate over the next 12 months of a single human being, or of a family, is unpredictable, but if the actuary considers the million policy holders as a group, regularities "in the large" emerge: the proportion of deaths is greater among the 50-year-olds than among the 20-year-olds, etc. The whole process of survival and death occurs as if it were governed by a chance mechanism which can be represented as follows. Each morning before breakfast every single one of us approaches an urn filled with white and black balls. We draw a ball. If it is white, we survive the day. If it is black, we die. The proportion of black balls in the urn is not the same for each day, but grows as we become older in accordance with the so-called Gompertz-Makeham law. Still there are always some white balls present and some of us continue to draw them day after day for many years.

Naturally this chance mechanism is a hypothetical one. However, the important point is that by using such a hypothetical chance mechanism actuaries can predict the frequencies of the various



DENSITY OF GALAXIES varies widely over the sky. Contour lines give numbers of galaxies per square degree. Serrated lines represent "holes," where density decreases within the line. The horizontal scale measures right ascension, or longitude on the celestial sphere; the vertical scale measures declination, or latitude. The map itself is marked off with respect to galactic coordinates.



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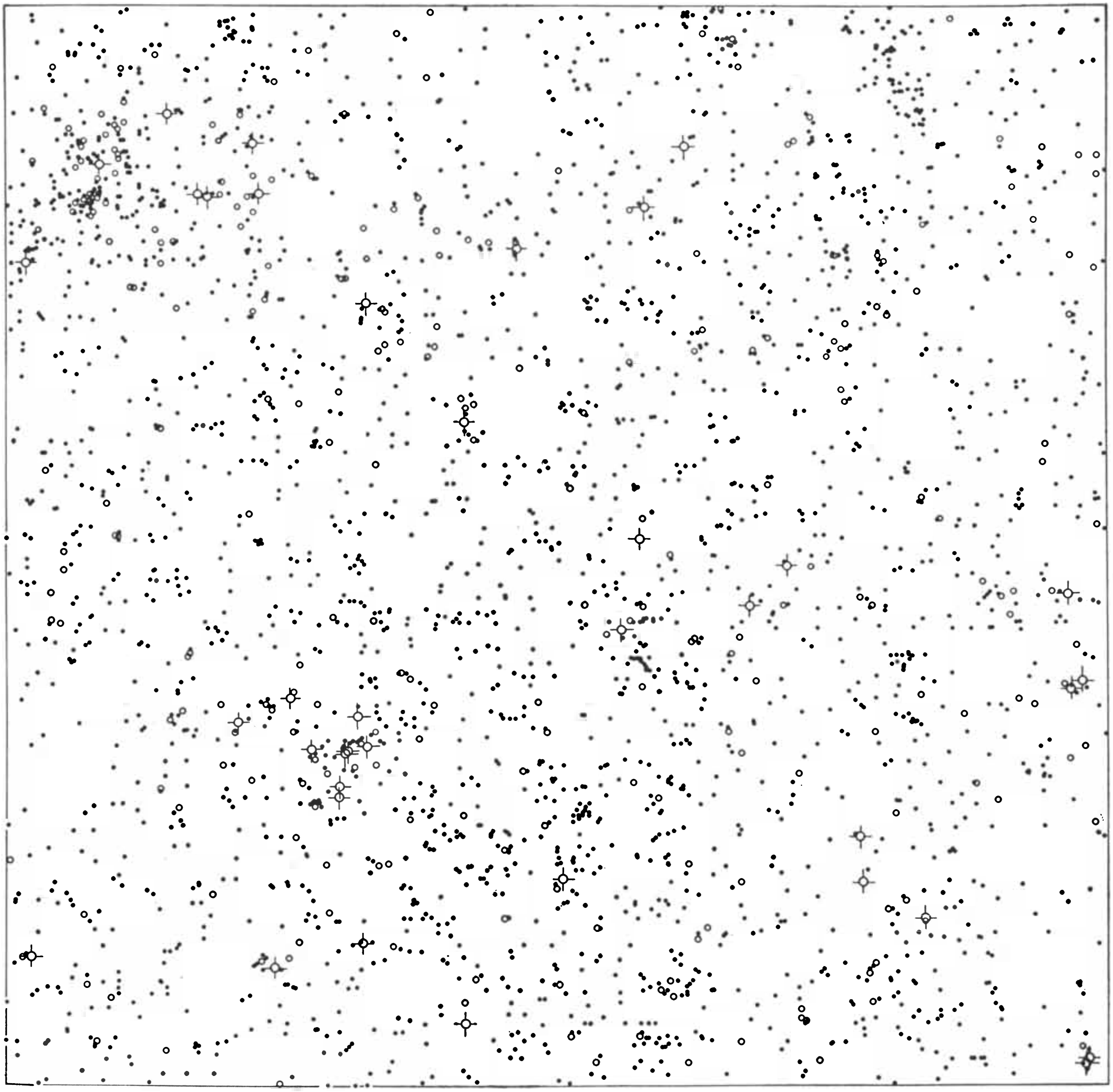

PLOT OF GALAXIES was prepared by C. D. Shane from a photographic plate exposed at the Lick Observatory. It covers a square area six degrees on a side. The sizes of the various symbols are a rough index of the brightness of the galaxies which they represent.

combinations of disasters that may occur in a family and provide us with insurance. In other words, all happens as if we actually did draw balls before breakfast.

It is plausible that a similar chance mechanism, functioning repeatedly over small units of space and time, would produce the observed large-scale regularities in the distribution of matter in the universe and the correct frequencies of the various local irregularities. In parallel with the division of the life span of an individual into days, we visualized space as divided into an infinity of elements of volume (small cubes, all of the same size). Just as each day is considered as a potential date of death, each elementary volume in space was treated as a potential location of a galaxy.

The simplest attack is to try to populate the universe by a single mechanism applied uniformly throughout space, and this is the one with which we began. Suppose that the chance mechanism is a roulette wheel with a very large, and specified, number of slots. Approach the first cube and spin the wheel. If the ball stops in the slot labeled O, put a galaxy in the cube. Otherwise leave it empty. Repeat the procedure for all the cubes. (To keep the mathematics manageable we consider space to be Euclidean—not curved—and infinite.) Carried out through all space, this process would produce some kind of arrangement of galaxies. By mathematical calculations it is possible to determine what the distribution of galaxies on photographs of the sky would be like if such a mechanism functioned uniformly through space.

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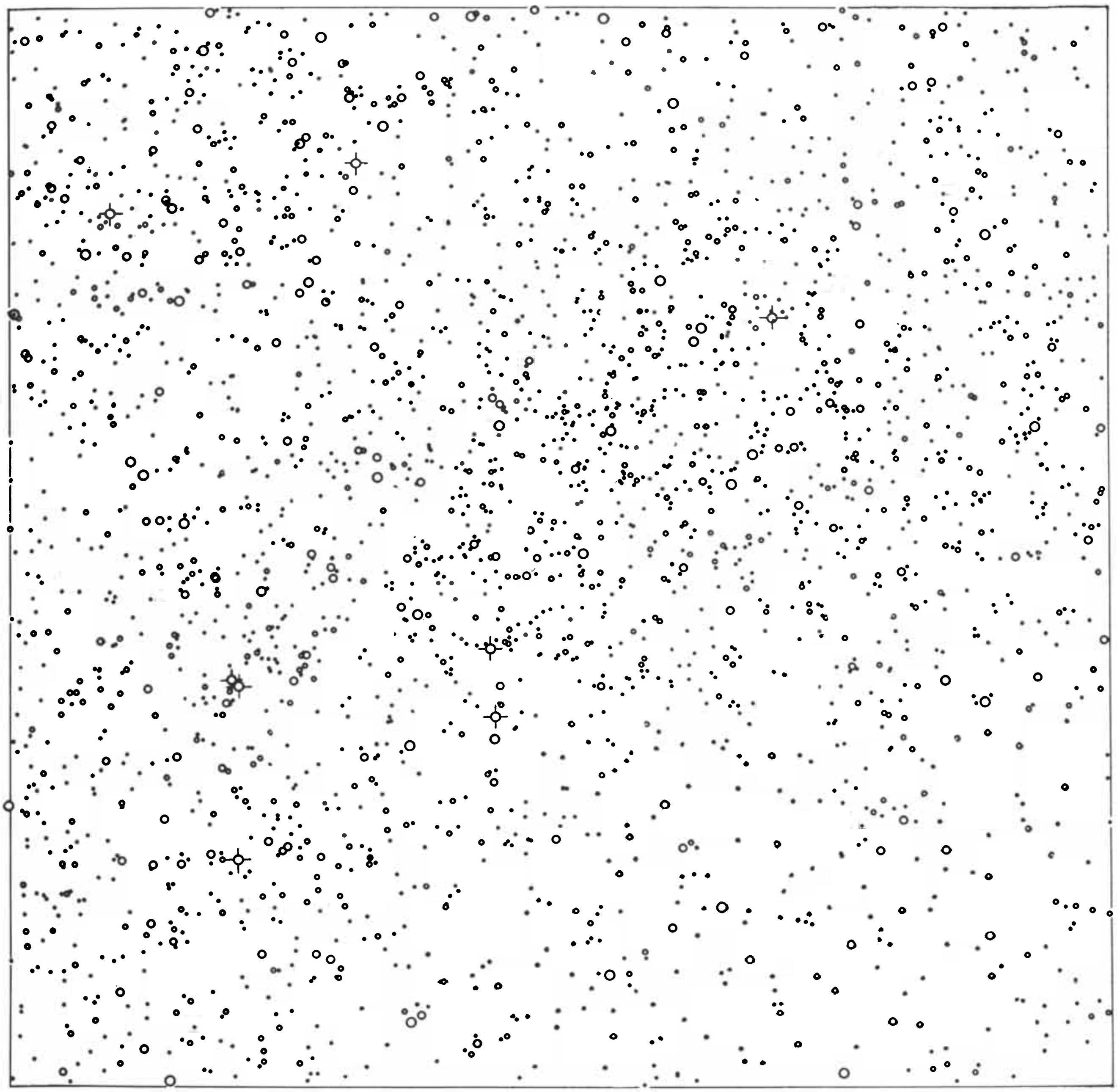


"SYNTHETIC" PLOT of galaxies was made by actually applying the chance mechanism described in the text. The clustering of galaxies, which this mechanism guarantees, is not apparent from a casual inspection. It is brought out only by statistical analysis.

bution was compared with the actual distribution of galaxies recorded in Shane's photographs of the sky [*see page 192*], it became apparent that the simple mechanism postulated could not produce a distribution resembling the one we see. In the real universe there is a much more pronounced tendency for galaxies to be grouped in clusters.

This suggested a different approach to the game. Suppose we assume that galaxies always occur in clusters, varying in the number of members. In principle we can consider even an isolated galaxy as a cluster containing but one member. We can then use a more elaborate chance mechanism to represent this situation. Approach the first cube, as before, and spin the roulette wheel. If the ball hits O, place in it not a galaxy but a "cluster center." After cluster centers have been placed by this random process in the whole space, we go back to the cluster centers to decide how many galaxies each cluster should contain. For each center we spin a roulette wheel again—this time a different wheel with a much smaller number of slots. If O comes up on the first spin, we place just one galaxy in the cluster. If it does not, we spin the wheel repeatedly until it comes up: the number of spins needed to hit O is taken as the number of galaxies in the cluster. Finally, we must arrange the galaxies in each cluster, deciding how far apart they shall be. For this we select a third appropriate roulette wheel.

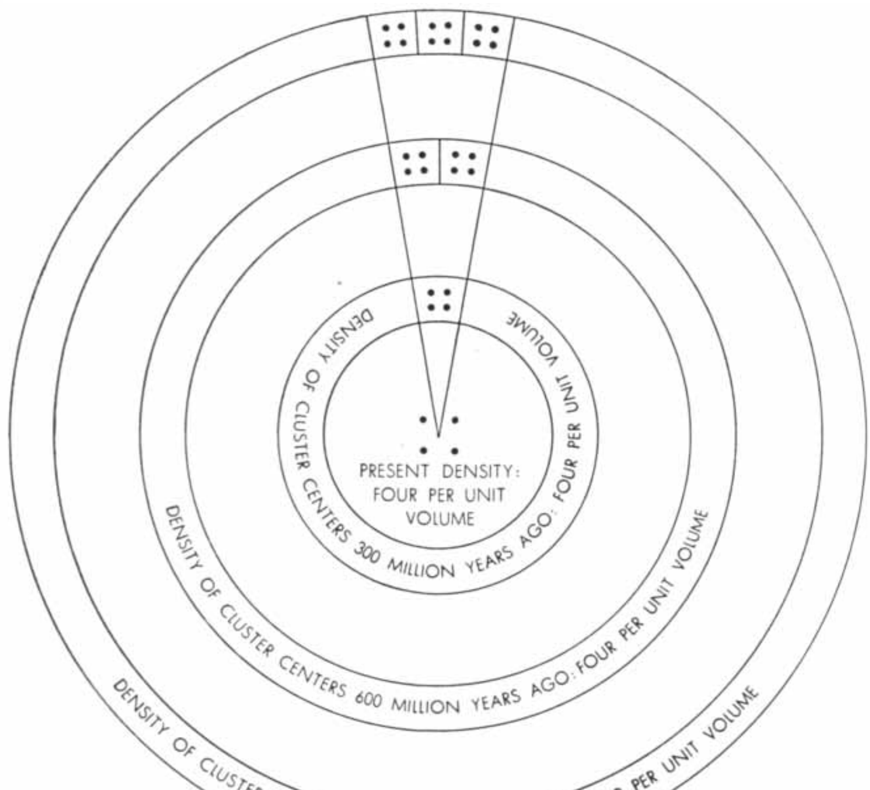
It is obvious that by trying many different chance mechanisms and combinations of mechanisms (*e.g.*, adding a fourth step to create clusters of clus-

ters), we can produce a great variety of different distributions of galaxies. To determine the constants (*i.e.*, the number of slots in each roulette wheel) that give the best fit with the observed universe is a tedious mathematical process. It involves hundreds of long and repetitive computations on the probability equations that represent the "game." These are best done on a large computer. On the observational side, the distribution of galaxies in photographs of the sky must be analyzed painstakingly to disclose their statistical anatomy for comparison with the chance-mechanism picture.

Some of this work has been finished and we have a tentative set of values for the constants which produces a distribution of galaxies of a kind similar to the one actually observed on photographic plates.

In the meantime a method of testing cosmological theories by studying the sky statistically has emerged. It rests upon the fact that the distribution we see is not a picture at one moment in time but represents distributions at widely different periods in the history of the universe. The more remote clusters are showing their distribution, or density, as it was hundreds of millions of years ago, because of the time it has taken their light to reach us.

The chance-mechanism process we have described for reproducing the universe assumes that the whole operation is carried out instantaneously. Thus any picture synthesized by this process is a picture of the universe at a single instant in time. If the universe is static (not expanding) or in a steady state, the density of galaxies in space should be the same, of course, however far back we look in time. But if the universe is expanding and no new matter is being created, the clusters of galaxies are more spread out now than they were in the past. Therefore in the far reaches of space, where we see a flashback to the population of space as it existed hundreds of millions of years ago, the clusters of galaxies should be closer together than they are now. That is to say, a given volume of "old," distant space should contain more clusters than the same volume of space near us [*see diagrams below and on next page*]. This indicates a test of the theories: if the density of



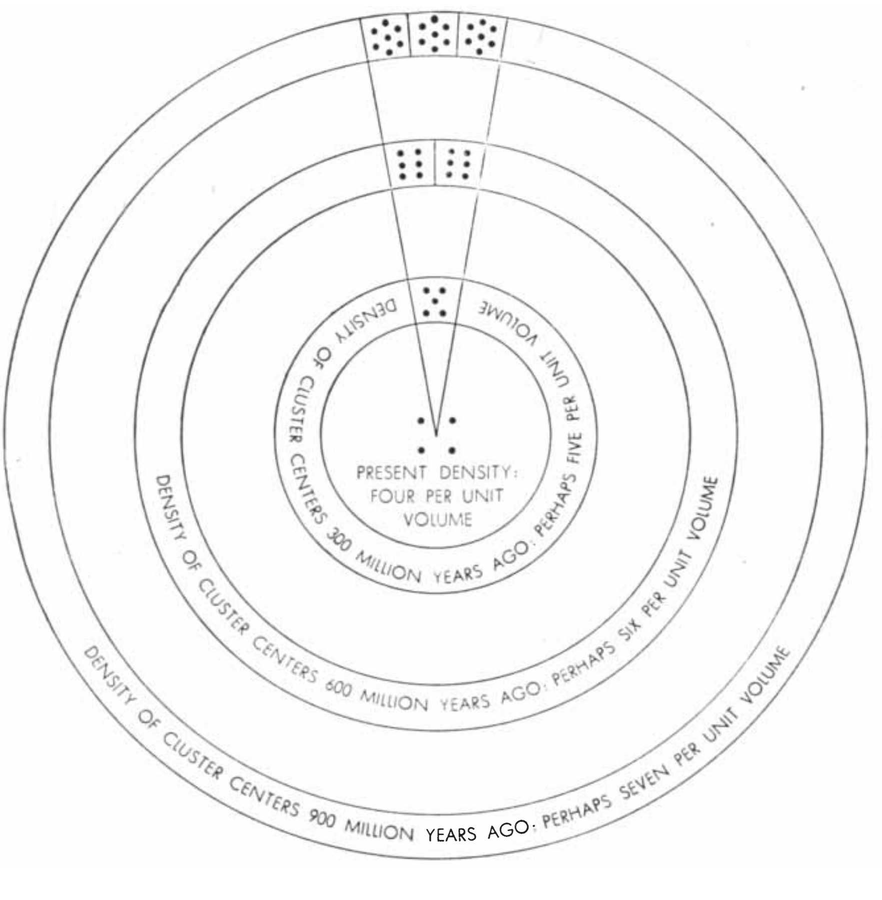
STEADY-STATE or static universe would have a constant density of clusters throughout all of space. In this diagram equal volumes of space at any distance contain four clusters.

clusters in space increases with distance from us, the universe is expanding and evolving; if the density remains constant, the universe is static or in a steady state.

How can we compare the density of nearby and distant space? On a photographic plate nearby clusters are superposed on more distant ones, so that the images of their member galaxies are thoroughly scrambled. It is therefore extremely difficult, if not altogether impracticable, to separate the distant clusters from the nearer ones. However, it occurred to us that a statistical analysis of the plate as a whole might resolve the question. The analysis depends on the fact that any cluster at a great distance will look smaller and more tightly packed than one of the same size close by. On this basis we can picture roughly how a plate might look if it contained a disproportionate number of distant clusters (as required by the evolving model) or a constant density (steady state). Greatly exaggerated versions of these alternative distributions are pictured in the diagrams on page 200. Comparing them with Shane's plate [*page 192*], it is plain that one cannot decide on the actual distribution simply by glancing at his plot. But they indicate that a statistical analysis could decide which alternative better fits the actual picture.

Briefly, the method is as follows: Each map is divided into many small squares. The galaxies in each square are counted. If a square happens to cover part of a rich cluster, this square will contain substantially more than the average number of galaxies. In that case the adjoining squares are also likely to be at least partly within the cluster and to have a high galaxy count. So, too, the squares next to these and so on, but with decreasing probability of high counts as we get farther from the center of the cluster. The larger the cluster, the farther out the high count will extend. The plate is gone over square by square, and correlations are computed for adjacent squares, squares once removed, and so on. These correlations provide a basis for determining the distribution of cluster sizes in space and thus deciding between the opposing theories.

The idea is simple enough but it involves an enormous amount of computation, which is now in progress on a high-speed computer. At the moment we are analyzing plates made with the 20-inch telescope at the Lick Observatory. How-



EVOLVING UNIVERSE would show increasing density of clusters at increasing distance. Here equal volumes contain from four clusters locally to seven at 900 million light years.

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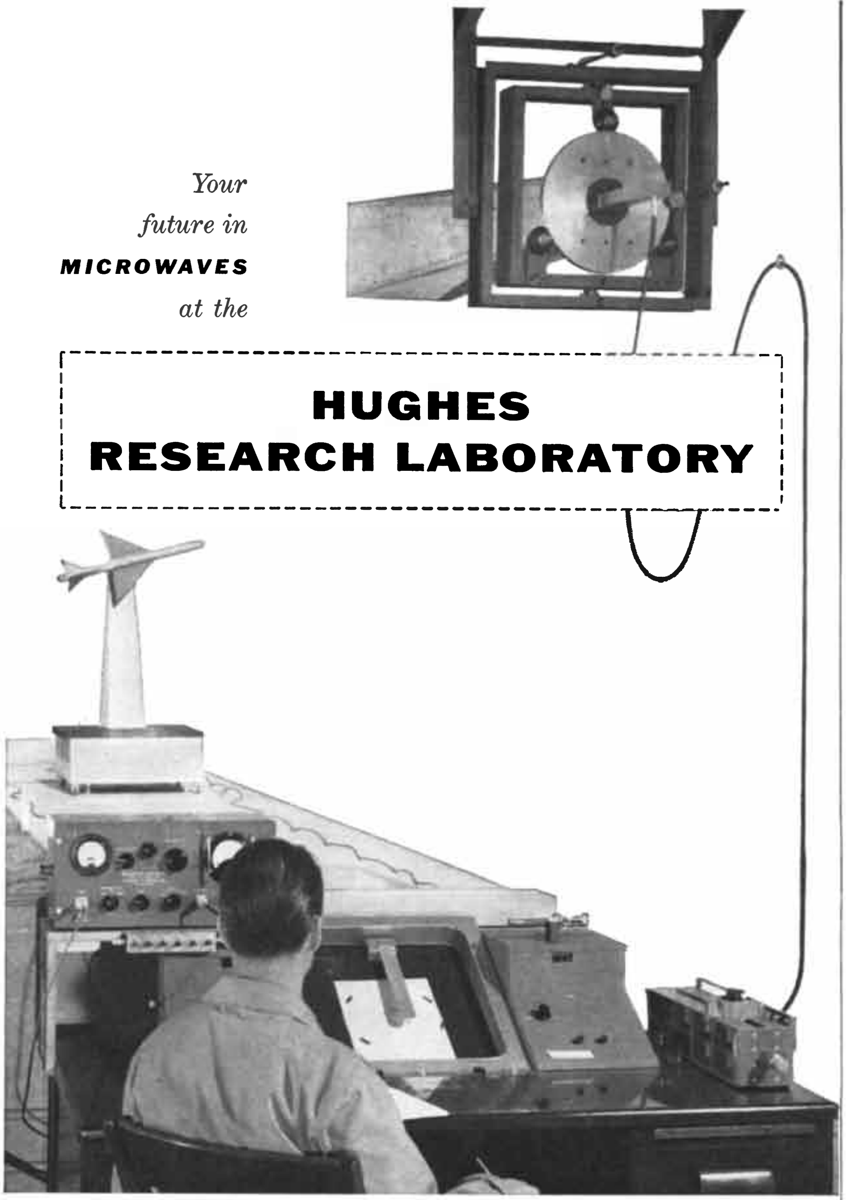

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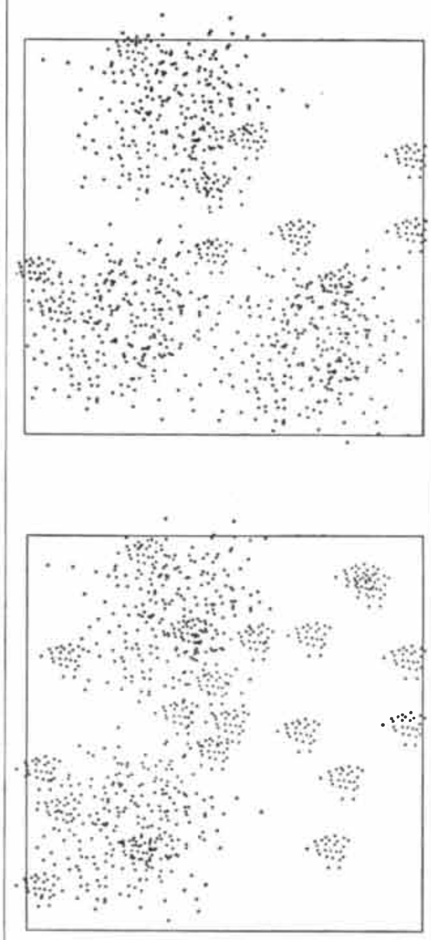
ever, this instrument, with a range of only a few million light-years, does not cover a sufficient span of time to show detectable differences in density. Our hopes for a decision are tied to the new 120-inch telescope now nearing completion at the Lick Observatory. According to the present plan, as soon as this telescope is in operation a new survey of galaxies will be undertaken in coordination with the old survey. When these data become available for analysis, the crucial moment will have come. Preliminary computations indicate that the 120-inch telescope is powerful enough to penetrate far enough back in time to tell which of the two categories of cosmological theories is closer to reality.



