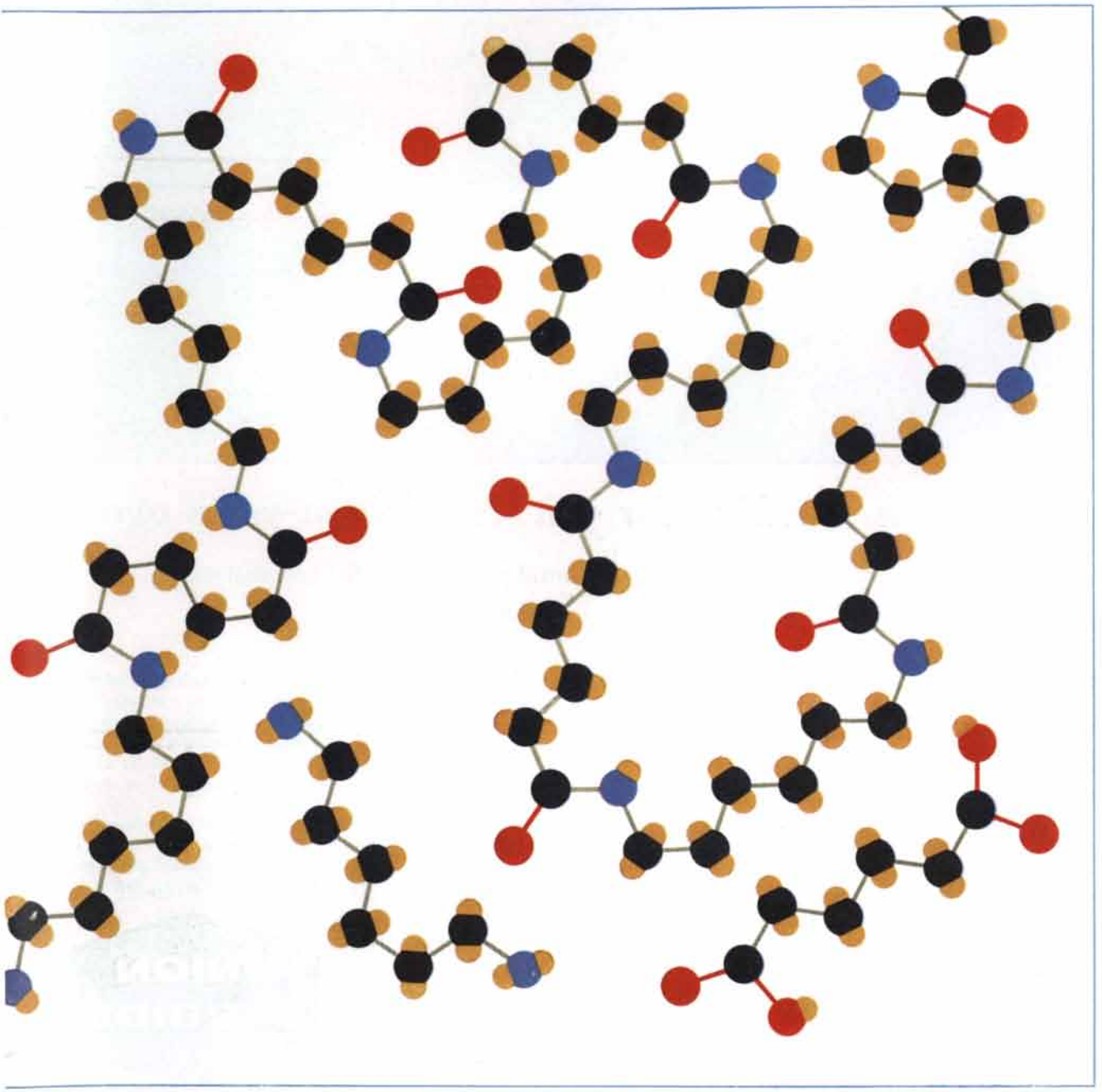
SCIENTIFIC AMERICAN



GIANT MOLECULES

FIFTY CENTS

September 1957

Nature was working for you . . . a billion years ago

Age-old natural gas supplies the raw materials for everything from new textile fibers to wonder drugs

CENTURIES BEFORE the time of man, great masses of plant and animal life were buried under layers of earth, rock, and water. Gradually, natural chemical reactions changed that buried matter into gas and oil.

The great importance of natural gas began when scientists learned to separate and use its parts. For example, out of Union Carbide's pioneering research in petro-chemistry came "Prestone" all-winter anti-freeze, which took the worry out of cold weather driving.

Life-saving antibiotics and exciting new textiles are also yours because of petro-chemicals. Then there are today's plastics . . . such as soft, pliable polyethylene film used as a protective wrapping for everything from food to clothing . . . and vinyl plastics that bring you tough, wear-resistant floor tiles and unbreakable phonograph records.

Wherever you turn today, you'll find something that's been made better by the magic touch of chemicals from the people of Union Carbide.

FREE: *Learn how many of the products you use every day are improved by research in alloys, carbons, chemicals, gases, plastics, and nuclear energy. Write for "Products and Processes" booklet J.*

Union Carbide Corporation, 30 East 42nd Street, New York 17, N. Y. In Canada, Union Carbide Canada Limited, Toronto.

UNION CARBIDE

UCC's Trade-marked Products include

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

THIS IS GLASS

a bulletin of practical new ideas from Corning

New, neat way to heat

You can't buy this heater, *yet*. It's new—in fact so new in concept that what you see is a preliminary design sketch.

What makes it so unusual is the heating element it is designed around. Corning's *new* tubular heating element called HEAT SHEATH®.

This is what the basic unit looks like.

Essential components are: VYCOR brand glass tubing, colored *red;* capped leads; and a completely enclosed, extremely efficient wire heating element.

True . . . sheathed heating units are not new. But HEAT SHEATH offers a *combination* of important advantages to you who seek a compact, efficient, versatile source of heat.

Let's start with the glass tubing. It's made of a VYCOR brand glass that contains 96% silica. And silica in such amounts gives this glass the ability to cope with the usually adverse effects of both *high temperatures* and sudden *thermal shock*.

For example: You can take an object made of a VYCOR brand glass, heat it to 900° C., and then plunge it into ice water *without* cracking, crazing, shattering, or any change in form.

Next, consider the freedom of design this tubing offers . . . and how little space it requires. (O.D. is 5/8".) With a tentative rating of 500 watts per linear foot, you can provide desired heat with short sections "banked," or long, single units.

These units heat up fast, too, going from room temperature to maximum rating within 5 seconds. The warm red coloring is right in the glass—it can't wear out or off. (Note: Specific shade depends on wattage input and varies from a deep red to a cheerful ruby glow—colors that add *psychological* value to the heat.)

Naturally, the glass enclosure protects the heating element from dirt, dust, and accidental shorting. Fire hazard is reduced to zero. And the heating element itself has a life rating of 5,000 hours, *plus*.

Not interested in portable heaters at the moment? How about laundry dryers, broiling units, baseboard heating, air conditioning, industrial dryers? Maybe you've already thought of other possible applications.

If you're interested in finding out more about this compact, attractive, versatile, and challenging item, contact our Appliance Parts Sales Department. Write, wire, or phone.

Afterthought: There are 7 different glasses in the VYCOR brand group. We have a booklet that tells about them, gives details on thermal characteristics, radiant energy control applications, and such. The booklet is Bulletin B-91. Free with the coupon.

On the level

This intriguing (though difficult to show to advantage) bit of gadgetry is part of a *turn-and-bank* indicator for airplanes.

We don't make such instruments. We do supply the glass tubing, made from one of our PYREX brand glasses.

Those who do fashion instruments of this type find Corning a reliable, economical source for this tubing. Besides being free from visual defects this tubing is rugged, accurate and easily worked.

Astute makers of many things have discovered the practical and profitable road to glass components. They bring their wants to Corning.

The list of items and special glasses involved almost defies enumeration. (There are some 65,000 glass compositions in our files.) But a good start is a pleasant book called "This is Glass." Free. And/or drop us a line briefing your problem and we'll investigate and report promptly.

How to prevent TV sunburn

Those who perform in front of TV cameras are occasionally subjected to an occupational hazard called "television sunburn."

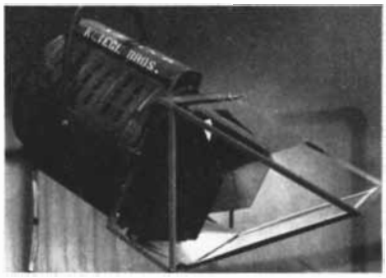
Cause of this unsought skin tinting is the intense heat generated by the big lights used to illuminate sets.

Now set the stage for another problem: Telecasting during the *summer* from a barn-like structure that has defied every effort of those versed in the art of air conditioning.

This "*double trouble*" is what the producers of a popular show, called "Grand Ole Opry," faced last summer. Putting the show on from Ryman Auditorium in Nashville, Tennessee, loomed as quite an ordeal.

Enter here a sensitive and knowledgeable person. His suggestion: Try PYREX brand infrared reflecting glass.

Sheets of this glass were placed in front of the lights with simple brackets. Here's what the setup looked like:



Heat output was reduced some 50%. Yet this PYREX brand infrared reflecting glass still transmitted 75% of the wanted light.

Conclusion: Where there's a knotty problem you'll often find a Corning glass to solve it. A number of good examples are detailed in Bulletin PE-34, a concise reference on infrared, sight glasses, flat glasses and sundry other useful items. A check in the coupon brings it to you.

Corning means research in Glass

CORNING GLASS WORKS, 49-9 Crystal Street, Corning, N. Y.

Please send me the following material: Bulletin B-91, "VYCOR brand Industrial Glassware by Corning" ☐; Bulletin PE-34, "Corning Flat Glasses" ☐; Illustrated booklet, "This is Glass" ☐.

Name_____ Title_____

Company_____

Street_____

City_____ Zone_____ State_____

available soon...

HYFEN

a big step toward automation of wiring harnesses

Crimped pins and sockets snap-locked in plug or receptacle. Individual circuit removal or gang disconnect.

Hyfen ends the need for time consuming solder operations — and the high rejection rate inherent with solder. Pins and sockets are speedily crimped on wire ends by automatic installation tooling — or where more convenient, by bench or hand tools. Dies control and provide a uniform depth of indent which can be inspected by depth micrometer assuring absolute unvarying reliability. Crimping may be done before or after harness is in place.

Hyfen meets or exceeds MIL specifications for voltage drop, dielectric strength, contact engaging force, and contact retention force. It provides high corrosion resistance since there are no fluxes or dissimilar metals involved. Floating contacts in both plug and receptacle make for uniform mating and disconnecting force by the alignment flexibility provided.

Hyfen principle is not limited as to size, shape of plug and receptacle nor to number or size of connections. Wire for bulletin.

Burndy, Norwalk, Connect.—Scarboro, Canada

Established 1845 **SCIENTIFIC AMERICAN** September, 1957 Volume 197 Number 3

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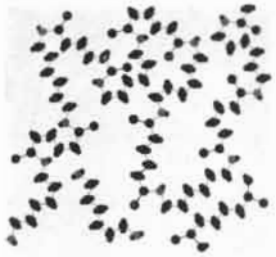

THE COVER

The pattern of colored balls on the cover is a symbol of the subject to which this issue of SCIENTIFIC AMERICAN is devoted: giant molecules. Known to chemists as polymers, these molecules consist of hundreds or even thousands of relatively simple molecules linked in chains. The giant molecules of such substances as proteins and nucleic acids comprise the basic fabric of living matter. Now giant molecules unknown in nature are synthesized by man to make fibers, plastics and a host of other useful materials. The pattern on the cover schematically depicts a short section of the polymer chain of nylon 66 and the simpler molecules of which it is made. The chain begins at the lower left and ends at the upper right. Carbon atoms are represented by black balls, hydrogen by yellow, nitrogen by blue and oxygen by red. At the lower left center is the molecule of hexamethylenediamine; at the lower right, that of adipic acid. When these two molecules are joined by the process described in the illustration at the bottom of pages 86 and 87, they form the basic repeating unit of the nylon chain. Although the nylon chain on the cover twists and turns, the angle between any two bonds in the backbone of the chain remains the same. This represents in two dimensions the angle of the bonds between a carbon atom and its two neighbors in the chain. The angle of bonds is 109.5 degrees.

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209	Massachusetts Institute of Technology.
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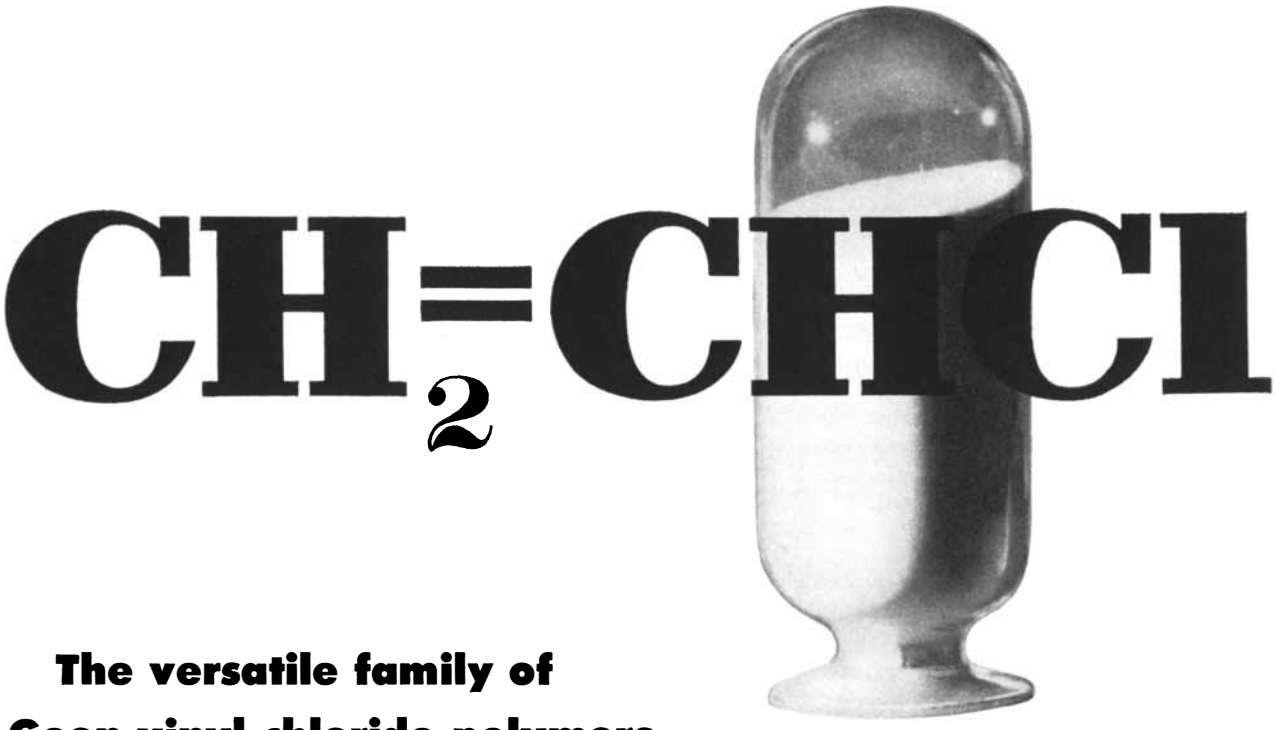
News about

B.F.Goodrich Chemical *raw materials*



The versatile family of Geon vinyl chloride polymers perfected by B.F.Goodrich Chemical can contribute to your new products

ALTHOUGH polyvinyl chloride was known for years, it long remained a laboratory curiosity until one of our scientists learned to make it into a workable, useful plastic. Geon polyvinyl materials are an example of how B.F.Goodrich Chemical research works for you, providing new latitudes for development of products in the plastics, rubber and chemical fields.

For example, today the uses for Geon polyvinyl chloride resins are legion—rigid pipe to flexible electrical insulation, protective coatings to foam padding, phonograph records to paint binder.

In the future, Geon will set new highs in a plastic's ability to withstand working heat. Rigid foamed Geon—extruded in sheets and various shapes—will make light, strong and functional products that insulate against heat and electricity.

In cement and mortar, Geon will improve adhesion and permit thinner walled construction. Durable die cast parts of all kinds will be made of Geon. Geon will introduce new concepts of fabrication; double and triple production for plastic product makers—with minimum capital investment for new equipment.

For suggestions on applications of Geon, write Department GM-1, B.F.Goodrich Chemical Company, 3135 Euclid Avenue, Cleveland 15, Ohio. Cable address: Goodchemco. In Canada: Kitchener, Ontario.

THE FOUR BASIC FORMS OF GEON MATERIALS

RESINS PLASTICS LATICES POLYBLENDS

Geon Polyvinyl Materials

B.F.Goodrich Chemical Company
a division of The B.F.Goodrich Company

B.F.Goodrich GEON polyvinyl materials • HYCAR American rubber and latex • GOOD-RITE chemicals and plasticizers • HARMON colors

A report to American Industry regarding:

the development of *improved* Urethane formulations

Many of the country's important industries in a wide variety of fields were quick to recognize the vital role that urethane can play in its vast range of applications. Included is its demonstrated ability to improve existing products, make new ones possible, and effect *substantial savings* on labor and material costs.

Whether in flexible, semi-rigid, rigid, foamed-in-place or custom-made formulations to suit specific requirements, this versatile synthetic foam opens up vast new profit opportunities for you.

Although some have entered the urethane producing field from other lines, it is logical that manufacturers look to Dayton Rubber for leadership and important new developments, due to the company's wealth of successful experience in pioneering with elastomers, including natural and synthetic rubbers and urethanes, over the years.

For Dayton Rubber the advent of POLY-KOOLFOAM*, the *improved* urethane, was a natural technological evolution. You would *expect* this from the manufacturer of the first cold rubber tire, a co-owner of Copolymer Corporation's great synthetic rubber plant, the co-producer of the patented Talalay foam, the holder of all major urethane licenses, the operator of the largest and most advanced machine in America for production of preformed urethane!

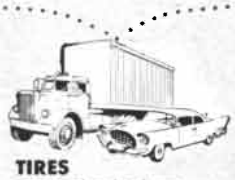
Dayton Poly-Koolfoam includes a complete line of *improved* formulations of preformed flexible urethane in sheets, rolls and blocks, in a wide range of densities, compressions and colors . . . with varying physical, chemical and thermal properties as desired.

For foamed-in-place applications, Dayton Rubber features liquid or "ready-mix" prepolymers for *both* flexible and rigid foams . . . in standard or custom formulations for every need. Our development of new, *slower-reaction* chemicals results in a superior cell structure with vastly improved processing control.

DAYCOLLAN * is the name for Dayton's cast urethane, compounded and cast to custom specifications, and supplied to industry as finished mechanical components. All Daycollan has the common properties of high energy absorption with exceptional Shore hardness, tear strength and abrasion resistance.

Dayton Rubber's research chemists, engineers and service staff, backed by an incomparable back-log of experience in six great plants, are ready to advise and assist you in assignments involving immediate or potential uses of Poly-Koolfoam and Daycollan, in any of its types. Write or wire for full information now, giving your requirements. Also ask us for informative literature and samples today!

THIS IS **Dayton Rubber**

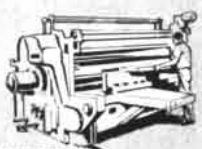


TIRES
Dayton Thorobred passenger car and truck tires, both tubeless as well as tube-type, in a complete range of sizes.

FOAM PRODUCTS
Koolfoam latex pillows, mattress pads, mattresses, and molded furniture cushions.

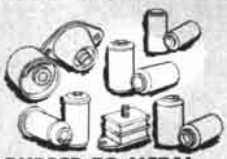
V-BELT DRIVES
Dayton offers the most complete line of V-Belts for every power transmission need, from fractional to 1000 HP.

VACUUM HOSE
Lightweight, plastic, flexible Dayflex is the largest selling hose for the vacuum cleaner industry and many other uses.



PRINTING
Dayco offset and letterpress rollers, Gold Seal offset Blankets, Color Separators and Fountain Dividers for all makes of printing presses.

TEXTILE
Dayton manufactures a complete line of natural and synthetic rubber textile machinery quality parts for spinning and weaving operations.



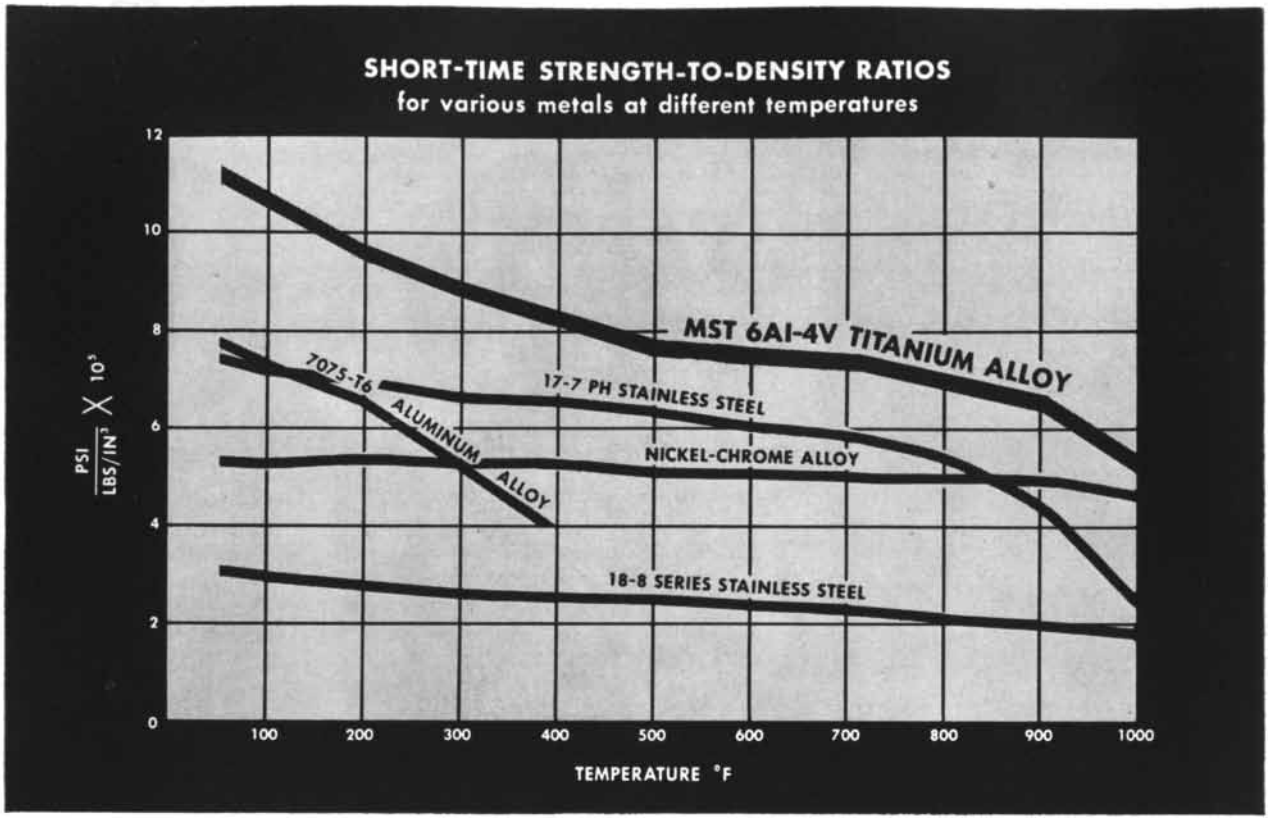
RUBBER-TO-METAL
Metalastik includes rubber-to-metal products, made to specific requirements, for vibration and noise control.

AND OTHER PRODUCTS

Dayton Rubber

*Registered U.S. Patent Office

THE DAYTON RUBBER COMPANY, DAYTON 1, OHIO



TITANIUM ON TOP

in medium-high temperature range

Today's most popular titanium alloy, MST 6Al-4V, excels all other metals in strength to density ratio through 900°F. At room temperature, considering only strength, a part made of this alloy need have only 60% of the weight of the equivalent part in stainless steel.

Performance for extended times at elevated temperatures is likewise good. In typical creep tests, with 1% permanent deformation allowed, MST 6Al-4V alloy shows 100,000 psi allowable stress at 750°F for 1 hour; 77,000 psi at 100 hours; 65,000 psi at 1000 hours.

Meanwhile new alloys extending the elevated temperature usefulness of titanium—to as high as 1000°F—are now emerging from the laboratory into production.

Write Dept. C-5 for copy of "Titanium Alloy Properties"

SELECTION GUIDE TO MST ALLOYS

Typical Mechanical Properties of Annealed Titanium and its Alloys

	Form	Ultimate Tensile Strength, psi	Yield Strength, psi	Elongation %*
COMMERCIALLY PURE TITANIUM				
MST Grade III	Sheet, Bar	70,000	50,000	25
(3 different strength levels)	Sheet, Bar	85,000	65,000	23
	Sheet, Bar	100,000	80,000	20
TITANIUM ALLOYS				
MST 6Al-4V				
Annealed	Bar	140,000	130,000	15
Age hardened (1)	Bar	165,000	155,000	12
Age hardened (2)	Bar	180,000	165,000	10
Annealed	Sheet	140,000	125,000	12
MST 3Al-5Cr	Bar	155,000	145,000	13
MST 4Al-4Mn	Bar	150,000	140,000	14
MST 8 Mn	Sheet	137,000	125,000	16

(1) 1650°F—1 hour—WQ; 1100°F—2 hours—AC
(2) 1700°F—1 hour—WQ; 1000°F—8 hours—AC

WQ—Water Quench
AC—Air Cool

* Values for 1" on bar and 2" on sheet

MALLORY Ti SHARON

MALLORY-SHARON TITANIUM CORPORATION · NILES, OHIO

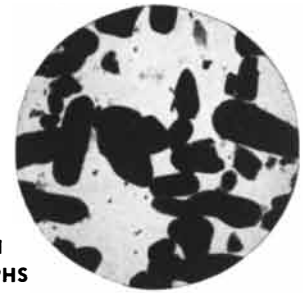
Producers of titanium and titanium alloy sheet, strip, plate, rod, bar, billets

DEVELOPING *Better* MAGNETS

Determination of proper particle size, shape and structure made possible by RCA Electron Microscope at Fullam Laboratories.