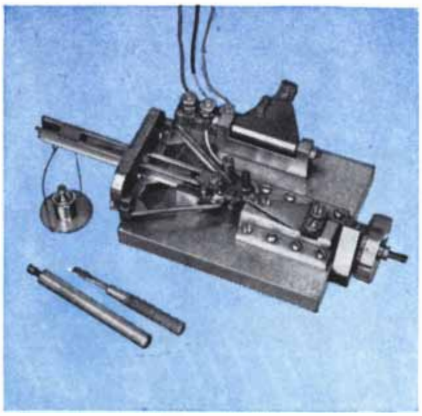
CLUSTER PLOTS made with large telescopes may settle the question of the expansion of the universe. An excess of small, distant clusters over large, near ones would indicate expansion. The diagrams above are greatly exaggerated schematic illustrations of two possibilities. At the top is a plot which might represent a static universe. It contains three large clusters and 10 small ones. At the bottom is a plot containing two large and 20 small clusters. A distribution of this type would be strong evidence in favor of the idea that the universe is expanding.

putting IDEAS *to work—research at* IBM

- **Whisker Loader: allows accurate measurement of contact area between pointed .005″ diameter wire and semiconductor surface. IBM Bulletin No. 300.**
- **Thimbleful of Liquid Memory: using the nuclei of hydrogen to store information. IBM Bulletin No. 301.**

Whisker Loader

Transistors are a "natural" for computers because of their small size, long life, and lower power needs than vacuum tubes. While most transistors used today are of the junction type, some applications require the point-contact type. In this type, the desired trace element is introduced into the germanium "heart" by

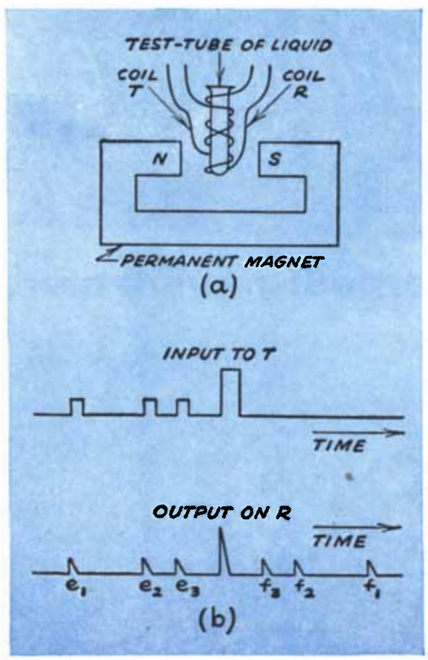


passing a large pulse of current through the pointed wire—which contains the desired trace element and which is in contact with the germanium. The result: heat causes the element to penetrate—or diffuse into the germanium. An important problem in the development of a manufacturing process for this type of transistor was to determine—one at a time—the influence on the diffusion process of each of the various factors involved. Jim Hanson, of our Poughkeepsie Research Laboratory, tackled this problem and came up with some of the answers by using what he calls the Whisker Loader. This precision instrument which he developed makes it possible to place the point of a five one-thousandths inch diameter wire upon the germanium surface; momentarily press the point against the surface with an accurately determined force of several grams; remove the wire and measure and inspect the area of contact between the wire and the germanium with a microscope (as small as one hundred-millionth of a square inch); and then replace the wire on the germanium, in the same position it first occupied, for electrical pulse forming. Our knowledge and understanding of pulse-forming techniques have been greatly increased by the use of this instrument.

A full report that clearly details test procedures, test results and other pertinent data is available in IBM Bulletin No. 300. Write for your copy.

Liquid Memory

Put a small amount of liquid such as glycerine in a d-c magnetic field, apply radio frequency pulses, and one can obtain radio frequency "echoes" of the applied pulses! This is the essence of the spin-echo effect which has been used by IBM scientists to store information in



liquids containing hydrogen nuclei. By proper combinations of r-f pulses, hundreds of echoes in "mirror order" or in "normal order" can be obtained. Referring to schematic below, when a liquid containing hydrogen—such as water or glycerine—is put into the test tube and pulses of r-f current are applied to coil T, pulses will be produced across the terminals of coil R as shown. The pulses e_1, e_2, and e_3 are found only if pulses f_1, f_2, and f_3 have been applied and hence are called "echoes."

The effect may be understood in terms of the magnetic moments and angular momenta or spins of the hydrogen nuclei. In the d-c magnetic field, the nuclear moments are aligned so that the net moment throughout the sample is parallel to the field. A weak r-f pulse tilts the net moment away from the d-c field, about which it then precesses. But, due to inhomogeneities in the field, moments in different parts of the sample process at slightly different rates . . . get out of phase with one another, and hence cannot be detected. The strong r-f pulse rotates all of the moments so that those which were farthest ahead in phase become farthest behind, and conversely. Subsequent precession brings the moments back into phase, giving rise to the echo signal.

A research group at the IBM Watson Laboratory in New York City, headed by Robert M. Walker, has investigated this effect and succeeded in storing a thousand "bits" of information in a thimbleful of liquid. Some day this form of memory may be an important component of a computing machine.

This method of storage based upon the principles of free nuclear induction is more fully described in IBM Bulletin No. 301.

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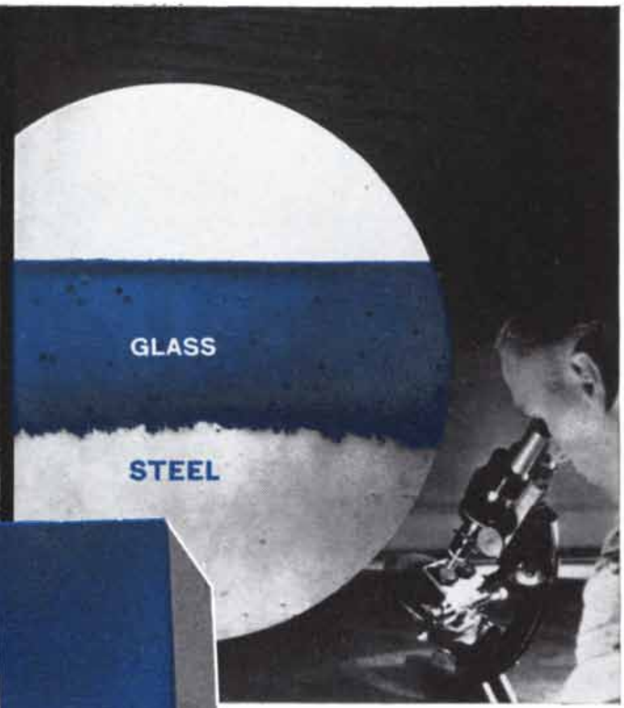

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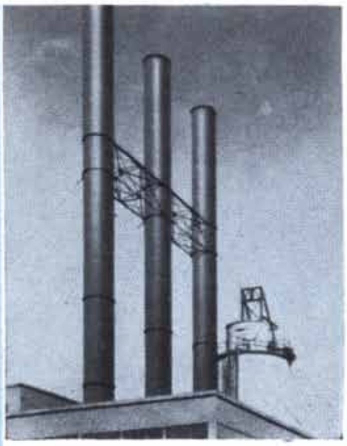

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RADIO SOURCE IN CYGNUS was located by radio interferometer in a rectangle of less than one square minute of arc, drawn on this 48-inch Schmidt telescope photograph. A 200-inch photograph (*see page 125*) identified the source as two galaxies in collision.

Radio Galaxies

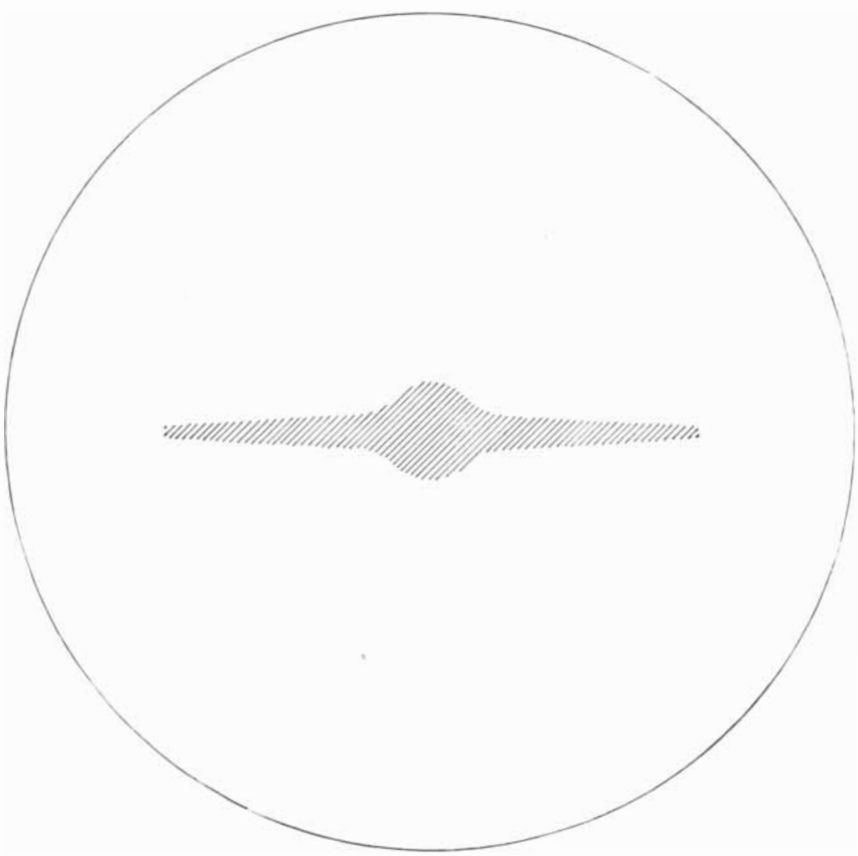
As indicated earlier in this issue, colliding galaxies emit radio waves. The distribution of radio sources suggests that many are galaxies in collision beyond the range of the 200-inch telescope!

by Martin Ryle

Just 25 years ago, when astronomers on Mount Wilson were beginning to get their first glimpse of the expanding universe and to measure the flight of distant galaxies, a radio engineer at the Bell Telephone Laboratories named Karl G. Jansky picked up some puzzling radio "static" which he decided must come from outside the atmosphere of the earth. It would have been impossible then to see any connection between the two events. But in the intervening 25 years, indeed mainly by rapid developments within the last 10, Jansky's static has ranged itself alongside the giant optical telescopes as a remarkable new window upon the universe. Radio astronomy gives us a totally new picture of our sun, of the Milky Way and even of what lies in interstellar space; but more than that, it now promises to extend our view into the depths of the universe and answer some of the central questions of cosmology.

As Rudolph Minkowski relates in his article in this issue [*page 125*], five years ago radio astronomers located a pair of colliding galaxies some 300 million light-years away. The radio signals from this collision, called Cygnus A, are sufficiently strong so that it could be detected even if it were at a much greater distance, beyond the range of the 200-inch telescope. Moreover, radio has an inherent advantage over light in probing to great distances. Reception is less weakened by the red-shift. This shift is very substantial at great distances. At three billion light-years, for example, the light from galaxies (there moving away from us at half the speed of light) would be shifted so far toward the red that photographic plates could record only part of their spectrum in the visual range; the rest of their light would be lost [*see diagrams on page 218*]. Radio energy also suffers some loss with a wavelength shift, but this loss is comparatively small, as analysis of the Cygnus A radio spectrum shows.

Apart from the advantage in detecting galaxies at greater distances, this difference between radio and light has other important consequences. Because of the increasing red-shift, beyond a certain remote distance optical telescopes will fail to get any appreciable light at all, and the background of the sky will therefore appear dark. Radio telescopes, on the other hand, should receive the merged background radiation to much greater distances, some of it originating from extremely distant sources. Thus ra-



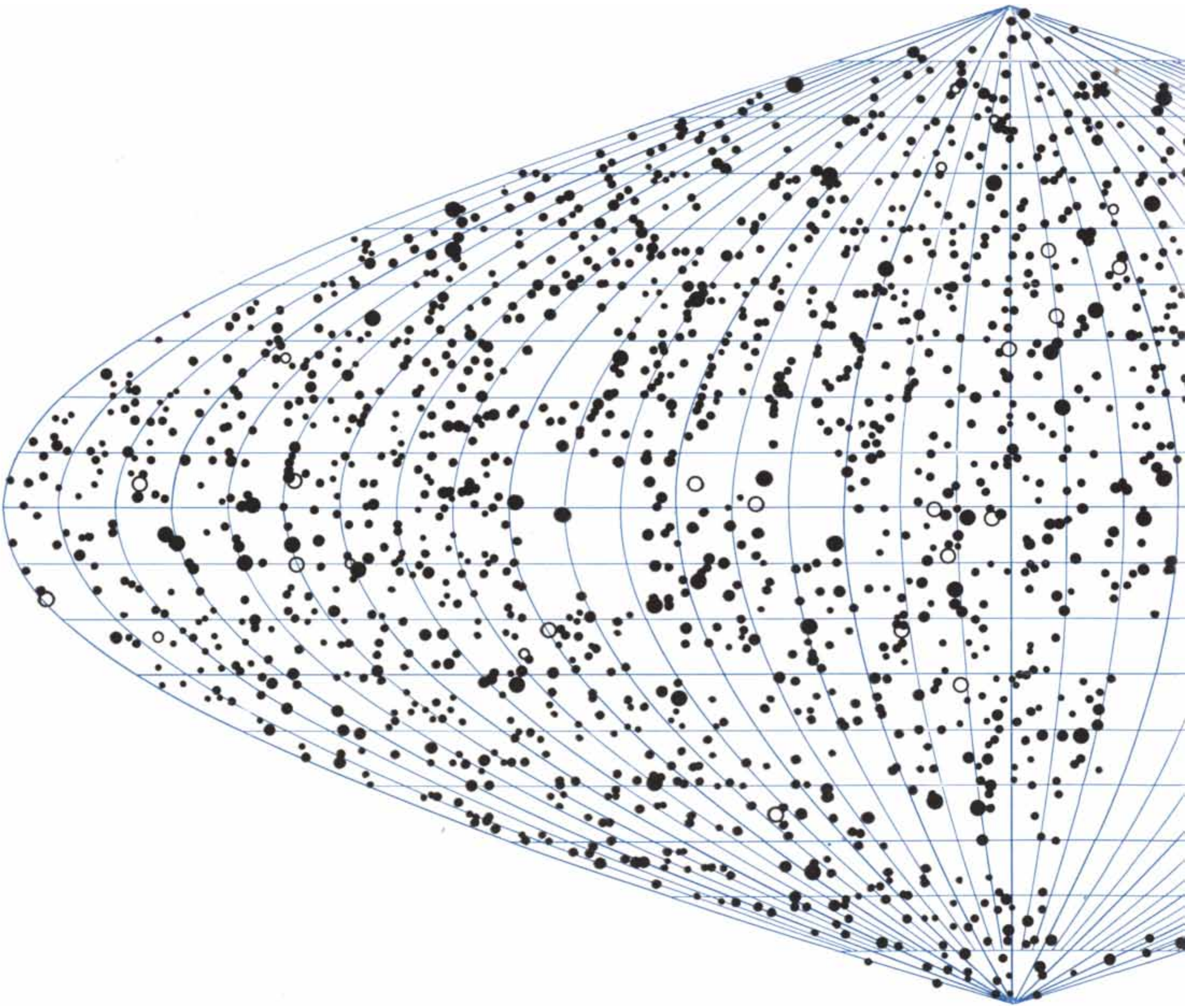
BACKGROUND OF RADIO WAVES from the sky originates largely in a spherical "halo" (*circle*) which surrounds our galaxy. The galaxy is shown edge on in the center of the picture.

dio astronomy offers the possibility of sampling the material content of the universe in very remote space and thereby testing cosmological theories.

How has this possibility come about? To see how Jansky's discovery has become a tool for exploring the universe we must briefly examine the nature of the technique and the significant developments that stimulated interest in it. At first, radio astronomers could find only diffuse regions of radio emission in the sky. The basic problem of radio astronomy is that radio waves are so much longer than light waves. To equal the resolving power of the human eye would require a radio telescope about 10 miles wide. A second major problem is the weakness of the celestial radio signals as we receive them on the earth: the faintest now detected have only a hundred-millionth of the power of a television signal. There is a limit to the sensitivity that can be achieved in a receiver.

The cure for both problems, of course, is larger antennas. Increasing the size of the antenna improves resolution and collects more radio energy from the source, just as a larger mirror in an optical telescope collects more light from a star. The wartime radar "dishes" first used gave way to larger and larger bowls and then to arrays of linked antennas spread over acres of countryside. As antennas grew in size, radio astronomers were able to narrow down the radio sources to smaller and smaller regions.

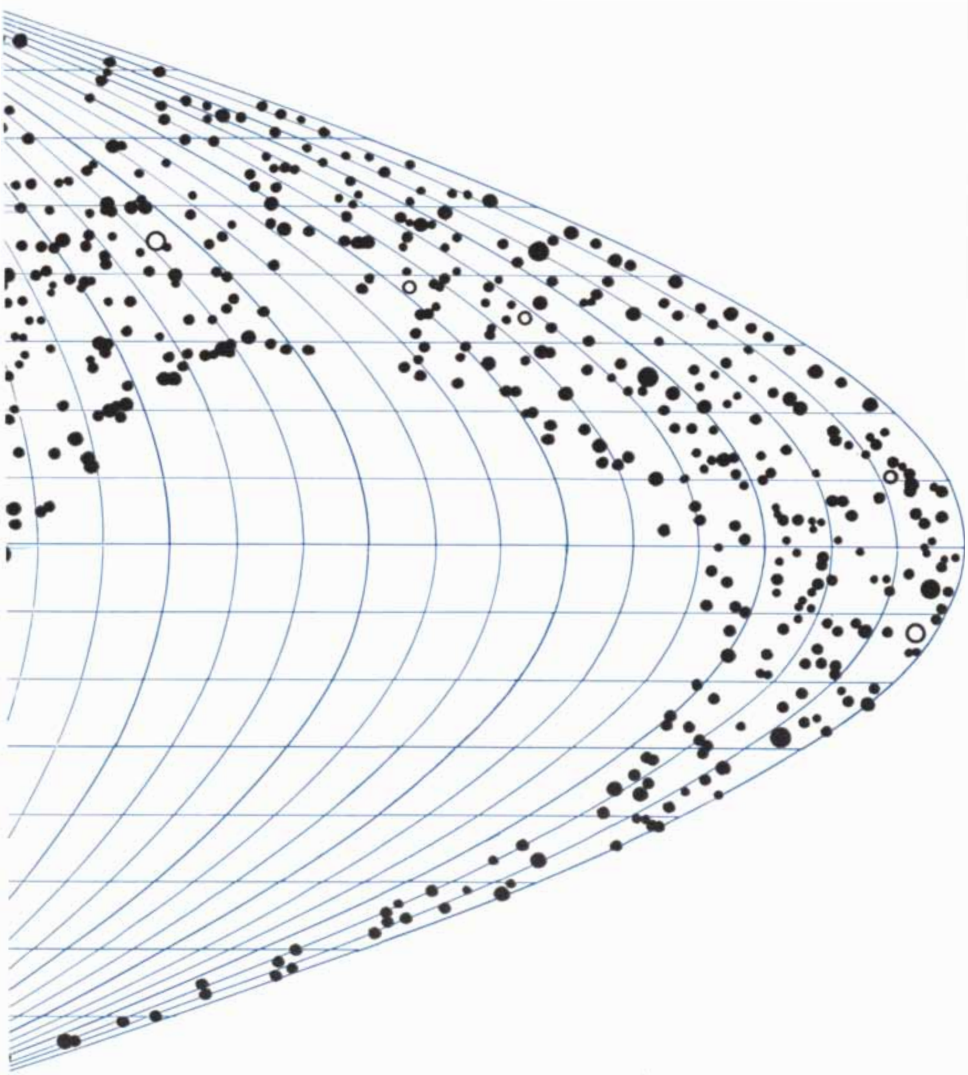
It was less than ten years ago that the first so-called "radio stars" were discovered. They were located as narrow centers of radio emission—almost "point" sources of radio energy. Quite evidently these objects were not ordinary stars: none corresponded to a visible star, but a



RADIO SOURCES located by the University of Cambridge survey are shown in this sky map. The map is drawn on galactic coordinates; *i.e.*, the North Pole of the galaxy is at the top, and the plane of the Milky Way is the equator. Open circles mark sources of

few coincided with nebulae of peculiar characteristics. One of the first objects pinpointed as a radio star was the well-known Crab Nebula, an expanding gaseous cloud in our galaxy which represents the remains of a supernova whose explosion was recorded by Chinese astronomers in the year 1054.

The finding of radio stars naturally stimulated efforts all over the world to erect radio telescopes of higher resolving power. Their development has taken two main lines. The first followed the lead of optical astronomy in building bigger and bigger instruments of the reflector type—taking the form in the radio case of a huge paraboloid bowl. This approach is illustrated by the 50-foot dish at the Naval Research Laboratory in Washington, the 75-foot one recently completed in the Netherlands, and finally the 250-foot giant soon to be put in operation at the University of Manchester in England. The paraboloid type of antenna has many advantages, especially maneuverability in scanning the sky. For the study of radio stars, however, it is necessary to tune into the longer radio wavelengths, where the stars' emission is strongest. To obtain sufficiently fine reso-



large diameter; the intensity of the other sources is indicated by the size of the black dots. The vacant space at the right is the portion of the sky that cannot be seen from Cambridge.

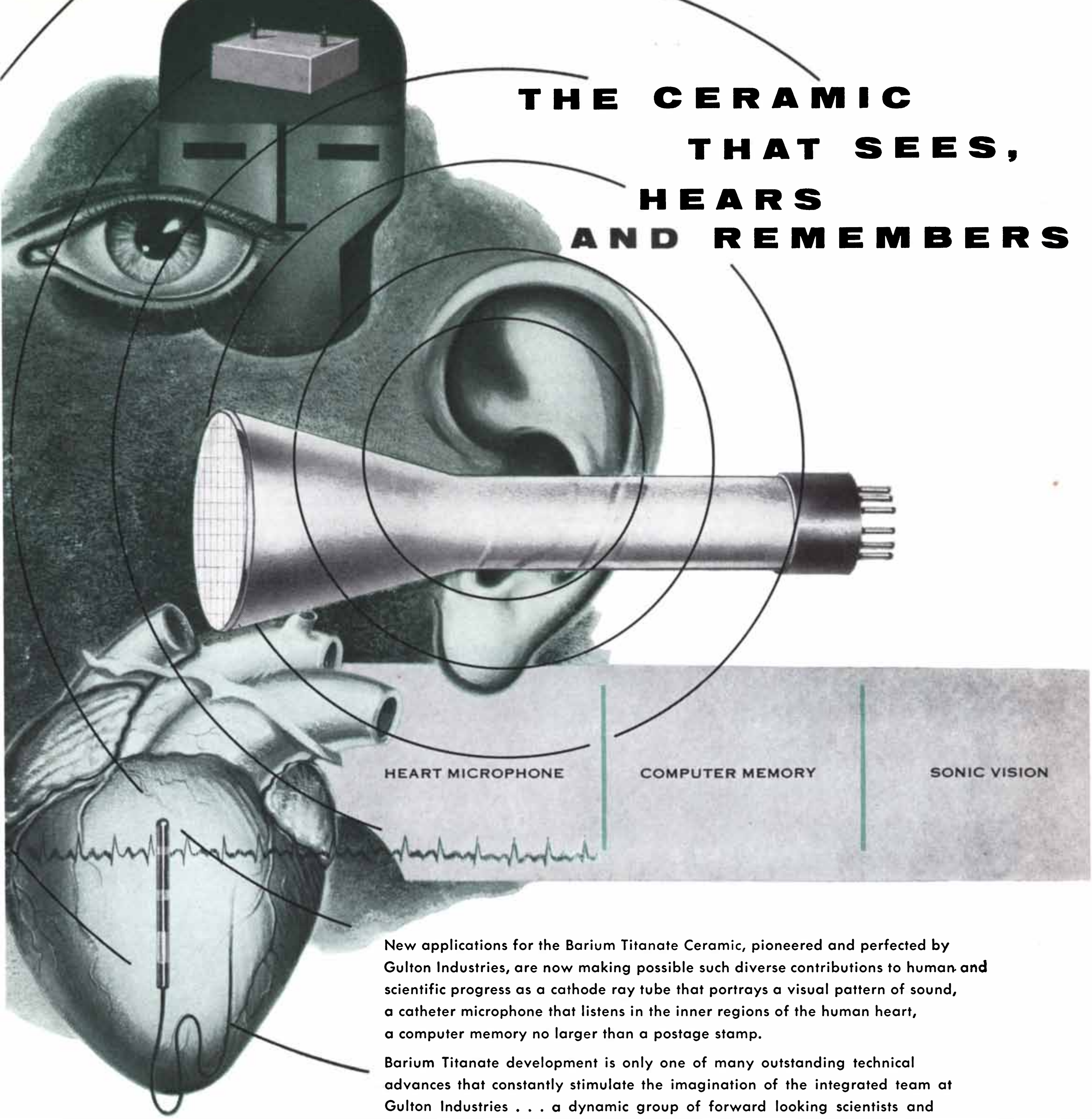
STRONGEST RADIO SOURCE, located in Cassiopeia, has been identified with the faint nebulosities, apparently thin wisps of interstellar matter, shown in this 200-inch photograph.

lution at these wavelengths any feasible dish is too small: larger antennas are needed. Most of the radio star observations so far have been made with extended antenna systems based on the interferometer principle.