Magnetic Particles

ELECTRON MICROGRAPHS



Ferritic Particles

Studies made at the laboratories of Ernest F. Fullam Inc., Schenectady, using the RCA Electron Microscope, have led to the discovery of a new material. The new material promises stronger, smaller, more versatile magnets than any now available. It is composed of microscopic particles of iron, lined up parallel to one another and pressed together in a matrix of nonmagnetic substances.

According to Mr. Fullam, "Only through the use of the RCA Electron Microscope has it been possible to determine the most desirable particle size, shape and structure for producing the strongest magnets." Through the use of the selected area electron diffraction feature, the crystallographic orientation of the individual particles is also determined. In a similar manner, the desirable features of particle structure, size and orientation of ferritic materials such as used on magnetic tapes have been determined by use of the electron microscope.

Wherever industrial research men and consultants to industry are on the threshold of achievement, developing new products, advancing quality control, improving economy of operations, in all probability the RCA Electron Microscope is making its own contribution. Like other famous RCA products, these instruments derive their reputation for superiority from unmatched engineering. Compact, one-piece units, they assure operating ease and convenience with safety and reliability. Installation supervision by the RCA Service Company and contract service are available to keep your equipment at its peak.

Additional information on the features, construction and operation of the RCA Electron Microscope is yours for the asking.

Write to RCA Dept. X-111, Building 15-1, Camden, N.J.

RCA® Tmk(s)

RADIO CORPORATION of AMERICA

CAMDEN, NEW JERSEY

YTTRIUM

Availability of high purity yttrium and rare earth oxides

A report by LINDSAY

Only three years ago, most high purity rare earths were little more than laboratory curiosities.

Today they are extensively used for an amazing variety of chemical and industrial applications.

What happened? Lindsay technicians pioneered the first commercially installed ion exchange unit for the production of separated rare earths. The process was patterned after techniques developed by Doctors Spedding and Powell of the Institute for Atomic Research at Ames, Iowa.

Lindsay's pilot plant rare earth ion exchange installation had 40 six-inch columns. This unit made purified rare earths available to industry for the first time in practical, even though still limited, quantities.

The response from industry was so enthusiastic, we were forced to expand our ion exchange facilities rapidly. Today we have in continuous operation more than 100 columns with large production units of eighteen-inch and sixty-inch diameters.

With our larger production facilities, we are now making prompt shipments of high purity yttrium and rare earth oxides in quantities from a gram to hundreds of pounds.

TYPICAL MAXIMUM IMPURITIES IN LINDSAY PURIFIED RARE EARTH AND YTTRIUM OXIDES

ATOMIC NO.	OXIDE	CODE	PURITY	% RARE EARTH MAXIMUM IMPURITIES AS OXIDES
57	La_2O_3. LANTHANUM OXIDE	528 529	99.99 99.997	0.01 Pr, 0.001 Ce. 0.0025 Pr, 0.0005 others
58	CeO_2. CERIC OXIDE	215 216	99.8 99.9	0.2 (largely La + Pr + Nd). 0.1 (largely La + Pr + Nd).
59	Pr_6O_{11}. PRASEODYMIUM OXIDE	726 729.9	99 99.9	1 La + Nd + smaller amounts of Ce and Sm. 0.1 Ce + Nd.
60	Nd_2O_3. NEODYMIUM OXIDE	628 629 629.9	95 99 99.9	1-4 Pr, 1-4 Sm, 0.5-1 others. 0.1-0.4 Pr + 0.1-0.4 Sm + 0.5 others. 0.1 (largely Pr + Sm).
62	Sm_2O_3. SAMARIUM OXIDE	822 823	99 99.9	0.2-0.7 Gd, 0.2-0.6 Eu, and smaller amounts of others. 0.1 (largely Nd + Gd + Eu).
63	Eu_2O_3. EUROPIUM OXIDE	1012 1011	98-99 99.8	1-2 Sm + smaller amounts of Nd + Gd + others. 0.2 (largely Sm + Gd + Nd).
64	Gd_2O_3. GADOLINIUM OXIDE	928.9 929.9	99 99.9	1 Sm + Eu + trace Tb. 0.1 Sm + Eu + trace Tb.
65	Tb_4O_7. TERBIUM OXIDE	1803 1805	99 99.9	1 Gd + Dy + Y. 0.1 Gd + Dy + Y.
66	Dy_2O_3. DYSPROSIUM OXIDE	1703 1705	99 99.9	1 (largely Ho + Y + Tb + small amounts of others). 0.1 Ho + Y + traces of others.
67	Ho_2O_3. HOLMIUM OXIDE	1603 1605	99 99.9	1 (largely Er + Dy + small amounts of others). 0.1 Er + Dy + traces of others.
68	Er_2O_3. ERBIUM OXIDE	1303 1305	99 99.9	1 Ho + Dy + traces Yb and Y. 0.1 Ho + Tm.
69	Tm_2O_3. THULIUM OXIDE	1405 1403	99.9 99	0.1 Er + Yb + trace Lu. 1 Er + Yb + trace Lu
70	Yb_2O_3. YTTERBIUM OXIDE	1201 1202	99 99.9	1 Er + Tm + trace Lu. 0.1 Tm + trace Lu + Er.
71	Lu_2O_3. LUTETIUM OXIDE	1503 1505	99 99.9	1 Yb + Tm + traces of others. 0.1 Yb + Tm + traces of others.
39	Y_2O_3. YTTRIUM OXIDE	1112 1115 1116	99 99.9 99.9+	1 Dy + Gd + traces Tb and others. 0.1 Dy + Gd + traces Tb Approx. 0.05 Dy + Gd.

COSTS GREATLY REDUCED

Of course, as production of purified rare earths increased, costs came down. For example, only three years ago Terbium Oxide cost $500 a gram. Today you can obtain moderate size lots at less than $3 a gram.

Now that you know these high purity oxides are so readily available and the cost so remarkably low, what are *you* waiting for?

Rare earths, in purities up to 99.99%, have captured the interest and imagination of scientists in many industries as valuable new tools for the improvement of processes and products.

Your research, product development and production people should investigate the possibilities of these materials. Our bulletin "Purified Rare Earth and Yttrium Oxides" will give you detailed information and prices.

PLEASE ADDRESS INQUIRIES TO

LINDSAY CHEMICAL COMPANY

264 ANN STREET, WEST CHICAGO, ILLINOIS

OPERATIONAL INFORMATION SYSTEMS discussed by *Hank Bechard*

Fundamentally, Operational Information Systems are designed to provide immediately available digital information about selected physical phenomena affecting a process. Such information can be related to plant operating efficiency or used continuously to check product specifications. At present such process trend information is computed manually, and results are usually not available for several hours after corrective measures could have been instigated. The design goal is to obtain an information gathering system which will provide data on a real-time basis so that such corrections may be made immediately.

If properly designed, an Operational Information System can be made to provide better process information than is now being obtained by tailoring individual data-collecting systems for each specific function of a process. The versatility achieved with this approach is characterized by the fact that data-handling modifications of the Operational Information System are made possible without having to resort to redesign. Thus, adding to or expanding the System is readily accomplished within the limitations of the computing and memory capacities designed into it. The changes can also be made rapidly without the loss of any information pertaining to the physical phenomena being studied.

The design of a universal system of this type implies functional construction. Its distinctive feature is that it incorporates a specially designed digital computer as the fundamental building block. Analog to digital conversion as well as input scanners and output recording components are then added to it. And in contrast to special purpose computing elements, the Operational Information System features completely flexible internal programming.

In the conventional data-logging system, programming is accomplished by means of an input switching system where an additional contact for each input is needed in conjunction with a patchboard in order to introduce the specific instruction peculiar to the input. In the Operational Information System, pinboards or patchboards—accessories to sequence-scanning devices—are entirely eliminated. Programming is accomplished by punching paper tapes with all the necessary instructions and feeding this information into the computer where it is stored magnetically. The instructions can therefore be varied at any time without making any physical changes to the equipment. A single memory unit is incorporated for all memory requirements such as: scanning sequence, sampling schedules, linearizations, scaling factors, range suppressions, alarm levels, alarm conditions, temperature and pressure values for flow adjustment, computation instructions, etc. Since this memory unit is designed to permit random access, the greatest freedom is available to schedule sampling rates and sequences. For instance, the repetitive scanning of a selected input may be intermingled with single sequential scanning of other inputs.

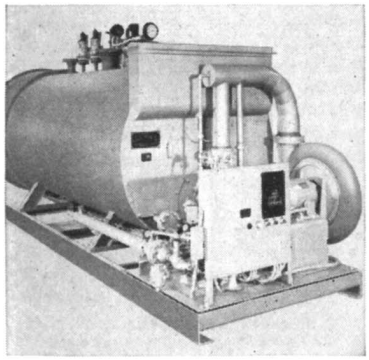
Henry L. Bechard, administrative engineer, describes Operational Information Systems.

In the Operational Information System all analog voltages are converted to the digital form before any operations whatever are performed upon them. By digitizing the voltages immediately, and not operating upon them in the analog form, inaccuracies introduced by analog computations are completely avoided. This is particularly important in the more intricate computing operations, and guarantees digital accuracy for all operations.

Progressive industrial management has invested in conventional data-logging systems primarily in the interest of gaining experience in this area. Time and again such experience has yielded significant process information leading to improved plant performance and more economical operation, and in scattered cases has even led to minor loop control.

The concept of the Operational Information System capitalizes upon this accumulation of experience gained in data-handling and process control and now, in a single versatile system, takes the boldest step yet forward toward filling industry's ultimate goal of "closing the overall process loop."

Deep cooked . . . and always uniform in color and flavor



A horizontal vaporizer (above) is used by the Wise Potato Chip Co. Low pressure performance (144 p.s.i. at 750°F.) of Dowtherm permits the use of compact, thin-walled equipment.

Wise Potato Chip Company solves uniform process heating problem with Dowtherm, Dow heat transfer medium

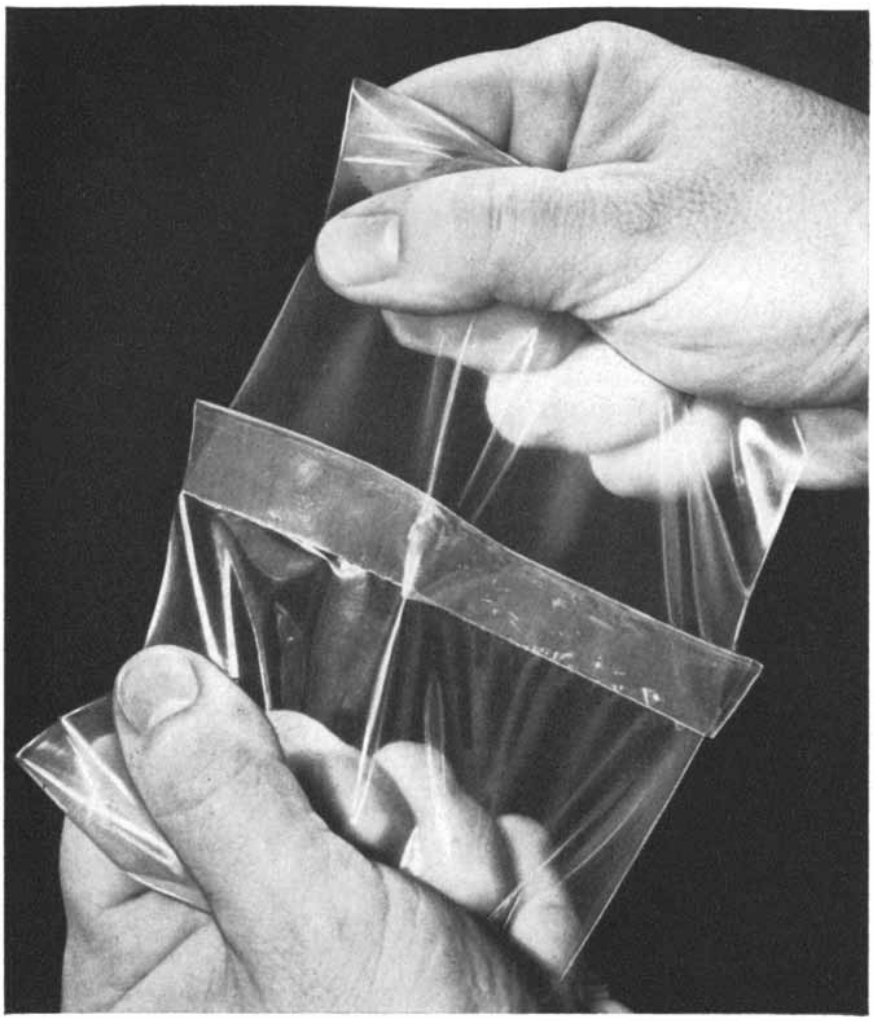
Faced with the unique problem of deep cooking uniform color, taste and crispness into their chips, a few years ago the Wise Potato Chip Company, Berwick, Pennsylvania, sought the answer to maintaining a constant temperature with varying heat loads.

Intense examination of many heating systems led the Wise Potato Chip Company to select an entirely closed heating system using Dowtherm® as a vapor heating medium.

These results were soon apparent: Now heating efficiency is very greatly improved. Fuel costs are reduced. Fire hazards are reduced because with Dowtherm the heating source is placed far from the processing area. Quality is controlled more easily by the use of Dowtherm.

For your own peace of mind, if you have a process heating problem ranging from 350° to 750°F., we advise you to talk with us. We might have the answer that will improve your product—and save your company money. THE DOW CHEMICAL COMPANY, Midland, Michigan, Dept. BD 845L-1.

YOU CAN DEPEND ON DOW



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HEAT-SEALABLE POLYESTER FILM

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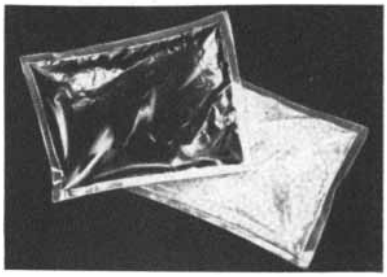
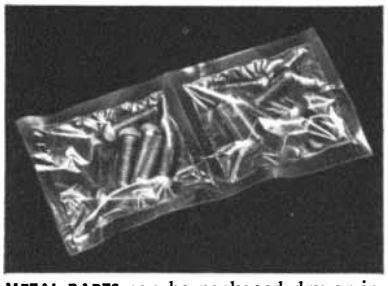
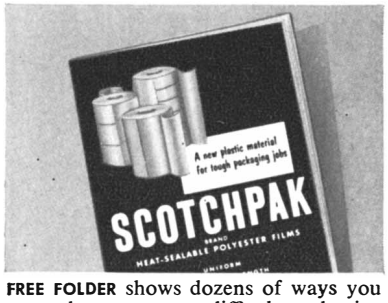


ACIDS or volatile chemicals can be packaged easily, handled safely, shipped without fear in heat-sealable containers of new "Scotchpak" Polyester Film. Also lines drums and cartons.

FOOD ITEMS are packaged safely in clear-as-glass "Scotchpak" Film. Contents can be frozen . . . even boiled *right in the package*. Low gas penetration rate . . . inert and non-toxic.



METAL PARTS can be packaged dry or in oil or grease to protect them against corrosion. Transparent packages are easy to handle, easy to ship and to store. Simplifies issuing of parts and units.



FREE FOLDER shows dozens of ways you can solve your most difficult packaging and shipping problems with new "Scotchpak" Polyester Film. Just write on your letterhead: Film Products Group, 3M Co., St. Paul 6, Minn., Dept. PU-97

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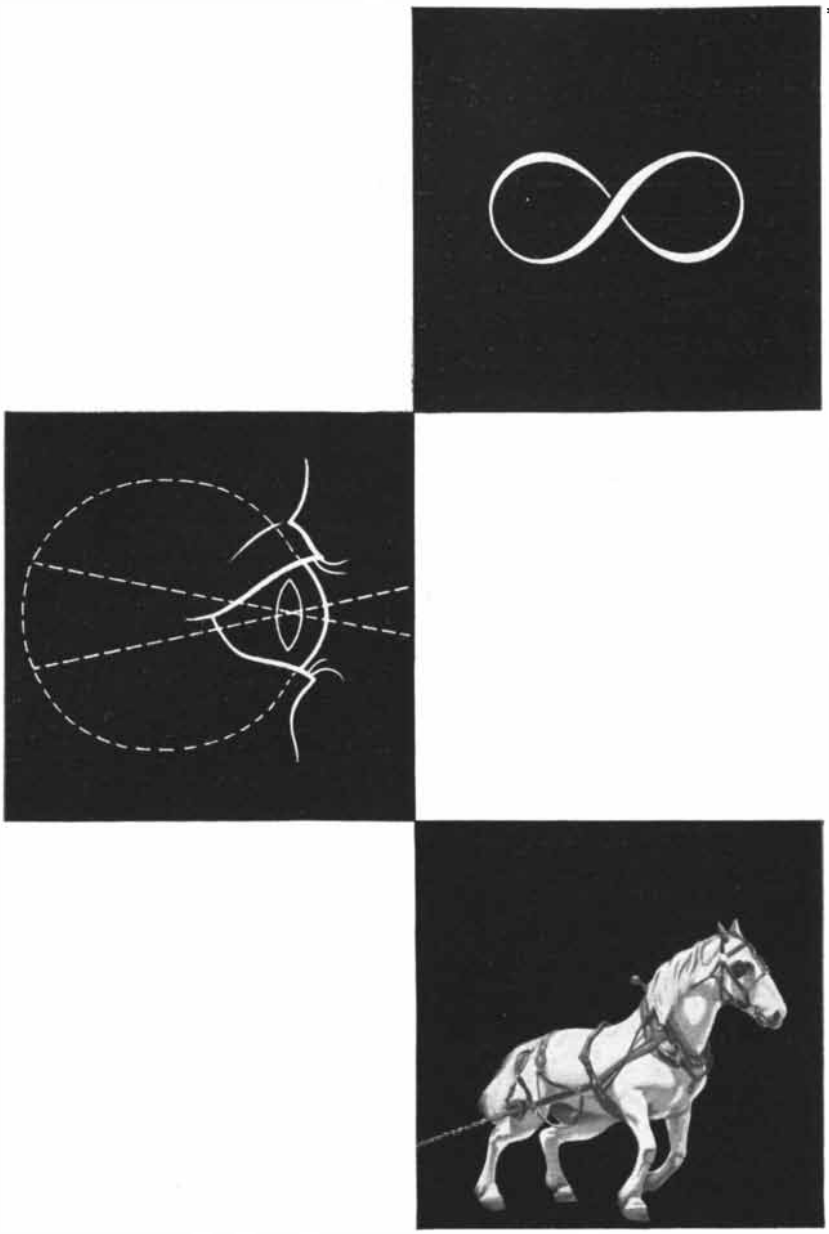

*TRADEMARK FOR W. R. GRACE & CO.'S POLYOLEFINS

Building-blocks for a brand new plastic

Today's new plastics spring from infinite imagination. Yet the best of them have the strict functionalism of a workhorse. To succeed, they must be wholly practical.

A good example is GREX – one of the newest. Fundamentally it is a type of polyethylene, a familiar, dependable plastic resin long since broken to harness, well suited to varied but limited tasks.

Imagination – and knowledge – now transform this material into a completely new substance. Its molecules are rearranged, re-aligned, tightly compacted. Now it can be used to provide new strength and rigidity in manufactured articles. Highly resistant to heat, it can be sterilized by boiling.

It resists chemicals and solvents as well. It is an effective barrier to moisture-vapor transmission. It has a rich, glossy appearance. And for all the difference in its performance, GREX can be made into finished products by conventional methods such as molding, extrusion and vacuum forming.

Still functional, yes. But the scope and number of functions has been enormously increased.

Your own imagination and knowledge may suggest important new uses for GREX. To learn more about this remarkable product, simply write to us on your business letterhead.

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W. R. GRACE & CO.
POLYMER CHEMICALS DIVISION

Plant
Baton Rouge, La.

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Clifton, N. J.

10 useful properties of plastics and fibers

Giant molecules do things better.

That's why we are interested in them in the form of plastics, resins and man-made fibers.

Just ten ways better? Hardly. The ten major properties we are going to cite are certainly basic, useful properties. But taken individually they do not fulfill a practical application.

Other materials claim many of these properties. But as a class, synthetic giant molecules are more versatile in combining them for usefulness and aesthetic appeal.

This check-list then is first of all a singling out of one desirable asset from among many. It is also a demonstration of how Allied Chemical plastic and fiber products can meet specialized needs.

1. Toughness

Many high polymers are tough or attractive, but CAPROLAN polyamide fiber successfully manages the difficult combination of toughness and beauty. This toughness is combined with a rich, long-lasting color for upholstery fabrics, carpeting and similar strength-beauty applications. The secret of the color is in CAPROLAN'S complete dye absorption.

CAPROLAN also makes an amazingly durable — and safe — tire cord, or a sturdy rope with all the properties of conventional nylon — plus extra values of its own.

2. Durability

There are more than five dozen different PLASKON alkyd coating resins, and the property they have in common is the ability to build different kinds of durability into a product easily. They also can add gloss, adhesion, color retention and flexibility to a coating.

PLASKON alkyd appliance coatings, for example, are soap- and alkali-resistant, and they bend with the steel sheet if it is dented. This flexibility is also useful in making non-cracking coatings for venetian blinds. The fine weathering properties of alkyds are shown in outside paints of all kinds.

3. Hardness

Many materials are hard, few can be fully colored. PLASKON melamine molding compound has outstanding hardness from the surface all the way through. Yet it can be produced in any color from the purest white through delicate pastels and rich hues to midnight black.

The products which capitalize on these assets? Smartly styled and break-resistant melamine dinnerware is one of the most familiar. Others range from cutlery handles to fine chess sets, or anywhere solid color is to be combined with durable molded parts which cannot chip, craze, crack or peel like painted surfaces.

4. Chemical Stability

From fluorine, the most active element, come some of the most stable compounds, the fluorocarbons. GENETRON Plastic HL (a high molecular weight polymer of trifluorochloroethylene) is not attacked by inorganic acids, alkalis, oxidizing agents and most organic compounds. Most important, it retains useful properties all the way from –320° F. to as high as 390° F.

Extruded as a film, GENETRON Plastic HL has a unique combination of qualities. With high moisture and gas impermeability, and transparency, it is better than laminates for many applications. The plastic is suited for electrical applications, electronic components, laboratory ware, piping and tubing — just to mention a few of its possibilities.

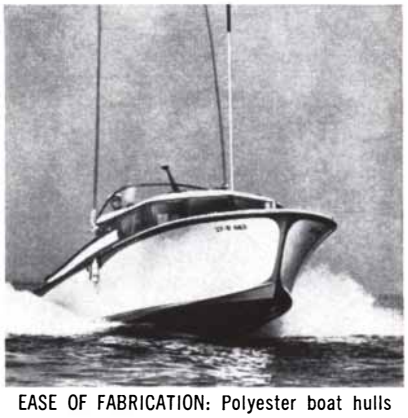
5. Impact and Temperature Resistance

PLASKON nylon is a new type of nylon molding compound — a polymer of polycaprolactam, generally known as "nylon 6." It has

TOUGHNESS: Caprolan upholstery fiber

HARDNESS: Melamine dinnerware

FINISH: Injection molded polyethylene



EASE OF FABRICATION: Polyester boat hulls

the assets associated with nylon molding compounds: strength, light weight, self-lubrication, high melting point, abrasion- and solvent-resistance. It also adds a few of its own: ease of molding, controllable crystalline structure, and ease of colorability.

These properties make PLASKON nylon molding compound well suited for sterilizable equipment in hospitals and restaurants, corrosion-resistant fasteners and shower door rollers, self-lubricating gears and bearings, textile bobbins and lighting fixtures and heavy-duty industrial parts.

6. Built-In Color

Solid color objects have a deep-set lustre and permanence that are useful as well as handsome. PLASKON urea molding compounds can be tinted in virtually any color, and the color is unaffected by common organic solvents, soaps, oils and greases. Moldings are hard, smooth and scratch resistant.

This combination makes urea a popular molding material for cosmetic containers and closures, for colorful and long-lasting buttons, for heat-resistant appliance knobs and handles. A special housing-type compound is molded to make colorful cabinets for radios, television sets and adding machines.

7. Finish

Finish of injection molded polyethylene depends on the flow property of the resin. One effective solution is using low molecular weight A-C polyethylene in the mix to improve flow. The entire appearance of molded articles is improved with the use of this polymer as a modifier: color dispersion is improved, and the use of polished molds gives a high-gloss finish. It is also economical, for the faster cycle time results in increased production and decreased costs.

Low molecular weight A-C polyethylene is used in the injection molding of toys, housewares and such large items as quiet trash cans that won't corrode, leak or dent. In its emulsifiable form, A-C polyethylene is used to produce superior emulsion polishes. It adds durability, toughness without hardness and non-slip properties to household and industrial floor polishes, car polishes, shoe polishes and other coating formulations.

8. Environmental Stability

One of the newest polymer products is high molecular weight A-C Polyethylene Pipe Compound, based on a distinctly different polyethylene resin made at low pressure. This amazing new plastic has high bursting strength, resistance to impact, shows no stress cracking, has superior heat resistance and is resistant to chemicals, organic solvent and hydrocarbon liquids.

The unique combination of these properties in high molecular weight A-C Polyethylene Pipe Compound makes a superior plastic pipe, but biggest future uses of this and related compounds are not yet known. Likely candidates are films, sheets, moldings and fibers.

9. Simplicity of Fabrication

PLASKON polyester resins reinforced with glass fibers are thermosetting plastics that cure at either room or elevated temperatures. They offer these desirable properties: high strength, dimensional stability, color, light weight and durability. The high strength-to-weight ratio of reinforced polyester resins makes these materials anywhere from half to several times as strong as structural steel.

These versatile materials are being successfully used for durable boat hulls and car bodies, translucent panels, and sturdy modern furniture.

10. Economy

Almost any property can be built into a product. But PLASKON phenolic resins offer the broadest range of properties while remaining one of the cheapest plastics in price. Some of these properties are excellent heat resistance and chemical resistance, strength and dimensional stability.

As molding compounds, PLASKON phenolics are used for electrical applications, housings for telephones, appliance handles and washing machine agitators. Phenolic resins make excellent laminates, industrial or decorative (such as burn- and stain-resistant table tops). One of the newest resins is a very high temperature-resistant phenolic for aircraft components.

* * *

If you want to know more about any of these products, write to Information Service, Allied Chemical, 61 Broadway, New York 6, N. Y.

Two of them are more recent developments, and their availability is limited. GENETRON Plastic HL is available only in experimental quantities, while the entire production of A-C Polyethylene Pipe Compound is committed and not available for general distribution at this time.

The capitalized product designations on these pages are Allied Chemical trademarks.

Big molecules from little ones

The raw materials of polymers are monomers, and Allied is interested in both. A creative research program supports its position as the leading producer of industrial chemicals.

In the mushrooming field of urethane foams, for example, National Aniline Division makes one of the key ingredients — NACCONATE diisocyanates (which are combined with PLASKON polyester resins, or other materials containing three reactive groups, to yield urethane plastics). Urethanes have been attracting attention even in the exciting plastics field, opening up such new areas as foamed-in-place insulation for refrigerators, boats, aircraft, flexible foams for carpet pads and upholstery, and interlining for coats.

National Aniline also makes caprolactam monomer (the starting material for polyamide fiber), and raw materials for plastics and fibers, including adipic acid, maleic anhydride, fumaric acid, phthalic anhydride, aniline and curing agents.

Another interesting monomer is Solvay Process Division's vinyl chloride, the base material for polyvinyl chloride. Shower curtains, rainwear and packaging are a few applications which capitalize on vinyl's toughness and low water absorption. Solvay also makes ammonium chloride, used as a catalyst in urea resins and other plastics, and methyl chloride and aluminum chloride, which play integral parts in butyl rubber. SOLVAY caustic soda and chlorine are also important in the production of giant molecules.

Vinyl garden hose

Many intermediate building blocks for high polymers come from Nitrogen Division, whose products include formaldehyde, methanol, urea, urea-formaldehyde concentrate, ethylene oxide and glycols, and ethanolamines.

And General Chemical Division, in addition to its fluorocarbons, is a leading supplier of sulfuric, nitric and many other industrial acids.

Barrett Division, Allied's largest producer of high polymers, also manufactures plasticizers, solvents, maleic anhydride and phthalic anhydride.

LETTERS

Sirs:

George E. Henry's article "Radiation Pressure" [SCIENTIFIC AMERICAN, June] contains the statement: "Light beams will not propel our vehicles or push open our doors." I think, with all due respect to Mr. Henry's knowledge on the subject of radiation pressure, that he should have considered studies in this field by Dr. Eugen Sänger and various projects on the part of leading aircraft companies in this country in the field of propulsion by radiation from intense fields of light created by some nuclear means. So-called "photonic propulsion" has come in for extensive and serious scientific investigation in the past few years. I think commentary on this subject should have been included.

PITT TYSON MANER, JR.

Montgomery, Ala.

Sirs:

It is quite true, as Mr. Maner points out, that competent and sober theoretical study has been given to the subject of photonic propulsion. It is in the best creative engineering tradition to consider seriously any technical principle whatever that holds out the slightest hope of solving a particular technological problem. Subsequent critical

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Igniting Liquid Propellant Rocket Engines

by Leonard Dombras

A research physicist in the Physics Department, Component Development Division, Reaction Motors, Inc., Mr. Dombras has currently been investigating ignition phenomena as applied to rocket engines. A graduate of Rutgers University, where he received a B.S. in Physics, he has been with RMI since 1951.

Rocket engines operate with a wide variety of liquid propellants having various chemical and physical properties. These properties, in conjunction with the application of the missile, dictate the type of ignition system that will be most effective. Although the exact mechanism involved in the ignition process is not completely understood, it is generally believed that, under specific conditions, there exists a minimum threshold energy requirement below which the combustion wave does not propagate. Rocket engine igniters are generally designed to provide this energy on a "more than enough" basis.

Many liquid propellants require no external source of energy to achieve ignition. Hydrogen peroxide, for example, may be catalytically decomposed in the presence of silver or platinum metals, and many bipropellant combinations react spontaneously merely on contact with each other.

Non-spontaneous propellant combinations must be ignited by some form of energy introduced from an exterior source. In early rocket experiments, ignition was achieved with burning kerosene-soaked rags held at the end of a long pole. After several explosive starts, the trend shifted to the use of electrically fired pyrotechnic charges—a technique successfully used in the V-2 and Viking engines and still employed in many single-shot rocket applications. Later ignition techniques employed ultrasonics, catalytic agents, pyrophoric fuels (which react spontaneously in the presence of an oxidizer), electrothermal devices (operating with arcs, sparks, and heated filaments) and torch or flame-type igniters.

The advent of piloted rocket research aircraft required lighter, more compact ignition systems capable of repetitive starts at high altitudes and presented several difficult problems. The experimental X-1, X-1A, and the Douglas Skyrocket, powered with RMI engines, had four thrust chambers which required starting during flight. To insure smooth and positive ignition, torch-type igniters, operating with oxygen and alcohol, were developed. Small quantities of these propellants were injected into a precombustion chamber, ignited, and the resulting flame projected into the rocket motor. This unique device provided high ignition energy, operated at all altitudes, and assured smooth, reliable starts.

Preventing the accumulation of unreacted propellants in the combustion zone is the most important factor in rocket motor starting, regardless of the ignition technique employed. An insignificant ignition delay—in the order of milliseconds—or a sudden propellant surge during the ignition period can result in a buildup of mixtures that may explode with destructive violence.

A successful rocket motor start, therefore, is a function of numerous variables. Propellant flow rates must be accurately controlled and the propellants intimately mixed. The mixture ratio must be ignitable, and the ignition energy must be adequate. These factors are continuously being investigated at RMI for the purpose of advancing rocket science.

Solving some of tomorrow's specific rocket problems—by conducting experiments pertaining to the development or investigation of theories, principles or techniques concerning operation of rocket engines and related equipment—is the general work of the team of specialists comprising RMI's Component Development Division. Our door is open to qualified men interested in this challenging work.

If you desire one or more reprints of Mr. Dombras' article, or would like to receive further information about employment at RMI, write to Information Services, Reaction Motors, Inc., 20 Ford Road, Denville, N.J.

Power for Progress
RMI

evaluation will eliminate the impractical solutions; meanwhile the momentary admission of these unworkables will have had a beneficial effect on the thinking of all concerned. Especially in rocketry, the doors are wide open for the proponents of radical ideas, if only on account of the difficulty and high cost of achieving performance by conventional means.

So, as early as 1947, we find Seifert and Mills discussing a nuclear-powered rocket, weighing the merits of three different schemes for producing thrust: (a) emission of photons, (b) emission of fission fragments, (c) backward acceleration of an inert working substance. Almost a decade later, Sänger reviews the same three possibilities, with certain modifications due to his having started from the assumption of a fusion reaction. These and others are interesting studies, which might well have been mentioned in my article if I had happened to think of them.

All this, however, makes no rebuttal of the common-sense prophecy: "Radiation pressure will not propel our vehicles." On the contrary, I find Sänger's recent work a most impressive documentation of my own argument. Sänger is famous for his willingness to talk about man-hours and dollars on a grandiose scale, with technical conceptions to match. His photon rocket has a reacting core at 100 million degrees Kelvin; this is surrounded by gas at a modest 100,000 degrees, under pressure of 4,000 atmospheres—all this to attain a driving pressure of a couple of ounces per square inch. Let's not count on any such motor as this to move us around from place to place.

GEORGE E. HENRY

Ultrasonics Engineer
General Engineering Laboratory
General Electric Company
Schenectady, N.Y.

Sirs:

I have read the interesting article "A Rocket around the Moon," by Krafft A. Ehricke and George Gamow [SCIENTIFIC AMERICAN, June].

The authors would have us believe that only three factors must be considered to send a rocket around the moon: theoretical calculations, effort and luck. What they do not tell us is that there exists a gigantic abyss of unreliability between theory and practice in the development of such complex

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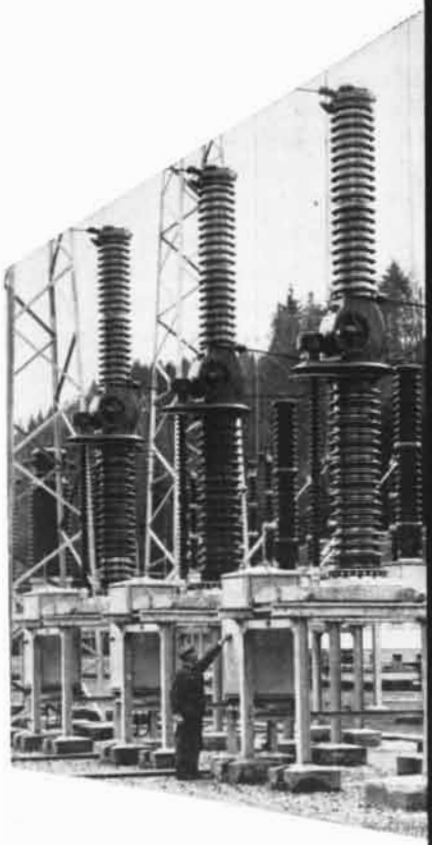
Only an Araldite Epoxy-based adhesive proved acceptable for repair of the broken bronze Moonbeam Buddha. Gakko Bosatsu in Nara.

In the United States...
Araldite Epoxy Resins adapt to large and small scale precision designed structural uses, such as this 14 ft. aluminum reflector. The skin of Araldite Epoxy Resin and glass cloth is joined to aluminum and honeycomb with an Araldite Epoxy to complete structure. Emerson & Cuming, Inc., I.T.E. Circuit Breaker Co.



In Switzerland...
Improved efficiency and service life for many insulating parts of these giant 220-KV low-oil switches was assured by use of glass cloth with a heat-cured Araldite Epoxy Resin. (Mfrs: Sprecher & Schuh AG., Aarau.)

In Switzerland...
Cross-sectional view of straightway valve shows how an Araldite Epoxy Resin met mass production, dimensional, and other exacting specifications to improve durability and overall efficiency of such units in service. (Mfrs: AG. Oederlin & Cie., Baden.)

CIBA Company Inc., Plastics Division
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machines as guided missiles and spaceships.

Complex, automatic machines are inherently unreliable and will remain so. Note the many recent reports in newspapers of guided missile failures. Even the mundane problems our guided-missile developers face in achieving the accuracy, performance and reliability required in moderately long-range guided missiles are nearly insurmountable. But to believe one can develop a three-stage rocket weighing 240,000 pounds, so precise, so accurate and so reliable as to have an initial velocity of 23,827 miles per hour, to pass within 1,281 miles of the moon and then return to earth with all of its delicate electronic equipment functioning, is certainly naive, to say the least.

The public is being bombarded daily by space propaganda to the extent that not only the layman, but also many who should know better, believe that a trip to the moon is merely a matter of a few years' effort and of having someone foot the bill.

Project Vanguard enthusiasts initially claimed that they could shoot six satellites into predetermined orbits for less than $1 million. To date they have spent more than $57 million and already President Eisenhower has asked for $34.2 million more. I am reminded of a story in Gamow's book *One, Two, Three . . . Infinity*. King Shirham, in rewarding his grand vizier for inventing the game of chess, agreed to grant the clever vizier's request to "give me a grain of wheat to put on the first square of this chessboard, and two grains to put on the second square, and four grains to put on the third . . .," etc. "You do not ask for much, Oh my faithful servant," exclaimed the king. But it turned out that this amounted to 18,446,744,073,709,551,615 grains, which is equivalent to the world's wheat production for some 2,000 years!

GEORGE A. HENDERSON

Past President
Alabama Chapter
American Rocket Society
Huntsville, Ala.

Sirs:

I enjoyed B. D. Cullity's article "Diffusion in Metals" [SCIENTIFIC AMERICAN, May].

One statement, to the effect that case hardening of steel produces a "hard surface to resist wear and a ductile interior

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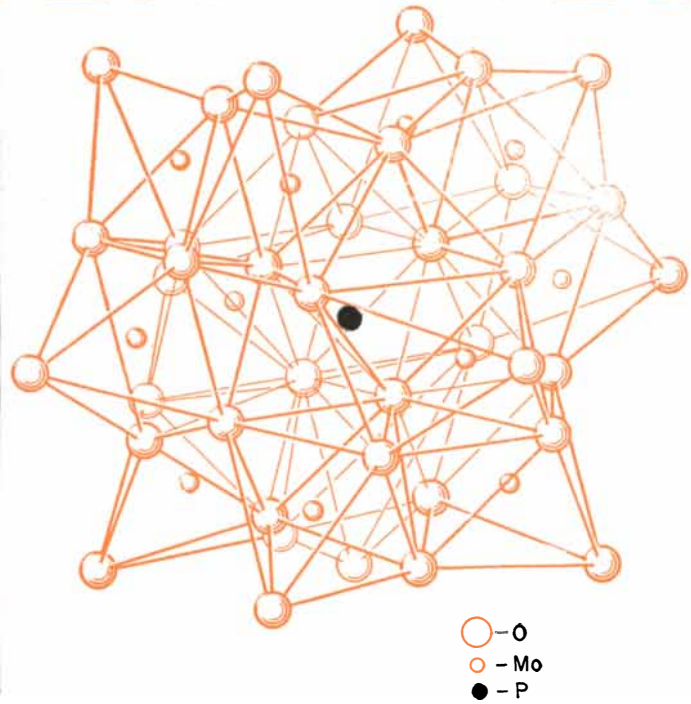

The heteropolymolybdates comprise a unique family of giant molecules. Perhaps you can put them to work. To help you evaluate them, Climax has edited the vast and sometimes conflicting literature on these compounds into a new technical bulletin, "Properties of Heteropolymolybdates". It is a concise presentation that will serve as a guide to existing and potential industrial applications of these unusual chemicals.

For samples and a copy of "Properties of Heteropolymolybdates", write Climax Molybdenum Company, Dept. 24, 500 Fifth Avenue, New York 36, N. Y.

These heteropolymolybdates are now available in laboratory quantities

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Mol. wt. >1800

2:18 SERIES

$Na_6P_2Mo_{18}O_{62} \cdot xH_2O$ Mol. wt. >2800

SOME PROPERTIES OF HETEROPOLYMOLYBDATES

EXTRAORDINARY SOLUBILITY

Free acids are soluble in water up to 85% by weight of solution and are also soluble in alcohol and ether. Most metal salts (including those of heavy metals) are also very soluble in water.

REACTIONS WITH ORGANIC BASES

Heteropolymolybdates precipitate alkaloids, proteins, basic dyestuffs and many other organic bases. They are strongly adsorbed by nitrogen fibers, such as nylon and wool.

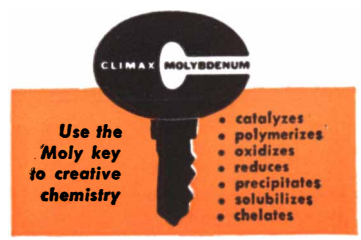
OXIDATION AND REDUCTION

Heteropolymolybdates are powerful oxidizing agents. Reduced compounds with 1, 2 or 3 oxygen atoms removed are very strong reducing agents.

HYDRATION

Heteropolymolybdates are highly hydrated. Most compounds have several stages of hydration, and can be converted reversibly from one stage to another.

CLIMAX MOLYBDENUM



to stand up to sudden shocks without breaking," is open to question, and further clarification would be interesting. The belief that a ductile interior is advantageous because of its toughness, resisting shock and deformation without breaking, is common and appears in many books.

However, a ductile steel is tough because it can be plastically deformed to a considerable extent without breaking; a brittle steel will resist a higher load but cannot be given much plastic deformation. Therefore the toughness of the ductile interior of a case-hardened part can be utilized in service only if the deformation is great enough to cause plastic deformation of the interior. But if the interior is so deformed, the outside must be deformed as much or more, and being brittle, will break. The fracture may take the form of small cracks, and these are likely to propagate through the ductile interior.

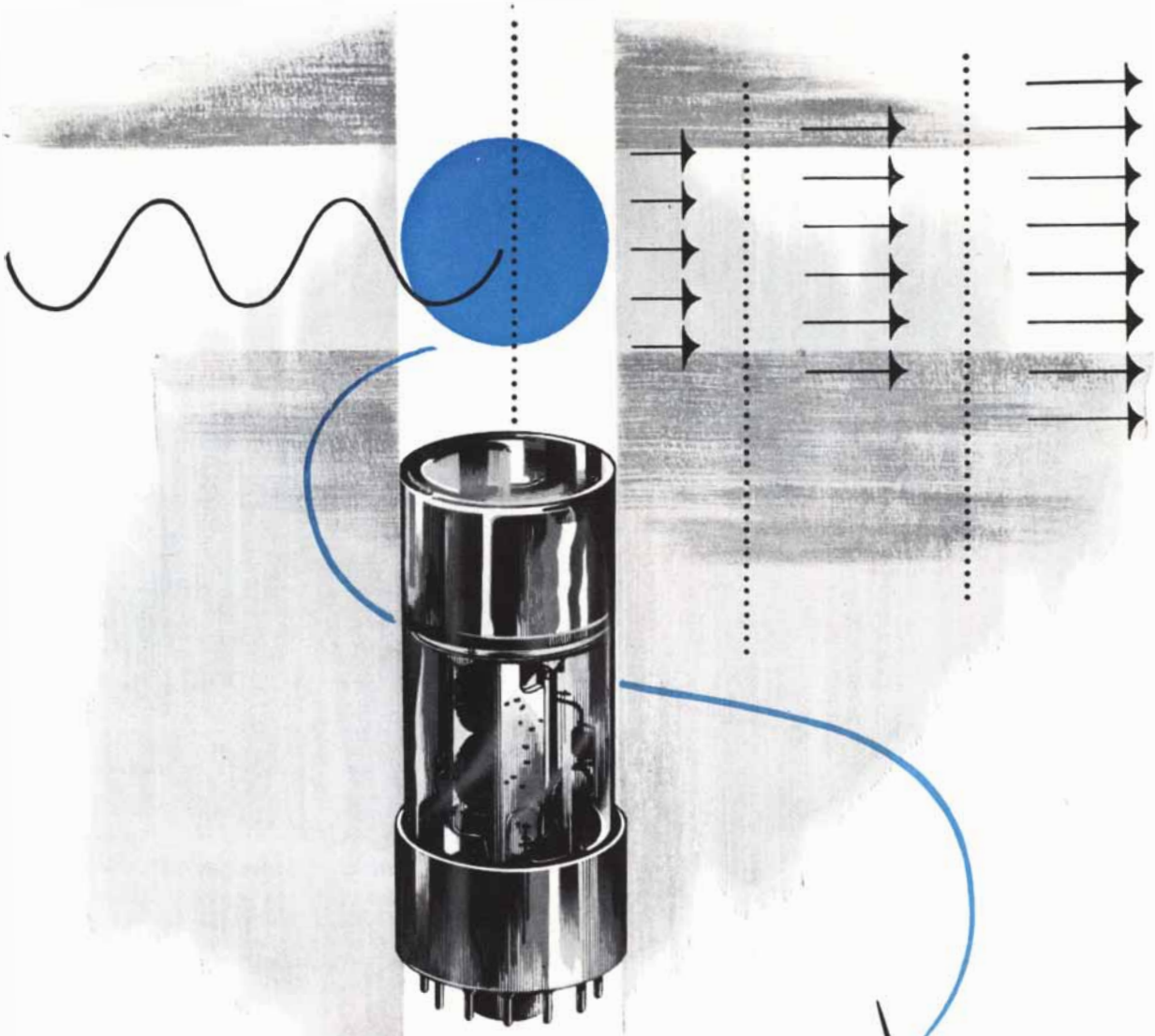
In spite of the apparent failure of the "tough interior" explanation, case hardening has been used for a long time, often with beneficial results compared to hardening the steel throughout. The correct explanation seems to be that hardening the surface by any of several methods produces residual compressive stress in the surface, with compensating tensile stress in the interior. Since failure usually starts by tensile stress at a scratch or other surface irregularity, residual compression will increase the load required to produce sufficient tensile stress to initiate failure; the extra tensile stress in the interior will not be harmful since the interior usually does not contain such irregularities as scratches.

There are many different types of loading to which steel parts may be subjected, and there is statistical variation in the results of any one type of test, so that a simple comparison of case hardening and through hardening is not possible. However, in many applications case hardening does appear to be superior for the reason discussed above, as well as because there is less distortion when only the surface is heat treated.

These comments are from the viewpoint of a mechanical engineer rather than a metallurgist, but I hope they may be of interest.

PETER L. BALISE

Assistant Professor
Department of Mechanical Engineering
University of Washington
Seattle, Wash.



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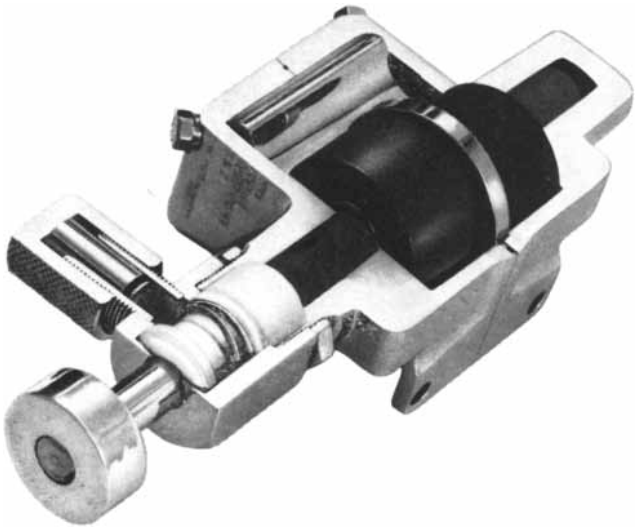
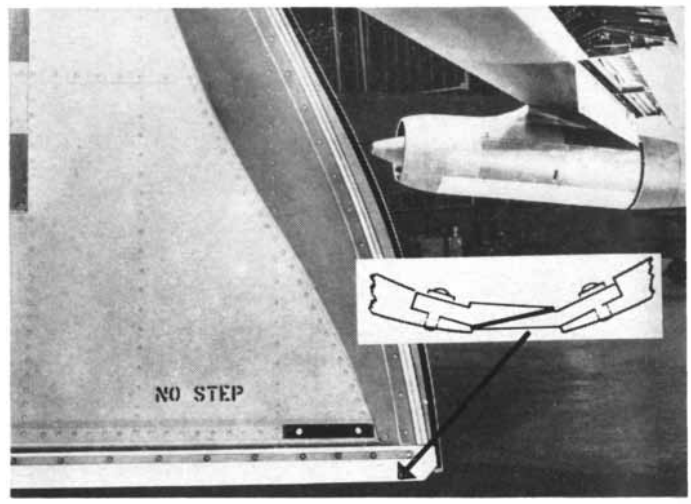
Du Pont Polymers make

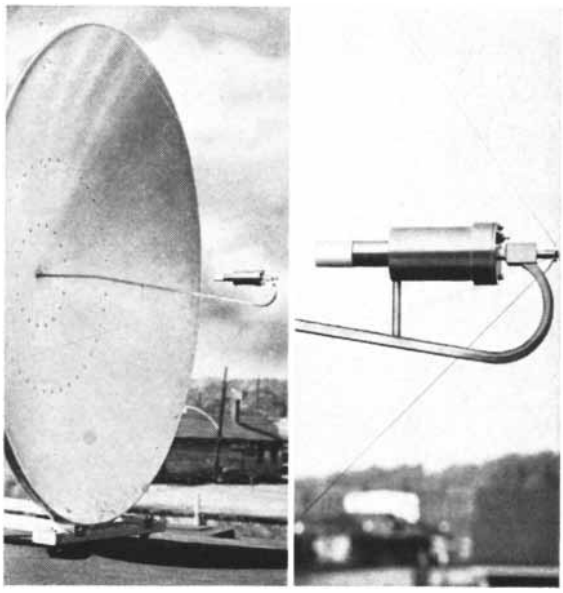
TEFLON® tetrafluoroethylene resins



CHEMICAL PUMP for missiles uses three products made of TEFLON tetrafluoroethylene resins—solid, fluid dispersion, and glass-reinforced. TEFLON resins have practically universal chemical inertness . . . withstand heat to 500°F. In this pump, TEFLON provides both the lubrication and sealing, as well as being the principal ingredient of the impeller. (Made by ECO Engineering Co., Newark, N.J.)



SEALS fabricated from heavy film of a TEFLON resin bonded to silicone rubber base are used on bomb-bay door of B-47. The slick surface aids closure and prevents sticking of ice and snow. Seals operate equally well in stratospheric cold and desert heat. (Made by The Connecticut Hard Rubber Co., New Haven, Conn.)



TEFLON RESINS combine nearly all the characteristics of the perfect electrical insulator. Here, a TEFLON resin performs efficiently as a radome for new radar antenna, providing both impedance matching and weather protection. Its extremely low dielectric constant remains stable. (By Diamond Antenna and Microwave Corporation of Wakefield, Massachusetts.)

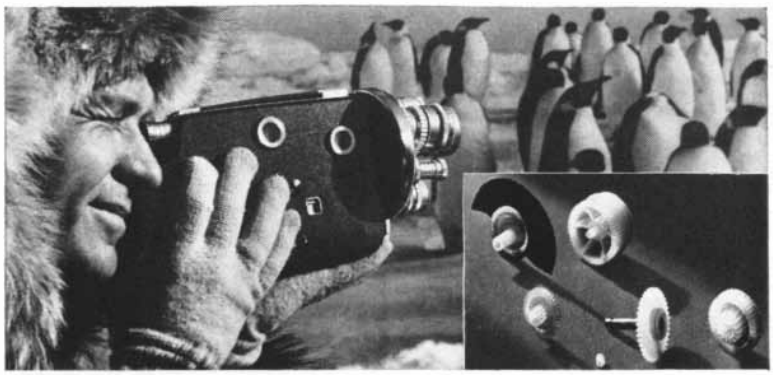
Here you see typical applications for three of the polymers developed by Du Pont research. The range of properties available in Du Pont ZYTEL, LUCITE and TEFLON resins makes them ideal materials for a great variety of scientific, industrial and military uses.

For heat resistance and chemical inertness, TEFLON resins are superior to all other plastics. They also possess phenomenally low surface friction and ideal electrical insulating characteristics. For strength, durability and ease of fabrication, consider lightweight ZYTEL nylon resin. Its moldability, toughness and resilience have made it a favorite for such applications as gears, cams and bearings. LUCITE provides the properties of optical glass, and is shatter- and weather-resistant.