The simplest of these systems uses two dishes stationed a considerable distance apart. Where a single dish, scanning the sky, records the aggregate radiation from a region, the two-dish system picks out radio stars from the background [*see charts on page 217*]. With a device called phase switching, the background radiation can be wiped out so that the receiver records only the "point" sources. By increasing the sensitivity of the receiver, weaker radio stars can be brought into the picture, as the last chart in this group shows. In this case the "images" overlap, however, and fainter sources can be detected only by improving the resolution. One way of doing this is to use two narrow antennas oriented in different directions, one receiving a pattern in the north-south plane and the other in the east-west; it is thereby possible to resolve sources at the point where the

EXTRAGALACTIC SOURCE of high intensity is identified with this peculiar object: an otherwise typical elliptical galaxy distinguished by the curious bright jet near its nucleus.

THE CERAMIC THAT SEES, HEARS AND REMEMBERS



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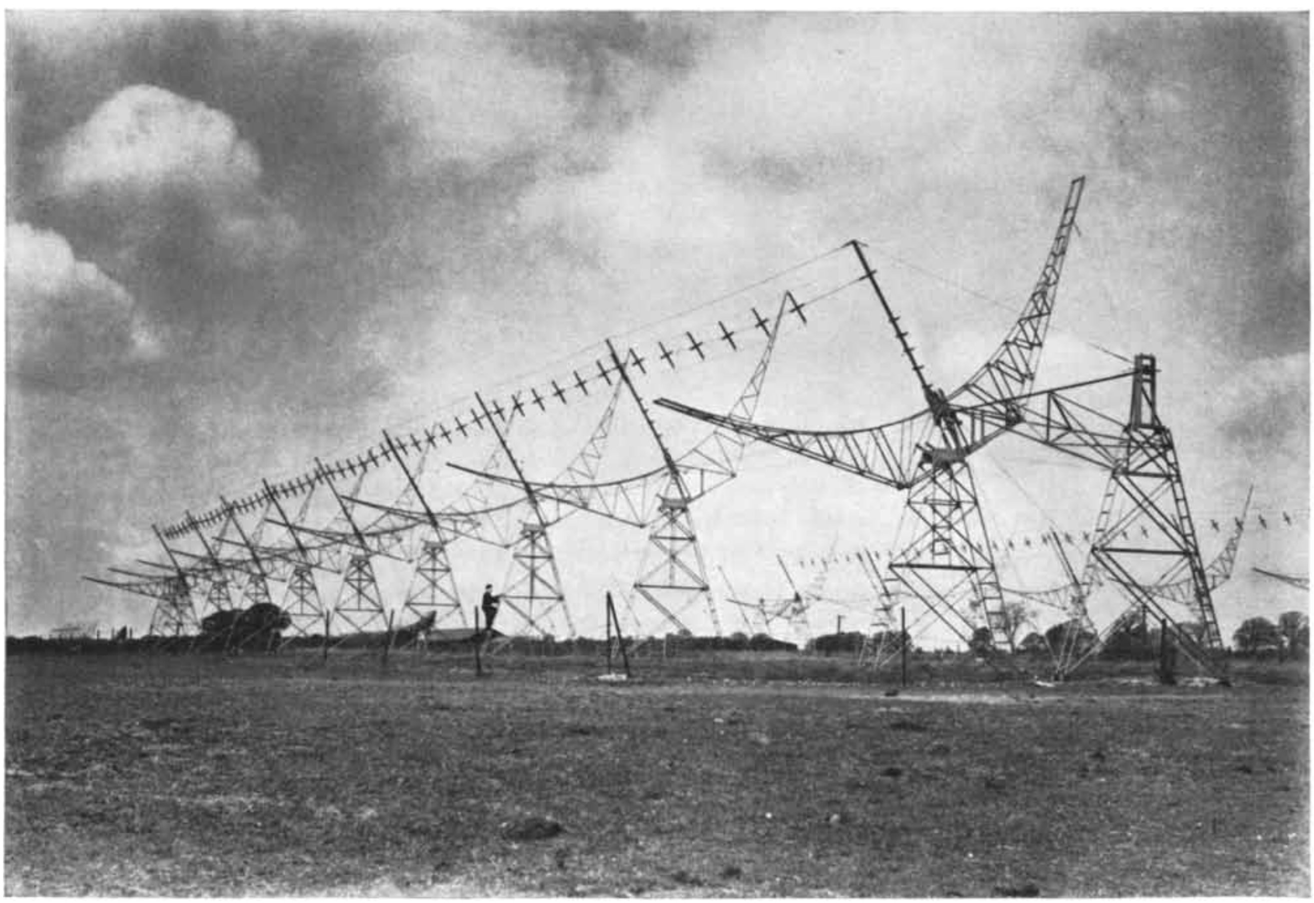
reception patterns coincide. B. Y. Mills in Australia has recently completed a large system of a similar type in which the two narrow antennas cross each other (the "Mills cross"). This system corresponds to a single dish of high resolving power [*see diagrams at bottom of page 212*].

By 1950 our group at the University of Cambridge had located 50 radio stars in the northern hemisphere of the sky, and workers in Australia had found a similar number in the southern hemisphere. Of all these objects, only a few could be identified with luminous bodies. One was the Crab Nebula; another was the galaxy known as M 87, which has an unusual bright "jet" near its nucleus. The light from both the Crab Nebula and M 87 has been found to be strongly polarized, which may be a clue to the origin of the radio emission. It seems probable that the radio energy and part of the light from these two sources is generated by the motion of high-energy electrons in a magnetic field.

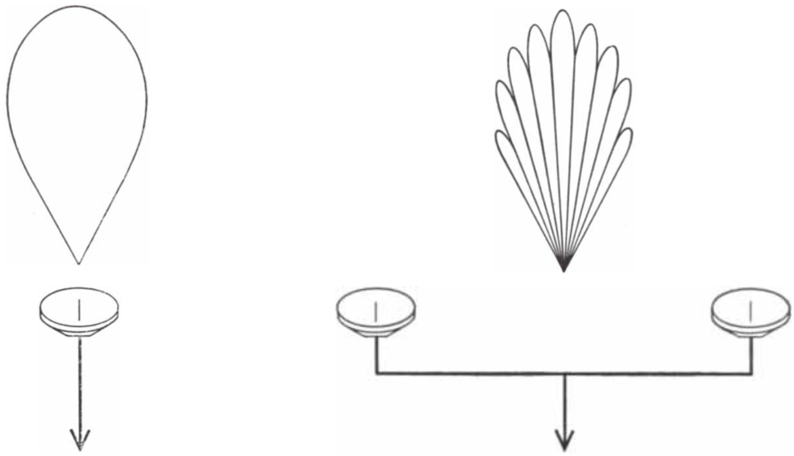
The immediate question was: Where did the unidentified radio stars lie in space? Were most of them within our own galaxy, or did many of them, like M 87, represent objects outside our galaxy? For information on this question our group made a special study of the two strongest radio stars so far located—one in the constellation of Cassiopeia and the other in Cygnus. It soon became clear that to pinpoint the sources with sufficient accuracy to identify them with any visible object would require higher resolving power than we had available. A new radio telescope of the interferometer type was therefore built for the special purpose of identifying these two sources. During the spring of 1951 F. G. Smith succeeded in narrowing down the positions of both radio stars to small areas about one hundredth the size of the earlier locations.

Walter Baade then photographed the positions with the 200-inch telescope on Palomar Mountain. The Cassiopeia source turned out to be a gaseous nebulosity in our own galaxy, perhaps the remains of a supernova. But the source in Cygnus was identified with a faint nebula whose red-shift showed it to be about 300 million light-years from us—far outside our galaxy. The radio emission of this object was calculated to be about equal in energy to its light emission. Further study, as described in Minkowski's article, revealed that the object, named Cygnus A, was actually a pair of colliding galaxies.

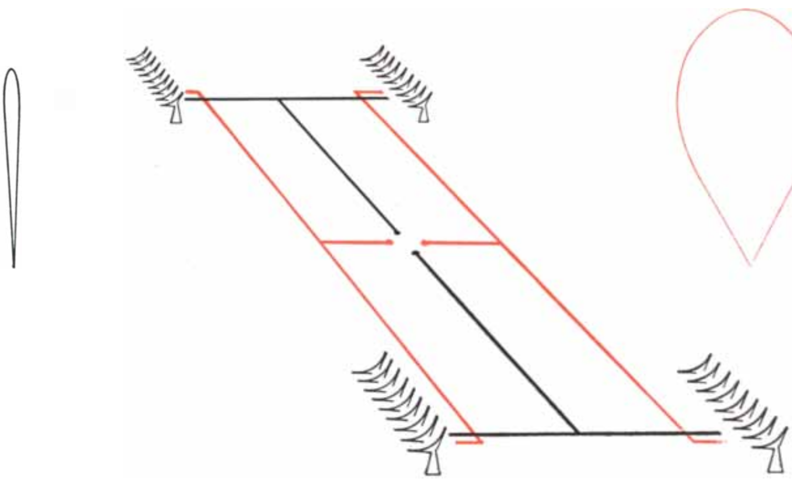
The discovery was at once recognized to be of profound importance for cosmological research. Not only did it open the prospect of extending our view beyond the reach of the 200-inch telescope but it promised specific information of a kind that could never be obtained by optical means, however large the telescope. Extragalactic radio sources as intense as Cygnus A must be extremely rare: it is so much "brighter" than any other detected radio star (except for identified objects in our galaxy) that there cannot



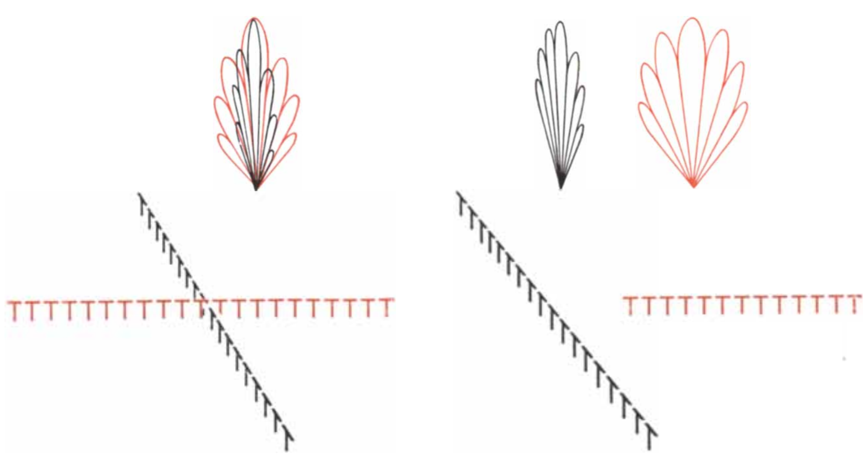
RADIO INTERFEROMETER at University of Cambridge employs a battery of four cylindrical parabolic antennas, three of which can be seen in this photograph. The antennas are oriented east to west and may be rotated about their longitudinal axes, making it possible to sweep the entire sky as the earth rotates. The map of radio sources shown on pages 206 and 207 was made with this instrument.



RECEPTION PATTERNS of a single-antenna telescope and an interferometer are contrasted. The large single lobe at left indicates the wide angle of resolution of the single antenna. The interferometer pattern, represented by multiple lobes, achieves finer resolution.



CAMBRIDGE INTERFEROMETER, shown in photograph on page 210, is diagrammed here. The circuit indicated by red lines sets up a high-resolution reception pattern (*left*). The circuit indicated by the black lines produces a pattern with lower resolution (*right*).



ORIENTATION OF ANTENNAS at right angles increases the resolution of radio interferometers. Australian "Mills cross" is diagrammed at left; another Cambridge installation, at right. The two systems register only sources that are picked up by both of their antennas.

be more than one such source in every 100 million normal galaxies. Objects of this kind should therefore be detectable even at very great distances. If a way is found to recognize colliding galaxies and to determine what fraction of the radio stars are of this type, it should become possible, by statistical analysis, to make direct deductions about the most distant parts of the universe.

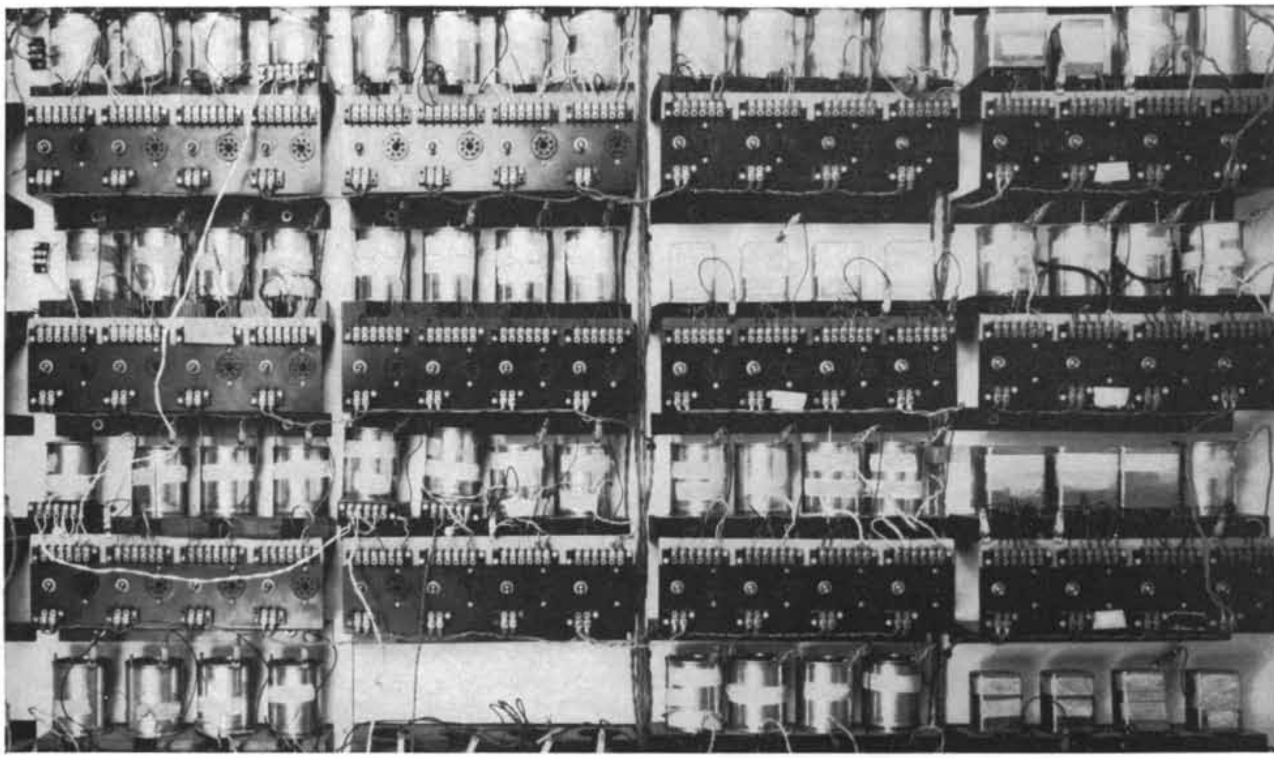
With the object of detecting more radio stars to increase the number for analysis, and of obtaining more accurate positions, a new, considerably larger telescope was constructed at Cambridge in 1952. It is a double interferometer consisting of four aerials each 320 feet long [*see middle diagram at left*]. The aerials can be tilted, and with the earth's rotation they can survey the whole sky at Cambridge.

A comprehensive survey with this instrument, completed early in 1955, located 1,936 radio stars [*see pages 206-207*]. The first question to be determined, of course, is whether they lie in our own galaxy or outside it. Thirty of them give indications of being part of our system: their diameter is comparatively large; they tend to be concentrated near the plane of the Milky Way, and several have been identified with gaseous nebulosities within the galaxy.

The remaining 1,906 are "point" sources, distributed uniformly across the sky. Very few of them can be identified with visible objects, and these give us no enlightenment on the population as a whole. Two are near supernovae in our system (discovered respectively by Tycho Brahe in 1572 and by Johannes Kepler in 1604); but, on the other hand, some coincide with extragalactic objects, including one in the Perseus cluster which has been identified as a collision between galaxies.

Even intensive inspection of photographic plates, then, fails to answer the question whether most of the radio stars are members of our galaxy or outside it. Their uniform distribution across the sky might suggest that they are extragalactic, because galaxies are distributed uniformly over the whole sky while our own system is concentrated near the circle of the Milky Way. But it is conceivable that we are surrounded by radio-emitting objects within our galaxy—a class of objects which we cannot see and whose existence we have not hitherto suspected. Since we do not know what the intrinsic intensity of these radio sources is, we cannot tell how far away they are—whether close to us or outside the galaxy.

We undertook to attack the problem



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*Dissymmetry:	Less than 4%
Temperature:	−55°C to 100°C
*Switching time:	15° ± 5°
Operating position:	Any
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Stray contact capacitance:	Less than 15 mmf.
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6.47

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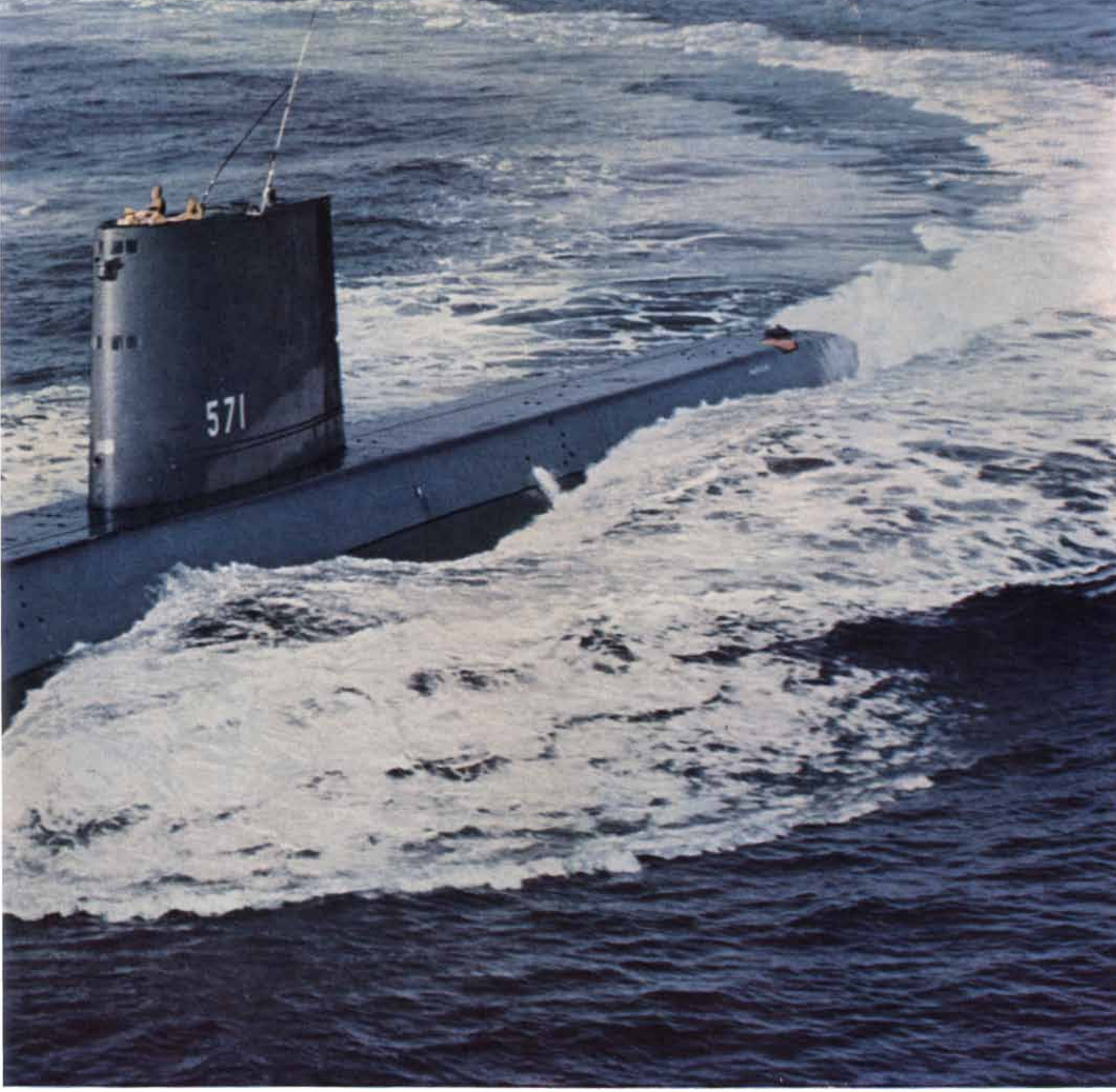

atomic fuel. The atomic reactor which powers the *Nautilus* was built by Westinghouse for the Navy and the Atomic Energy Commission.