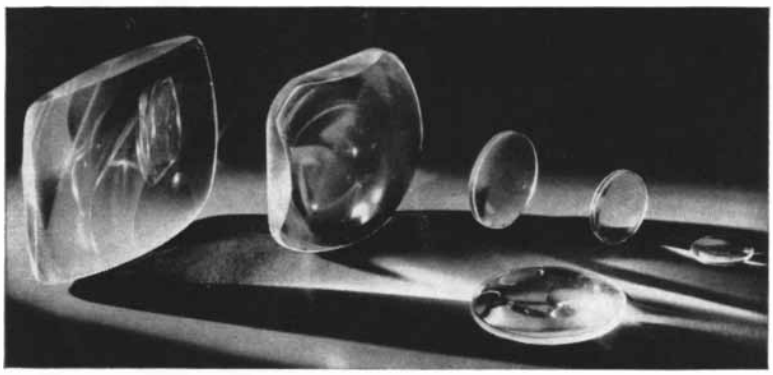
Pinpointing these major properties only highlights the story of the many ways these resins may be valuable to you. Clip the coupon to learn more about their interesting physical properties and applications.

product news

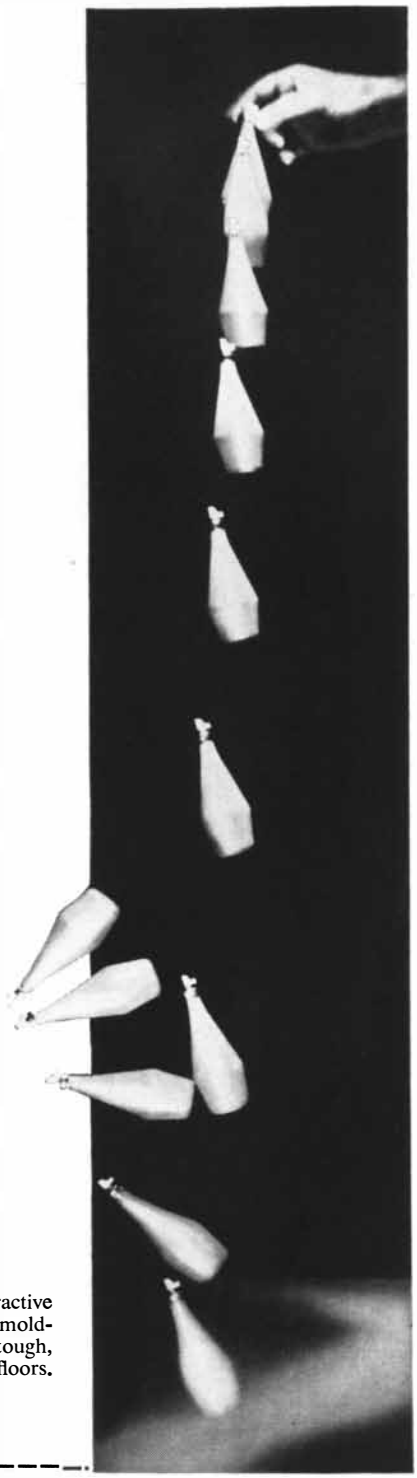
ZYTEL® nylon resins LUCITE® acrylic resins



COMPONENTS made of ZYTEL nylon resin are very strong, wear-resistant and light in weight. Precision-molded parts used in Cine-Kodak K-100 motion picture camera operate silently. Parts of ZYTEL need little or no lubrication. (Camera by Eastman Kodak Co., Rochester; parts molded by Quinn-Berry Corp., Erie, Pa.)



LENSES of LUCITE are easily molded in sizes and shapes to fit every optical need. The optical properties of these lenses are comparable to those of the finest glass. Moreover, LUCITE acrylic resin is light in weight (about one-third that of glass) and has outstanding dimensional stability, impact strength and shatter resistance.



AEROSOL BOTTLES can be made in unique shapes and attractive colors. Using new ZYTEL 42, they can be produced by blow molding or from ZYTEL 101 by welding molded sections. Bottles are tough, durable, attractive—undamaged when bounced off hard floors.

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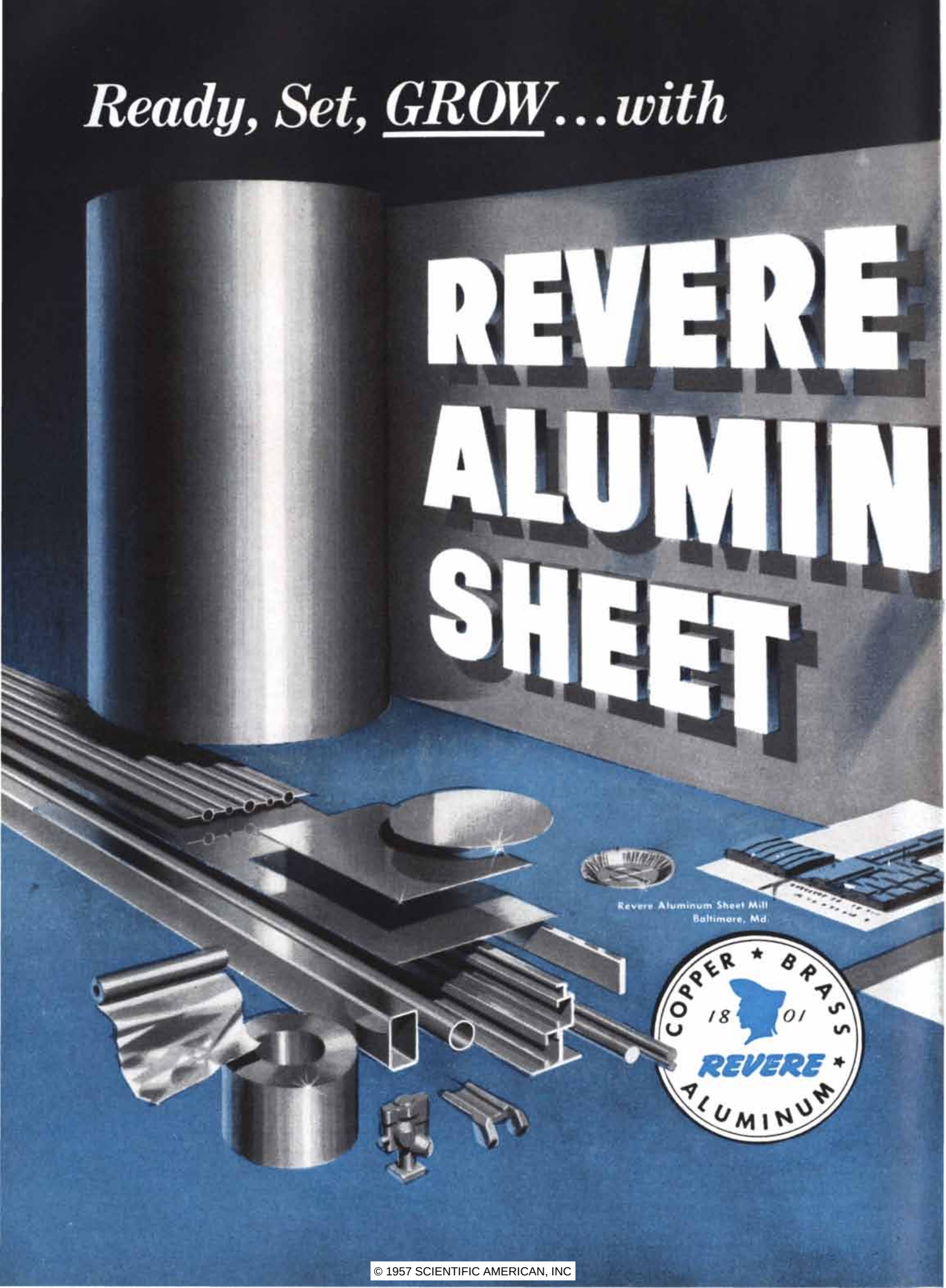

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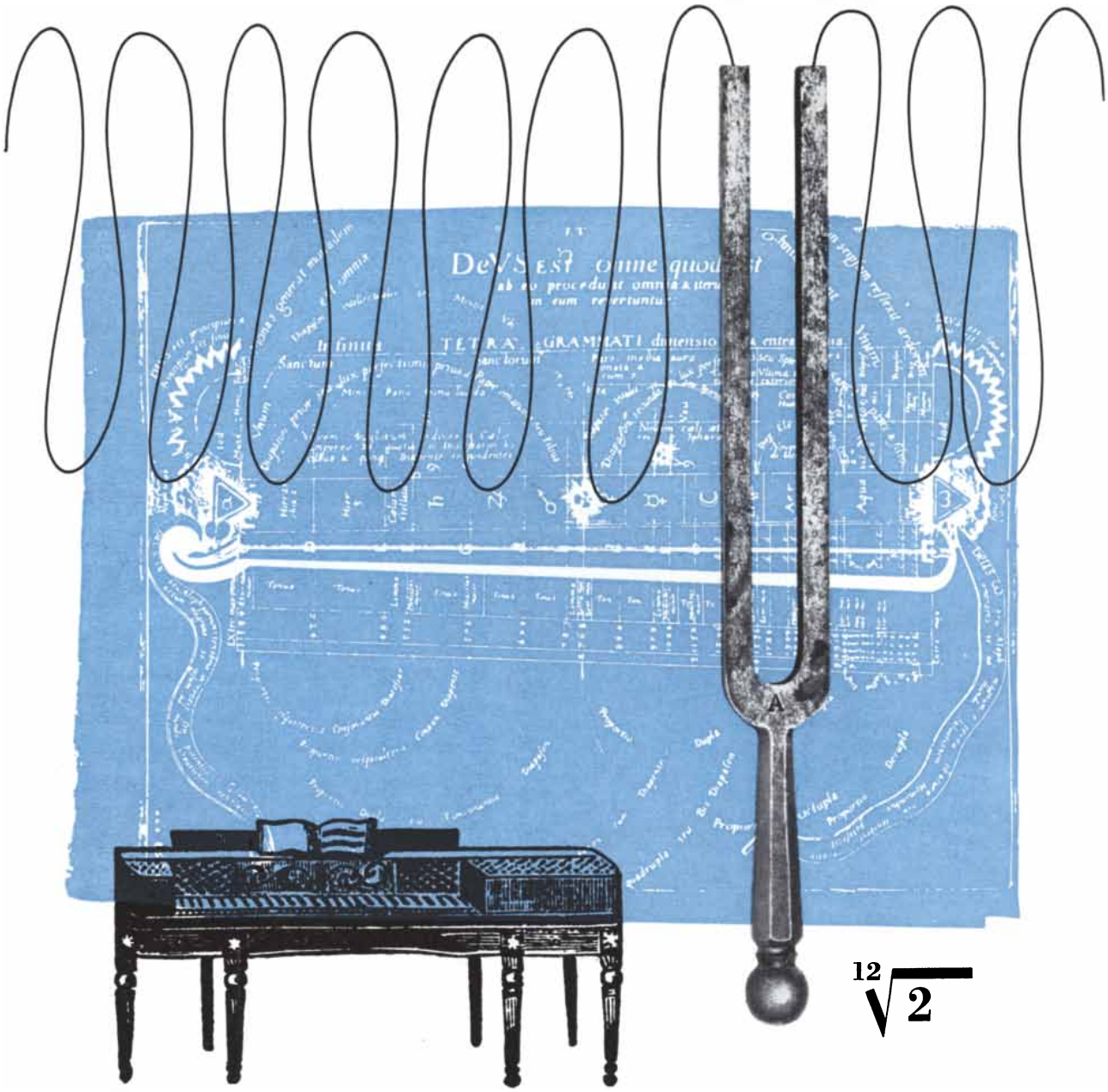

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MATHEMATICIANS long ago divided an octave into 12 equal semitones, each a successive power of the twelfth root of 2. This "equal temperament" formula was the key to a new world of music that could be created for much-simplified instruments. We like this example of one of the Arts benefiting from one of the Sciences—and of mankind benefiting from both. The example contains the mightiest of the Sciences, a new world of thought, creativeness, and refinement of design. These elements exemplify the work of Litton Industries in advanced electronics.

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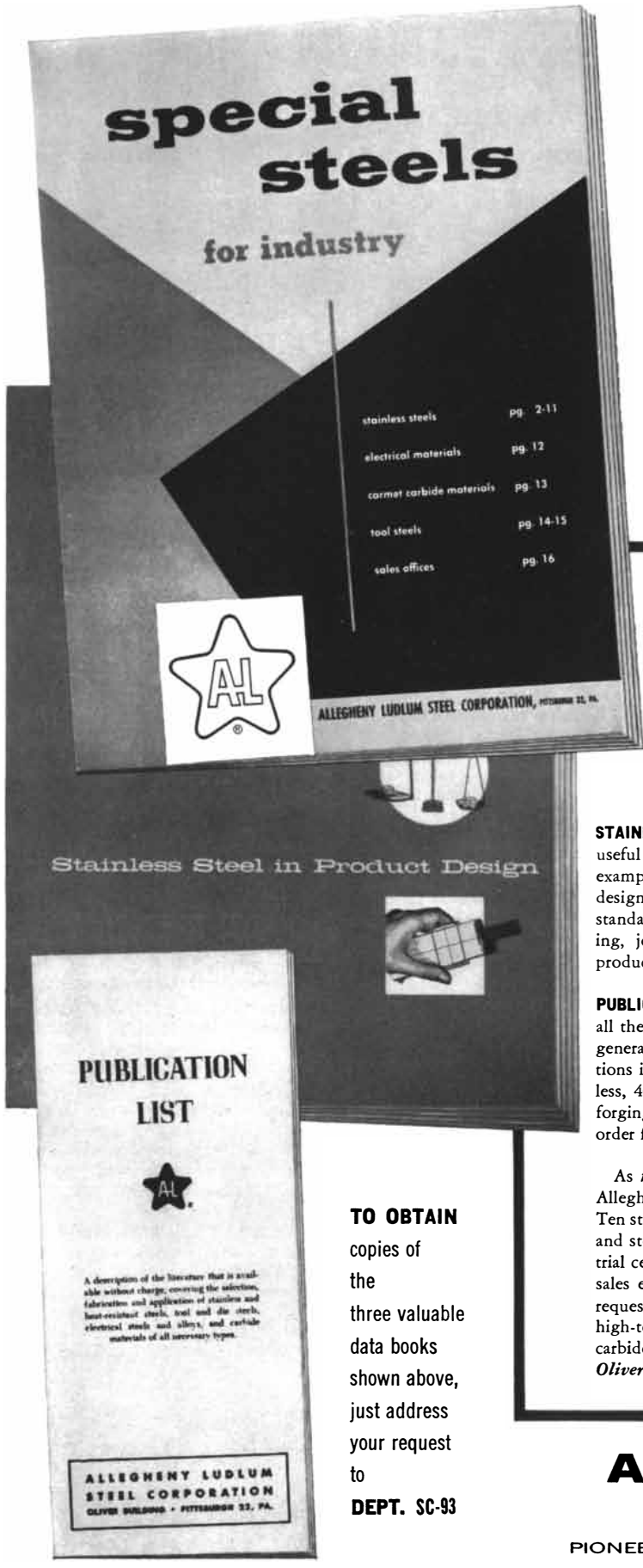

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ALLEGHENY LUDLUM

PIONEERING on the Horizons of Steel

New trends and developments for design engineers . . .

How Carboloy® cemented carbides' wear-resistance and other unique properties solved three tricky problems

Carbides' low coefficient of thermal expansion keeps tiny parts tiny

The Van Keuren Co., Watertown, Mass., specializes in precision measuring tools, and tiny parts such as bearings and pivots for instruments, components, and missiles.

Dimensions of these parts are often measured in thousandths . . . and their tolerances in millionths.

It's hard enough to *make* anything as small as the pivot shown in Figure 1, but once it's done, making sure it *stays* that size despite ambient temperatures and rugged operating conditions is another problem.

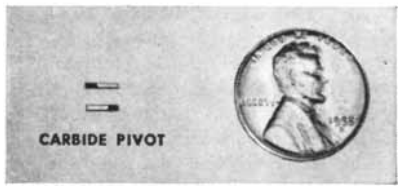

FIG. 1 — Carbide pivots measure .0030" in diameter, .0165" in length.

Carboloy cemented carbides were the perfect solution because they do not expand and contract like other materials. Their coefficient of thermal expansion is less than half that of SAE 1095 heat-treated steel.

For example, from 70° to 1292°F., Carboloy Grade 779 has a coefficient of 2.80×10^{-6}/°F. — compared to 8.20×10^{-6}/°F. for SAE 1095.

In addition, carbides resist atmospheric corrosion and erosion. They can be lapped and polished to a mirror finish for smooth, accurate bearing action. And they're ideal materials where compressive loads are high because carbides' ultimate limit in compression is 2 to 16 times that of steel.

Carbides' high temperature resistance solves soldering problem for H. & A. Selmer

Soldering clarinet keys in place takes a steady hand with the gas torch, and special jigs for holding and positioning tiny assemblies (Figure 2).

H. & A. Selmer, Inc., leading manufacturer of band instruments had no trouble getting the steady hands. The problem was with the jigs.

FIG. 2 — Carbide points hold and position clarinet key assembly during soldering.

Because of the high temperatures needed for silver soldering the nickel-silver keys, Selmer was using stainless steel jigs. Unfortunately, the keys often ended up soldered to the jig; as well as to their own parts. This meant hours of hand filing, extra cleaning, frequent repairs of the jigs.

Then Selmer engineers introduced the use of Carboloy cemented carbide location points. In addition to being the hardest metals made by man, they have the ability to resist excessive oxidation at temperatures of 1500° to 1600° F.

And, once carbide is coated with a thin layer of oxide, neither the solder, nor the keys, will stick to the holding and location points.

Soldering operations were speeded up; hand filing eliminated; jigs stayed accurate longer—and Selmer's costs came tumbling down.

Carbide's resistance to corrosion keeps printing ink flowing for IBM

When IBM makes IBM cards, it makes them by the millions. And it makes them on special high-speed machines that automatically print, cut, and count 1600 cards a minute.

Each machine has its own miniature printing press. Ink is metered out by a stainless steel pump submerged in a well in the machine base.

Wear on the pump parts was problem enough. But the ink was also corroding its impeller bushings and shaft.

IBM engineers solved the problem by installing Carboloy cemented carbide bushings and shafts.

Normally, carbides are not used for their corrosion resistance alone.

But, as in cases like this, where a *combination* of corrosion-resistance and wear-resistance is needed, Carboloy cemented carbides can more than pay their own way.

They have good resistance to organic acids, many inorganic acids and bases . . . and are practically inert to attack by salt water spray.

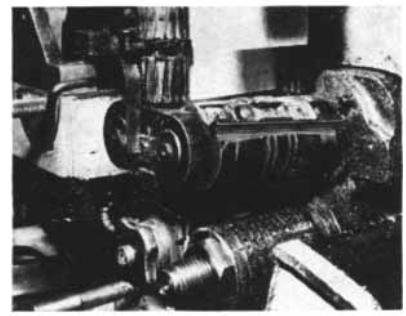

FIG. 3 — Miniature printing press in IBM card machine. Note carbide shearing knives above the printing plate.

Incidentally, IBM is also saving an estimated $40,000 a year in labor costs for regrinding the rotary shear knives used to cut the cards to length.

By changing to Carboloy carbide knives, 267 million cards are trimmed before resharpening — compared to only 16 million with steel knives.

IBM, Selmer, and Van Keuren each used a *different* grade of carbide. Because Carboloy carbides are available in 19 standard grades, they could select the grade with exactly the right characteristics for their particular needs.

If you would like additional technical data on the unique properties of this material—or expert assistance on design problems, write: *Metallurgical Products Department of General Electric Company, 11199 E. 8 Mile Blvd., Detroit 32, Michigan.*

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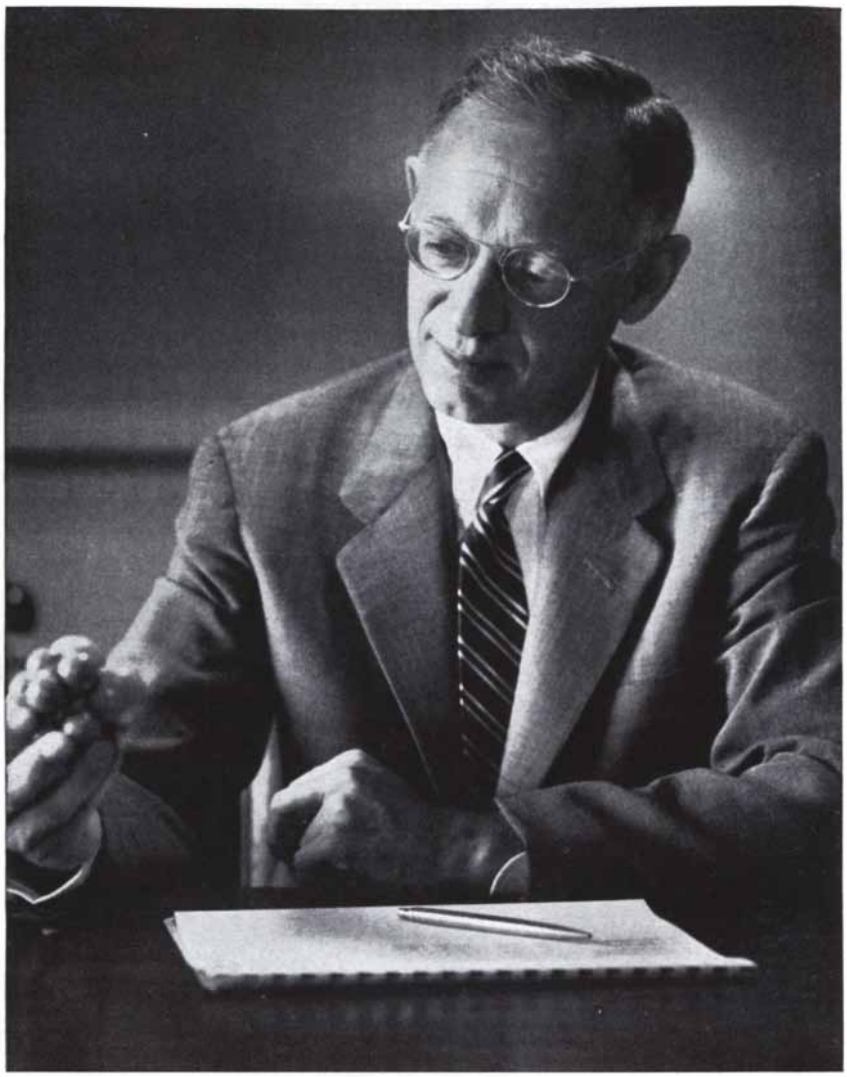

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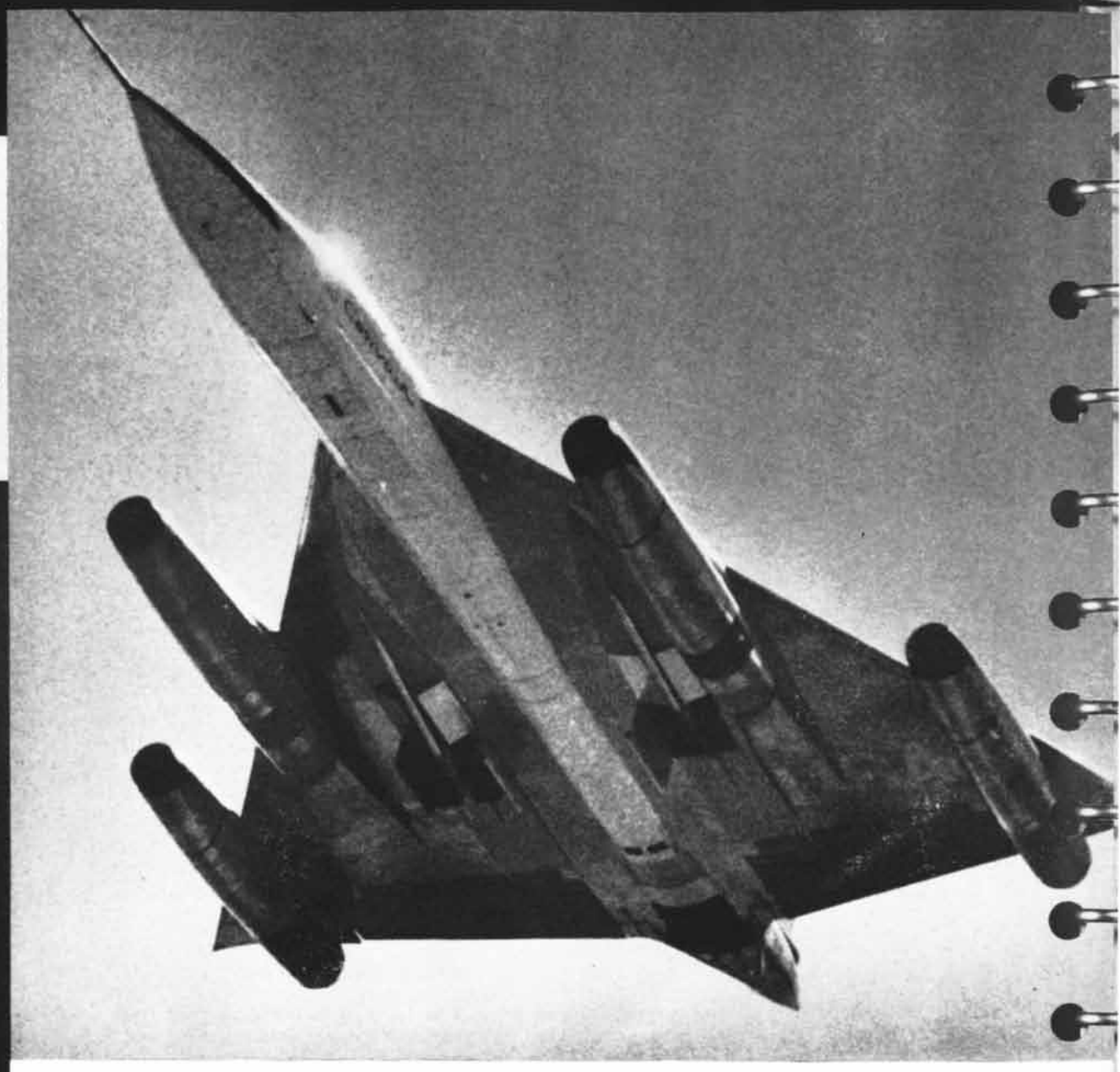

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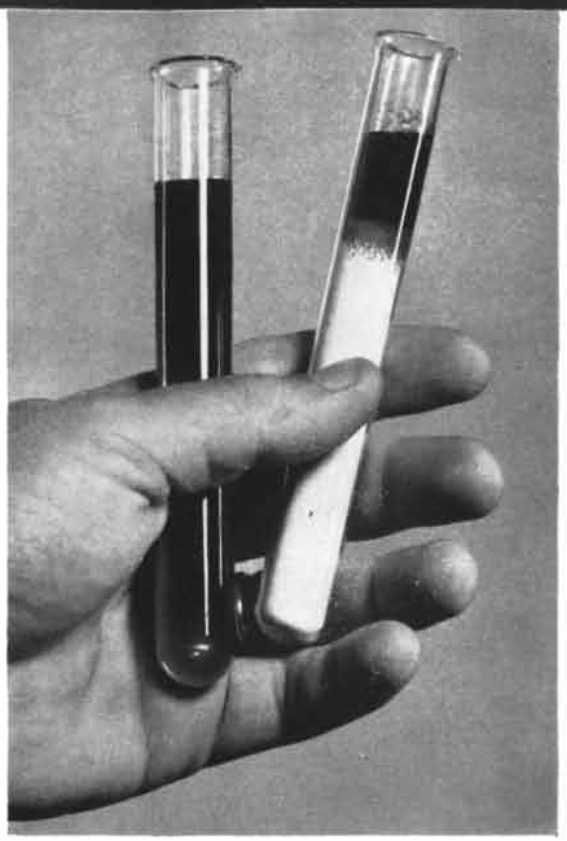


Here soluble powder contains no Guartec. Colored water quickly seeps through. Tubes have been standing 4 hours.