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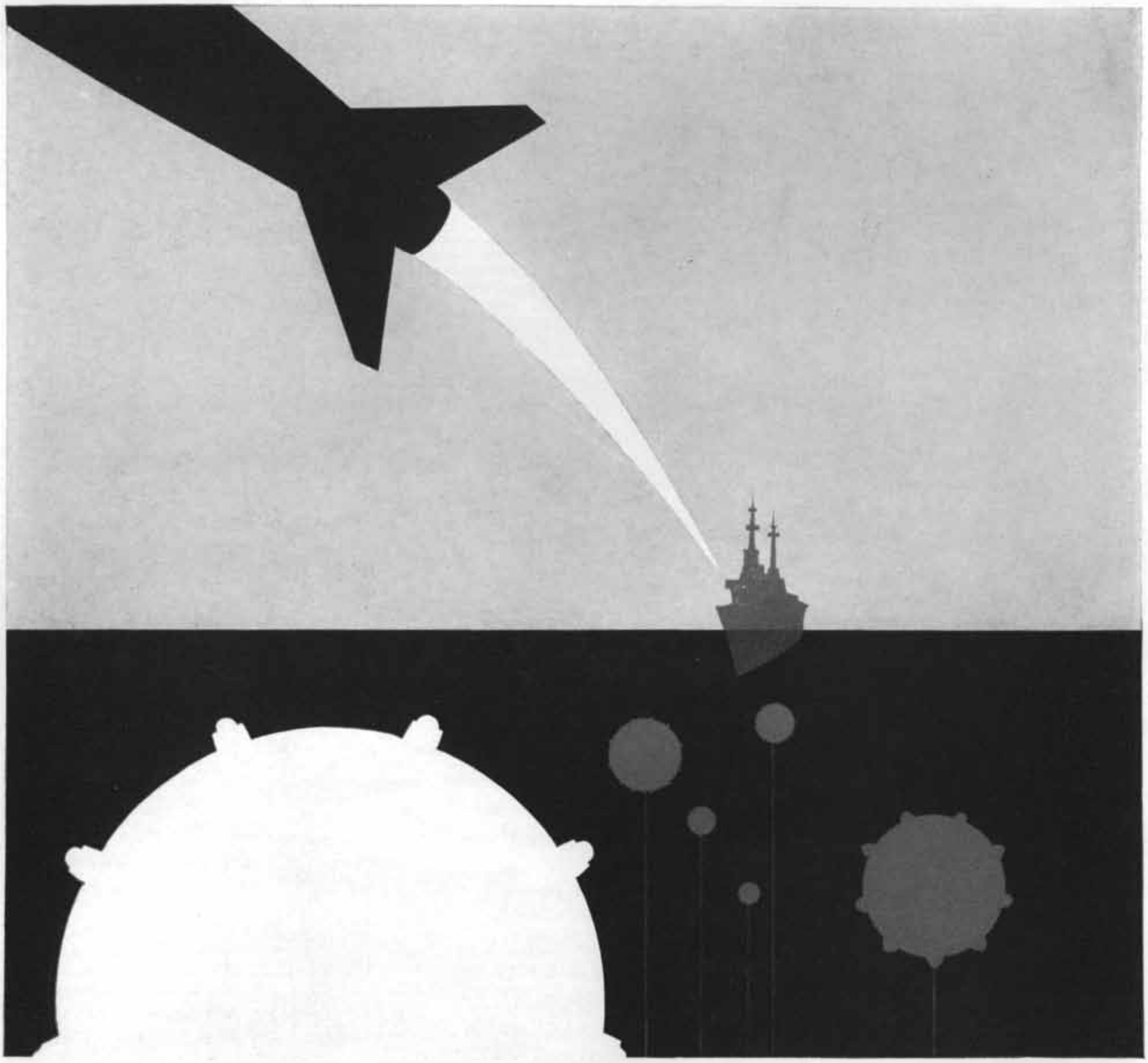
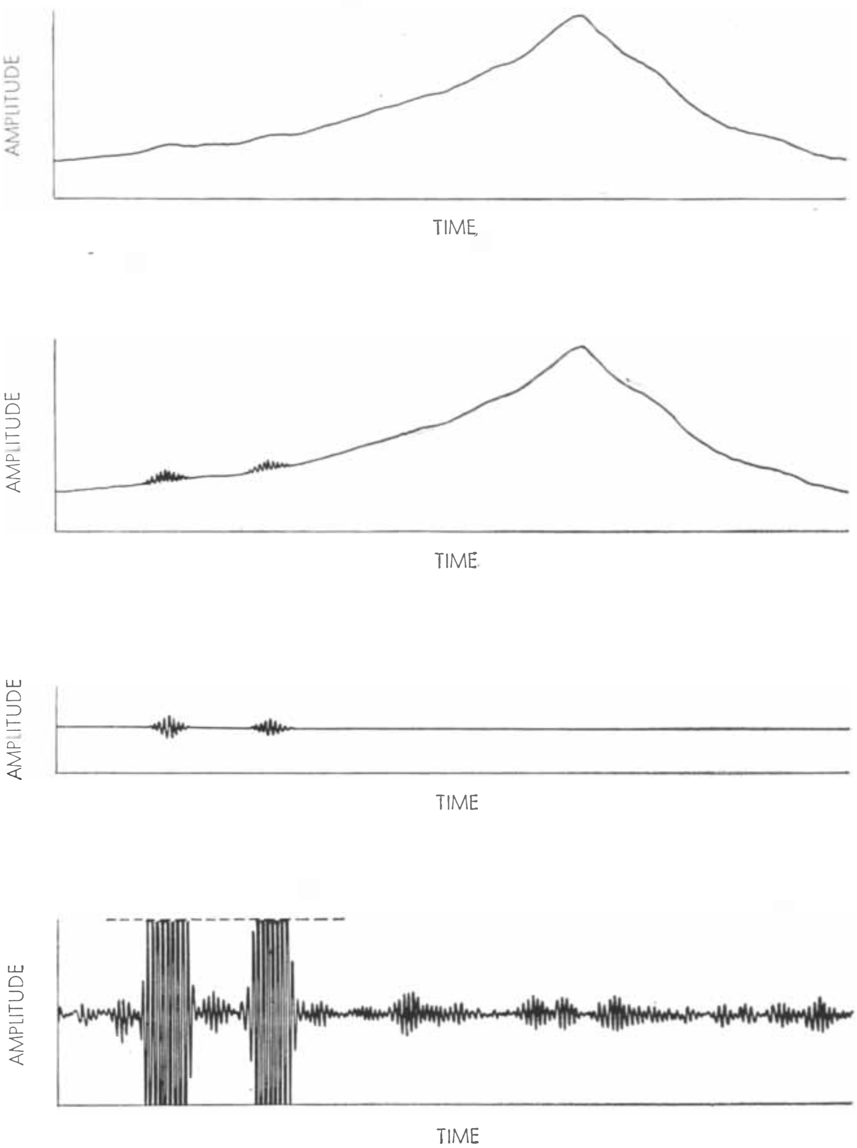
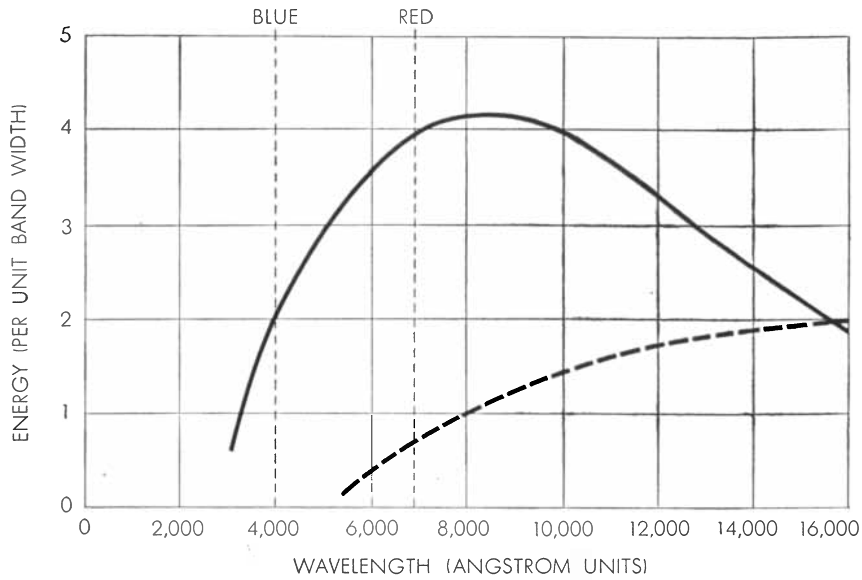


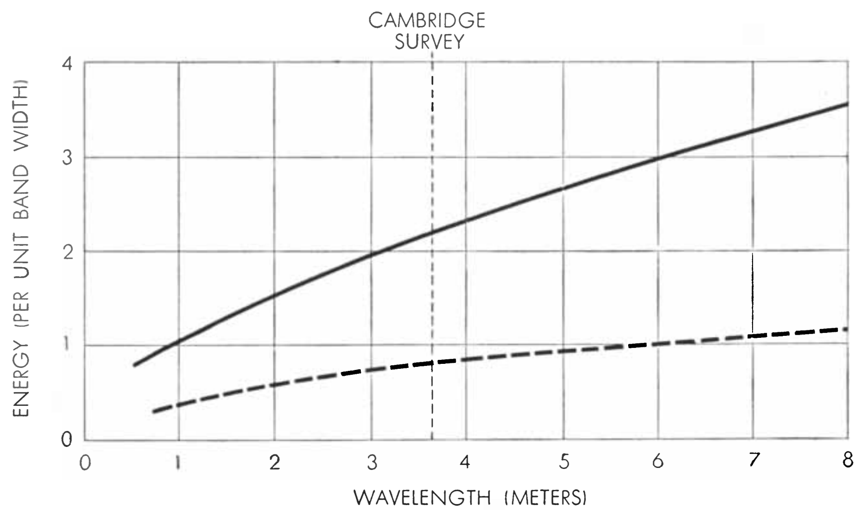
in another way: an analysis to determine whether the density of distribution of the radio stars changes with distance from us. The basis of this analysis is the law that the intensity of a source of radiation (light or radio) decreases as the square of the distance. As a consequence of the law, it is possible to calculate how many stars within a spherical region will have more than a given brightness, if the stars are uniformly distributed through it. For example, if we count a certain number of stars of one brightness, we should find that the number of stars with at least one quarter of that brightness is eight times as great. But the ratio will vary from this if (1) the average density of the sources changes with distance from us, or (2) the average power of the sources changes with distance.

When this method of analysis was applied to the 1,906 radio stars, it was found that there were too many weak sources in relation to the intense ones. This result implied that one or the other of the nonuniform alternatives was true: that is, either the density of sources



AMPLITUDE CURVES produced by various radio telescope systems are diagrammed here. In the curve at the top, recorded by a single antenna, it is difficult to distinguish the radio stars from the smooth variation in amplitude across the Milky Way. The second curve, recorded by an interferometer, registers the existence of two discrete sources, along with the variation in background. In the third curve, the background variation is suppressed and only the discrete sources are recorded; this is achieved by "phase-switching." With higher sensitivity, a phase-switching interferometer will produce the curve at bottom, which shows not only the strong sources but also numerous weak sources, so close together that they overlap.



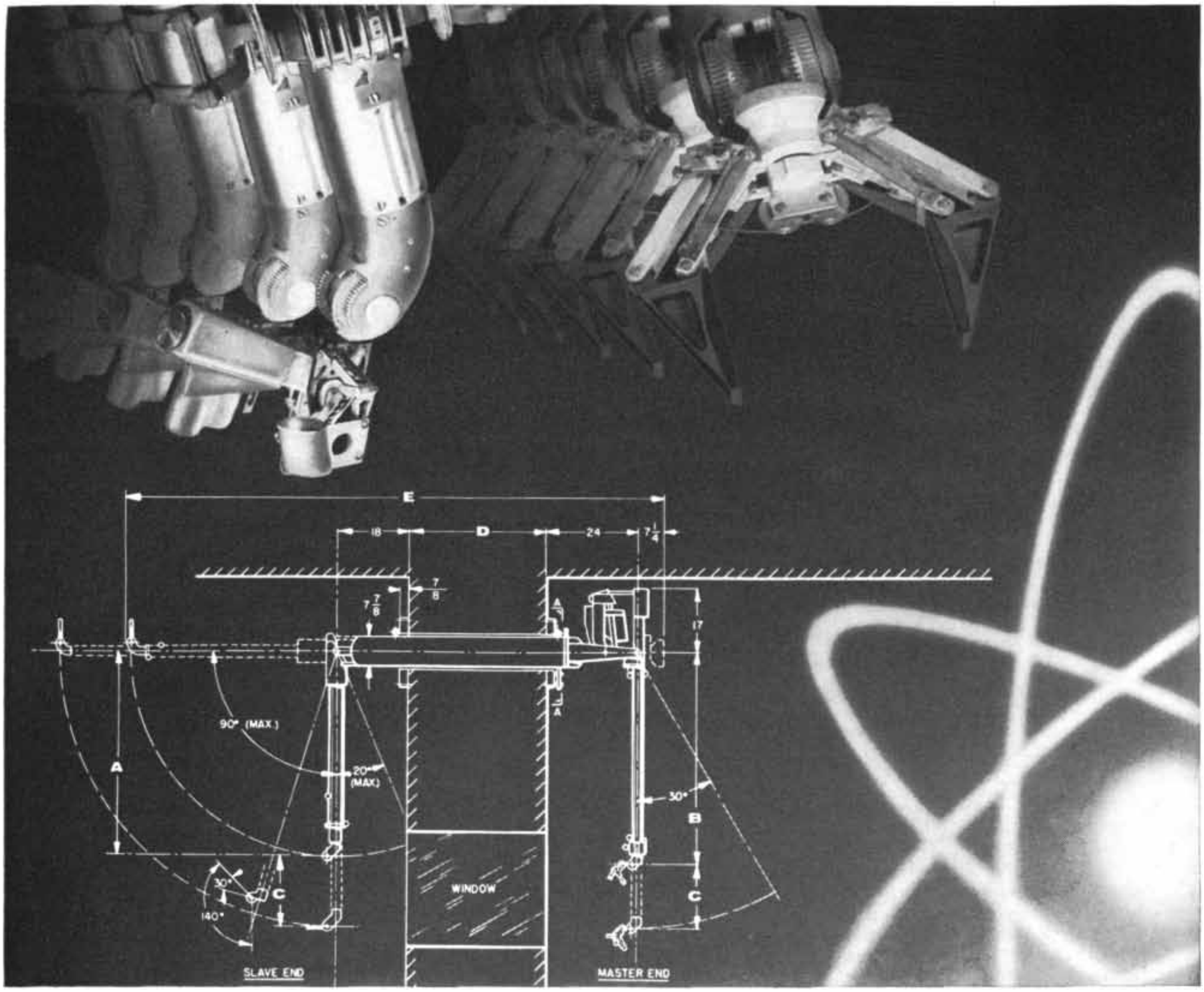


EFFECT OF RED-SHIFT on light waves and radio waves is contrasted in these two charts. The solid curve in chart at top shows the distribution of energy across the optical spectrum, from blue to red, in the light from a nearby star. The broken line in that chart shows how the red-shift of a distant galaxy may cut off reception of light in the blue region to which photographic plates are most sensitive. The chart below similarly shows the distribution of energy in the spectrum of radio waves received from a nearby and a distant source. Though the radio spectrum is shifted, the reduction in the intensity of the radio energy received is slight. The Cambridge radio-source survey was made at a wavelength of 3.7 meters.

or the average power emitted increases with distance. Careful checks of both the data and the interpretation, including an analysis by an independent method, confirmed this conclusion.

Now the result may be interpreted in either of two ways. We may suppose that the radio stars are within the galaxy but we happen to lie in a region where their density is abnormally low, so that the density rises with distance from us. But then it is very difficult to explain why the radio stars are distributed symmetrically over the whole sky, for the supposition of a variation in density implies that these objects are not spread uniformly over the galaxy. Moreover, the aggregate amount of radiation from these radio stars is so large that they could not be a small eddy: they would have to occupy a considerable part of the galaxy.

If, on the other hand, we suppose that most of the radio stars are outside our galaxy, we can see a consistent and reasonable picture. Calculations of the aggregate amount of radiation from the radio stars led our group to conclude that the region containing the detected radio



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3972	55¾	58¾	39	30
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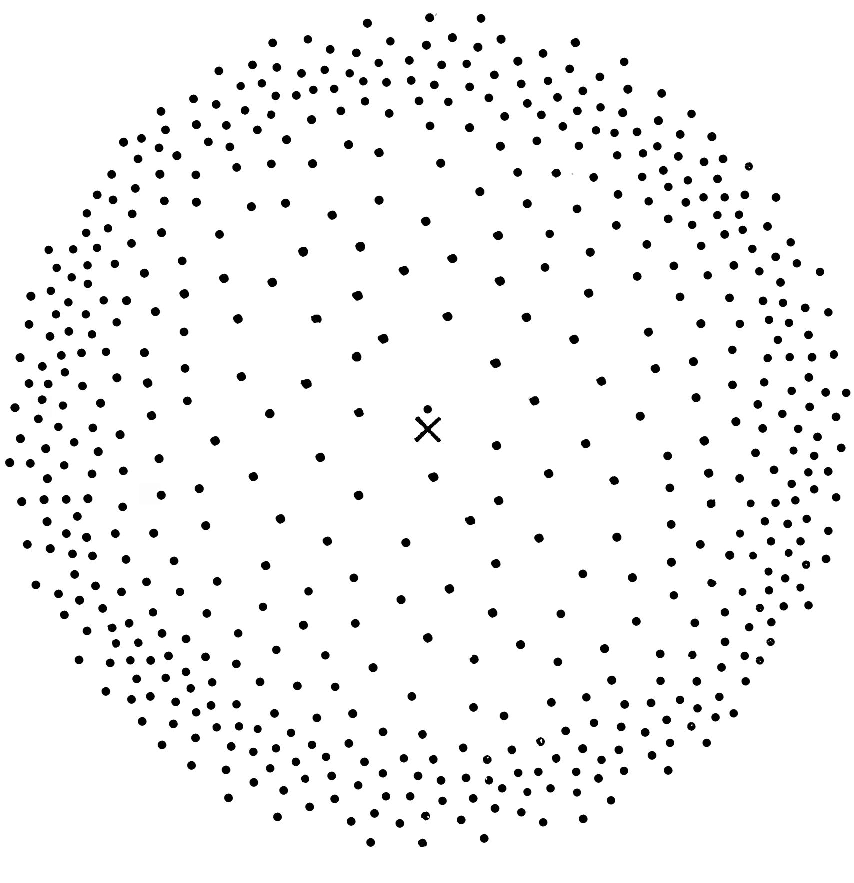
stars must extend out to at least 500 million light-years, and that a large fraction of the stars are extragalactic sources of great power—comparable to that of Cygnus A. The apparent increase in density of the sources with distance may then be accounted for as an effect associated with the large red-shifts of the distant sources. Further, it becomes possible to explain why no visible objects appear at the positions of most of the radio stars: if these stars are colliding galaxies, only a few dozens of them lie within reach of the 200-inch telescope; the rest are beyond the visible range.

The Cambridge conclusion about the distribution of radio stars in space far beyond our galaxy has been questioned by workers in Australia. A survey with the Mills-cross radio telescope has failed to show a marked excess of faint sources such as was found by the Cambridge group. The Australian survey, however, has not yet covered a large area of the sky, and it does indicate that radio stars are not distributed uniformly with distance. At Ohio State University observations with a pencil-beam radio telescope by the radio astronomer John D. Kraus have confirmed the excess of faint sources. The question may be settled conclusively within the near future by completion of the Australian survey and of a new survey, using higher resolving power, which is now under way at Cambridge.

If these surveys verify that the density of radio sources in space does indeed increase with distance, they should help to make possible a decision between the evolutionary and steady-state theories of the universe. If most of the radio stars are in fact collisions between galaxies, such encounters apparently are considerably more frequent in distant space (perhaps billions of light-years away) than near us. This disparity would argue against the steady-state hypothesis that the density of matter in space remains constant. The radio signals we are now receiving from distant collisions started on their way billions of years ago. If the evolutionary theory is correct, the universe should have been denser then, and encounters between galaxies more likely. Thus our present conclusions from the radio work at Cambridge support the evolutionary view.



DISTRIBUTION OF RADIO SOURCES in space, as deduced by the group at Cambridge, is diagrammed. The distribution of sources is symmetrical, but from the number of sources of different intensity it appears that they must increase in density with distance.

Research and Development Engineers

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COSMOLOGY AND SCIENCE

A historical epilogue to this issue. The argument: In earlier times the search for knowledge was handicapped by presupposed cosmological principles. Modern cosmologists must guard against the same tendency

by Herbert Dingle

Since the advent of Einstein's general theory of relativity the subject of cosmology has assumed a much more prominent position in the world of physical science than it had occupied in recent times. It is natural to assume, as many do, that this is a result of the development of our knowledge and our means of observation—our ability to examine very distant regions of space with powerful telescopes and the growing ability of mathematicians to make trustworthy deductions from the seen to the unseen. In the earlier stages of science, so it is thought, men had to confine their consideration to the parts of the universe that were within reach, and so were concerned not with the universe as a whole but only with the local and the partial.

Nothing could be further from the truth. The fact is that during by far the greater part of its history astronomy has been nothing but cosmology. Until the 17th century the one aim of the astronomer (apart, of course, from such practical applications as navigation, time measurement, astrology and so on) was to describe the working of the whole system of the universe as he saw it. But early in the 17th century two independent things happened at about the same time: the collapse of Aristotelian cosmology and the birth of the telescope. Thenceforward observational astronomy advanced step by step and cosmology lay dead. Before very long a promise of a resurrection of cosmology in a new form came with the conception of universal law introduced by Newton's great work. But universal law told you nothing about the actual structure of the universe. It told you how any possible universe would operate, and therefore could not distinguish between one possible universe and another.

The distinctive feature of our time, underlying the present revival of cosmology, is that our improved knowledge of universal law, together with our extended knowledge of the actual content of the celestial spaces and the behavior of the bodies in them, have reached a point at which they can be brought together into a single scheme. The freedom allowed by the former can be so limited by the latter as to give us a first approximation to an understanding of the whole universe which is capable of satisfying both our reason and our observation of the heavens.

It is the purpose of this article to compare the points of view of the ancient and the modern cosmologies and to indicate how the one gave place to the other. This is not merely of historical interest. It can serve a very practical purpose in enabling us to avoid the errors that brought the work of our predecessors to grief.

To appreciate what kind of thinking created the cosmology of the Greek pioneers, beginning, as it inevitably had to in early times, from the natural assumption that the earth was the center of the universe [*see article on page 72*], we must understand a fundamental characteristic of Greek thought—which is at variance with the scientific outlook. They presupposed certain *principles*, which were assumed to be inviolable and were accepted without question. If appearances seemed to contradict them, then the appearances were deceptive. These principles must not be confused with what we call rational necessities, such as, for instance, the axiom that things which are equal to the same thing are equal to each other. This cannot conceivably be violated within the framework of ordinary geometry, because it is inherent in the definition of equality, and not an assertion about the characteristics of things. But the ancient Greek principles (of which those that persisted longest were due mainly to Aristotle) were assertions about the characteristics of things. For example, they asserted that the only activity possible to heavenly bodies was perfectly uniform and circular movement, and that apart from such eternal circulations no change of any kind could take place in the heavens. If a sunspot or some other change appeared to occur on the face of the sun, it could be taken only as an appearance and must be due to something in the earth's atmosphere passing between the observer and the sun. And similarly, since the planets appeared not to move in circles at uniform speed, the apparently erratic movements of each planet must be the resultant of a set of circular movements.

The aim of Greek cosmology was to arrive at the complex system of interlocking spheres in motion that made up the universe. The individual heavenly bodies themselves were merely straws from which to determine how the wind blew: the wind was the important thing. Geometers of genius such as the Greeks produced were able to represent the observed movements of the planets with an accuracy equal to that of their imperfect observations at any given time, but as time went on the discrepancies

STAR CATALOGUE was compiled by Nicolaus Copernicus. Its first page is shown at the right. On it the stars are identified by the part of a constellation they occupy. Their positions and magnitudes are given at the right side of the page. The reproduction was made from the original catalogue in the Burndy Library in Norwalk, Conn.

SIGNORVM STELLARVMQVE DESCRIPTIO CANONICA, ET PRIMO quæ ſunt Septentrionalis plagæ.

Formæ ſtellarum	Lõgitudinis partes		Latitudinis partes		magnitudo
VRSAE MINORIS SIVE CYNOSVRAE.					
In extremo caudæ.	53	1/2	66	0	3
Sequens in cauda.	55	1/2 1/3	70	0	4
In eductione caudæ.	69	1/3	74	0	4
In latere q̃drãguli p̃cedẽte auſtralior	83	0	75	1/3	4
Eiuſdem lateris Borea.	87	0	77	1/2 1/6	4
Earũ quæ in latere ſequẽte auſtralior	100	1/2	72	1/2 1/6	2
Eiuſdem lateris Borea.	109	1/2	74	1/2 1/3	2
Stellæ 7. quarum ſecūdæ magnitudinis 2. tertiæ 1. quartæ 4.					
Et q̃ circa Cynoſurã informis in latere ſequẽte ad rectã lineã maxĩe auſt.	103	1/3	71	1/6	4

VRSÆ MAIORIS QVAM ELICEN VOCANT.

Quæ in roſtro.	78	1/2 1/6	39	1/2 1/3	4
In binis oculis præcedens.	79	1/6	43	0	5
Sequens hanc.	79	1/2 1/6	43	0	5
In fronte duarum præcedens.	79	1/2	47	1/6	5
Sequens in fronte.	81	0	47	0	5
Quæ in dextra auricula præcedente.	81	1/2	50	1/2	5
Duarum in collo antecedens.	85	1/2 1/3	43	1/2 1/3	4
Sequens.	92	1/2 1/3	44	1/3	4
In pectore duarum Borea.	94	1/3	44	0	4
Auſtralior.	93	1/3	42	0	4
In genu ſiniſtro anteriori.	89	0	35	0	3
Duarũ in pede ſiniſtro priori borea.	89	1/2 1/3	29	0	3
Quæ magis ad Auſtrum.	88	1/2 1/6	28	1/2	3
In genu dextro priori.	89	0	36	0	4
Quæ ſub ipſo genu.	101	1/6	33	1/2	4
Quæ in humero.	104	0	49	0	2
Quæ in ilibus.	105	1/2	44	1/2	2
Quæ in eductione caudæ.	116	1/2	51	0	3
In ſiniſtro crure poſteriore.	117	1/3	46	1/2	2
Duarũ p̃cedẽs in pede ſiniſtro poſter.	106	0	29	1/2	3
Sequens hanc.	107	1/2	28	1/4	3

Quæ

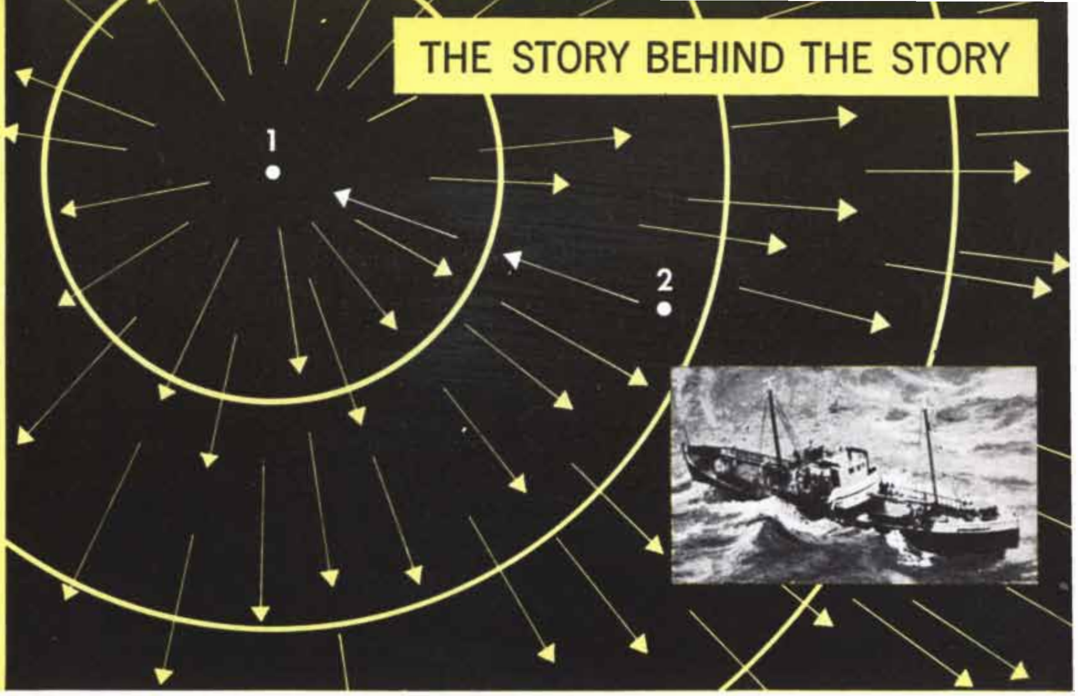
PRE-COPERNICAN UNIVERSE appears in Peter Apian's *Cosmographia* (1539). The earth is in the center. The sun, moon, planets and stars occupy a series of concentric spheres.

between the geometrical requirements and the observed positions of planets increased, and so more spheres were introduced to annul them. This went on throughout the Middle Ages, until by the 16th century more than 80 spheres were necessary to account for the observed movements, and even that number did it very imperfectly.

Now if astronomy had stood by itself as an isolated study, this complexity might well have stimulated efforts at reform earlier than it did. But the other spheres of study were so thoroughly interwoven with astronomy that it was impossible to reform astronomy without also reforming physics, chemistry, physiology, psychology and theology (to use modern terms for subjects not so clearly differentiated from one another then as now). It could not be done without upsetting the whole scheme of belief. The universe was then a universe in a much more literal sense than it has ever been since. A diagram taken from a textbook of the time makes this very evident: Heaven, where God dwelt with the elect, had a location which was as much a part of the physical universe as the earth and the cosmic spheres. Each of the planets had its particular influence on human temperament: thus we get our adjectives mercurial, martial, jovial, saturnine. A human calamity was a *dis-aster*—against the stars. An unnatural action was *ex-orbitant*—out of orbit. Terrestrial bodies were compounded of four elements—earth, water, air and fire—each of which tended to seek "its own place," and the heavenly bodies were composed of a perfect, unchangeable fifth element—a "quintessence"—which had no parallel on the changeable earth. And so on.

Into this closely interwoven scheme it was clearly very hazardous to introduce any modification of a single part, because of its possible unforeseen effect on the whole. Nevertheless, by the 16th century the cosmic machinery of spheres had become so unwieldy that Copernicus, a man dominated by the mathematician's passion for simple generalization, ventured to make what seemed to him the very slight change of transferring the center of the universe from the

THE PRINCIPLE OF ALL RADAR is illustrated at right. Radio waves, indicated by arrows, bombard any objects in their path and bounce back, presenting the object on the scope and indicating its range and bearing. With his Sperry Marine Radar, for example, the master of a ship (1) sees on the scope above the image of a ship in distress 9 miles away (2) and in total darkness.



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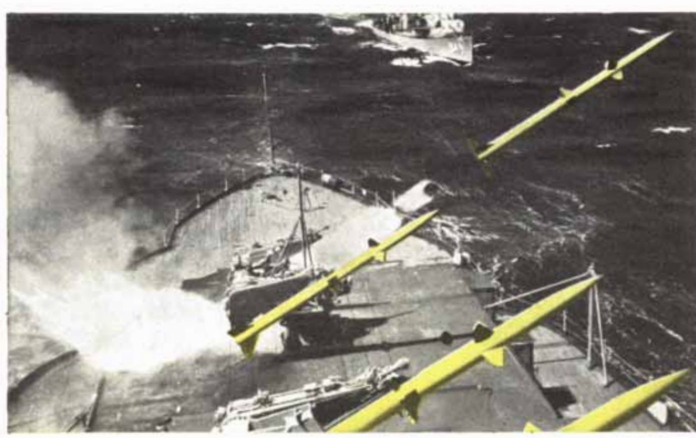
GUNFIRE CONTROL SYSTEMS owe much of their precision to radar. For example, an important one, this Mortar Locator developed by Sperry for the Army, uses radar to track an enemy shell, then plots its point of origin to locate an enemy battery.



MISSILES FOLLOW COURSES established by radar whether launched from air, land or shipboard, as in the case of these Navy Terriers, radar-guided by Sperry.

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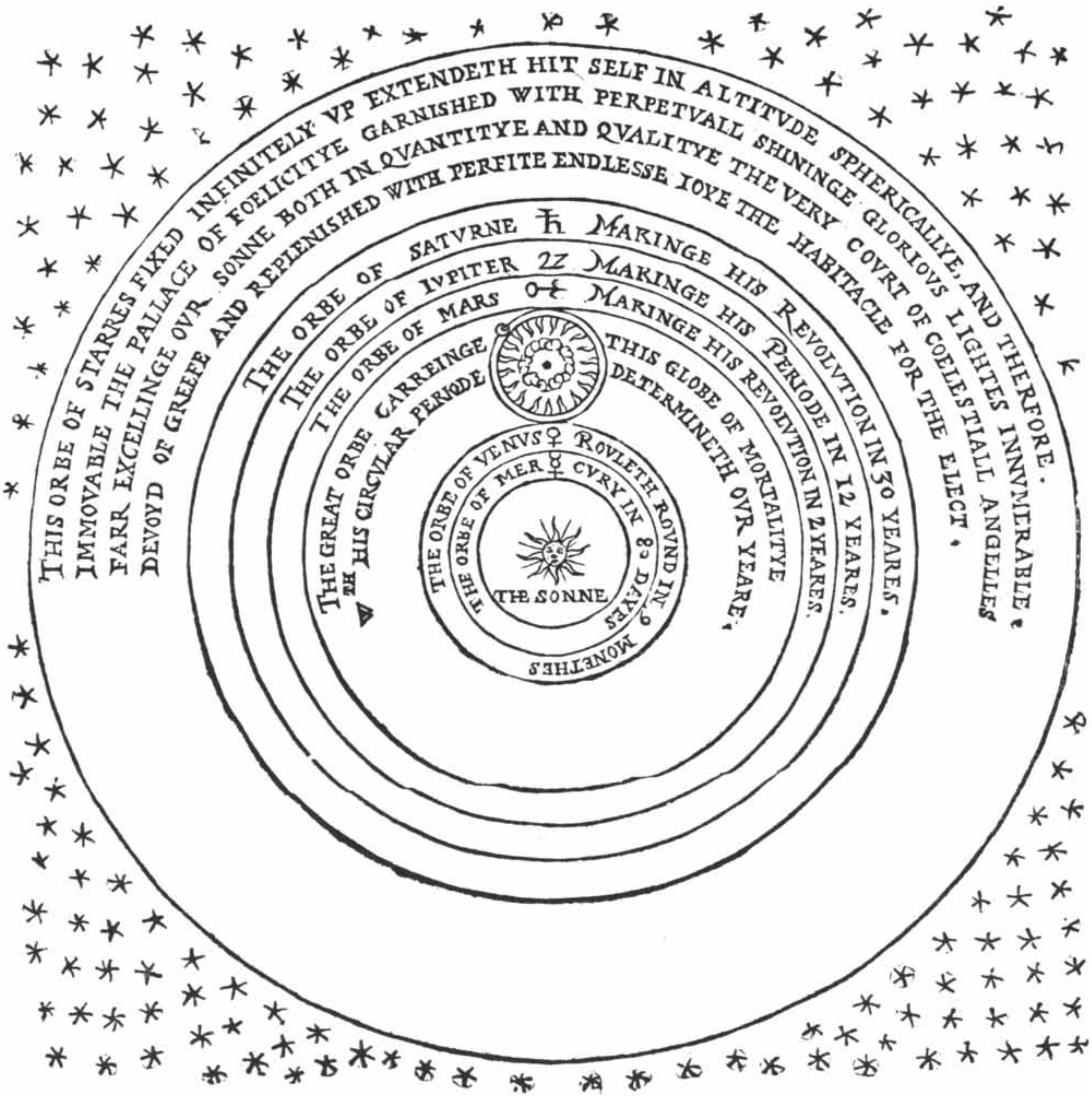
earth to the sun. By this device he was able to reduce the number of cosmic spheres by more than half.

He made no other change, nor did he realize that any other was necessary. He clung as firmly as the most orthodox medieval philosopher to the machinery of spheres and to the Aristotelian principles of perfect celestial substances and uniform circular motions. He thought he could simplify without destroying. But in fact this one small change shattered the whole medieval universe. By the time of Galileo, some three quarters of a century later, it had become clear that there was no need for any spheres at all, and the simple change that we would now describe as no more than choosing a different origin of coordinates had generated a conflict of world-views such as the world had never before known. The cosmic conception of more than 2,000 years' standing had in fact received its deathblow.

Tycho Brahe and Johannes Kepler completed the job—the former by observing change in the supposedly immutable sphere of the stars and the latter by showing that the motion of a planet could be represented by a simple ellipse. Galileo and the invention of the telescope gave birth to a new astronomy—and to a new philosophy of science. Soon afterward the work of Newton opened up the possibility of a kind of cosmology not previously conceived.

The contrast between the old and the new attitude can be fittingly introduced by the words of Newton himself: "To tell us that every Species of Things is endow'd with an occult specifick Quality by which it acts and produces manifest



COPERNICAN UNIVERSE was depicted by Thomas Digges in 1576. The sun is in the center, and the moon travels around the earth. Digges added another feature, though he was not aware of its importance. The stars are not in a sphere, but extend to infinity.

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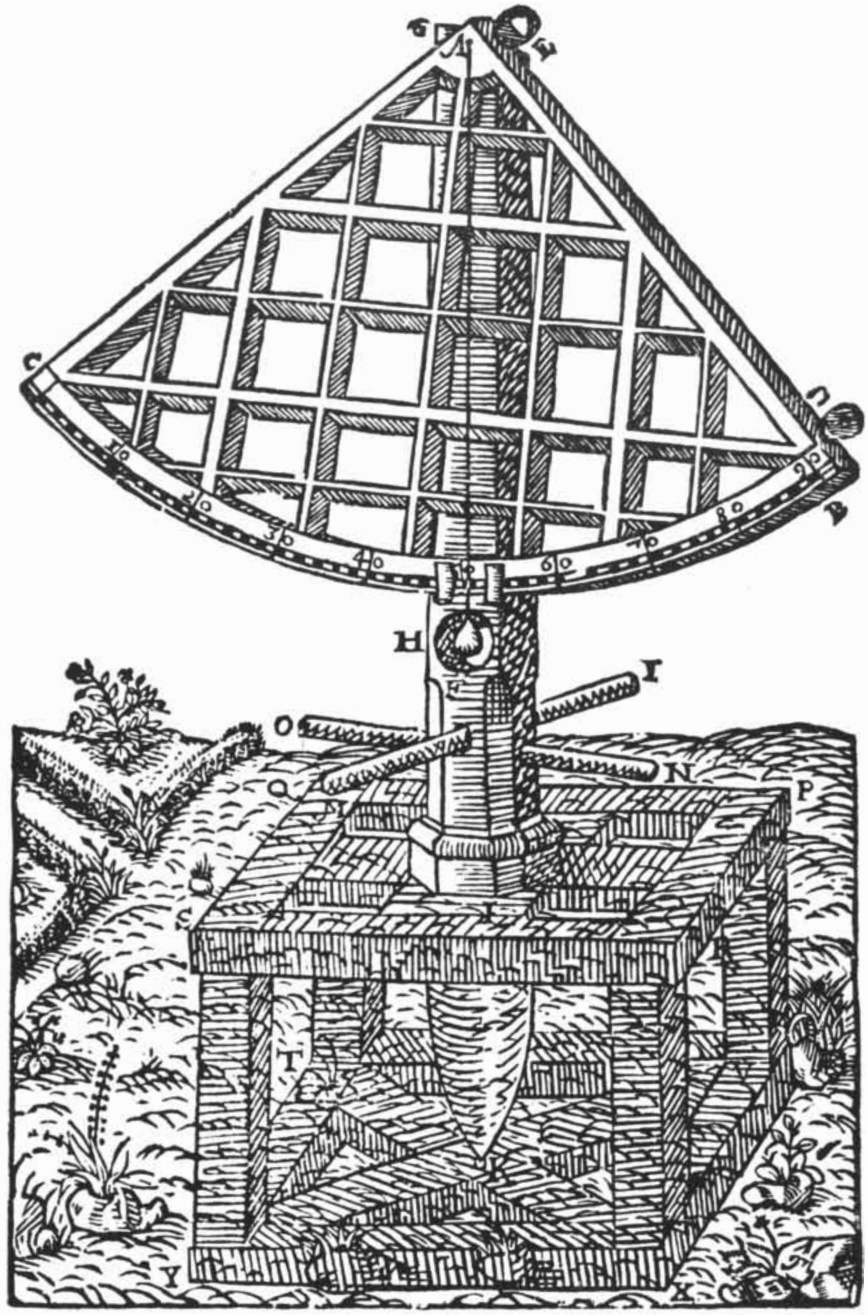


PRE-GALILEAN ASTRONOMY relied on such nontelescopic instruments as this quadrant reproduced from Tycho Brahe's *Astronomiae Instauratae Mechanica*, published in 1598.

Effects, is to tell us nothing: But to derive two or three general Principles of Motion from Phaenomena, and afterwards to tell us how the Properties and Actions of all corporeal Things follow from those manifest Principles, would be a very great step in Philosophy, though the Causes of those Principles were not yet discover'd." What Newton referred to as "occult qualities" were neatly illustrated by the notions of "gravity" and "levity" in the old cosmology: this body fell downward because it was subject to gravity, that body rose upward because it was subject to levity. The principles were conceived merely because they seemed fitting. Neither gravity nor levity had any characteristics by which it could be identified except the movement it was supposed to explain. They were mere names for the phenomena observed, masquerading as causes of those phenomena. The whole scheme of cosmological principles resolved itself into a series of tautologies. It was logically impeccable but scientifically barren—completely unproductive of knowledge.

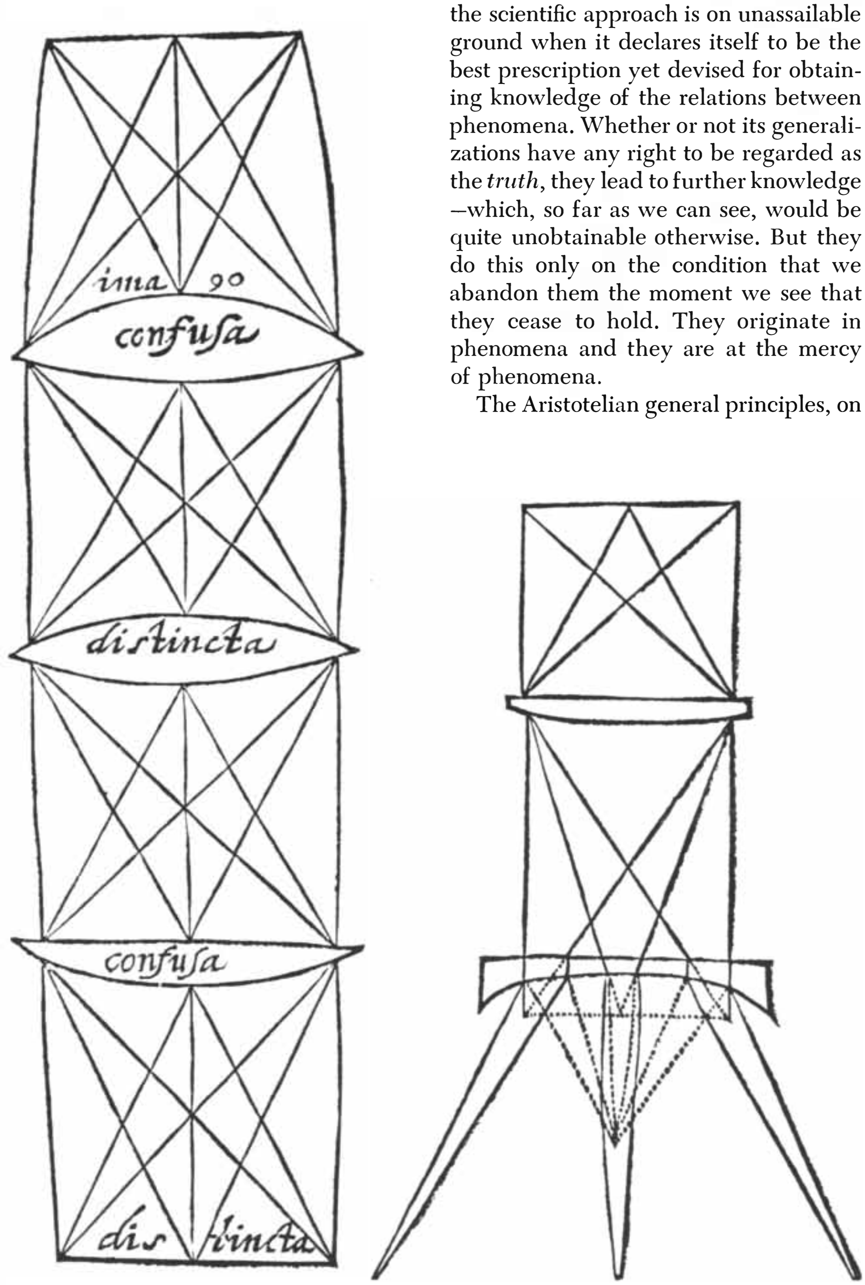
The Galilean-Newtonian philosophy, on the contrary, brought knowledge in

apparently boundless measure but was logically outrageous. From a few phenomena, or experiments, it proposed to derive principles to be applied universally. Some bodies attract one another; this is a body; therefore it attracts every other body in the universe. No more patently invalid syllogism could be imagined; it was an error in Aristotelian logic of which even the youngest scholastic child could hardly have been capable.

But it worked. And not only so, but similar generalizations later in other fields were found to work, and they go on working. We have never known heat to flow by itself from a colder to a hotter body, and we take it that it never has nor ever will anywhere in space. The brightness of a lamp in our laboratory falls off as the square of the distance as we walk away from it; hence we infer what the brightness of a distant galaxy must be. That is science. Its assertions about the universe are unlimited generalizations from a few momentary observations at a point in space.

From a purely logical point of view scientific cosmology would appear to have no justification, to be a gigantic impertinence. It is saved from this by a frank recognition by scientists of what it is and what its limitations are. The work of three centuries has shown that the scientific approach is on unassailable ground when it declares itself to be the best prescription yet devised for obtaining knowledge of the relations between phenomena. Whether or not its generalizations have any right to be regarded as the *truth*, they lead to further knowledge—which, so far as we can see, would be quite unobtainable otherwise. But they do this only on the condition that we abandon them the moment we see that they cease to hold. They originate in phenomena and they are at the mercy of phenomena.

The Aristotelian general principles, on



OPTICAL SYSTEM OF THE FIRST TELESCOPE, made by Hans Lippershey and Zacharias Jansen, is reproduced from Peter Borelli's *De Vero Telescopie Inventore*, published in 1655.

the other hand, were conceived *a priori*, independently of phenomena, and phenomena were distorted at liberty so as to exemplify them. The problem was to "save the phenomena." The basic principles themselves could not be threatened; it was the phenomena that stood in need of salvation.

Contrast with this the point of view that caused modern cosmologists to discard the Newtonian cosmology for the totally different Einsteinian cosmology—on the basis of the tiniest of differences between theory and observation. At the behest of measurements so fine that only in this age have they become possible at all, we have thrown over the whole picture of a universe in which bodies are pushed along by a conspiracy of alien forces and have substituted in its place a system of free bodies moving along the paths which, so to speak, offer them the easiest course. We are prepared to revise our principles to fit observation because man's whole experience in seeking knowledge has taught us that nature is far more likely to follow in the large the laws we observe her to follow in the small than to behave according to our intuitive ideas of decorum.

In most branches of science this philosophy has been adhered to unswervingly. The activities of experimental physicists, chemists and biologists are for the most part beyond reproach: we learn where we can, generalize from observation and extend the generalizations until they are found to fail, when we replace them by wider ones. But in cosmology this restraint does not always hold. Some cosmologists have returned to the discredited practice of inventing arbitrary general principles, with no justification except that they seem "right," and fitting phenomena to the requirements of the principles. We have been presented, for example, with a "cosmological principle" which demands that, on the large scale though not on the small (where it might readily be tested), every part of the universe must be exactly the same as any other. This has been extended to a "perfect cosmological principle" which says that the uniformity of the universe must *always* hold true, its general appearance being eternally the same. If the scientific procedure of generalizing from observation leads to anything inconsistent with this, it must be wrong. The principles are of necessity inviolable, and all phenomena must be interpreted in accordance with them. There could scarcely be a more complete return to a kind of philosophy

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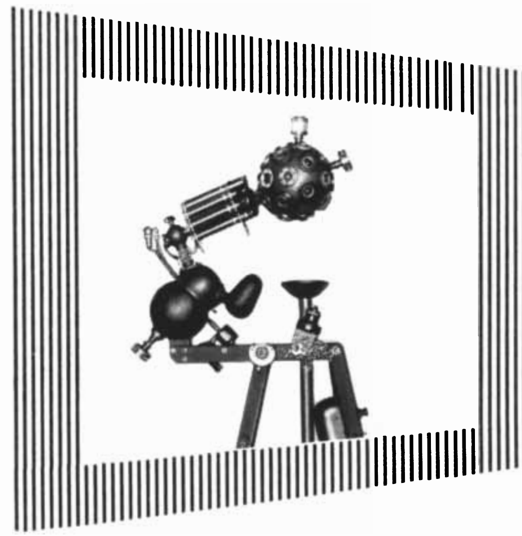

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Anyone acquainted with the history of cosmology can recognize the cosmological principle and the perfect cosmological principle as having precisely the same nature as perfectly circular orbits and immutable heavens. Indeed, the perfect cosmological principle is largely identical with the Aristotelian principle of unchanging celestial regions.

We should not confuse the cosmological principle with the valid scientific procedure of assuming, for purposes of investigation, that the rough approximation to homogeneity which we observe in space as far as we can see it extends to the whole of space. That is the normal type of scientific generalization, and it is usually made in relativistic cosmology in order to restrict the almost limitless field of investigation that would be open if all possibilities were taken into account. We calculate what it demands of the yet unexamined regions and hold ourselves ready to discard it if they should fail to meet those demands. The cosmological principle, however, alters observed facts to make them accord with its requirements. Observation appears to show that the density of matter in the universe is continually decreasing. This cannot be so, says the principle: unobservable matter must be in process of creation out of nothing in just the right amount to keep the density constant. We have no evidence of such matter. The only reason for supposing its creation is that otherwise the perfect cosmological principle would be violated, and the only reason for supposing that this cannot happen is that a few mathematicians would not like it. It seems an insufficient reason.

Such atavisms notwithstanding, in the main the cosmologies of our day are founded upon the scientific procedure: generalizing from what we know and then testing our generalizations by observations on a larger scale. We have reached a point at which the theoretical generalizations can be compared with a sufficiently wide field of observation to entitle us to think that we can truly say something about the universe as a whole—not only about its laws of operation but also about the particular arrangement of bodies that exhibit those laws. Doubtless our present views will be modified and enlarged in the future, but they do embrace a far wider range of knowledge than has ever been possible before. What that knowledge comes to in the year 1956 A.D. is well summarized in the series of articles presented here.

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RESEARCH CENTER

BOOKS

The record of the Geneva conference on the peaceful uses of atomic energy

by E. U. Condon

Peaceful Uses of Atomic Energy. United Nations (16 volumes; $6.50 to $10 each).

This truly monumental work is a complete record of the conference on peaceful uses of atomic energy which was held under the auspices of the United Nations in Geneva in August, 1955. Its 16 volumes cover the discussions of the role of nuclear power in the world's energy requirements, the physics, chemistry and technology of reactors and their materials, biological effects of radiation, the uses of radioisotopes, and the legal, administrative and safety aspects of any large-scale use of nuclear energy.

Clear forecasts of the rapidly expanding energy needs of the world were presented. Coal, oil and hydroelectric power reserves are simply inadequate to meet future demands in view of the modernization and industrialization of Asia and Africa. Therefore nuclear power must be used: whatever the cost, eventually the price structure for power will adjust to it. There was an exchange of a great deal of specific scientific and technological information about detailed problems and proposed solutions in the now-developing power industry based on uranium and thorium fission. The conference provided an excellent forum for broadcast of information on applications of radioactive isotopes to every phase of physics, chemistry, metallurgy, biology, medicine, agriculture and other useful arts.