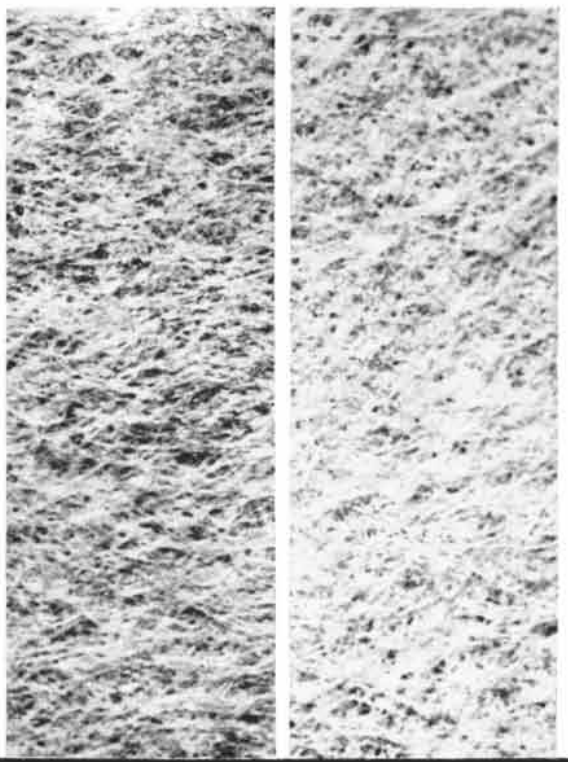
The powder in this tube contains a trace of Guartec which forms a barrier when wet to stop moisture penetration.

amazing new **Guartec** keeps dry materials dry— with their own built-in dam

See how a pinch of Guartec, our trade name for granulated guar gum, keeps the soluble powder dry in the water-filled test tube at near left. Guartec granules can be added in minute quantities to many dry materials to prevent unwanted water from seeping in and causing leaching or deterioration. Upon contact with water, Guartec swells and forms a gel which inhibits moisture penetration.

Special Commodities Division

Without Guartec • With Guartec



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The more uniformly distributed paper fibers in the micro-enlarged photo at near left resulted when a trace of Guartec was added to the pulp. Such processing produces stronger, more uniform papers in less time—with tremendous savings.

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continued next page

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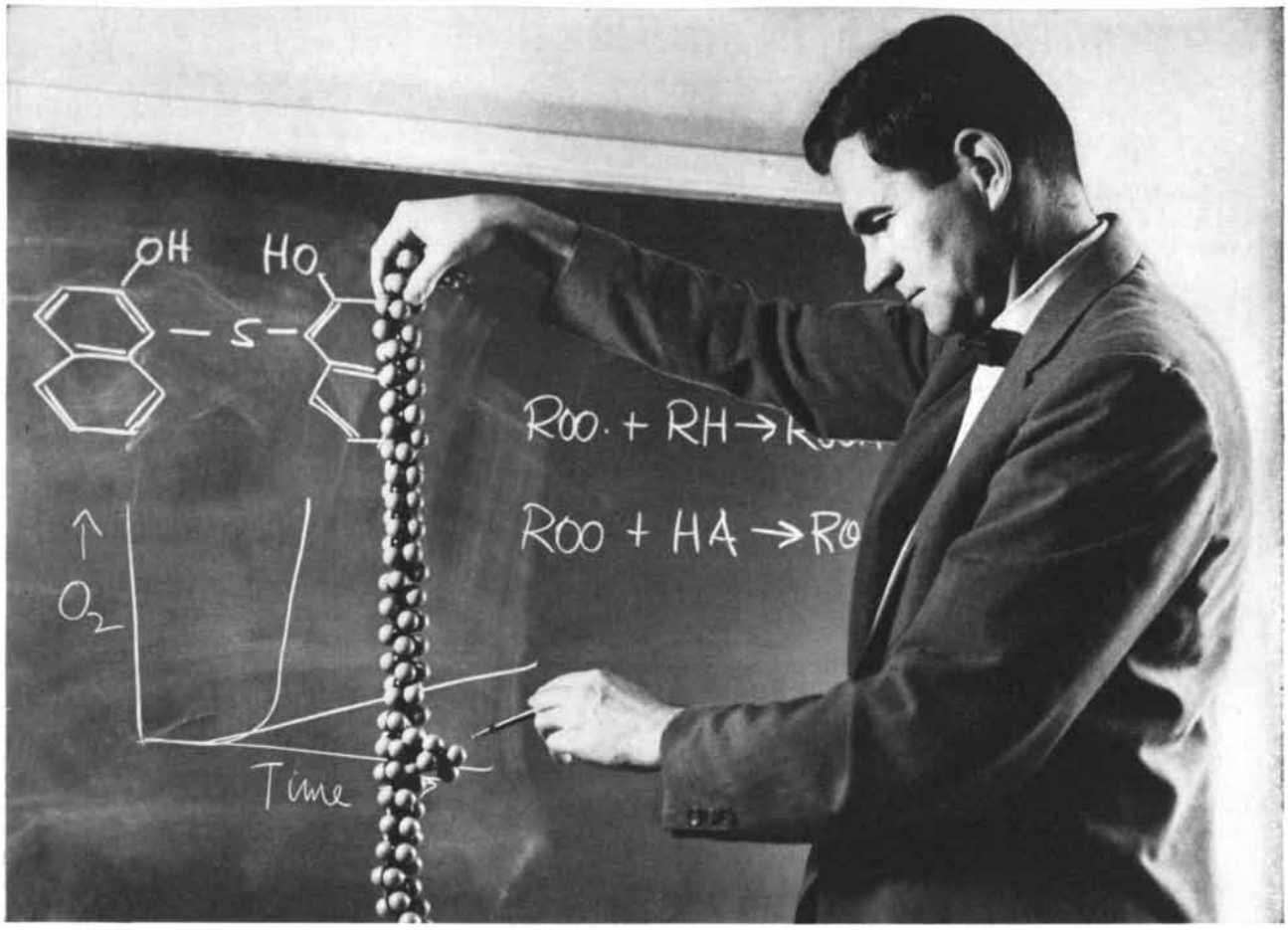
50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

SEPTEMBER, 1907: "The collapse of the great Quebec cantilever bridge, with a loss of over 80 men, is one of the greatest disasters in the history of bridge construction. For a parallel we must go back to the disaster of the Tay Bridge in Scotland, when several spans were blown down in a fierce gale, carrying a whole trainload of passengers to their graves. At the present writing the information available is too meager to state the immediate cause of the disaster. Because the portion of the bridge on which it actually commenced is lying in 200 feet of water, the facts may never be brought to light. This is the more likely because the lives of all of the workmen who were engaged on this portion of the bridge were lost, and there will therefore be no close-at-hand eyewitnesses to state where the breakdown began and from what cause. The great Quebec Bridge, as designed, was the largest of the cantilever type in the world. Quite apart from the lamentable loss of life which it involved, the fall of the bridge is the most disastrous calamity that could possibly have overtaken the profession of bridge engineering in this country."

"Prof. Jacques Loeb has presented his latest conclusions as to artificial generation in a paper entitled 'The Chemical Character of the Process of Fertilization.' He maintains that, as all life phenomena are ultimately chemical, we can only hope to produce life by a series of definite chemical reactions. In the process of fertilization, the most obvious chemical reaction is an enormous synthesis of nuclear material. After the entrance of the spermatozoon, the one nucleus of the egg successively divides into two, four, eight, etc. Each nucleus is the same size as the original one. Evidently, therefore, the chemical effect is the synthesis of nuclear matter. The nucleus consists of a salt, composed of some protein and nucleic acid, the skeleton of which acid seems to be phosphorus."

"According to recent researches the products of decomposing atoms form



Bell Laboratories chemist Field H. Winslow, Ph.D., Cornell University, with a scale model of a small section of a polyethylene molecule. Branch formation indicated by pencil is vulnerable to oxidation. Dr. Winslow and his associates worked out a simple way to protect long polyethylene molecules needed for durable cable sheathing.

THE DILEMMA OF GIANT MOLECULES

Solution: 2 plus 2 equals 5

Polyethylene is used to protect thousands of miles of telephone cables. It is tough, light and long lasting. Its strength lies in its giant molecules—a thousand times bigger, for example, than those of its brittle chemical cousin, paraffin wax.

But polyethylene has a powerful enemy: oxidation, energized by light and heat, shatters its huge molecules to pieces. This enemy had to be conquered if polyethylene was to meet the rigorous demands of cable sheathing. Paradoxically, it was done by making the whole better than the sum of its parts—just as though 2 plus 2 could be made to add up to 5.

To check the ravages of light, Bell Laboratories chemists devised the simple yet highly effective remedy of adding a tiny dose of carbon black. Then antioxidants, such as those commonly used to protect rubber, were added to check attack by heat. But here the chemists encountered a dilemma: although the carbon black protected against the effects of light, it critically weakened the effectiveness of the antioxidants.

To solve this dilemma, Bell Labs chemists developed entirely new types of antioxidants—compounds not weakened by carbon black but which, intriguingly, are very much more effective when carbon black is present. The new antioxidants, plus carbon black, in partnership, provide long-lasting cable sheath—another example of how research at Bell Telephone Laboratories works to improve your telephone service.

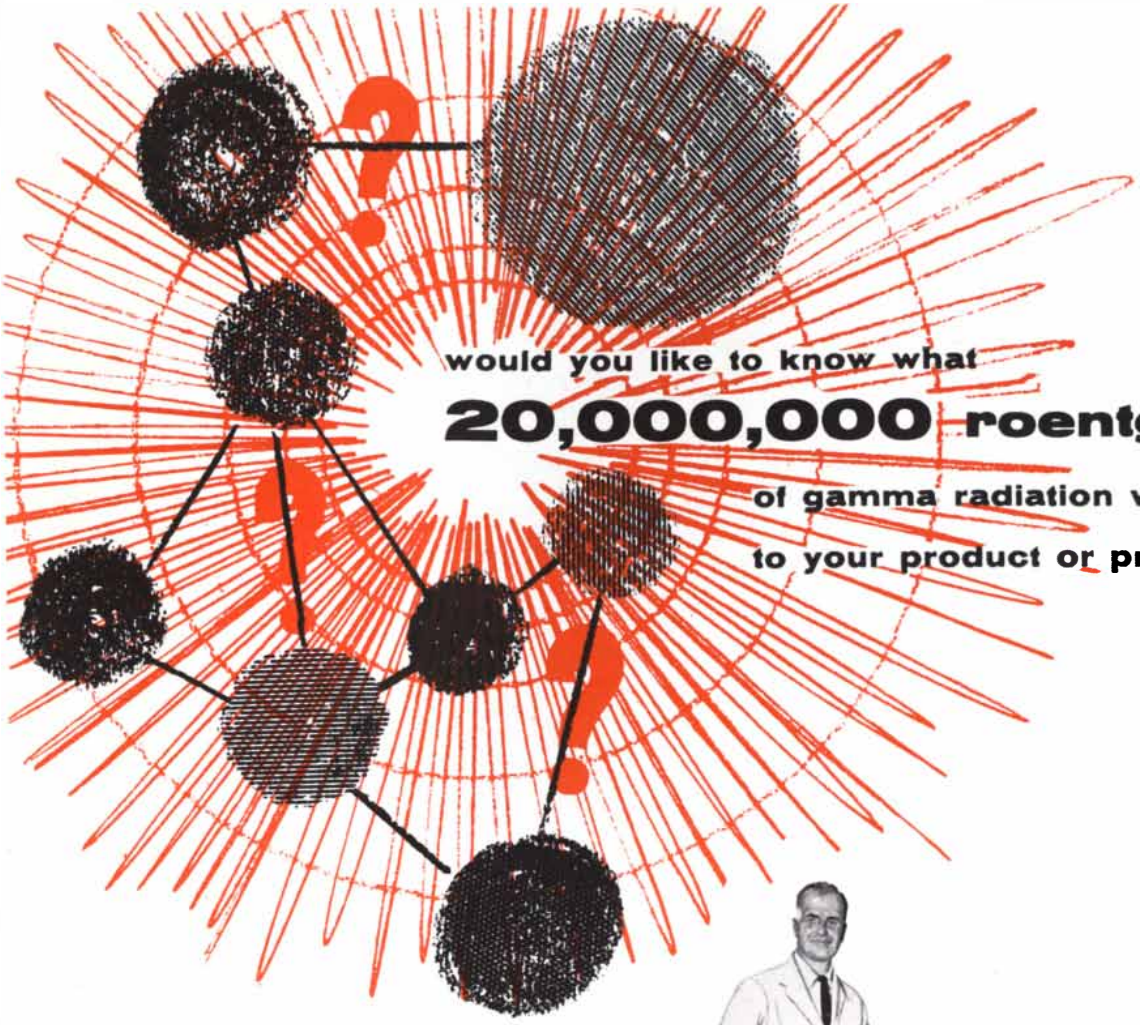
BELL TELEPHONE LABORATORIES

WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

substances with properties between ponderable bodies and imponderable ether, that is, between two worlds which science has so far kept strictly separated. While matter was once considered inert, it now appears to be an enormous reservoir of energy. By the dissociation of atoms, the stable form of energy called matter is transformed into its unstable forms—electricity, light, heat, etc. The idea that a transmutation of atoms, according to the dream of alchemists, some day might become quite practicable is obviously in agreement with these theories. The importance of the doctrine will be fully appreciated only when a process for accelerating the disintegration of bodies has been found. When this has been achieved, a practically infinite source of energy will be at the free disposal of man, the consequence of which can hardly be foreseen."

"It is certainly good news to learn that progress on the Panama Canal has been so rapid that the Isthmian Canal Commission has thought wise to ask for about eight million dollars, in addition to the appropriations already made, in order that the present working force may be permitted to go about uninterruptedly at the high rate of speed which has characterized operations during the past few months. It seems that the American steam shovel, which has now been installed in large numbers at the Culebra cut, is living up to its noble reputation, and that the plan of excavation, including the arrangement of various levels and tracks worked out by the late Chief Engineer Stevens, has proved so thoroughly adequate that the time of completion is going to be very much shortened."

"Count Ferdinand von Zeppelin's huge airship—the largest in the world—has been remodeled and improved of late. It now has a length of 420 feet, a diameter of 38 feet, and a capacity of 11,000 cubic meters (388,465 cubic feet). Its total lifting capacity is several tons. Improvements in the form of a searchlight and of Telefunken wireless telegraphy instruments have also been added. Recently the airship emerged from its floating shed (which is arranged on pontoons so that it can be pointed directly into the wind) and made a complete circuit of Lake Constance, easily beating all water craft. Its speed at times reached 38 miles an hour. The airship made numerous sharp turns and performed difficult evolutions in front of the royal castle at Friedrichshafen. At times it would almost dip into the lake, and



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of gamma radiation would do to your product or process?

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The Picker "Hotpot" Cobalt 60 irradiator is no bigger than your desk, and safe enough to keep in your office.

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if it has to do with radiation it has to do with

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then again it would rise to a height of 600 feet or more. The flight lasted four and a quarter hours. The new airship showed itself the equal of the Wright aeroplane as far as speed is concerned, while its adaptability to commercial use would seem to be greater. No fewer than seven men were on board during the flight."

"A French scientist, G. Garet, has invented an improved device for working a distant apparatus, as, for instance, a torpedo, by means of electric waves. It is also adapted for use on a wire circuit for the same purpose; likewise for railroad signals and many other devices. With a single wire it can carry out operations which now take as many as 10 or 15 different wires."

"Now that the Singer office building has been carried up beyond the 500-foot level, its really stupendous proportions assert themselves with dramatic effect. It is indeed a complicated task to erect, on a foundation only 65 feet square, a building which will lift its head more than 600 feet heavenward and maintain itself, free from tremor and absolutely secure, against the fiercest hurricane that can blow upon it. The tower itself forms the most striking feature in this elaborate reconstruction of the old Singer Building at the corner of Liberty Street and Broadway. The new structure, with a frontage of 76 feet on Broadway, has been built on the northern side of the old building, and the great tower rises above this addition, with its front standing about 15 feet back from the Broadway building line. The completed tower will extend 28 stories above the main building and contain 42 stories in all."

SCIENTIFIC AMERICAN

SEPTEMBER, 1857: "We greet our friends with gladness, for it is our birthday anniversary. SCIENTIFIC AMERICAN is 12 years old. Let us note a few of the prominent scientific developments which have been chronicled since our journal entered into existence. The Electric Telegraph, as a practical invention, was only a year old when SCIENTIFIC AMERICAN started in life. The first 44 miles of telegraph had just been put in operation. There are now throughout the world about *80,000 miles*. Twelve years ago, the artist's pencil was almost the only means of reproducing natural objects.

ARGON,

the gas that wanted to be alone ...helps man to explore space

Among the various gases in the earth's atmosphere, argon is one of the rarest—and most uncongenial. It is such a poor mixer that it is never found in chemical combination with other elements.

But scientists at LINDE reasoned that, because argon doesn't combine with other elements, it could be effectively used to protect other materials from impurities and contamination.

Today, LINDE argon protects the tiny filaments in electronic tubes, helping to make rocket and jet plane mechanisms, radar, and your television set operate dependably. In the welding of metals for use in rockets, missiles, and aircraft—or in the production of titanium—argon is the "invisible curtain" protecting the metal from impurities.

LINDE *argon, 99.99++ per cent pure, is as close to you as the nearest highway or railroad track.* A nationwide, flexible distribution system assures satisfaction of argon requirements for the factory or the laboratory —in any volume, whenever and wherever needed.

For more than 50 years, LINDE has been extracting gases from the atmosphere . . . finding better methods for their practical use. If your industry, plant or shop has a special problem involving the use of argon, oxygen, or nitrogen, or the equipment they require, LINDE can help you. For specific information, call or write your nearest LINDE office.

LINDE COMPANY, Division of Union Carbide Corporation, 30 East 42nd Street, New York 17, N. Y. Offices in other principal cities. *In Canada:* Linde Company, Division of Union Carbide Canada Limited.

Linde
TRADE-MARK

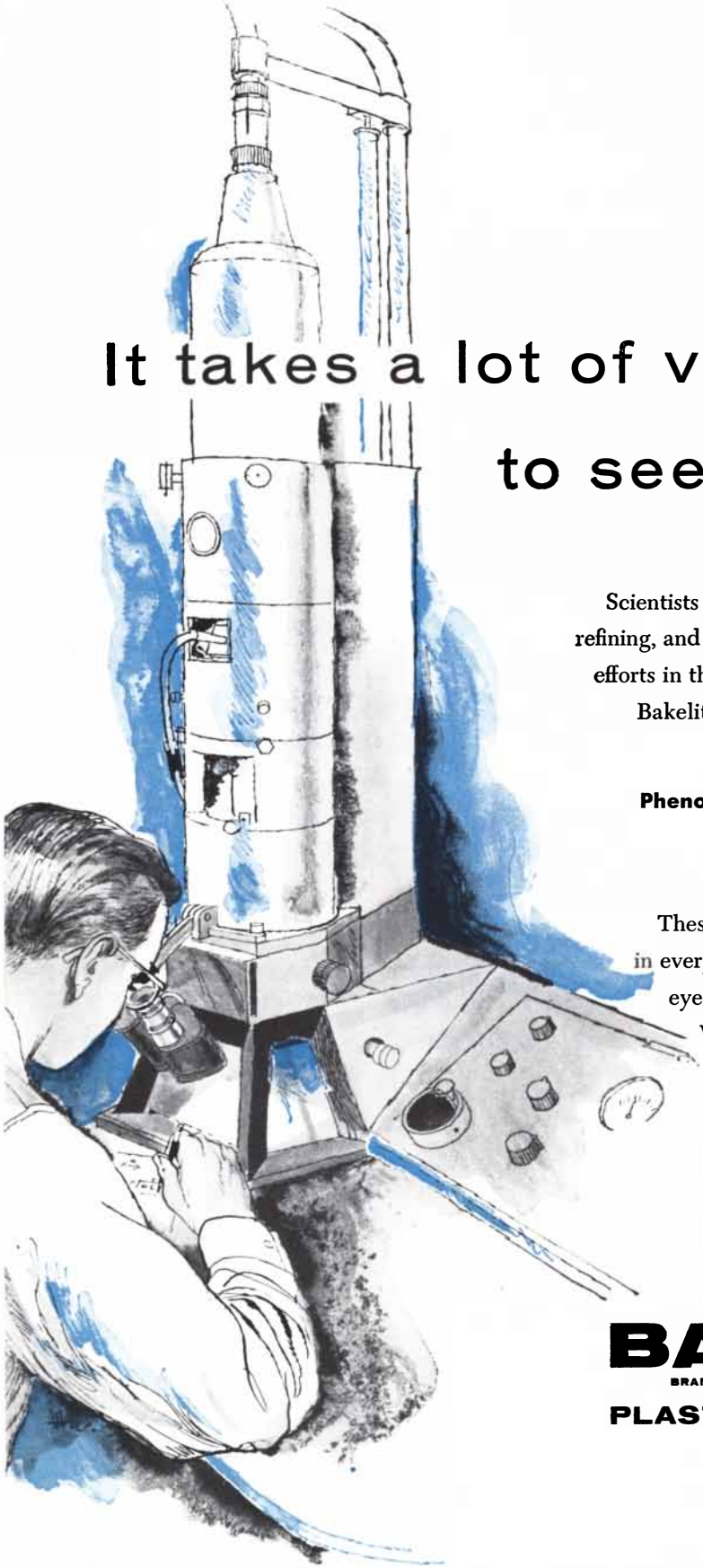
UNION CARBIDE

LINDE argon protects the filaments in electronic tubes that guide rockets into the vast reaches of outer space.

But now the Sun gives us any picture we may desire, *in an instant*. In chemistry what wonders have been developed! Fish no longer constitute the chief source of our oleaginous products. Oil made from coal has become a common article of commerce. The touchstone which actually converts base metals into gold and silver has not, it is true, been discovered; but a new metal, aluminum, wonderful and precious in its character, has been produced from common clay. Last and foremost, the shrieks of patients, writhing under the surgeon's knife, are no longer heard; for chloroform now soothes the nerves, and brings 'deep sleep' upon its subjects."

"The great experiment has failed. The arrival of the *America* brings a dispatch announcing that the Atlantic cable, after 343 miles had been paid out, parted, and the company has been obliged to abandon the enterprise for the present. Professor Morse was on board the *Niagara* at the time, and he lays the blame for the accident directly upon the engineer, Mr. Bright. Professor Morse writes: 'At 3:45 in the morning, lat. 52°30″, long. 17°30″, our ship was moving at four miles two fathoms per hour, and the cable running out at five miles an hour. Mr. Bright asked the mechanic in charge of the brakes what strain was upon the cable, to which the answer was "3,000 pounds." Mr. Bright directed him to put on 100 pounds more to check the speed of the cable. The mechanic expressed a fear that it would not be prudent. Mr. Bright, however, *persevered*. The brakes were applied, which suddenly stopped the wheels of the paying-out apparatus, and brought the unchecked speed of the ship to bear on the cable. The total strain would have parted a cable four times the strength. Hence it is no wonder that our cable should snap like a pack-thread. We got an electric current through till the moment of parting; *and yet the further we paid out the feebler were the currents,* indicating a difficulty that will require attentive investigation.' "

"Dr. Snow, in a paper read before the Medical Society of London, has directed attention to amylene as an anesthetic agent, and numerous trials of this substance for producing insensibility have been made with satisfactory results. In regard to its odor, it is more objectionable than chloroform, but much less so than sulfuric ether. The odor of any volatile substance is, however, no longer perceived after a patient begins to inhale. In respect to its pungency, it has a great advantage over both ether and



It takes a lot of vision to see a **GIANT**

Scientists at Union Carbide are constantly exploring, refining, and improving the leading plastics today. Their efforts in this continuing research program have made Bakelite Company a leader in providing a variety of these materials to industry.

Phenolics • Vinyls • Styrenes • Impact-Styrenes
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These BAKELITE Brand Plastics are widely used in every kind of business and industry. Keep your eye on these giants. They're still growing fast! Why not write Dept. GWC for information on a specific plastic or for a copy of the 1958 Condensed Reference File of BAKELITE Brand Plastics?