Besides these gains, a notable advance for science on the socio-political front was achieved. This was the first time since the war that the governments of the U. S. and the U.S.S.R. had permitted their scientists to sit down face to face and carry on normal scientific discussions. In this respect it was a welcome indication of a reversal of the policies of scientific isolationism that have dominated the governmental actions of both countries during the past decade.

In his remarks opening the conference Dag Hammarskjold, secretary-general of the UN, said:

"We have a long road to traverse before nations can hope to eliminate the threat of atomic destruction. But we cannot hope to travel at all unless we begin to take down the barriers to understanding and friendship and begin to work together in growing confidence. The exchange of scientific and technical data which will take place here is only a first step, but it is an important and indispensable first step. By the willing help that the participating governments have given in the preparations for this conference and by the character and quality of the contributions that they are making to its harvest, there is every hope that this first step will prove even more valuable than had been anticipated."

Fortunately in the year that has elapsed since this first step was taken there have been signs of further progress in removing the barriers to international and scientific freedom.

Many curtains still exist, of course. There are large areas of research unnecessarily shrouded in secrecy. A notable omission in the Geneva conference was the absence of any discussion of, or even reference to, research on control of thermonuclear energy at the technical sessions of the conference. To my mind the controlled use of fusion energy for power is by all odds the most important technical problem today in the peaceful applications of atomic energy. The long-run economic importance of finding a solution to this problem lies in the fact that uranium and thorium probably will suffice to satisfy world power requirements for only a century or so. But the deuterium content of the oceans constitutes an energy resource which could meet the world's needs for a good many centuries.

Yet the only mention of this subject at Geneva was a few brief words by Homi J. Bhabha of India in his opening address as president of the conference:

"It is well known that atomic energy can be obtained by a fusion process as in the H-bomb, and there is no basic scientific knowledge in our possession today to show that it is impossible for us to obtain this energy from the fusion process in a controlled manner. The technical problems are formidable, but one should remember that it is not yet 15 years since atomic energy was released in an atomic pile for the first time by Fermi. I venture to predict that a method will be found for liberating fusion energy in a controlled manner within the next two decades. When that happens, the energy problems of the world will truly have been solved forever, for the fuel will be as plentiful as the heavy hydrogen in the oceans."

Much of the material in the 16-volume proceedings of the conference, valuable and important as it is, consists of specific detail and presupposes a thorough knowledge of the scientific background of what is being reported. It is therefore not suited for general readers. But Volume 16, which contains the speeches at the opening and closing sessions and the 10 evening lectures by distinguished scientists, has broad interest.

Two of the evening lectures were concerned with high-energy accelerators. Ernest O. Lawrence of the University of California reviewed concisely the progress of thinking on how to overcome difficulties imposed by the theory of relativity on the design of machines for getting nuclear particles accelerated first to the range of hundreds of millions of electron volts, then to billions of electron volts, and now up to tens of billions of electron volts. In the old days of prewar cyclotrons, the increase of particle mass with velocity entailed a fairly small correction of the classical theory of mechanics. But with proton energies of hundreds of millions or billions of electron volts, relativistic considerations dominate the entire problem. At one Bev a proton has double its normal mass; at nine Bev, 10 times.

Lawrence placed emphasis on the importance of getting large currents of particles as well as high energy. He gave specific details of the new A-48 accelerator being built at Berkeley by a group headed by Luis W. Alvarez, and mentioned the highly original beam-focusing ideas of Keith R. Symon of the University of Wisconsin. These are being incorporated into the design of a new super-accelerator planned for construction by physicists of a cooperative group of Midwestern universities. The machines are becoming too large for the scientific and technical resources of any single university.

Vladimir I. Veksler of the U.S.S.R. gave a similar summary of advances in high-energy accelerator work in Russia. His major news was the announcement of the Soviet Union's construction of a 10-Bev proton accelerator, on the same general principle as the Brookhaven Cosmotron and the Berkeley Bevatron in the U. S.

Veksler pointed out that present ideas for accelerator designs could hardly go beyond 100 Bev, and he added:

"Insofar as the potentialities of the usual proved methods appear to be exhausted, new ones will have to be looked for. For instance, we could make great progress if we could devise means of creating ultrapowerful magnetic fields, or of considerably increasing the maximum voltages of the electric field in linear accelerators. It is true that even ultrapowerful magnetic fields will not lead to a substantial increase in the upper limit of the energy of electrons, as this limit is in practice determined by radiation. . . . Therefore my personal opinion is that we must seek completely new approaches. There are several possibilities, I think. But it would be premature to discuss the problem here, as it still needs very thorough examination. I do not doubt, however, that experimental physics will succeed in solving this problem, too, and that we shall learn how to create artificially particles with enormous energies of the order of 10^{12} and 10^{13} electron volts."

Leafing through these admirable volumes, no one can fail to feel that these are exciting times in which to be a physicist. Truly it is to be hoped that international cooperation of scientists will again flourish in the future as it did in the past and that another such conference will soon take place.

Short Reviews

KIBBUTZ: VENTURE IN UTOPIA, by Melford E. Spiro. Harvard University Press ($4.50). The Hebrew word *kibbutz,* which means literally a gathering or company, is used in Israel to denote a collective settlement. Three types of cooperative agricultural villages have sprung up in Israel, with a total population of 76,000 members; among these, the kibbutz represents the sharpest departure from individualistic farming and living. With minor exceptions all property is collectively owned, all work collectively organized, and living arrangements, including the rearing of children, are to a great degree collective. The author of this book, on the staff of the University of Connecticut, and his wife lived for almost a year in an uncompromisingly socialistic kibbutz to which they have given the name Kiryat Yedidim, preserving its anonymity. The Spiros are anthropologists who have had experience conducting field work among the people of Ifaluk, an atoll in the central Caroline Islands. Their Israel project was a continuation of a study, started in Micronesia, of "social cooperation and aggression." Kiryat Yedidim was founded 35 years ago by a small group of young Polish Jews. They were boys and girls 18 and 19 years of age, middle class, urban-reared and of idealistic and intellectual inclination. They departed their native country partly to escape anti-Semitism, partly in rebellion against parental authority, seeking mainly to achieve a "normal" existence and a fulfillment of the values of a primitivistic, back-to-nature youth movement to whose social, economic and moral principles they were dedicated. Over the years they succeeded, despite severe adversities and hardships, in building a vigorous and successful farming community—self-supporting, self-governing, robustly independent. The founding principles have to a considerable extent been maintained. The members are opposed to all formal religious creeds. Their economy is communist. Their sovereignty resides in the town meeting, which by popular vote promulgates and enforces the rules of living and laboring in the village. They have their own dairy, carpentry and tool shops; they maintain trucks, tractors and the most modern farming equipment; they have built homes, schools, a hospital, an assembly hall; they have no police, judges or courts, having found no need for such appurtenances of polity; they eat in communal dining rooms served by a communal kitchen; their children live and are raised and educated apart from them in communal nurseries, dormitories and schools. Kibbutz living reflects the ascetic and the "anti-bourgeois" philosophy of the original youth movement. The members are opposed to premarital sexual relations, smoking, drinking, fancy clothes and "fast" living. Mar-

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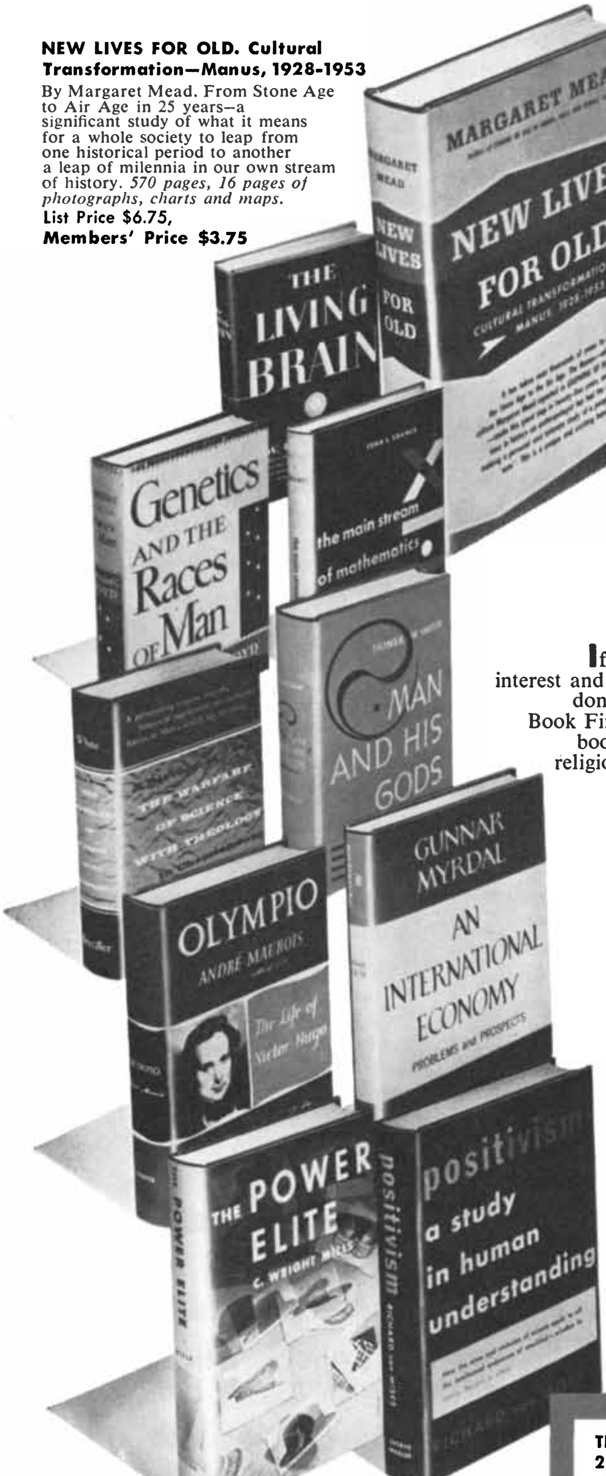

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riage does not exist as an institution; a man and a woman simply become a "pair," and if they no longer wish to live together, they separate. Nevertheless "divorces" are infrequent and the family ties are as strongly knit, especially where there are children, as in more conventional communities. There is an exaltation of physical labor; thus, while all members are equal, those who do the hardest work in the fields are most admired. At the same time physical labor detached from intellectual and artistic values is regarded as "boorish and stultifying," so that the ideal is the person "who combines in a harmonious whole an attachment to the soil, a joy in work and an appreciation for, if not creativity in, art, science and literature." Freud and Marx, especially the latter, are looked up to as the prophets of the kibbutz faith; the sacred writings are Marx, as interpreted by Lenin and as reinterpreted by the Soviet Union, which, according to Spiro, occupies in the kibbutz belief system a position "combining that of the Vatican and of heaven." That a fiercely independent, thoroughly democratic people admires a despotic state, that a Jewish kibbutz venerates a government bitterly hostile to Zionism and Israel—these are among the paradoxes on which this paradoxical community seems to thrive. But not everything is rosy at Kiryat Yedidim. There is, Spiro concludes, a crisis in the kibbutz. Tensions within the social structure are increasing. The sense of social well-being is deteriorating. The older men and women are showing signs of fatigue; pressures are mounting for more privacy and more private property. There is less ardor for taking on communal responsibility and there are more resignations. The older women especially are beginning to chafe. They feel that despite their theoretical equality with men they have never really cast off the yoke of domestic chores—merely exchanging family housekeeping for housekeeping for an entire kibbutz. The women miss the full joys of motherhood. Spiro's book enables readers to see and understand and sympathize with the problems of this complex and gallant society. His study is of social and scientific importance.

AUTOMATION, FRIEND OR FOE?, by R. H. Macmillan. Cambridge University Press ($1.95). Automation has already made itself felt technologically and economically; no one, however, has made clear how we are to prepare ourselves either for the crises or the benefits which this "second industrial revolution" is likely to bring about. Macmillan's little book is a modest contribution to broader understanding. He sketches the history of control devices, the gradual evolution of automatic fabricating processes, the problems of control system design, the economics of automation, the operation of computers. A final chapter considers future prospects. The author is an engineer on the staff at the University of Cambridge and has lectured at the Massachusetts Institute of Technology and other U. S. universities on automatic control. The best feature of his essay is his illustration of the uses of automation in manufacturing, but his attempts to simplify the workings of machines and to explain feedback, nonlinearity, multiple loops, instability and other topics of the trade are not invariably lucid.

Electrons, Waves and Messages, by John R. Pierce. Hanover House ($5). Dr. Pierce, noted for his work in high-frequency electronics and microwave radar, presents a broad survey of the art and science of modern electronics. His aim is to explain to readers without a technical background the principles of radio, television, long-distance message transmission and radar. He finds it necessary, therefore, to develop his subject from the ground up, to set forth the fundamentals of physics upon which the technology rests. The preparation consists of chapters on the laws of motion, electric fields and electrons, magnetic fields, waves and Maxwell's equations. There follow discussions of signals, band width, traveling wave tubes, noise, radiation, microwave systems, television and communication theory. Pierce's book, brilliant in parts, is not wholly successful. When the exposition is good, it is very, very good, but often it bogs down in technical details. The book can be highly recommended to persons with some scientific and mathematical training but it is in the main beyond the resources of the beginner.

Classics of Biology, by August Pi Suner. Philosophical Library ($7.50). Dr. Suner, a Catalonian physician and biologist who has contributed importantly to the growth of medical science in South America, has gathered in this volume extracts from some of the classics of biology. The book divides into 16 topics, such as cell theory, metabolism, growth and reproduction, sexual and asexual reproduction, heredity, embryology, evolution, paleontology, the nervous system. Among the pioneers of biology represented are Robert

Hooke, Rudolf Virchow, Claude Bernard, J. J. Berzelius, Charles Darwin, Gregor Mendel, Hugo De Vries, Charles Sherrington and Sigmund Freud.

Language, Thought and Reality: Selected Writings of Benjamin Lee Whorf, edited by John B. Carroll. Published jointly by The Technology Press and John Wiley & Sons, Inc. ($7). In this ably edited volume, prefaced by an excellent biographical essay, are collected the principal papers of an exceptionally gifted social scientist. Benjamin Whorf had an unusual but tragically short career. He was born in Massachusetts in 1897, graduated from M.I.T. in 1918 with a degree in chemical engineering, got a job with the Hartford Fire Insurance Company as a fire-prevention engineer and after 20 years of service, which he discharged with great technical skill, was elected an executive of the company just the year before he died at the age of 44. Along the line he became interested in linguistics, psychology and anthropology, and to each of these subjects, though he could give them little more than leisure time, he made provocative contributions. In 1924 he became concerned about the conflict between science and religion and this led him to the study of Ancient Hebrew. A book by a forgotten 19th-century French philologist and mystic, Antoine Fabre d'Olivet, which attempted to show that the "hidden meanings of the Book of Genesis could be elucidated by an analyses *au fond* of the triliteral Hebrew root," made a strong impression on Whorf. According to Fabre d'Olivet, each letter of the Hebrew alphabet contains an inherent meaning (for example, *aleph* is "the sign of the power and stability of ideas"). Once the meanings are known, all Hebrew roots and the words in which they appear can be properly interpreted. Whorf elaborated this idea and extended it to other languages; it inspired him throughout his work to persist in the struggle "to wrest from the bare linguistic fact its ultimate purport." He made a trip to Mexico to examine Maya hieroglyphs and began to write technical papers on linguistics. He became a pupil of the late Edward Sapir of Yale University, a foremost authority on American Indian languages and the science of language. Under Sapir's tutelage Whorf took up the study of the Hopi language and was fascinated by its strange grammar, which indicated to him that the Hopi perceived and conceived things differently from other people. Their notions of space and time and their descriptions of physical phenomena are, as he came to believe, far more penetrating and accurate than those reflected in European languages. In English we say, "The light flashed," but a Hopi Indian simply says, "Flash"—which fits the field concepts of physics better than the clumsy subject-predicate proposition. In these and various other areas, Whorf said, "English compared to Hopi is like a bludgeon compared to a rapier." After years of research and reflection he conceived a theory of linguistic "relativity," which says, "at least as a hypothesis, that the structure of a human being's language influences the manner in which he understands reality and behaves with respect to it." Language does not merely mirror thought but by its structure shapes thought, thus taking part in a kind of feedback process. Whorf's methods and conclusions have won supporters and have attracted sharp criticism. No one denies, however, that he was an exquisitely sensitive and subtle student of language and culture, brimming with original ideas.

FREUD: THE MAN AND HIS MIND, by Richard L. Schoenwald. Alfred A. Knopf ($4). SIGMUND FREUD: FOUR CENTENARY ADDRESSES, by Ernest Jones. Basic Books, Inc. ($3.75). Freud was born 100 years ago and has been causing trouble ever since. Some of it, of course, is very good trouble. These two volumes celebrate the memory and accomplishments of this remarkable man. Schoenwald's 250-page book explains each of Freud's writings—a considerable service to laymen interested in an over-all view of the evolution of psychoanalysis. The author's prose is facile, sentimental and very zippy. It is unlikely that Freud himself would have appreciated it, but the book clearly helps to propagate the faith. The Jones essays are pure hero-worship. The first piece is a mishmash about the nature of genius, quoting authorities on the subject from the Marquis de L'Hôpital to Thomas Mann. Freud, says Jones, had all the essential attributes of greatness, including a critical credulousness, or perhaps a credulous criticalness—it is hard to tell which. Jones is a graceful writer, but unless you are a collector you can skip this book.

MAN AND THE UNDERWATER WORLD, by Pierre de Latil and Jean Rivoire. G. P. Putnam's Sons ($5). MAN UNDER THE SEA, by James Dugan. Harper & Brothers ($5). The story is told that during the Irish Saint Brendan's epic sea voyage in search of paradise his party of monks landed one day on a small, round island, without sand or grass, harbor or rocks. They hauled up their boat and started to cook their evening meal, when suddenly the island began to move. They had landed, it appeared, on a whale. "My sons," Saint Brendan apostrophized them, "do you not admire Him who made this island?" "We do, Father, we do," they replied, "but, above all, we are afraid." The story may be taken as a paradigm of men's feelings about the sea ever since they ventured upon or under it. Nevertheless they have persevered, and despite their fears have steadily extended the knowledge of the deeps. These two books deal with the different ways men have explored the underwater world and their different motives: curiosity, adventure, exploration, military advantage, pearls, sunken treasure, fish, oil, zoological and archaeological research and, more recently, *l'amusement sportif.* The first book, by a Parisian journalist and a deep-sea practitioner, covers the history of submarine exploration from the Greek and Roman founders of the art of diving to the latest craze for "underwater tourism." In August, 1955, a monumental statue of Christ was erected *on the bottom* of the Bay of San Fruttoso on the Genoese Riviera—a neighborhood much favored by Italian underwater buffs. Among other historical items, the book describes the legend of Alexander the Great's glass diving case, which was covered with asses' skins and in which, accompanied by two secretaries, he sat deep under water for two days sketching pictures of hideous monsters; the contributions to diving of Leonardo da Vinci (including the webbed flippers in use today); the exploits of the astronomer Edmund Halley in a diving bell of his own design. The second book—less assertively learned—is an accomplished piece of journalism by the author of *The Great Iron Ship.* There is not a dull moment as Dugan recounts the adventures of J. B. S. Haldane and his father in perfecting the art of self-suffocation and in battling the bends; the submarine exploits of the U. S. S. *Tang;* the gallantries of the wet saboteurs of the Italian Tenth Light Flotilla; the insane journeys of sundry underwater cave explorers; the exciting descents of bathyspheres and bathyscaphes; and various incredible salvage operations, including the location of the hundreds of scattered pieces of the B.O.A.C. jet airliner *Yoke Peter,* which exploded over the Ligurian Sea. Other diversions: The grouper is a fish which can grow big enough to swallow a man whole; a 50-year old man on Babelthuap Island was swallowed by a grouper and made his escape through a gill. Japanese divers 100 years ago raised a number of vases containing Imperial treasure by lowering octopuses into the wreck. The octopuses wriggled into the vases; the salvors hauled on the lines; the octopuses "braced themselves," and "up came vases and tenants." Dugan lingers lovingly over gory details, but even the squeamish will find this a hugely entertaining book.

CULTURE, PSYCHIATRY AND HUMAN VALUES, by Marvin K. Opler. Charles C. Thomas ($6). Dr. Opler is not a winning writer. His delivery is dense, jargon flourishes, and he crowds as much into each sentence as if he feared it might be his last. Nevertheless, when you have ground your way through this book you realize that it is a learned, sympathetic, thoughtful and worthwhile work. It is concerned with the relation between environment and mental illness. The subject is not new, but most psychiatrists have neglected it. While realizing that patients do not live in a cultural vacuum, that mental disorders in some sense constitute an accommodation to the demands and pressures of the social jungle, many psychiatrists continue to diagnose and treat cases as if each represented a disease caused solely by innate qualities and the individual's response to his immediate environment—family, friends and the like. Psychiatrists have shrunk from formulating general rules linking culture and personality. Dr. Opler runs through a long roll call of recent cultural studies by social scientists—principally anthropologists—who have tried to relate mental disease to the ways of society. Their results have lit the imagination and widened the understanding of a number of leading psychiatrists. Some fruitful collaborations between psychiatrists and social scientists have been achieved. But the work has barely begun and has been marred in not a few instances by pretentiousness, extravagant claims and plain humbuggery. Besides reviewing the literature, Opler presents his own views on the cultural determinants of mental illness and the emerging "dynamic psychiatry," which may make a more effective assault upon the "processes destructive of human happiness."

THE OUTLOOK FOR NUCLEAR POWER IN JAPAN, by Michael Sapir and Sam J. Van Hyning. National Planning Association ($3.00). This volume is the second in a series of National Planning Association case studies on the productive uses of atomic energy. Other reports are in preparation on Brazil, India, Israel, Italy and Pakistan. On the basis of field observations and economic and statistical analysis the authors conclude that the Japanese economy as a whole, both by reason of its weaknesses and strengths, is in a position to derive substantial benefits from the development of a nuclear-power program. Japan is a predominantly hydro-based economy. But costs are rising and it seems probable that hydropower "will cease to be economically attractive or available, as compared with thermal plants, much beyond 1965." Expansion of the coal industry faces serious physical obstacles, and oil-fired capacity depends upon oil imports, which, in turn, must continue to burden an unsatisfactory balance-of-payments position. The initial capital outlay required to erect central-station nuclear power plants of 75,000 kilowatts and above would be large; but by 1975, say the authors, Japan might develop the capacity to build domestically most of the equipment required in nuclear plants. (The uranium fuel costs, as such, are a minor factor.) Thus the exchange burdens of capital imports would gradually vanish, and total nuclear power costs would probably fall to a level well under that of oil-fired capacity. Low-cost nuclear power would be strongly reflected, of course, in heavy-power-consuming industries, such as iron and steel, aluminum, nitrogen fertilizers, soda, chlorine and salt, and would generally stimulate the over-all expansion of national output. But, the report cautions, lower-cost power would not by itself have a revolutionary impact on the Japanese economy. A sober and enlightening analysis of wide significance.

INVESTIGATIONS ON THE THEORY OF THE BROWNIAN MOVEMENT, by Albert Einstein. Dover Publications, Inc. ($1.25). This book is an English translation of five papers by Einstein which appeared between 1905 and 1908. The Brownian movement was described for the first time in 1828 by the botanist Robert Brown, who observed that small pollen particles dispersed in water displayed an uninterrupted and irregular "swarming motion." Various 19th-century investigators followed up this discovery, noting, among other things, "that the motion is the more lively the smaller the viscosity of the liquid," and that the velocity of the movement decreases with increase of size of the particles and increases with rise of temperature. The fact that the kinetic energy of the particle equals that of a gas molecule was first suggested by the Austrian

physicist Franz Exner, but the relationship, as demanded by the molecular-kinetic theory of heat, was not verified until measurements were made according to methods laid down by Einstein. His several papers discuss the fundamental theory of Brownian movement, the determination of molecular dimensions, the methods of theoretical observation; a concluding section presents an attractively lucid exposition of the phenomenon on an elementary level ("for chemists"). The present edition, a reprinting of a 1926 issue, contains useful notes by R. Fürth.

ESSAYS AND SKETCHES IN BIOGRAPHY, by John Maynard Keynes. Meridian Books ($1.35). Bound together in this attractive and well-printed paper-back are Keynes's *Essays in Biography* and *Two Memoirs.* The subjects of the biographical sketches include Robert Malthus, Alfred Marshall, Frank Ramsey, William Stanley Jevons, Winston Churchill, Leon Trotsky, David Lloyd George, Edwin Montagu, Isaac Newton. The memoirs include "My Early Beliefs," a charming reminiscence of Keynes's years at Cambridge, his philosophical preoccupations, his friendships with, among others, Bertrand Russell, G. E. Moore, Lytton Strachey and David Garnett. A delectable literary package.

PSYCHOLOGY OF INDUSTRIAL CONFLICT, by Ross Stagner. John Wiley & Sons, Inc. ($8). WORK AND AUTHORITY IN INDUSTRY, by Reinhard Bendix. John Wiley & Sons, Inc. ($7.50). Many a corporation president has been shocked by the determination of his workers to strike even when they obviously would not be able to recoup for years the amounts lost in unpaid wages. Union leaders, on the other hand, have often listened incredulously to management's aggressive rejection of sound suggestions for improvement of production methods. Ross Stagner, of the University of Illinois, has dug beneath the hostile and irrational behavior common in labor-management disputes to reveal the hidden frustrations that motivate both sides. His description of the psychological pressures that push worker and manager into conflict is the core of a many-sided work that merits close study by every practitioner and serious student of industrial relations. It is perhaps to be regretted that he did not devote more space to the effect of family difficulties on workers' states of mind—a field that needs further investigation—but his book stands as an exceptionally comprehensive and useful review. The men on

whom industrial peace depends, he makes it plain, need to strip off their mental blinders if they are to communicate effectively with one another and achieve sustained cooperation. The book by Dr. Bendix, of the University of California, approaches the problem of maintaining industrial peace through an examination of several historical situations: England in the Industrial Revolution; Russia under the Tsars and the Soviets; the U. S. since 1880; East Germany today. He deals essentially with the ideologies and techniques through which the private or public managers of industry, in each of these societies, succeeded in establishing their authority over their labor forces. One of the keys to his thinking is the statement that "the revolutionary dangers of industrial civilization materialize when the various dominant groups are unable or unwilling to compromise."

THE MARINE AND FRESH-WATER PLANKTON, by Charles C. Davis. Michigan State University Press ($10). The tiny, delicate plankton organisms, now recognized as the main source of food for the larger life of the sea, figure in the planning of many who are concerned about man's future food supply. This scholarly monograph describes these dwellers in the watery world whence man came and to which he may have to turn for nourishment. Many illustrations and an extensive bibliography.

THE MEANING OF RELATIVITY, by Albert Einstein. Princeton University Press ($3.75). For this fifth edition of his celebrated little book, based on lectures he gave in Princeton in 1921, Einstein completely revised the "Generalized Theory of Gravitation" under the title "Relativistic Theory of the Non-Symmetric Field." He expressed the hope that he had thereby simplified the derivations and form of the field equations and made the whole theory "more transparent without changing its content." The work was completed shortly before his death.

BETWEEN THE PLANETS, by Fletcher G. Watson. Harvard University Press ($5). A revised edition of Dr. Watson's book on the small fry of the solar system. He offers an up-to-date, concise but remarkably comprehensive account of the thousands of little bodies that move around the sun (principally in the region between the orbits of Mars and Jupiter); asteroids, comets, meteorites and dust. An attractively written and instructive

volume for amateurs and professionals. Fine illustrations.

Notes

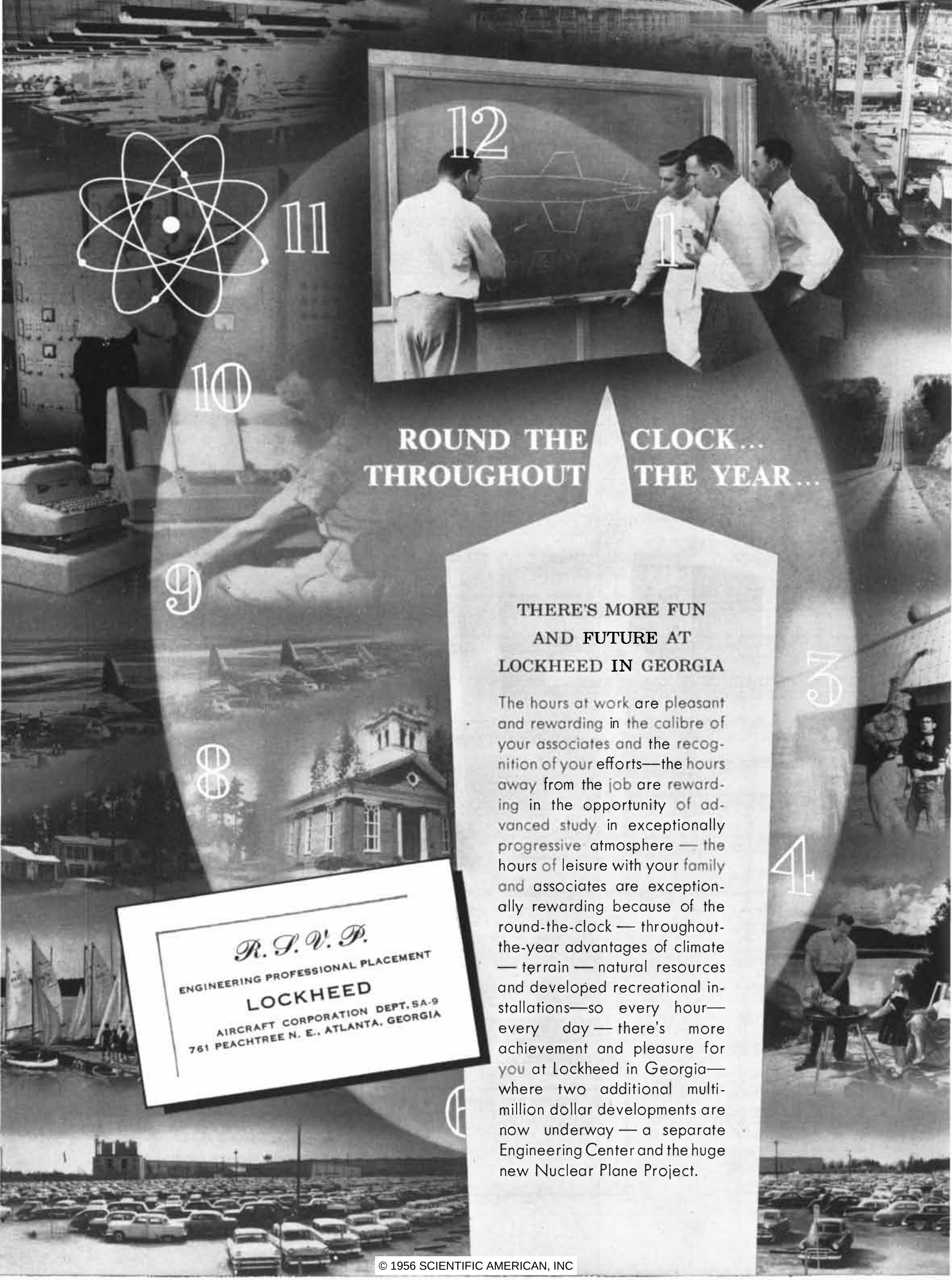
Advances in Biological and Medical Physics, Vol. IV, edited by John H. Lawrence and Cornelius A. Tobias. Academic Press Inc. ($8.80). This volume contains, among other articles, papers on X-ray diffraction applied to crystalline proteins, information transfer from the nucleic acids to proteins, the biophysical and biochemical study of cell division, the aging process, infrared spectrometry, lethal effects of high and low temperatures on unicellular organisms.

Bacterial Anatomy, edited by E. T. C. Spooner and B. A. D. Stocker. Cambridge University Press ($6). The Sixth Symposium of the Society for General Microbiology includes articles on cellular organization in bacteria, bacterial flagella, osmotic function and structure in bacteria, bacterial protoplasts, chromosomes in microorganisms, bacterial cytoplasm.

Statistics, by L. H. C. Tippett. Oxford University Press ($1.20). Tippett's little volume in the Home University Library series has long been recognized as one of the best introductions to statistical ideas and methods for the general reader. This second edition takes account of developments in the subject during the past few years and replaces some of the original illustrative material with more up-to-date examples.

The Wren, by Edward A. Armstrong. The Macmillan Company ($6). Another engaging book in the New Naturalist series. The author, a distinguished "parson ornithologist" in the tradition exemplified by Gilbert White, describes from long and loving observation the behavior and habitat of this familiar bird, its songs and calls, sexual display, nest building, care of the nestlings, victimization by the cuckoo and other species, arising and roosting. A quiet, gentle and immensely instructive monograph.

Hurricanes: Their Nature and History, by Ivan Ray Tannehill. Princeton University Press ($4.50). It is proof of how hurricane-minded we have become since Carols, Hazels and Ednas have been plaguing us that this excellent book is now in its ninth revised edition. A long appendix has been added on observing and forecasting hurricanes, and on the storms from 1952 through 1955.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ROUND THE CLOCK...
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THERE'S MORE FUN
AND FUTURE AT
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The hours at work are pleasant and rewarding in the calibre of your associates and the recognition of your efforts—the hours away from the job are rewarding in the opportunity of advanced study in exceptionally progressive atmosphere — the hours of leisure with your family and associates are exceptionally rewarding because of the round-the-clock — throughout-the-year advantages of climate — terrain — natural resources and developed recreational installations—so every hour—every day — there's more achievement and pleasure for you at Lockheed in Georgia— where two additional multi-million dollar developments are now underway — a separate Engineering Center and the huge new Nuclear Plane Project.
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THE AMATEUR SCIENTIST

About a diffraction-grating spectrograph made of materials costing less than $100

Strip the astronomical telescope of its clock drive, film magazine, spectrograph and related accessories and you put it in a class with a blind man's cane. Like the cane, it informs you that something is out in front. Shorn of appendages, the telescope tells you next to nothing about the size, temperature, density, composition or other physical facts of the bodies which populate space. Not more than 20 celestial objects, other than comets, appear through the eyepiece as interesting patterns of light and shade. Only one, the moon, displays any richness of surface detail. All other bodies look much as they do to the naked eye. There is a greater profusion of stars, but as a spectacle the night sky remains substantially unchanged.

That is why the experience of building a telescope leaves some amateurs with the feeling of having been cheated. A few turns at the eyepiece apparently exhaust the novelty of the show, and they turn to other avocations.

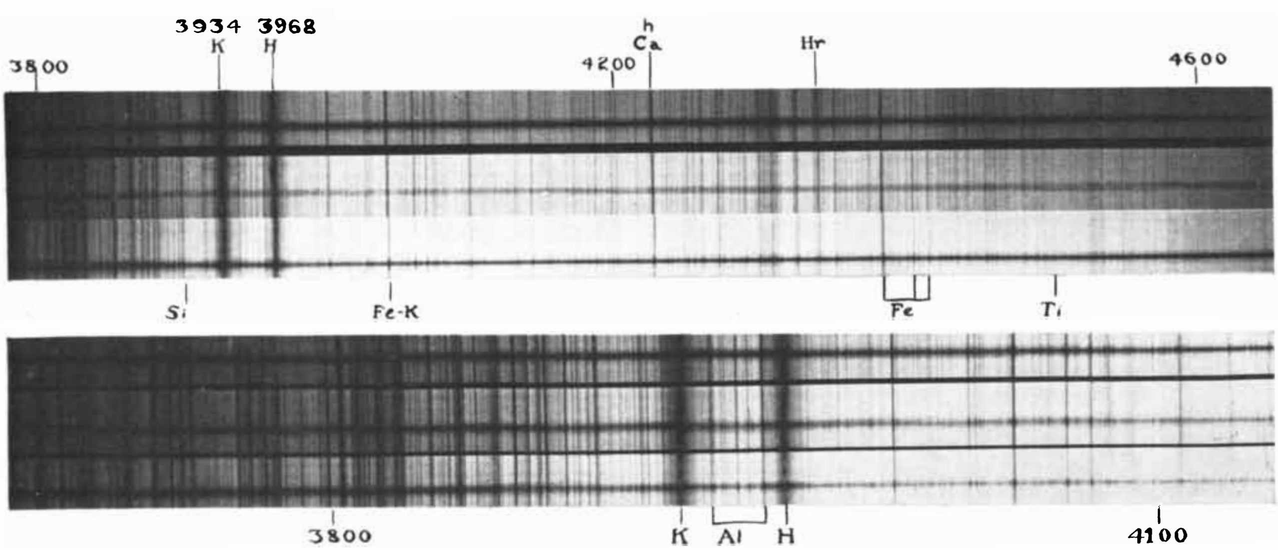
Other amateurs, like Walter J. Semerau of Kenmore, N.Y., are not so easily discouraged. They pursue their hobby until they arrive at the boundless realm of astrophysics. Here they may observe the explosion of a star, the slow rotation of a galaxy, the flaming prominences of the sun and many other events in the drama of the heavens.

Semerau invested more than 700 hours of labor in the construction of his first telescope, described in this department in May, 1948. "I must confess," he writes, "that what I saw with it seemed poor compensation for the time and effort. That, however, overlooks other satisfactions: the solution of fascinating mechanical and optical problems. Considered in these terms, that first instrument was the buy of a lifetime."

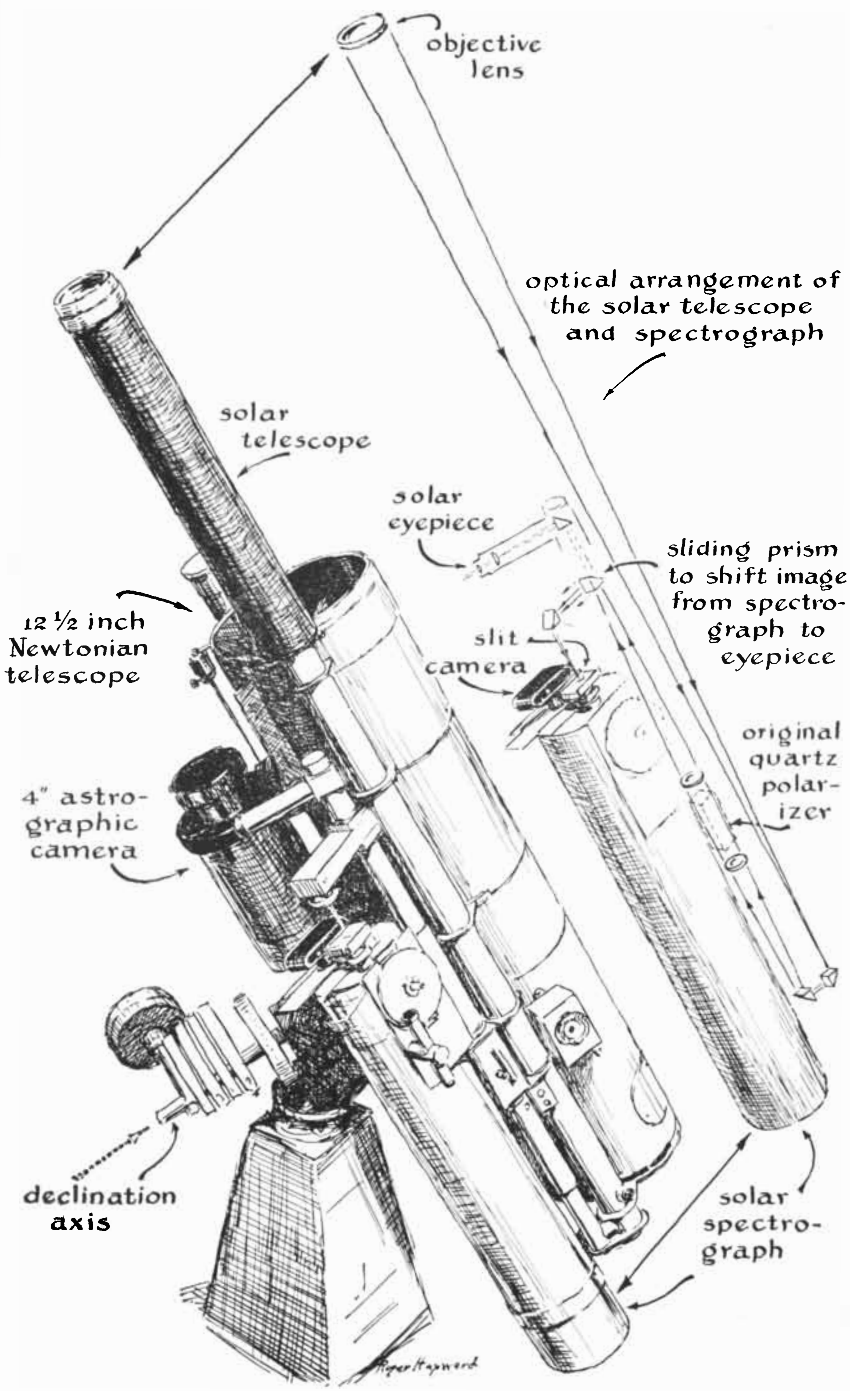
Semerau soon decided, however, that he had to have a larger telescope equipped with devices to gather more information than his eye could detect. Accordingly he went to work on a 12½-inch Newtonian reflector, complete with film magazine and four-inch astrographic camera. Both were assembled on a heavy mounting with an electric drive, calibrated setting-circles and slow-motion adjustments. He could now not only probe more deeply into space but also do such things as determine the distance of a nearby star by measuring its change in position as the earth moves around the sun. To put it another way, he had made his "cane" longer and increased his control of it. When the sensitivity of modern photographic emulsions are taken into account, Semerau's new instruments were almost on a par with those in the world's best observatories 50 years ago.

During these 50 years, as Cecilia Payne-Gaposchkin of the Harvard College Observatory has pointed out, we have gained most of our knowledge of the physics of the universe. Most of this knowledge has come through the development of ingenious accessories for the telescope which sort out the complex waves radiated by celestial objects.

Semerau now decided that he had to tackle the construction of some of these accessories and to try his hand at the more sophisticated techniques of observing that went with them. He went to work on a monochromator, a device which artificially eclipses the sun and enables the observer to study the solar atmosphere. Semerau's description of the apparatus, together with color photographs of solar prominences made



Sunspot spectrograms made by Walter L. Semerau. The first-order spectrum is at the top; the second-order, at the bottom



Semerau's telescope, astrographic camera, monochromator and spectrograph

with it, appeared in this department just a year ago.

Having built the monochromator, Semerau felt he was ready to attempt one of the most demanding jobs in optics: the making of a spectrograph. Directly or indirectly the spectrograph can function as a yardstick, speedometer, tachometer, balance, thermometer and chemical laboratory all in one. In addition, it enables the observer to study all kinds of magnetic and electrical effects.

In principle the instrument is relatively simple. Light falls on an optical element which separates its constituent wavelengths or colors in a fan-shaped array; the longest waves occupying one edge of the fan and the shortest the other. The element responsible for the separation may be either a prism or a diffraction grating: a surface ruled with many straight and evenly spaced lines. The spectrograph is improved by equipping it with a system of lenses (or a concave mirror) to concentrate the light, and with an aperture in the form of a thin slit. When the dispersed rays of white light are brought to focus on a screen, such as a piece of white cardboard, the slit appears as a series of multiple images so closely spaced that a continuous ribbon of color is formed which runs the gamut of the rainbow.

As previously discussed in this department [June, 1955], each atom and molecule, when sufficiently energized, emits a series of light waves of characteristic length. These appear as bright lines in the spectrum and enable the investigator to identify the chemical elements of the incandescent source. Similarly, the atoms of a gas at lower temperature than the source absorb energy at these characteristic wavelengths from light transmitted through the gas. The absorption pattern appears as dark lines. As the temperature of the source increases, waves of shorter and shorter length join the emission, and the spectrum becomes more intense toward the blue end. Thus the spectral pattern can serve as an index of temperature.

The characteristic lines of a substance need not always appear at the same position in the spectrum. When a source of light is moving toward the observer, for example, its waves are shortened—the Doppler effect so frequently mentioned in this issue. In consequence the spectral lines of atoms moving toward the observer are shifted toward the blue end of the spectrum. The lines of atoms moving away are shifted toward the red. Velocity can thus be measured by observing the spectral shift.

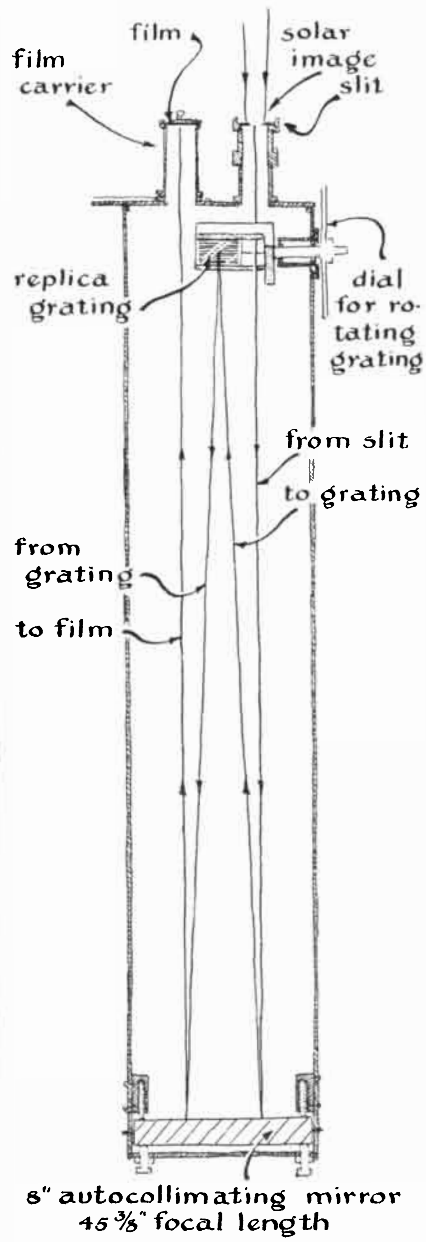
When an atom is ionized, *i.e.*, electrically charged, it can be influenced by a magnetic field. Its spectral lines may then be split: the phenomenon known as the Zeeman effect. Intense electrical fields similarly leave their mark on the spectrum.

These and other variations in normal spectra provide the astrophysicist with most of his clues to the nature of stars, nebulae, galaxies and the large-scale features of the universe. The amateur can hardly hope to compete with these observations, particularly those of faint objects. However, with well-built equipment he can come to grips with a rich variety of effects in the nearer and brighter ones.

"If you are willing to settle for the sun," writes Semerau, "you shuck off a lot of labor. A three-inch objective lens, or a mirror of similar size, will give you all the light you need. The rest is easy. Many amateurs have stayed away from spectroscopes because most conventional designs call for lathes and other facilities beyond reach of the basement workshop, and many are too heavy or unwieldy for backyard use.

"About four years ago I chanced on a design that seemed to fill the bill. My employer, the Linde Air Products Company, a division of the Union Carbide and Carbon Corporation, needed a special spectroscope for industrial research and could not find a commercial instrument that met their specifications. The Bausch & Lomb Optical Company finally located a design that looked promising. As things worked out, it was adopted and is now on the market. My instrument, shown mounted on page 260, is a copy of that design.

"The concept was proposed by H.