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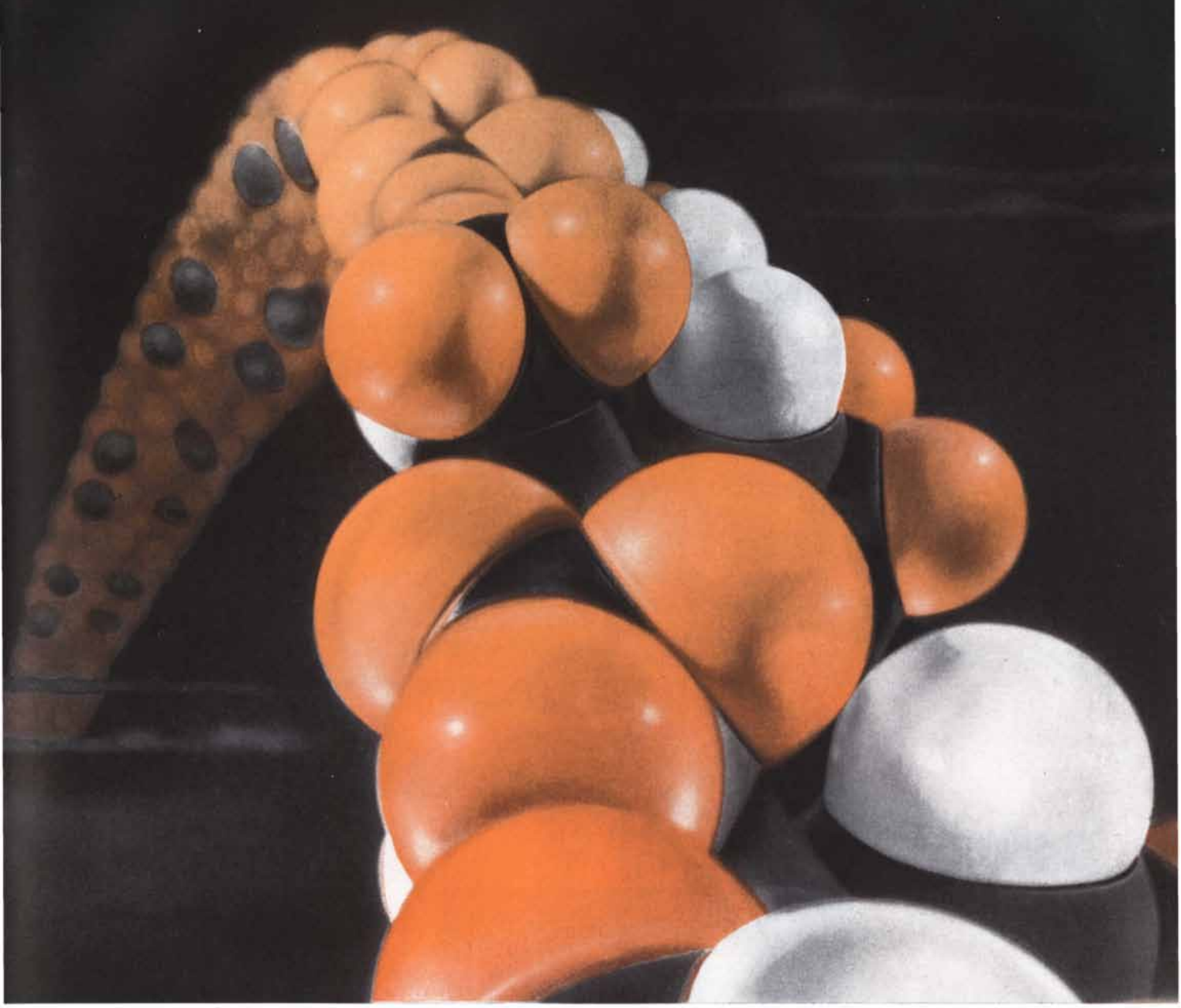
chloroform, being less pungent than either of them. Thus the patient can inhale the amylene of full strength within half a minute from commencing, and the operation may generally be begun within three minutes. Amylene is superior in preventing pain with a less profound stupor than that occasioned by the other agents, and in the ready waking and recovery of the patient."

"We see it stated that a firm in England has received instructions to fit the steamship *Great Eastern* with gas works and all necessary gas fittings, on a most elaborate scale. Some of the steamers on our rivers have been lighted with gas with tolerable success, and the effort will probably be highly conducive to economy, as well as safety and convenience, on so large a ship as the *Great Eastern*."

"California has passed a law to make the scientific development of the human body the order of the school hours upon the Pacific. All her common schools are to have apparatus and teachers of gymnastics, and with her delicious climate and extraordinary civilization, she will keep the lead she has got of all the States."

"We see from a report of the Registrar General to Sir G. Gray, just issued, that amongst English marriage statistics no fewer than 44,846 husbands, and 62,672 wives made their marks; and, out of the entire number married during the year 1855, more than one half could not sign their names. This is a fact which makes us think that the authorities had better at once stop arguing in favor of or against the voluntary or governmental systems of education, and at once adopt some system by which all English children shall be educated. As State education has so eminently succeeded here, might not England take a lesson in our school and follow suit?"

"M. von Siebold, the distinguished scientific author, states that the knowledge of the natural sciences amongst the Japanese is much more extensive and profound than is generally supposed. They possess a great many learned treatises thereupon, and an admirable geological map of their island by Buntsjo. They are well acquainted with the systems of European naturalists, and have translations of the more important of their works. They have also a botanical dictionary, in which an account is given of not fewer than 5,300 objects, and which is embellished with numerous fine engravings."



VINYL MONOMERS . . . endless possibilities, thanks to polymer chemistry

Vinyl acetate . . . vinyl propionate . . . methyl isopropenyl ketone . . . and now acrylic acid esters . . . these Celanese monomers are starting points for practically endless product improvements. They have already enabled production of better binders for non-woven fabrics and for water and grease-resistant coatings. They have improved plastics . . . they have improved the properties of emulsions for latex paints, leather, paper and textiles . . . they have enhanced properties of synthetic fibers and rubbers.

These are but a few of the improvements engendered by the Celanese series of monomers. And Celanese research, development and production know-how promise more and better basic materials for polymer chemistry. The new acrylic acid esters, for example. The unit for their production is nearing completion and soon will be "on stream," supplying acrylates in commercial volume.

Constant research for more productive basic organic chemicals...availability of a vast supply of raw materials to keep production in continuous volume...these are the factors upon which Celanese bases its service to industry. Celanese Corporation of America, Chemical Division, Dept. 582-S, 180 Madison Avenue, New York 16, N. Y. Celanese®

Basic reasons . . . . . for improved products

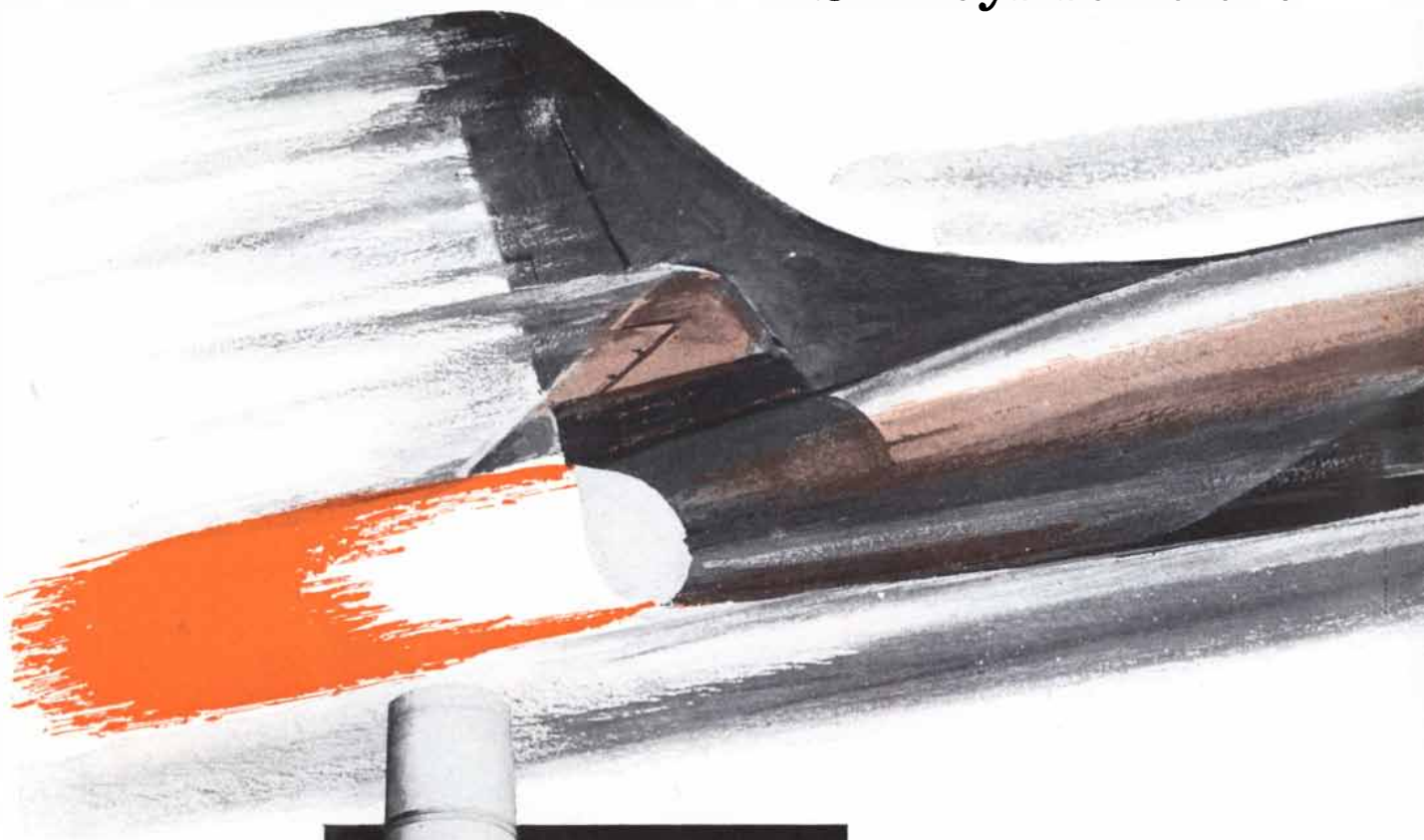
Acids	Functional Fluids	Polyols
Alcohols	Gasoline Additives	Plasticizers
Aldehydes	Glycols	Salts
Anhydrides	Ketones	Solvents
Esters	Oxides	Vinyl Monomers

Celanese CHEMICALS

Agricultural	Paper
Automotive	Pharmaceutical
Aviation	Plastics
Building	Surface Coatings
Electrical	Textiles

HEAT • WEAR • CORROSION

HAYNES Alloys solve the

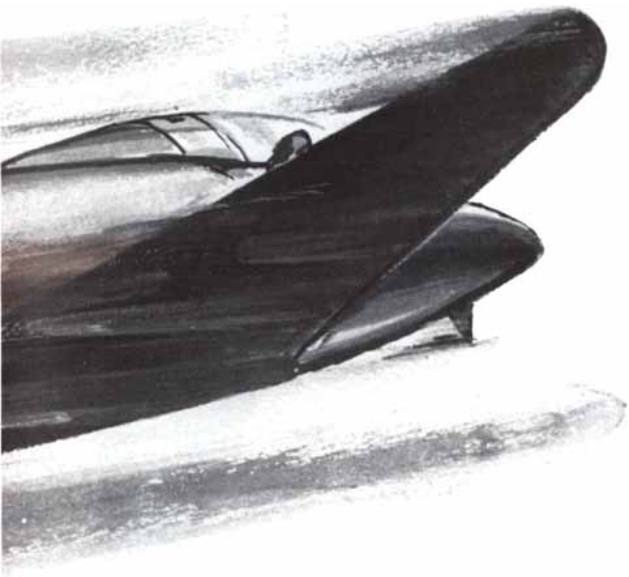


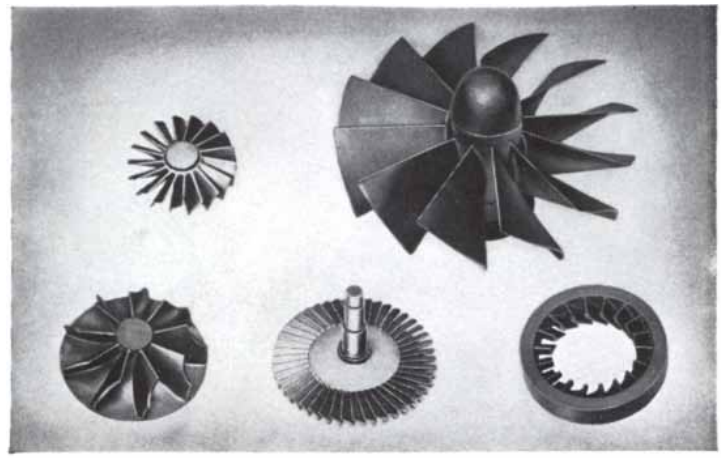
HEAT

2,000 degree jet blast!

The jet engine tailpipe of the Navy's A4D "Skyhawk" operates at extremely high temperatures. That is just one of the many reasons why this part is made of MULTIMET alloy. This is one of 6 HAYNES wrought alloys that have unusual resistance to high temperatures and oxidation. Because of their exceptional properties, HAYNES alloys are being used extensively in such parts as after-burner components, jet engine tailpipes, turbine blades, and nozzle vanes.

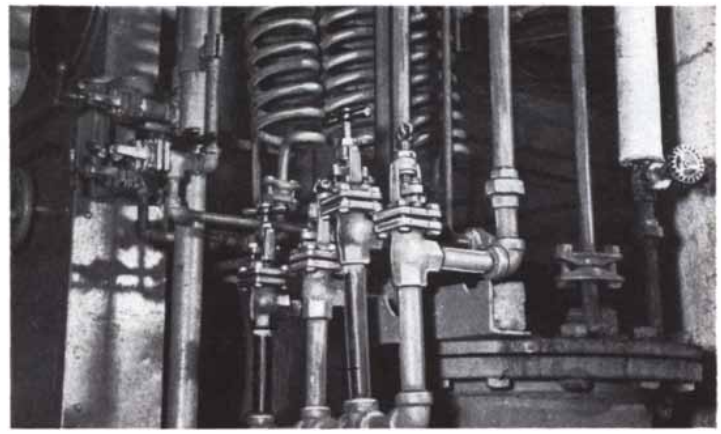
tough problems





PRODUCTION Intricate turbine wheels mass-produced.

HAYNES' investment-casting method offers a selection of alloys developed for economical operation over a wide temperature range. Blades and wheels are produced as one integral part to as-cast tolerances that permit operation with unusually fine clearances at high speeds.



CORROSION Withstands corrosive chlorine 10 years!

Handling highly corrosive liquid chlorine was an expensive maintenance problem—until valves made of HASTELLOY alloy C were installed. This is just one of the many corrosive difficulties met by HAYNES Alloys. They also have excellent resistance to hot mineral acids, strongly oxidizing salts, and powerful gaseous oxidants over a wide range of temperatures and concentrations.

If you have an application that is creating a tough heat, wear, or corrosion-resistance problem, you will find it profitable to check with HAYNES Stellite Company. In practically every industry, you will find HAYNES Alloys doing a better job, lasting longer, reducing maintenance and proving most economical.

Tell us your problem and we will send you descriptive literature on the HAYNES Alloy best suited to solve it. Write HAYNES STELLITE COMPANY, Division of Union Carbide Corporation, General Offices and Works, Kokomo, Indiana.

HAYNES ALLOYS

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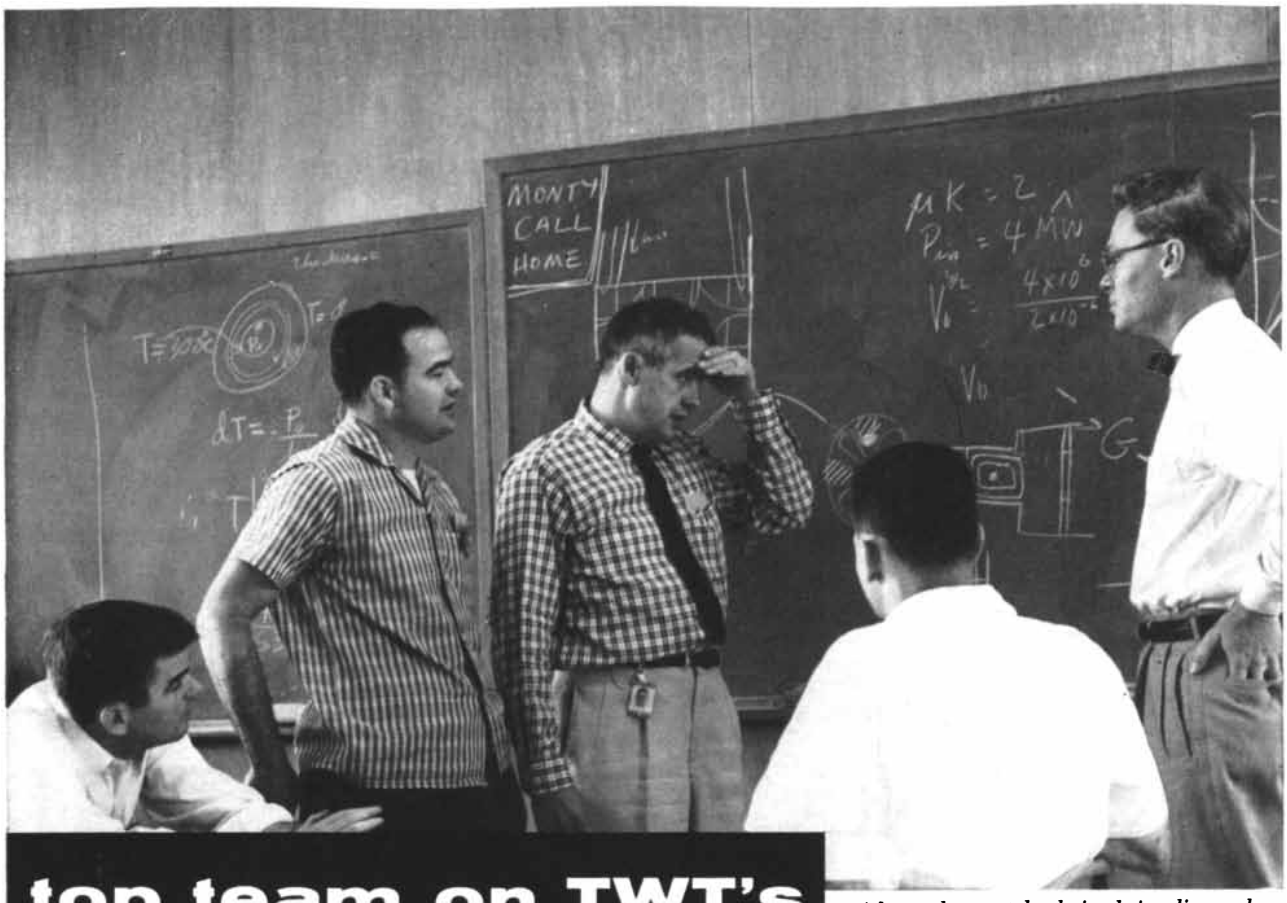


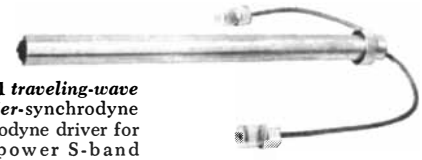
top team on TWT's

Advanced wave tube design being discussed at Varian by Jack Ruetz, Monty Rogers, Willis Yocom, John Sullivan and Wells Dodds.

Traveling-wave tubes, as any of the men above will tell you, are slated for an important place in the world of electronics. And these men, backed by Varian know-how, are out to assure the fullest possible realization of the wave tube's promising future.

With one of the industry's most competent wave tube development groups, Varian is geared to meet a wide range of difficult challenges in its field . . . applying to newer systems problems the same know-how and teamwork that just a few years ago established Varian's leadership in klystrons.

Many new ideas and applications are on the way, to back up the success of tubes like the VA-121 and VA-161 shown here. The entire Varian wave tube team is ready to go to work for you, to shape up a wave tube application or come up with the answers you've been looking for. Write or call your Varian representative or Varian's Application Engineering Department.



VA-121 ***traveling-wave amplifier*** synchrodyne or serrodyne driver for high power S-band pulse applications. Performs to detailed specifications of phase and amplitude stability to meet the stringent requirements of phase-coherent MTI radar systems.

Power Output	25-40 watts
Saturation Gain	30 db min.
Duty Cycle	.01 max.
Beam Voltage	2250 volts
Grid Pulse Voltage	+ 27 volts

VA-161 ***backward wave oscillator*** for use in tunable radar local oscillator, countermeasure and bench and test applications. In the frequency range from 8.2 to 12.4 kMc.

Power Output 30 to 120 mW
Anode Voltage 150 to 600 volts
Permanent Magnet
Size: 4⅛ x 5 x 6½ inches
Weight: Approx. 6 lbs.

THE MARK OF LEADERSHIP

VARIAN associates
PALO ALTO 7, CALIFORNIA
Representatives in all principal cities

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

This is

NATIONAL NORTHERN

...newest AP&CC division

Dedicated to research, development and production in

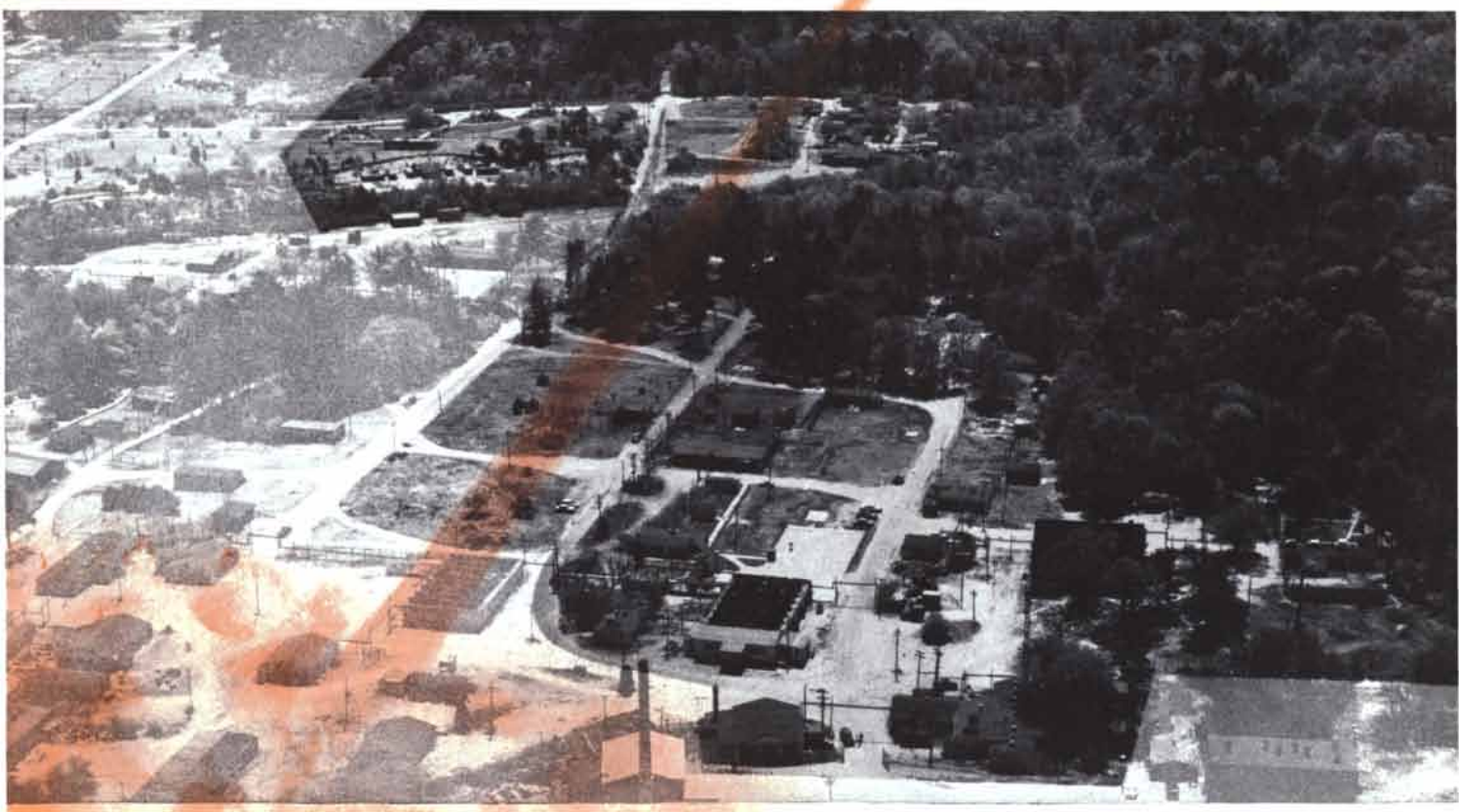
rocket power technology

Test a rocket motor's performance at 100,000 feet altitude... determine how extremes of temperature affect explosive and propellant charges... develop igniters of maximum sturdiness and reliability. These are typical activities at National Northern Division, West Hanover, Mass., latest addition to the AMERICAN POTASH family. Here, a qualified staff of scientists and technicians conducts research, development, field testing and production of propellants for rockets and missiles, explosives, pyrotechnics, detonators, igniters, squibs, gas generators, fuzes and other items.

Extreme environmental conditions are simulated in the laboratory or encountered in actual field tests on the firing range at West Hanover or the 1900-acre test range at Halifax, Mass. Here, too, AP&CC will extend its facilities for the investigation and development of TRONA* boron, lithium and perchlorate chemicals in high energy fuels.

For more than ten years National Northern has demonstrated its ability to work in close coordination with others. As an integral part of AMERICAN POTASH & CHEMICAL CORPORATION it is ready to go to work for you!

We invite inquiries leading to research and production contracts.