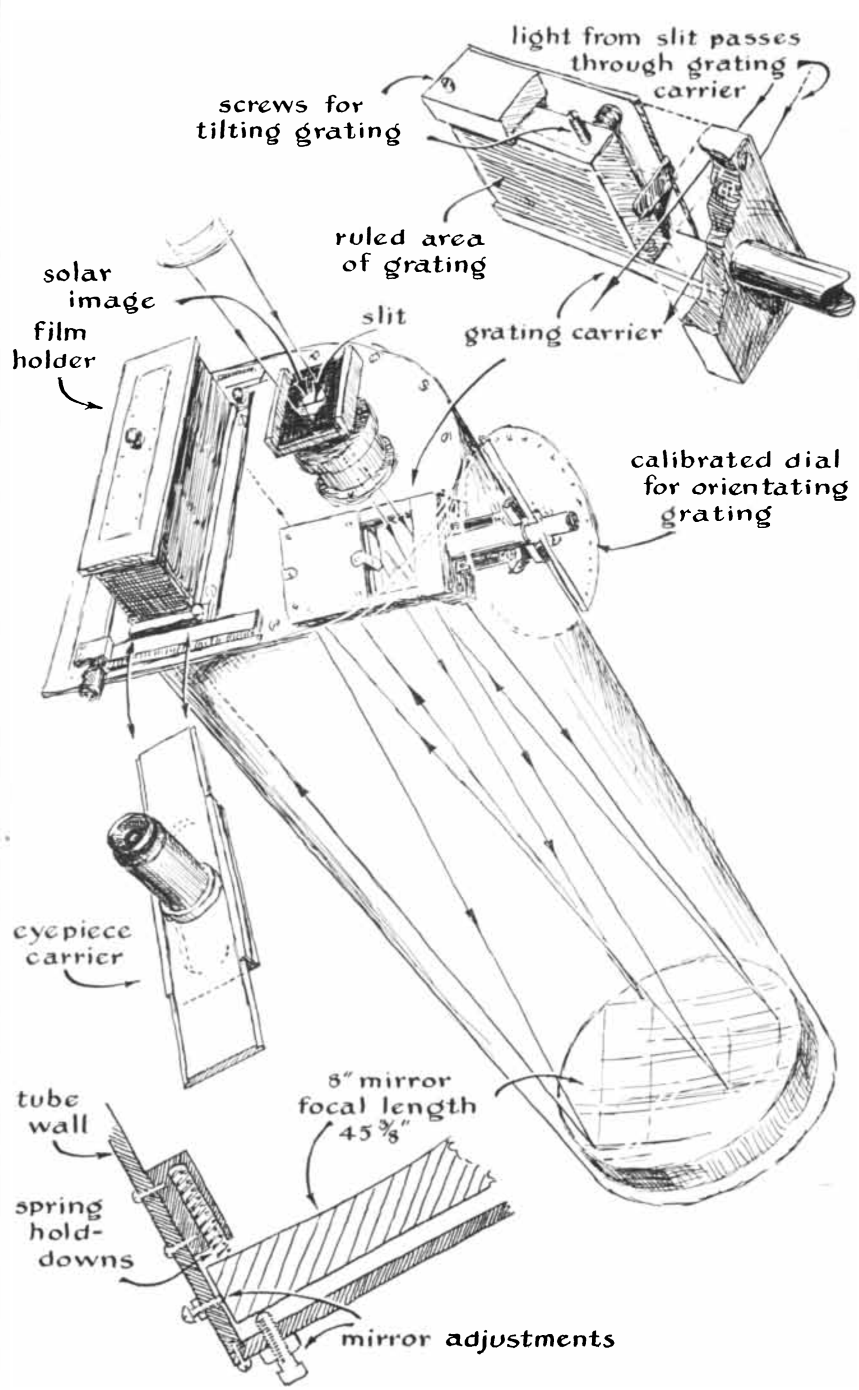


Optical train of the spectrograph

Ebert just before the turn of the century. The instrument is of the high dispersion, stigmatic type and employs a plane diffraction grating. As conceived by Ebert, the design was at least 50 years ahead of its time. In his day plane gratings were ruled on speculum metal, an alloy of 68 per cent copper and 32 per cent tin which is subject to tarnishing. This fact alone made the idea impractical. Ebert also specified a spherical mirror for collimating and imaging the light. Prior to 1900 mirrors were also made of speculum metal. It was possible but not practical to repolish the mirror but neither possible nor practical to refinish the finely ruled grating. Consequently a brilliant idea lay fallow, waiting for someone to develop a method of depositing a thin film of metal onto glass that would reflect light effectively and resist tarnishing. Then John Strong, now director of the Laboratory of Astrophysics and Physical Meteorology at the Johns Hopkins University, perfected a method of depositing a thin film of aluminum on glass.

"The process opened the way for many new developments in the field of optics. One of these is the production of high-precision reflectance gratings ruled on aluminized glass. Prior to being coated the glass is ground and polished to a plane that does not depart from flatness by more than a 100,000th of an inch. The metallic film is then ruled with a series of straight, parallel saw-tooth grooves—as many as 30,000 per inch. The spacing between the rulings is uniform to within a few millionths of an inch; the angle of the saw-tooth walls, the so-called 'blaze angle,' is held similarly constant. The ruling operation is without question one of the most exacting mechanical processes known, and accounts for the high cost and limited production of gratings.

"In consequence few spectrographs were designed around gratings until recently. About five years ago, however, Bausch and Lomb introduced the 'certified precision grating.' These are casts taken from an original grating. It is misleading to describe them as replicas, because the term suggests the numerous unsatisfactory reproductions which have appeared in the past. The Bausch and Lomb casts perform astonishingly well at moderate temperatures and will not tarnish in a normal laboratory atmosphere. The grooves are as straight and evenly spaced as those of the original. The blaze angle can be readily controlled to concentrate the spectral energy into any desired region of the spectrum, making the gratings nearly as effi-



Details of the spectrograph assembly

cient for spectroscopic work as the glass prisms more commonly used in commercial instruments. Certified precision gratings sell at about a tenth the price of originals; they cost from $100 to $1,800, depending upon the size of the ruled area and the density of the rulings. Replicas of lesser quality, but entirely adequate for amateur use, can be purchased from laboratory supply houses for approximately $5 to $25.

"The remaining parts of the Ebert spectrograph—mirror, cell, tube, slit and film holder—should cost no more than an eight-inch Newtonian reflector. Depending on where you buy the materials, the entire rig should come to less than $100. By begging materials from all my friends, and keeping an eye on the Linde scrap pile, mine cost far less.

"There is nothing sacred about the design of the main tube and related mechanical parts. You can make the tube of plywood or go in for fancy aluminum castings, depending upon your pleasure and your fiscal policy. If the instrument

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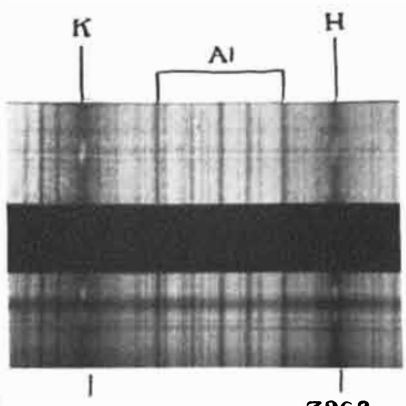
is to be mounted alongside the telescope, however, weight becomes an important factor. The prime requirement is sufficient rigidity and strength to hold the optical elements in precise alignment. If the spectrograph is to be used for laboratory work such as the analysis of minerals, sheet steel may be used to good advantage. For astronomical work you are faced with the problem of balancing rigidity and lightness. Duralumin is a good compromise in many respects. Iron has long been a favored material for the structural parts of laboratory spectrographs because its coefficient of expansion closely approaches that of glass. When mirrors are made of Pyrex, an especially tough cast iron known as meehanite has been used to counteract the effects of temperature variation.

"The optical elements of my instrument are supported by a tube with a length of 45 inches and an inside diameter of 8¼ inches [*see drawing on page 262*]. The walls of the tube are a sixteenth of an inch thick. The eight-inch spherical mirror has a focal length of 45⅜ inches. The grating is two inches square; it is ruled with 15,000 lines per inch. The long face of the saw-tooth groove is slanted about 20 degrees to the plane of the grating. The width of each groove is 5,000 Angstrom units, or about 20 millionths of an inch. Such a grating will strongly reflect waves with a length of 10,000 A., which are in the infrared region. The grating is said to be 'blazed' for 10,000 A. A grating of this blazing will also reflect waves of 5,000 A., though less strongly. These waves give rise to 'second-order' spectra which lie in the center of the visible region: the green. In addition, some third-order spectra occur; their wavelength is about 3,300 A. Waves of this length lie in the ultraviolet region.

"The angle at which light is reflected



Sunspot in the fourth spectral order

from the grating depends upon the length of its waves. The long waves are bent more than the short ones; hence the long and short waves are dispersed. A grating blazed for 10,000 A. will disperse a 14.5-A. segment of the first-order spectrum over a millimeter. My instrument thus spreads a 2,200-A. band of the spectrum on a six-inch strip of film.

"The film holder of my spectroscope is designed for rolls of 35-millimeter film. Light is admitted to the holder through a rectangular port six inches long and four tenths of an inch wide. By moving the holder across the port, it is possible to make three narrow exposures on one strip. This is a convenience in arriving at the proper exposure. The exposure time is estimated on the basis of past experience for one portion of the film; the interval is then bracketed by doubling the exposure for the second portion and halving it for the third.

"The most difficult part of the spectrograph to make is the yoke which supports the grating. Much depends on how well this part functions. It must permit the grating to be rotated through 45 degrees to each side, and provide adjustments for aligning the grating with respect to the mirror. The ruled surface must be located precisely on the center line of the yoke axis, preferably with provision for tilting within the yoke so that the rulings can be made to parallel the axis. In my arrangement this adjustment is provided by two screws which act against opposing springs, as shown in the drawing on page 264. The pressure necessary to keep the grating in the parallel position is provided by four springs located behind it. Two leaf springs, one above the other, hold the grating in place. The assembly is supported by an end plate from which a shaft extends. The shaft turns in a pair of tapered roller-bearings which, together with their housing, were formerly part of an automobile water-pump. A flange at the outer end of the housing serves as the fixture for attaching the yoke assembly to the main tube. It is fastened in place by two sets of three screws each, the members of each set spaced over 120 degrees around the flange. One set passes through oversized holes in the flange and engages threads in the tube. These act as pull-downs. The other set engages threads in the flange and presses against the tube, providing push-up. Adjusting the two sets makes it possible to align the yoke axis with respect to the tube.

"The shaft of the yoke is driven by a single thread, 36-tooth worm gear that carries a dial graduated in one-degree steps. The worm engaging the gear also bears a dial, graduated in 100 parts, each representing a tenth of a degree. The arrangement is satisfactory for positioning spectra on the ground glass or film but is inadequate for determining wavelengths.

"All plane gratings should be illuminated with parallel rays. Hence the entrance slit and photographic plate must both lie in the focal plane of the mirror. Small departures from this ideal may be compensated by moving the mirror slightly up or down the tube.

"The spectral lines of the Ebert spectrograph are vertical only near the zero order and tilt increasingly as the grating is rotated to bring the higher orders under observation. The tilting may be compensated by rotating the entrance slit in the opposite direction while viewing the the lines on a ground glass or through the eyepiece. The effect is aggravated in instruments of short focal length.

"The cell supporting the mirror, and its essential adjustments, are identical with those of conventional reflecting telescopes. If no cell is provided and the adjustment screws bear directly on the mirror—which invites a chipped back—then no more than three screws, spaced 120 degrees apart, should be used. This is particularly important if the screws are opposed by compression springs; more than three will almost certainly result in a twisted mirror.

"The film magazine is equipped with a 48-pitch rack and pinion, purposely adjusted to a tight mesh so each tooth can be felt as it comes into engagement. It is this arrangement that makes it possible to move the film along the exposure port and make three exposures on each strip of film. Lateral spacing during the racking operation is determined by counting the meshes. Although the magazine accommodates standard casettes for 35-mm. film, it is not equipped with a device for counting exposures. I merely count the number of turns of the film spool and record them in a notebook.

"The back of the magazine is provided with a removable cover so that a ground glass may be inserted as desired. It also takes a 35-mm. camera, a convenience when interest is confined to a narrow region of the spectrum such as the H and K lines of calcium or the alpha line of hydrogen. The back may be changed over to an eyepiece fixture which may be slid along the full six inches of spectrum. This arrangement provides for a visual check prior to making an exposure; it is especially helpful to the beginner.

"Care must be taken in illuminating

the slit. If the spectrograph has a focal ratio of $f/20$ (the focal length of mirror divided by the effective diameter of grating), the cone of incoming rays should also approximate $f/20$ and the axis of the cone should parallel the axis of the mirror. The slit acts much like the aperture of a pinhole camera. Consequently, if the rays of the illuminating cone converge at a greater angle than the focal ratio of the system, say $f/10$, they will fill an area in the plane of the grating considerably larger than the area of the rulings. Light thus scattered will result in fogged film and reduced contrast. Misalignment of the incoming rays will have the same effect, though perhaps it is less pronounced. Baffles or diaphragms spaced every three or four inches through the full length of the tube will greatly reduce the effects of stray light, such as that which enters the slit at a skew angle and bounces off the back of the grating onto the film. The diaphragms must be carefully designed, however, or they may vignette the film.

"The components are assembled as shown in the drawing on page 264. The initial adjustments and alignment of the optical elements can be made on a workbench. An electric arc using carbons enriched with iron, or a strong spark discharge between iron electrodes, makes a convenient source of light for testing. The emission spectra of iron have been determined with great precision, and the wavelengths of hundreds of lines extending far into the ultraviolet and infrared (from 294 to 26,000 A.) are tabulated in standard reference texts. Beginners may prefer a mercury arc or glow lamp because these sources demand less attention during operation and emit fewer spectral lines which are, in consequence, easier to identify. The tabulations, whether of iron or mercury, are useful for assessing the initial performance of the instrument and invaluable for calibrating comparison spectra during its subsequent use.

"Recently I have been concentrating on the spectroscopic study of sunspots. To make a spectrogram of a sunspot you align the telescope so that the image of the sun falls on the entrance slit. The objective lens of my telescope yields an image considerably larger than the slit. The image is maneuvered, by means of the telescope's slow-motion controls, until a selected sunspot is centered on the slit, a trick easily mastered with a little practice. The spectrum is then examined by means of either the eyepiece or the ground glass. The spot is seen as a narrow streak which extends from one end of the spectrum to the other. The ad-

justments, including the width of the entrance slit, are then touched up so the lines appear with maximum sharpness.

"Successive spectral orders are brought into view by rotating the grating through higher angles. The upper spectrum on page 259 shows the first order. The one beneath is made in the second order. Note that although fewer lines per inch appear in the second order, there is no gain in resolution. Shifting the grating for the detection of a higher order is analogous to substituting eyepieces of higher power in a telescope. You get a bigger but proportionately fuzzier picture. The film magazine is substituted for the eyepiece and three exposures made in both the first and the second order. In many cases the range of intensity between the faintest and brightest lines exceeds the capacity of the film to register contrast. Three exposures, one estimated for the mid-range intensity and the other two timed respectively at half and twice this value, will usually span the full range.

"Gases in the vicinity of a sunspot often appear to be in a state of violent turbulence. At any instant some atoms are rushing toward the observer and others away. The spectral lines show proportionate displacement from their normal positions in the spectrum—the Doppler effect—and register as a bulge in the central part of the line occupied by the sunspot. This explains the dark streak extending through the center of the spectra reproduced on page 259.

"A portion of this same spectrum, photographed in the fourth order and enlarged photographically, appears on page 266. It includes the H and K lines of calcium, at wavelengths of 2,933 and 3,960 A. respectively. Observe that a segment in the center of each of these two lines—the segment representing the sunspot—is split. The light streak occupying the area within the split section is referred to as 'emission over absorption' and, in this instance, indicates the presence of incandescent calcium at an altitude of about 100,000 miles above a region of cooler matter in the spot. Had the glowing calcium been lower, its emission would have been absorbed by the intervening solar atmosphere and it would have photographed as a dark absorption line. My interpretation of this spectrogram is that a solar prominence, carrying incandescent calcium from the sun's interior, arched up and over the sunspot. We are looking down on top of it. Reconstructing such events from evidence buried in the myriad lines of spectra is an endless challenge and one of the hobby's many fascinations."

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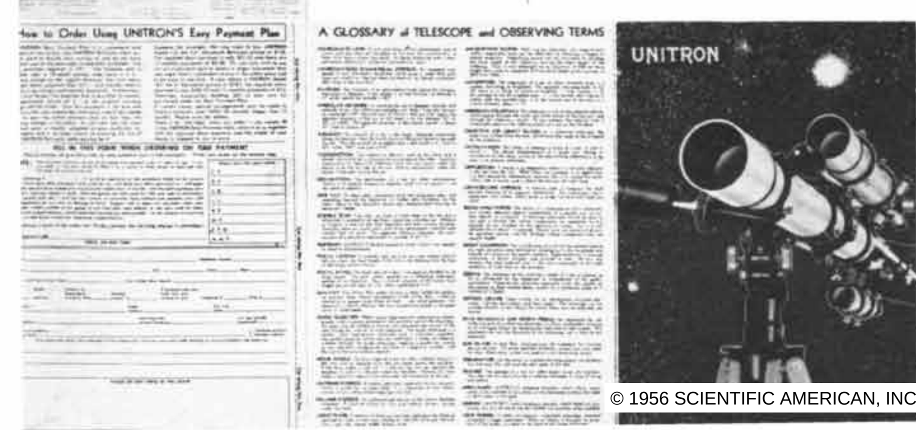

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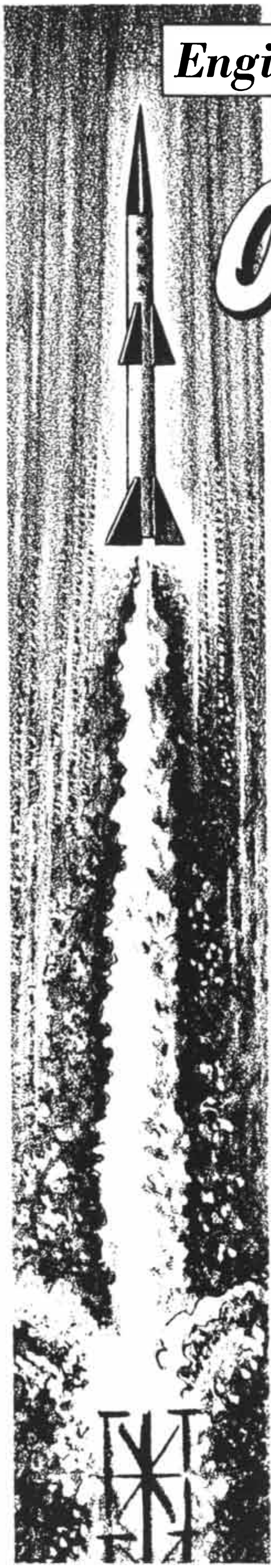

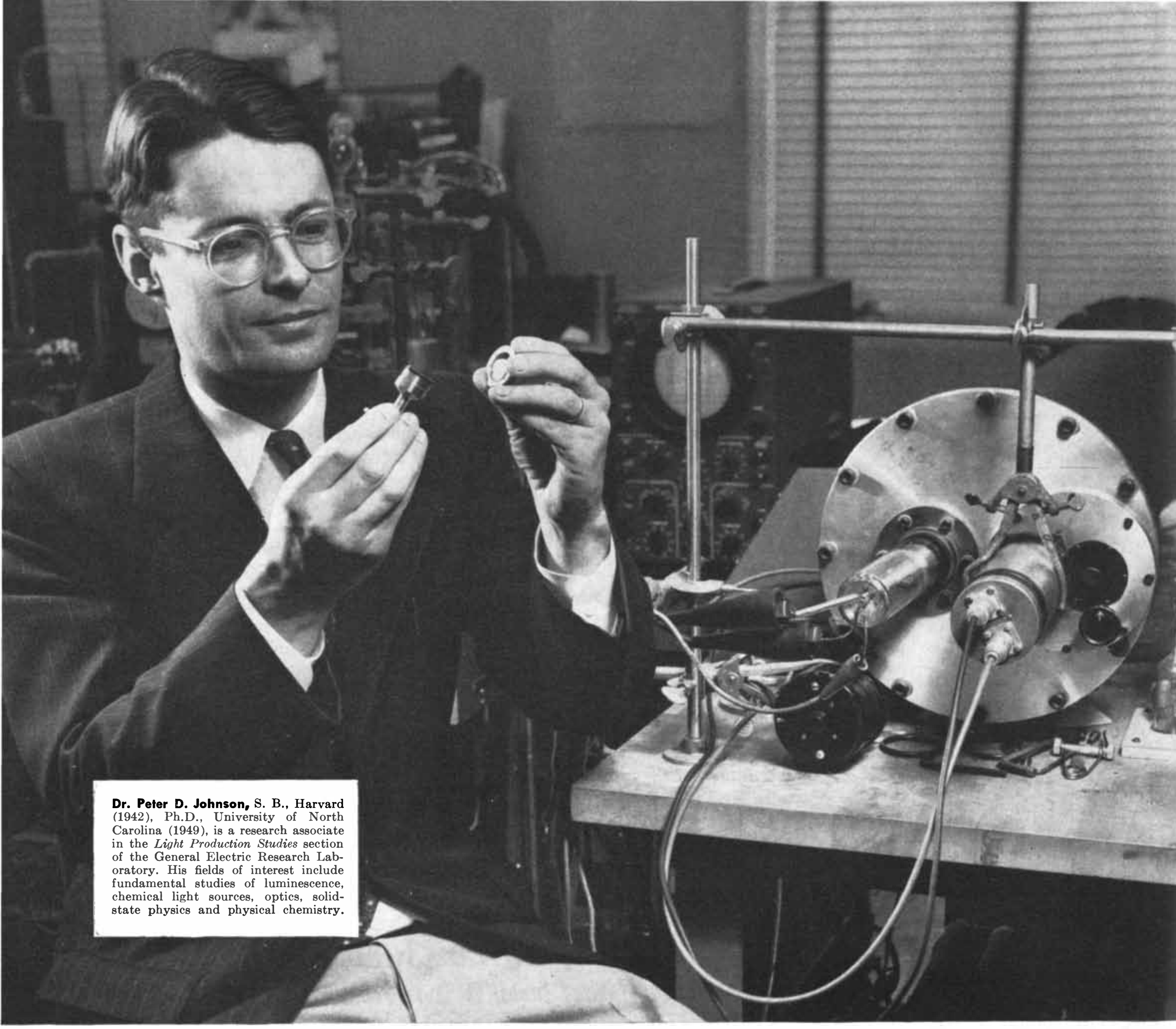

Dr. Peter D. Johnson, S. B., Harvard (1942), Ph.D., University of North Carolina (1949), is a research associate in the *Light Production Studies* section of the General Electric Research Laboratory. His fields of interest include fundamental studies of luminescence, chemical light sources, optics, solid-state physics and physical chemistry.

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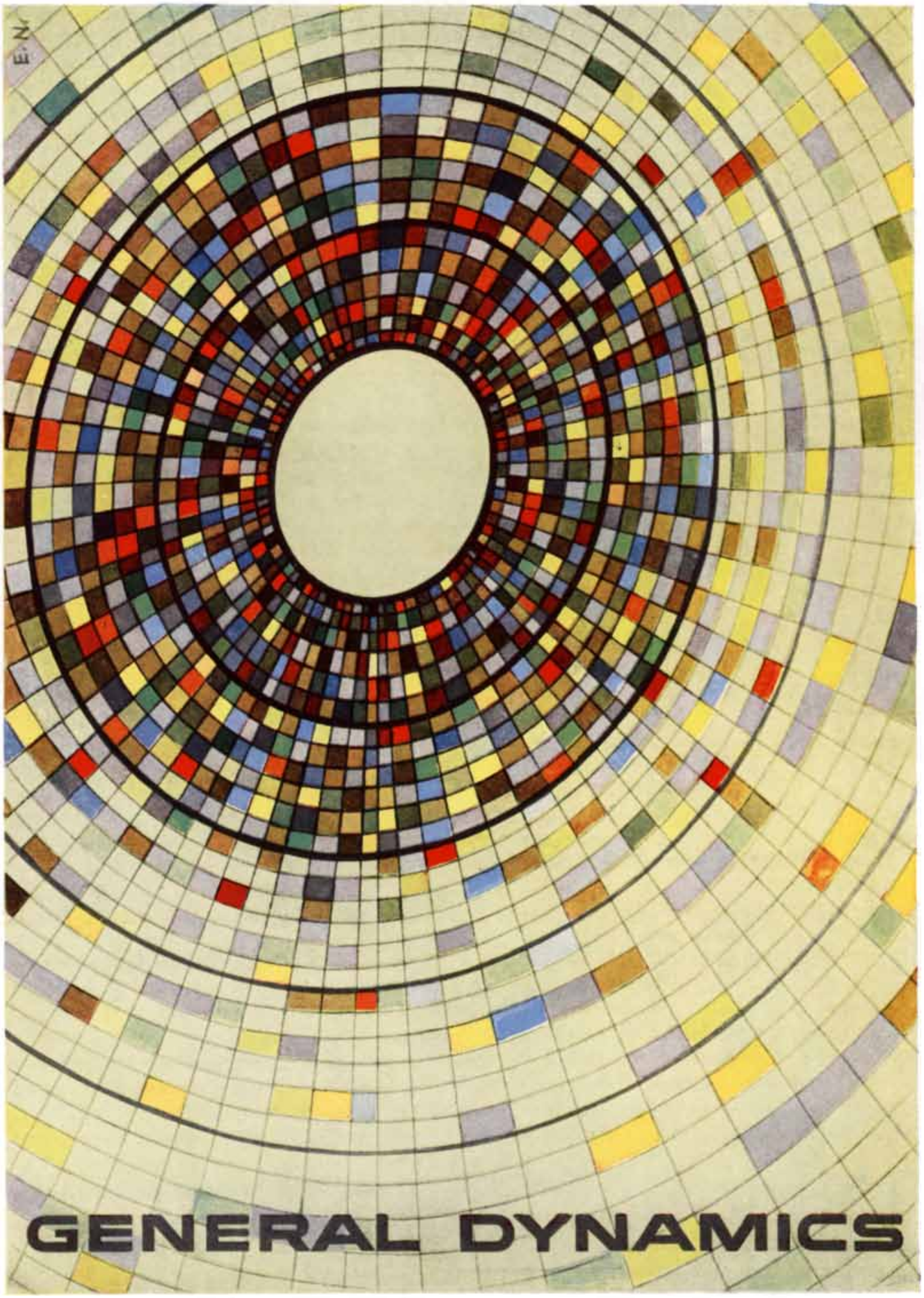

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