NATIONAL NORTHERN'S CURRENT FIELDS OF ACTIVITY:

ROCKET-MOTOR-IGNITER DEVELOPMENT • GAS GENERATORS • SURVEILLANCE TESTING OF EXPLOSIVES AND AMMUNITION • EFFECT OF ALTITUDE ON PERFORMANCE OF EXPLOSIVES, PROPELLANTS, TRACERS AND INCENDIARY ELEMENTS • DESIGN OF ELECTRIC DETONATORS AND SQUIBS • AIRCRAFT VULNERABILITY TESTS AND EVALUATION • EXPLOSIVE METAL FORMING

TRONA

American Potash & Chemical Corporation

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NATIONAL NORTHERN DIVISION
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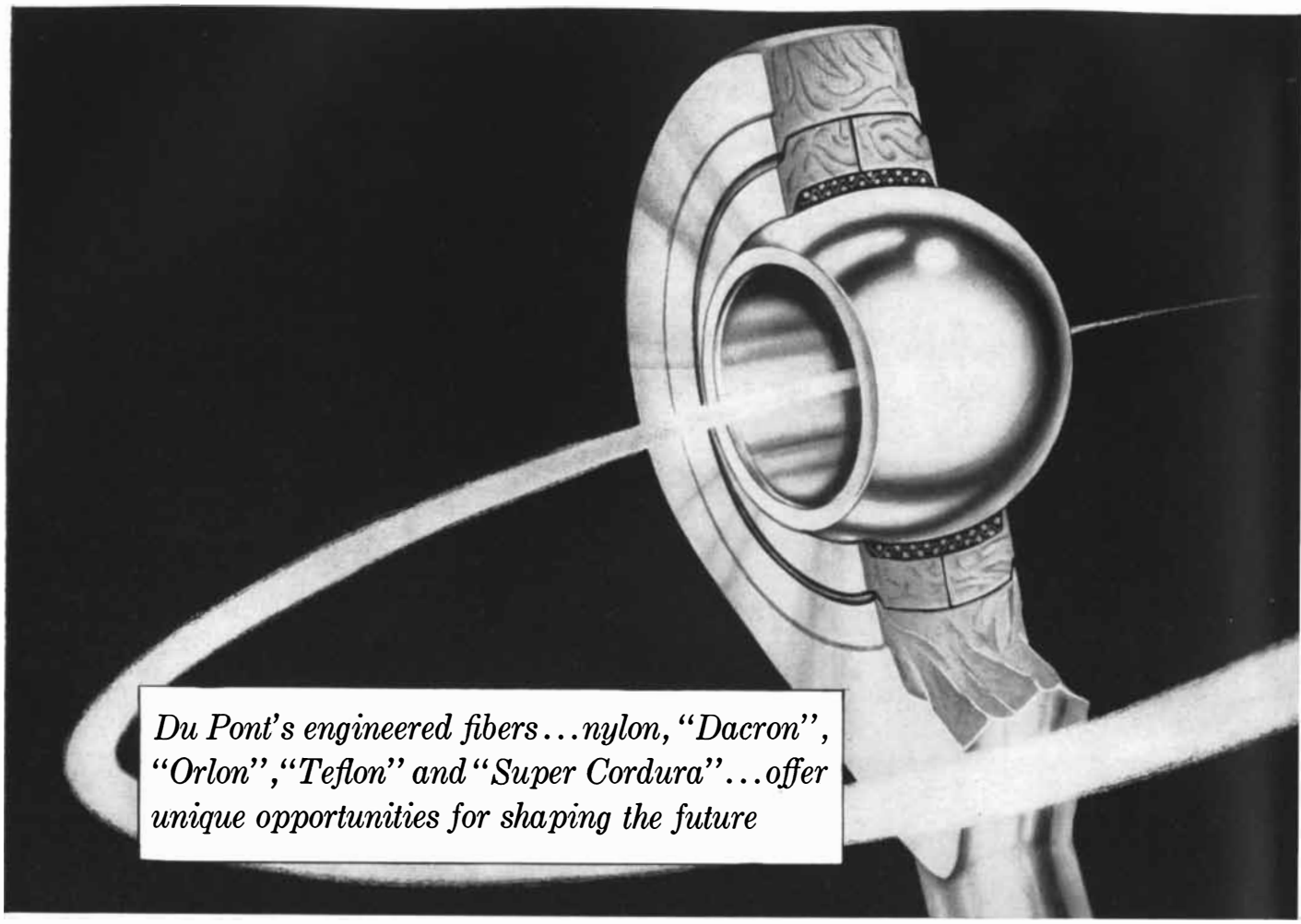


How a fiber solved an

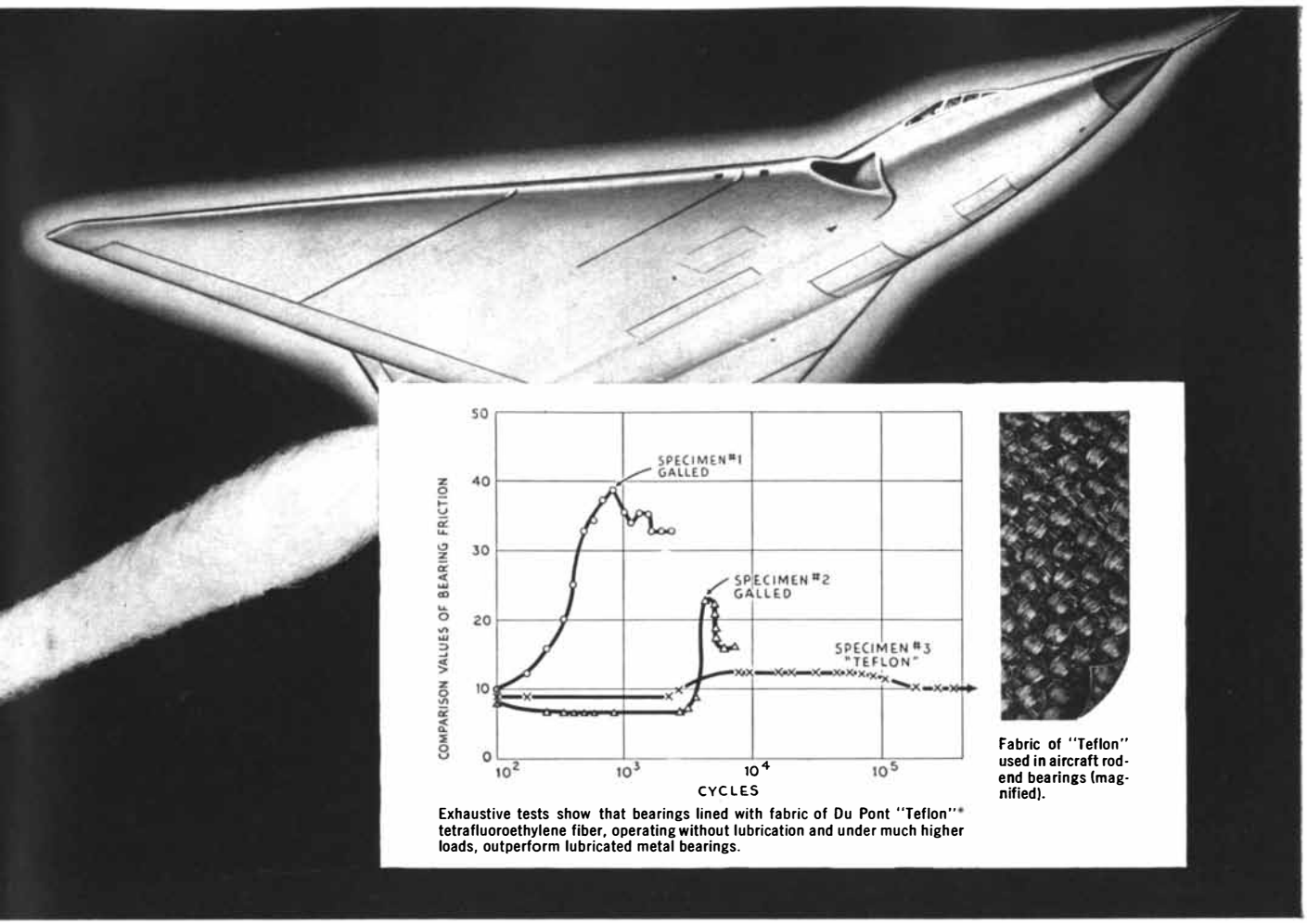
Imagine a fiber replacing a super-alloy! That's exactly what was done in the example shown above. The ball you see in the control-shaft rod end rotates against an inner liner made of a fabric of "Teflon" fiber. This bearing is free from any need for external lubrication. What's more, the breakaway friction of this joint is less than half that of a standard greased joint under the same compression load. The running friction is correspondingly lower, too. In fact, only "Teflon" fiber fully solves the bearing-material problem for rod ends as set forth in military specifications for supersonic aircraft. In addition, many civilian design problems are being solved by non-lubricated bearings—notably in the food and textile industries.

"Teflon" fiber has other properties that provide answers to many varied design problems. It is completely unaffected by practically all chemicals, including boiling aqua regia, and all other organic solvents. "Teflon" fiber may be used in continuous processes running at temperatures up to 525°F. It has given satisfactory performance in tests as low as -100°F. Moisture pickup of "Teflon" fiber is zero. It has a 0.22 coefficient of friction —lowest of any known fiber. Its cold-flow resistance is amazing. And the tensile strength of "Teflon" fiber at room temperature is 50,000 psi—25 times stronger than molded "Teflon" resin. Like other Du Pont industrial fibers, its combination of properties is unique among industrial raw materials. Many engineers are looking to the remarkable properties of these fibers to meet the increasing demands of modern equipment design. For example:

Do you know that "Dacron"** polyester fiber can be heated in air at 300°F. for a week, with no sign of color change or degradation? ("Dacron" made possible a rot-proof high-temperature drying felt that speeds production of papermaking machines.)

Do you know that cordage of Du Pont nylon has about twice the strength of natural-fiber ropes? (Nylon towing hawsers have outlasted conventional types 6 to 1.)

Do you know that "Orlon"† acrylic fiber is extremely resistant to moisture and weathering, even in the presence of industrial fumes? (Now, plastic ducts reinforced with "Orlon" tame storms of sulfuric-acid vapor.)



Exhaustive tests show that bearings lined with fabric of Du Pont "Teflon"* tetrafluoroethylene fiber, operating without lubrication and under much higher loads, outperform lubricated metal bearings.

Fabric of "Teflon" used in aircraft rod-end bearings (magnified).

"insolvable" bearing problem

Do you know that "Super Cordura"†† high tenacity rayon gives the most strength per dollar of any fiber? This rayon provides a *wet* strength greater than the *dry* strength of yesterday's rayon yarn. ("Super Cordura" makes possible ore-carrying conveyor belts that cut handling and shipping costs substantially.)

The offer (at right) of a new handbook of Du Pont fiber properties and uses may help to open new rewarding applications for you. We remind you, too, of our fiber information and technical-aid facilities. A new $2,000,000 Du Pont laboratory is solely devoted to research on the industrial uses of our fibers. We'll be glad to supply technical information about fibers that may be helpful in your own research and development work.

HANDBOOK OF DU PONT FIBERS IN INDUSTRIAL USES

The 80 pages of this definitive fact book are written for the engineer and designer. The properties of DuPont fibers are described in detail. For two dozen basic industrial applications—including fabrics, felts, hoses, nets, laminates, covers, ropes, etc.—technical and performance data are presented. This brand-new handbook is designed to assist you in using synthetic fibers to improve existing products and processes or in making new and unconventional products. For your copy, write to: E. I. du Pont de Nemours & Co. (Inc.), Textile Fibers Department, 5518 Nemours Building, Wilmington 98, Delaware.

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BETTER THINGS FOR BETTER LIVING . . . *THROUGH CHEMISTRY*

**"*Teflon*" *is Du Pont's registered trademark for its tetrafluoroethylene fiber and its fluorocarbon resins.*

***"*Dacron*" *is Du Pont's registered trademark for its polyester fiber.*

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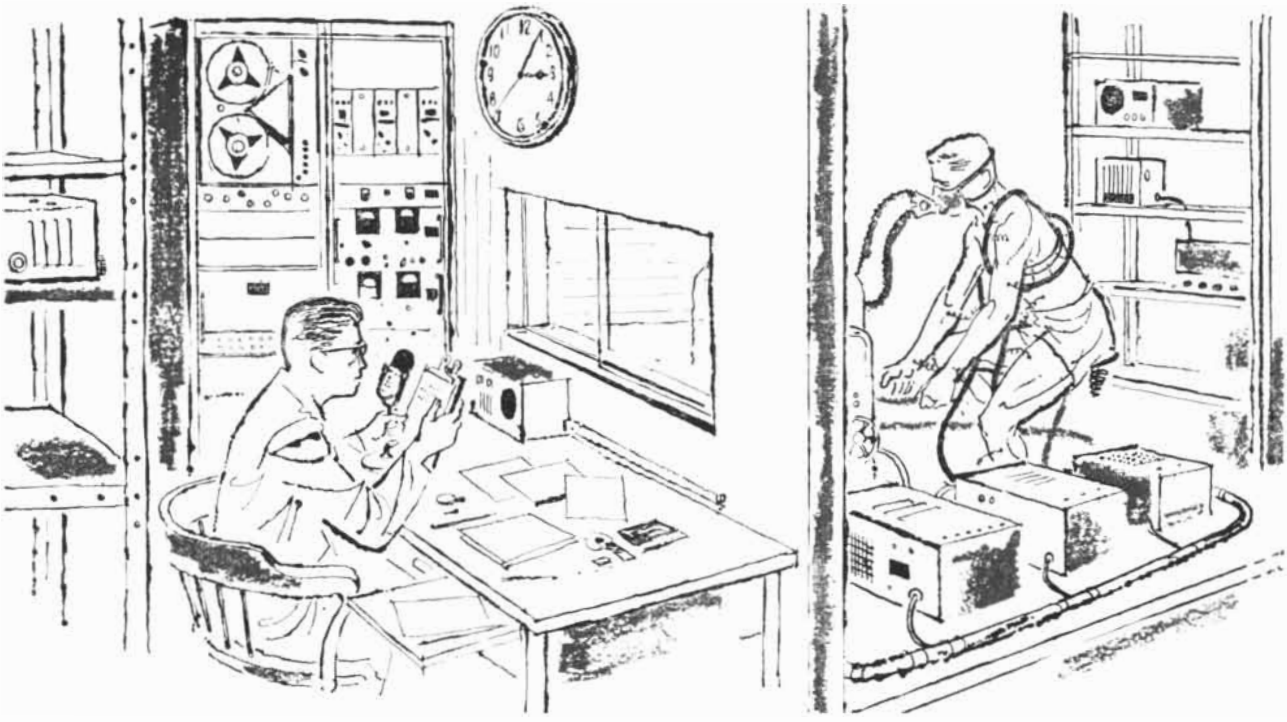
††"*Super Cordura*" *is Du Pont's registered trademark for its high tenacity rayon yarn.*



PUTTING BODY RESPONSES ON TAPE SPEEDS RESEARCH IN HUMAN PHYSIOLOGY

Q: How do environmental conditions affect the total physiology of a human being?

Q: What are the effects of age, sex, health, etc., on work performance, and what range of variation can be expected within each group?

Q: How does the body regulate temperature and respiration under varying environmental conditions and exercises?

The answers to the questions posed above cannot be found in the literature. Why? Not too little data, but far too much . . . so scattered that it cannot be brought together for integration and analysis. Now, strides forward in the techniques of automatic data handling may help scientists provide the answers.

Consider the problem posed by the study of a man repeating a simple manual task. The force he exerts can be measured by placing him on a ballistic platform. But ten minutes of experiment might easily necessitate a full day of computation. Repeating the experiment in other environments multiplies the days of computation. To study the effect of fatigue on his performance means a full day of experiment in each environment . . . months of computation. A significantly large number of subjects assures valid conclusions, but means scores of man-years of mathematics. And integrating body temperature, heart rate, etc., into your results requires scores more.

The availability of large computers has now made such analysis conceivable. But only the development of magnetic tape data recording has made it feasible.

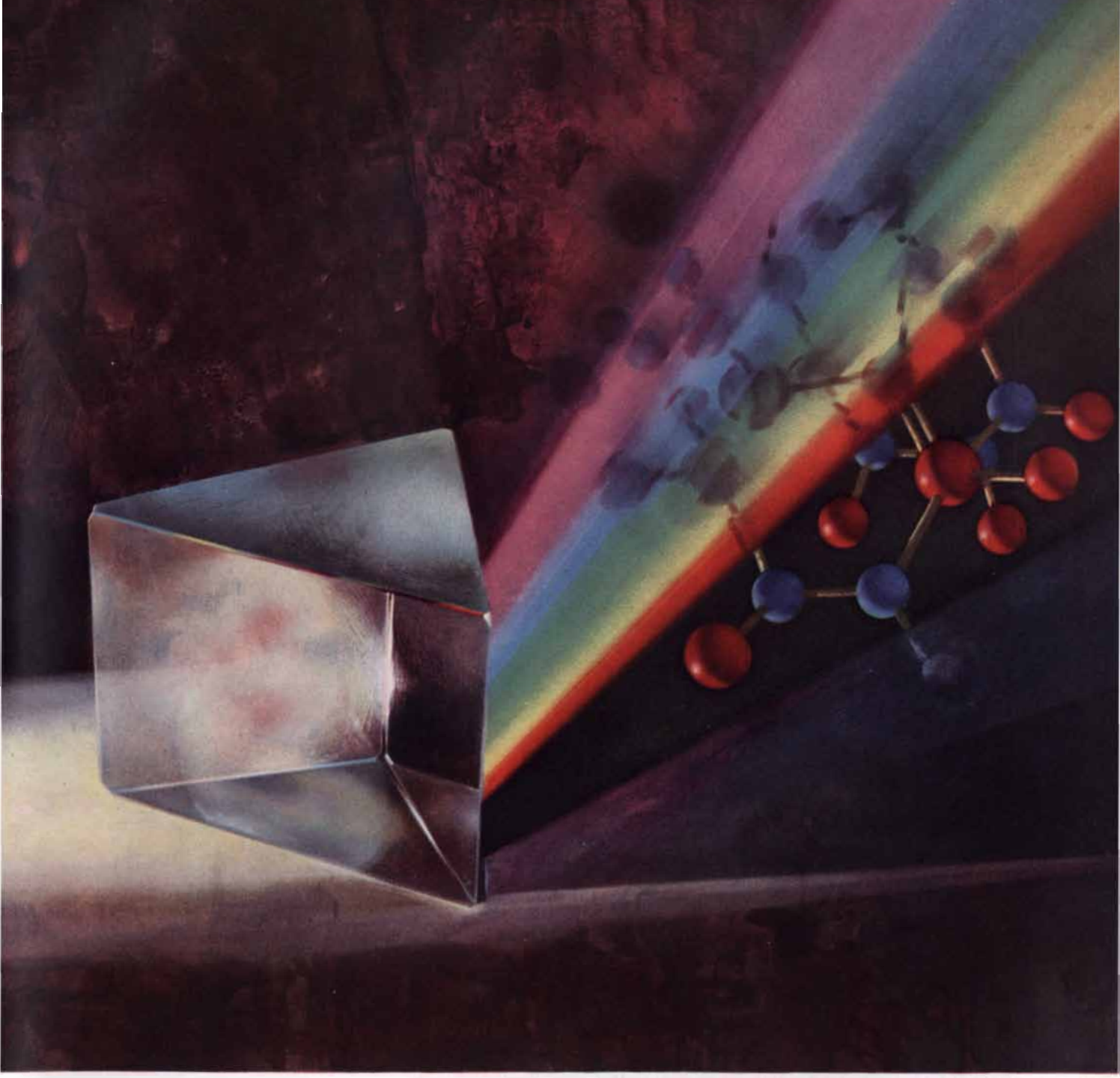
Magnetic tape is the vital link between experiment and computer. Accepting electrical signals from measuring instruments, it stores the information for long periods of time . . . plays it back in exactly the same form . . . the one language all electronic data analysis equipment understands. It further offers the facility of high data storage density. Far more data can be economically stored than a single typical experiment demands, and the surplus data used in future studies. Portability permits data recorded on the spot to be analyzed a continent away with no loss of time or accuracy.

The techniques of magnetic tape data recording were first developed less than a decade ago by the Davies Laboratories Division to solve similar problems in the field of aircraft vibration analysis. The first systems specifically designed for physiological research have just recently been placed in operation. Designed for flexibility, they economically meet initial demands for data capacity, yet may be expanded at little expense to satisfy changing requirements. Up to thirty-six individual tracks of data can be simultaneously recorded . . . and interchangeable electronics permit recording each kind of data by the most desirable technique . . . Direct, FM, or PWM. Up to six recording and playback speeds can be chosen at the flip of a switch for data expansion or contraction. The same system will play back data to associated analysis equipment, or the reel can be shipped to remote analysis facilities.

Considerable information on magnetic tape data recording and how it might be best applied to your data recording, reduction, and analysis needs is provided in our Bulletin 1001, available on request to Minneapolis-Honeywell Regulator Company, Davies Laboratories Division, 10721 Hanna Street, Beltsville, Maryland. WEbster 5-2700

MINNEAPOLIS **Honeywell**

DAVIES LABORATORIES DIV.



Invisible infrared unlocks the secrets of molecular structure.

The hue you can't see is the brightest

Beyond the visible lies an unseen hue—infrared—that is brightening industrial horizons in research and quality control. Infrared harnessed to electronics and optics lets you "see" molecules . . . identify them, determine their structure. For the military, infrared can spot targets—a plane, tank or factory. It can take a photo in pitch darkness, unerringly guide a missile.

To take full advantage of the capabilities of infrared requires optical, electronic and mechanical skills. Perkin-Elmer, because it combines these skills to a high degree, was one of the first to put infrared to work in the laboratory . . . has made over *half* of all infrared instruments for this use . . . produces related infrared equipment for process control in industry, and infrared systems for military reconnaissance and missile control.

* * *

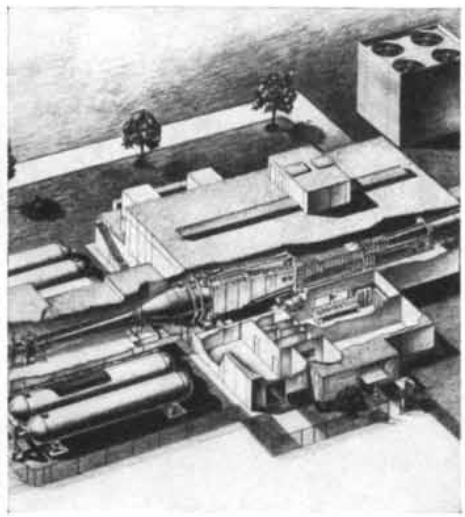
If you'd like to know more about IR, and what it can do for industry, write for "Infrared, Frontier Frequency."

Perkin-Elmer *Corporation*
NORWALK, CONNECTICUT

build tomorrow's missiles?

Chance Vought is making them right now...

FACILITIES—Chance Vought occupies 2½ million square feet of modern plant facilities situated in Dallas, Texas. Close to a large pool of skilled manpower, and with ample manufacturing space, Vought is able to handle quantity production with maximum quality control. Tools and equipment are modern and of sufficient scope to handle the toughest jobs in a complex missile age.



RESEARCH—R & D progress has always been of prime importance to Vought. Both in piloted aircraft and missile systems, research and development people at Vought have access to the finest equipment and facilities in the world—including the only low-speed wind tunnel in the Southwest and a now-building Mach 5 wind tunnel for advanced design research in hypersonic aircraft and missiles.

ENGINEERING—Traditionally strong in this vital area, Vought today has the capable mindpower to set the pace to tomorrow. In such important missile engineering areas as electronics, propulsion, guidance controls and aerodynamics, Vought engineering teams have the experience to give systems development full integration for the improvement of the final product.

The missile age belongs to those who can deliver the goods. Chance Vought *has* delivered...for through the highly successful *Regulus I* and the bold new *Regulus II* projects, U. S. Missile Power has gained two workable "birds", both capable of reliable high performance under a wide variety of conditions.

The experience gained by Vought missile engineers on the *Regulus I* project covers the entire weapons system development. From the missile itself, to training aids, operational techniques and logistics, Vought-perfected procedures condition the missile for life in its military environment. The same complete systems integration is now in work on *Regulus II*.

Today, there is no other company that has such a backlog of working knowledge in complete surface-to-surface missile systems development. This practical experience won by Vought engineers is a realistic expression of a capability that turns R & D knowledge into useful "hardware". Who will build tomorrow's missiles? The dynamic successes of many years of missile experience tell you that one of tomorrow's builders will be Chance Vought.

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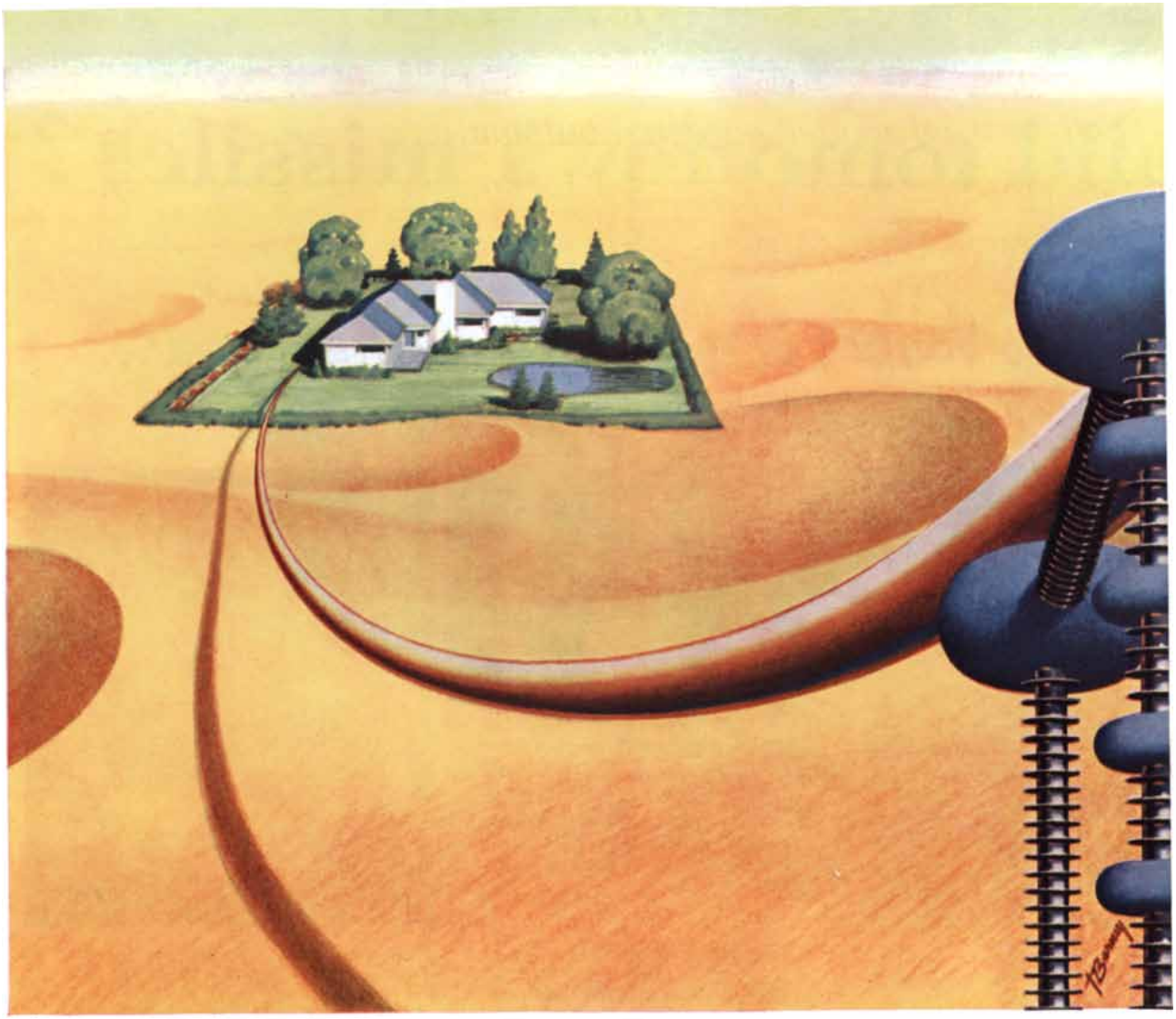

INCREDIBLE TOMORROWS...
THROUGH TODAY'S METALLURGY

Toward the useful application of man's newest servants, the electron and the neutron, ASARCO's Central Research Laboratories contributed much. Working with RCA electronic engineers, they have provided metals and elements of incomparable purity for the development of revolutionary electronic heating and cooling systems. Almost without exception, other major producers of electronics equipment use ASARCO's products, facilities or knowledge.

For the Atomic Energy Commission, ASARCO provides copper of such purity that contamination is measured in parts per million. Experimental work with this pure metal has shown great opportunities for increasing the efficiency and reducing the cost of electrical transmission apparatus.

For experimental purposes, and for production quantities as required, ASARCO makes available eleven high-purity non-ferrous metals and elements: Arsenic—Bismuth—Cadmium—Copper—Indium—Lead—Selenium—Silver—Tellurium—Thallium—Zinc. The knowledge of refining that makes these higher purity metals available also serves industry by providing process information to reduce metal-working costs and improve product performance.

If your research people need to know more about any of the non-ferrous metals and their alloys, ASARCO's metallurgists can provide information to save time and preliminary work. And, of course, pure metals and special alloys are available for detailed experimentation.

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ASARCO

Molecule Magic

Self-heating winter gardens, automatic rain at half price, and giant overcoats for buildings under construction are among the miracles now possible with polyethylene

By F. L. Pyle
Vice-President, Plastics Division
Spencer Chemical Company

Pansies among the snowdrifts are a common sight in the horticultural gardens of the University of Kentucky. For it is here that Dr. E. M. Emmert developed his famous "midget greenhouses"—knee-high tents of polyethylene film. Because these tents hold ground heat in, they become self-heating winter gardens.

Dr. Emmert has periodically startled the horticultural world with other imaginative applications of polyethylene film. For instance, he has used polyethylene film for mulch, and for building full-sized greenhouses at about 1/30 the cost of glass.

The miracles of polyethylene have produced equally startling results in other areas of human activity.

Polyethylene can make grass grow where it's never grown before. Technique is to scratch the bald spot with a rake, sow the grass, pat the earth over it, and soak the ground with a fine spray. Then cover the bald spot with a patch of polyethylene film. Sunshine does the rest.

In flexible pipe form, polyethylene can be installed in your lawn as a sprinkler system that will give you "automatic rain" at about half the price of the metal pipe.

Remarkable though these uses are, Spencer Chemical Company (makers of "Poly-Eth" Polyethylene) believes they are only the beginning for a plastic that breathes, stretches and bends, floats on water, makes ideal insulation, and is acid-proof and almost unbreakable.

In addition, Spencer has developed a special boilable polyethylene, a test-proven superior pipe resin, and resin for a glass-clear polyethylene film. Agreeing with those experts who predict a billion-pounds-a-year eventual consumption, Spencer is now doubling its polyethylene capacity.

If you'd like to know more about polyethylene, ask for Spencer Chemical Company's special reports. Among them are: "Polyethylene for Early Gardens," "58 Home Uses for Polyethylene," "New Uses for Polyethylene in Construction." Write to Spencer Chemical Co., 500 Dwight Building, Kansas City 5, Mo.

SPENCER CHEMICAL COMPANY
"America's Growing Name in Chemicals"

SPENCER ALSO MAKES Nylon for molding and extrusion that processes more easily than types previously available. Picture above shows some of the many applications.

CAREER OPPORTUNITIES with Spencer Nylon and Spencer "Poly-Eth" await technicians in research, production, technical service, development and sales.

ROSES CIRCLED THE GLOBE recently without water or dirt, wrapped in polyethylene-laminated paper. Scientist J. P. Mahlstead inspects roses after trip.

$10,000 GREENHOUSE FOR ONLY $455 is one of many amazing feats by Professor E. M. Emmert. Emmert has pioneered in applying polyethylene to gardening.

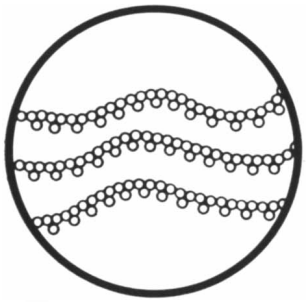
SNUG IN 60-MILE-AN-HOUR GALE, workmen continued building Brown University dorm. Construction was "gift-wrapped" in polyethylene film.

THE AUTHORS

HERMAN F. MARK ("Giant Molecules") is himself one of the giants of the exciting new field of polymer chemistry. Born in 1895 in Vienna, the son of a prominent physician, Mark early distinguished himself in athletics as well as scholarship: he played in the Austrian national soccer league at 17. An excellent skier, he joined an Austro-Hungarian mountain regiment during World War I, fought on two fronts, rose from private to captain and was captured by the Italians, from whom he eventually escaped disguised as a British officer. (His knowledge of the physical properties of snow later made him an invaluable member of the team that developed the snow-traversing "weasel" in 180 days during World War II.) In 1921 he received a Ph.D. *summa cum laude* from the University of Vienna. He taught for a year at the University of Berlin, then moved on to the Kaiser Wilhelm Institute for Fiber Chemistry, where the first X-ray studies of polymers were made. In 1926 he joined the research laboratories of I. G. Farbenindustrie, where he collaborated on classic studies of cellulose and other polymer structures. When the Nazis came to power, Mark resigned from I. G. Farben and became director of the First Chemical Institute of the University of Vienna. The German invasion of Austria caused his dismissal from the University and from the city's board of education, of which he had been an active member. For two years he worked for a Canadian pulp company; then he accepted a teaching post at the Polytechnic Institute of Brooklyn. There he gathered a group of U. S. and refugee scholars which in five years grew under his leadership into the Polymer Research Institute. The fact that five of the contributors to this issue of SCIENTIFIC AMERICAN have been associated with the Institute will give some idea of its importance in the development of polymer chemistry.

PETER J. W. DEBYE ("How Giant Molecules Are Measured") is, like Herman F. Mark, one of the pioneers in the new field of science to which this issue of SCIENTIFIC AMERICAN is devoted. Born in Maastricht, the Netherlands, in 1884, he was trained first as an electrical engineer at the University of Aachen, then acquired a Ph.D. in physics at the University of Munich in 1906. In the period from 1910 to 1934 he held professor-

WHAT CAN YOU DO WITH THESE 3 NEW COLLOIDS?



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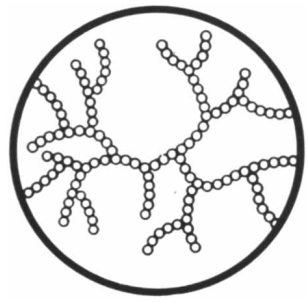
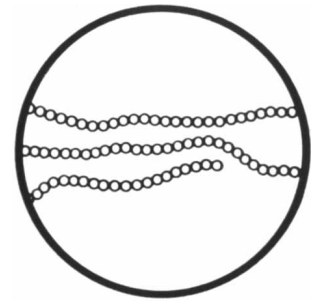


AMYLOPECTIN



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JAGUAR® NOW IN MANY TYPES

JAGUAR is Stein Hall's trade name for Guar Gum. JAGUAR, announced to the world only four years ago, is now being used by hundreds of industrial manufacturers because of its ability to solve unusually difficult problems, and to perform better and more economically than other colloids. You may also find one of the many new types and variations of JAGUAR useful in your laboratory, both in solving old problems and in developing new products.

JAGUAR produces extremely high viscosity at low concentrations

JAGUAR is cold water swelling

JAGUAR develops its properties over a wide pH range

JAGUAR has excellent thickening, film forming and stabilizing properties

JAGUAR in trace quantities has excellent flocculating and filter-aid properties

JAGUAR is a natural vegetable pure food colloid

JAGUAR is available in many standard types and can be tailor-made to meet specific end use requirements

JAGUAR is domestically produced in Stein Hall plants

JAGUAR is economical to use

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AMYLOSE AND AMYLOPECTIN FRACTIONS OF STARCH NOW COMMERCIALLY AVAILABLE

A unique, patented* and exclusive separation process now makes refined Amylose (straight chain fraction of starch) and Amylopectin (branched chain fraction of starch) available at low cost. Scientists familiar with starch have long been interested in working with the separate fractions of starch and exploring their possible uses. Now, Stein Hall makes these products commercially available in large tonnage quantities. Available in standard types or modifications to meet specific end uses.

Amylopectin is sold under Stein Hall's trade name RAMALIN. RAMALIN has many advantages over other commercially available Amylopectins:

RAMALIN is a giant molecule with a molecular weight of over 1,000,000

RAMALIN is readily dispersible and cold water soluble

RAMALIN has low viscosity at high concentrations

RAMALIN forms fluid stable solutions

RAMALIN is more reactive

RAMALIN, when combined with resins, forms water-resistant films and coatings

RAMALIN has a greater affinity to many fibers and other materials

RAMALIN has indications of superior flocculating properties

RAMALIN is a pure food material

Amylose is sold under Stein Hall's trade name SUPERLOSE. SUPERLOSE is the only commercially available Amylose. It has these known properties:

SUPERLOSE is a giant molecule with a molecular weight of 150,000

SUPERLOSE has outstanding film strength and is suitable for film and fiber manufacture

SUPERLOSE forms water and grease resistant films and coatings

SUPERLOSE is suggested for application in paper, textiles and other fields

SUPERLOSE can be made viscosity stable for extended periods of time

SUPERLOSE can be supplied as a dry powder or stabilized solution

SUPERLOSE is a pure food material

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ships of theoretical or experimental physics at the universities of Zurich, Utrecht, Göttingen and Leipzig. From 1934 to 1939 Debye was professor of physics at the University of Berlin and Director of the Max Planck Institute. In 1939 he left Germany and became professor of chemistry and head of the chemistry department of Cornell University. He became a naturalized citizen of the U. S. in 1946, and retired from Cornell in 1952. Since 1910 Debye has been investigating the scattering of light as a means of studying giant molecules. This profitable vein of research has led to the method of powder crystallography, the investigation of single molecules by X-ray and electron diffraction, and the explanation of the quasi-crystalline structure of liquids. In 1936 Debye received the Nobel prize in chemistry.

GIULIO NATTA ("How Giant Molecules Are Made") was born at Imperia on the Italian Riviera and studied chemistry at the Polytechnic Institute of Milan, graduating as doctor of engineering in 1924. He taught at the universities of Rome and Pavia before returning to his alma mater in 1939 as professor of industrial chemistry. Natta was the first chemist to synthesize wood alcohol; later he devised a method to convert alcohol into butadiene—a development which led to the founding of Italy's synthetic-rubber industry. He is a fellow of the Accademia dei Lincei, Italy's national academy.

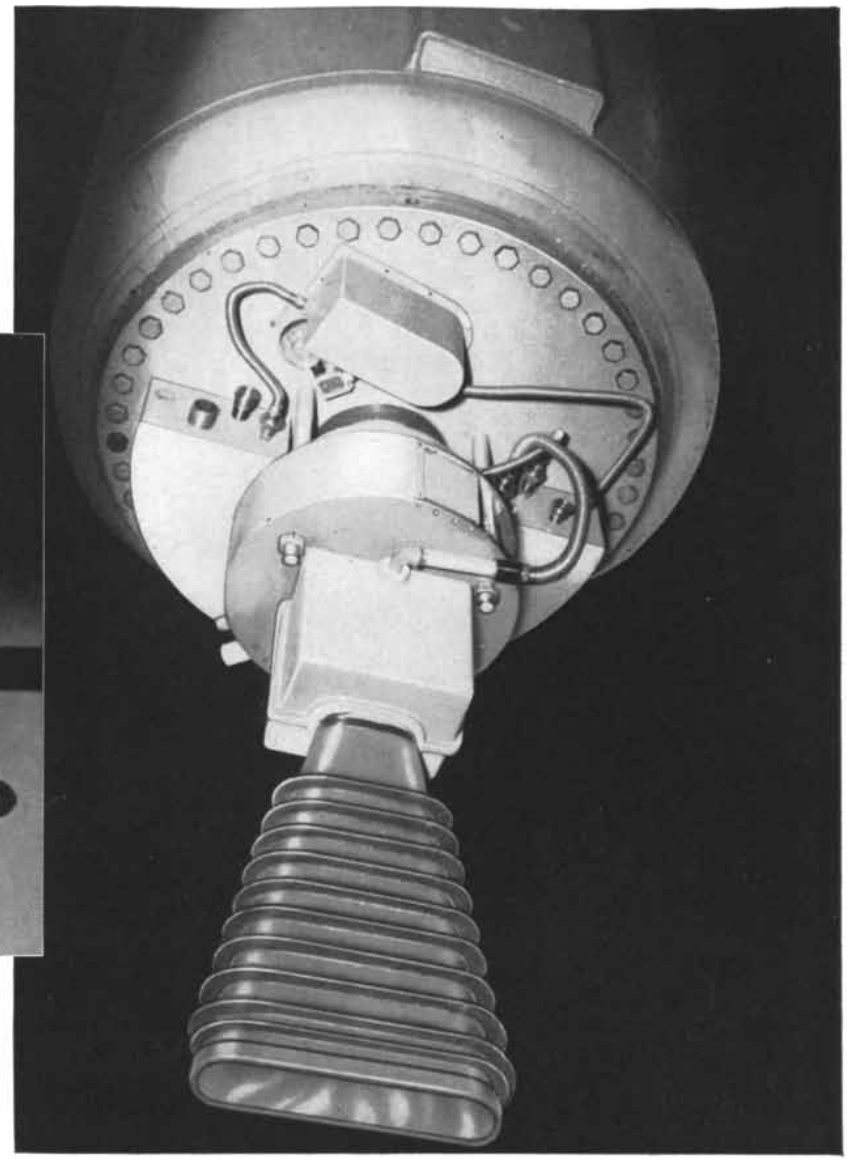
ARTHUR V. TOBOLSKY ("The Mechanical Properties of Polymers") last year won the Bingham Medal of the Society of Rheology for his contributions to the structural knowledge of giant molecules. He is associate professor of chemistry at Princeton University and, at present, chairman-elect of the Division of Polymer Chemistry of the American Chemical Society. Born in New York City, Tobolsky attended Columbia University, from which he graduated in 1940. In 1944 he earned his Ph.D. at Princeton, where he has been ever since, except for five years of commuting during which he doubled as adjunct professor at the Polytechnic Institute of Brooklyn.

GERALD OSTER ("Polyethylene") is associate professor of polymer chemistry at the Polytechnic Institute of Brooklyn, where he works in the High Polymer Institute and does research on the scattering of light and X-rays by viruses and giant molecules. Born in Providence, R.I., in 1918, he graduated from Brown

ELECTRON-BEAM GENERATOR

a G-E product in step with your progress

These polyethylene bottles were kept at 250° for 20 minutes. The erect irradiated pair also has improved resistance to detergents, acids, solvents.



Materials acquire new properties from this

giant-molecule maker

Speed up electrons in a vacuum to a velocity approaching that of light — and you've a means of imparting new and improved chemical and physical characteristics to familiar materials. Under the guidance of the electron chemist, irradiated low-molecular-weight monomers change to giant polymer molecules.

For instance, the long molecules of a high polymer like polyethylene can be crosslinked by irradiation to provide a better product. The only difference between the polyethylene bottles in the photo above is that the two still erect were irradiated with a General Electric Electron-Beam Generator before being subjected to the same temperatures as the shapeless masses.

Molecule building like this happens with no addition of heat, chemicals or catalysts. Other examples: polymer rubber is vulcanized (crosslinked) without sulfur or heat. Petroleum hydrocarbons are converted into gasoline hydrocarbons of higher octane ratings without catalysts.

Why not investigate the potential electron-beam irradiation holds for your products. Your G-E x-ray representative will be glad to initiate a mutual investigation. Or write for folder "Electron Chemistry — New Frontier of Science" to X-Ray Department, General Electric Company, Milwaukee 1, Wisconsin. Ask for Pub. TT-94.

Progress Is Our Most Important Product

GENERAL ELECTRIC

University in 1940 and received a Ph.D. in physical chemistry from Cornell University three years later. Thereafter he was a research associate of the Massachusetts Institute of Technology (in dielectrics) and Princeton University (in biophysics). From 1945 to 1948 Oster served on the staff of the Rockefeller Institute for Medical Research. He then was a Rockefeller Foundation Fellow for two years in London, first at the Birkbeck College Research Laboratory and then at the Royal Institution. The following year he was a visiting scientist at the universities of Strasbourg and Paris, and in 1951 he joined the staff of Brooklyn Poly.

R. D. PRESTON ("Cellulose") received his undergraduate and graduate training at the University of Leeds, where he is now professor of plant biophysics and dean of the faculty of arts and science. After taking a Ph.D. in botany in 1931 he held the 1851 Exhibition Fellowship at Leeds for three years, then came to the U. S. as a Rockefeller Foundation Fellow at Cornell University. In 1936 Preston returned to Leeds and took the post of lecturer in botany. There he carried out research on the submicroscopic structure of plant cells. In 1943 he received the degree of Doctor of Science. He has published some 80 scientific articles and a book on the molecular architecture of plant cell walls, and is editor of the *Scientific Proceedings of the Leeds Philosophical Society*. In 1954 Preston was elected a Fellow of the Royal Society.

PAUL DOTY ("Proteins"), editor of the *Journal of Polymer Science*, is a Harvard University physical chemist who was once an assistant professor of chemistry at the Polytechnic Institute of Brooklyn. Born in Charleston, W. Va., in 1920, Doty studied at Pennsylvania State College and at Columbia University, where he took his Ph.D. under J. E. Mayer. At that time he had already begun his association with Brooklyn Poly; during his three years there he directed a research project for the U. S. Army Quartermaster Corps. In 1946 Doty went to the University of Cambridge as a Rockefeller Foundation Fellow. The following year he taught at the University of Notre Dame, and in 1948 he joined the Harvard faculty, where he soon rose to full professorship. He is at present chairman of the Federation of American Scientists.

F. H. C. CRICK ("Nucleic Acids") disclaims the title of biologist. He says:

U.S.I. POLYETHYLENE PROCESSING TIPS

Vol. II, No. 1

WITH MORE TYPES THAN EVER, HERE'S HELP IN CHOOSING THE RIGHT POLYETHYLENE FOR YOU

In the last year polyethylene has become a whole family of resins with a wide range of properties and many new use possibilities.

Today manufacturers are learning how to tailor polyethylene to almost any end use and processing condition by varying three basic characteristics of the resin in the original manufacturing process:

(1) *Density*
(2) *Molecular Weight*
(3) *Molecular Weight Distribution*

The properties of polyethylene, whether made by a high pressure, modified high pressure, or any of the low pressure processes are fixed by *all three* of these characteristics. An extremely large number of resins having markedly different properties can be produced by controlling these fundamental characteristics.

The processor can usually describe the properties he needs and the manufacturer can then determine which resin is most likely to fill the bill. From that point the two can work together to determine the "ideal" resin for the application.

The following chart shows in very general terms how some of the polymer properties are affected as these characteristics are varied.

Figure I: How Properties Change With Molecular Characteristics

PROPERTY OF POLYETHYLENE	CHARACTERISTIC		
	Increasing Density	Increasing Mol. Wt.	Widening M.W.Dist.
Stiffness	increases	increases slightly	increases slightly
Tensile Yield Point	increases	little or no effect	little or no effect
Film Brittleness	increases	decreases	increases
Softening Point	increases	increases	decreases
Low Temperature Brittleness	decreases	decreases	increases
Resistance to Environmental Stress Cracking	decreases	increases	decreases
Permeability	decreases	little or no effect	little or no effect
Tear Strength (Elmendorf)	decreases	increases	increases
Impact Strength	decreases	increases	—

Effects of Density Variations

The term density describes the weight per unit volume of the resin, and is influenced by the amount of branching in the molecule. Densities can range from 0.910 to 0.965.

The effect of density variations on polyethylene properties will be discussed completely in the next issue of "Polyethylene Processing Tips". You may receive your copy by mail simply by requesting it.

Effects of Molecular Weight

The term molecular weight when applied to polyethylene describes the average or mean size of the molecules in the resin.

Melt index has been used to indicate molecular weight in the past, but since it is also affected by the degree of branching of the molecules, it is a close, but not a completely reliable guide. In these discussions, therefore, we will refer to molecular weight rather than to melt index.

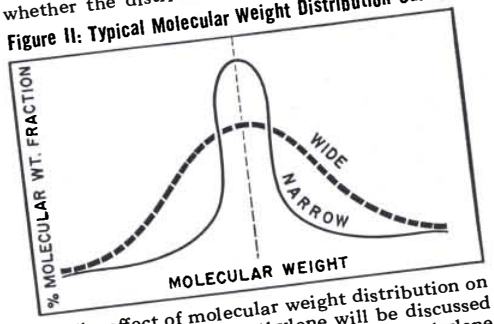
The effect of molecular weight variations on polyethylene properties will be discussed completely in a future issue of "Polyethylene Processing Tips".

Effects of M.W. Distribution

Distribution is determined by measuring how many of each size of molecule is present. When the percentage of each size of molecule is plotted against molecular weight, a distribution curve similar to the one shown below is obtained.

The shape of the curve for each resin tells whether the distribution is wide or narrow.

Figure II: Typical Molecular Weight Distribution Curves



The effect of molecular weight distribution on the properties of polyethylene will be discussed completely in a future issue of "Polyethylene Processing Tips".

U.S.I. Offers Technical Assistance

By indicating density, molecular weight and molecular weight distribution — or preferably by indicating the properties you want in your fabricated polyethylene product — you will be able to obtain from U.S.I. a polyethylene resin specific to your end use. Our technical service engineers will be glad to discuss your requirements with you.

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"I usually call myself a molecular biologist, a very different creature." At the University of Cambridge, where he pursues the discipline of molecular biology, Crick has done basic research on the structure of viruses, collagen and nucleic acids. He now finds himself most interested in molecular genetics and protein synthesis. This is his second article for SCIENTIFIC AMERICAN; his first, entitled "The Chemistry of the Hereditary Material," appeared in October, 1954. Recently he worked for a year at the Polytechnic Institute of Brooklyn.

FRANCIS O. SCHMITT ("Giant Molecules in Cells and Tissues") is Institute Professor of Biology at the Massachusetts Institute of Technology. Born in St. Louis in 1903, his first ambition was to be a surgeon and he took the premedical course at Washington University. There he became interested in cell structure and decided to give up surgery for cytology (his first paper on the subject was published in the year of his graduation, 1924). As a young graduate student at Washington University, Schmitt was inspired by the work of Jacques Loeb on proteins to abandon prepared slides and become a cell physiologist. But with the arrival of electron microscopy and polarization optics applied to cells, he began once more to study the molecular structure of life. After receiving his Ph.D. in 1927, he was a National Research Council Fellow for a year at the University of California, then did two more years of postdoctoral research in London and Berlin before returning to Washington University as a staff member. By 1940 Schmitt was head of the zoology department at Washington University. The following year he was made a professor at M.I.T., where he soon became head of the department of biology.

GILBERT RYLE, who reviews the life and work of Ludwig Wittgenstein in the book section of this issue, is Waynflete Professor of Metaphysical Philosophy in the University of Oxford and editor of *Mind*, the distinguished British journal of philosophy and psychology. A bachelor and lifelong Oxford man, he attended Queen's College (where he was captain of the boat club), graduated with first-class honors, and became a tutor in Christ Church College in 1924. In World War II he was commissioned in the Welsh Guards and rose to the rank of major. He is the author of two books, *The Concept of Mind* and *Dilemmas*.

LUBRICANTS...for the Daedalus to circle the moon

If you work with *avant-garde*, specialized engineering—for jet aircraft, rocket flight through space, or cross-country turnpike cruisers—you run smack up against a need for particular kinds of liquids for special kinds of work. You might find you need a special coolant that slows down neutrons; a hydraulic fluid with a particular viscosity range; a fire-resistant or high-temperature lubricant. Such *functional fluids* must be chemically made to meet the demands of the operation: higher temperatures, greater velocities, extreme pressures, highly critical operating environments.

In your development of new engineering design in the field of servomechanisms, aerodynamics, applied hydraulics—Monsanto can assist you greatly with the development of the kind of functional fluid your work requires—from synthetic lubricants for turbine-engine cars to operable hydraulic fluids for rockets that approach the thermal barrier.

Here are some examples of fluids now undergoing field evaluation which show how Monsanto can help meet specialized needs for "chemically tailored" lubricants:

Monsanto, to date, has developed: Fire-resistant hydraulic fluids for aviation and industrial applications including:

PYDRAUL* F-9, PYDRAUL 150, PYDRAUL 600, PYDRAUL AC, PYDRAUL 60, PYDRAUL 625, SKYDROL*, and SKYDROL 500.

Thermally stable synthetic hydraulic fluids for guided missiles and supersonic aircraft including OS-45, Type III, and OS-45, Type IV.

Monsanto is presently developing: Fire-resistant steam turbine lubricants; nuclear reactor coolants; radiation resistant hydraulic fluids and lubricants; 700° F. jet engine lubricants; synthetic automatic weapons lubricant.

Monsanto has programmed for development: "Chemically tailored" fluids for automotive use such as improved high-temperature brake fluids, superior automatic transmission fluids, synthetic lubricants for automotive gas turbine engines, and, for the aircraft field: hydraulic fluids and lubricants capable of operating in the range of 800° F.-1000° F.

When you require a special fluid for special needs, you are invited to contact Monsanto . . . the pioneer in development of synthetic functional fluids.

Organic Chemicals Division; Dept SA-2
MONSANTO CHEMICAL COMPANY
St. Louis 1, Missouri

*Reg. U. S. Pat. Off.

MONSANTO

NUCLEAR NEWS FROM ATOMICS INTERNATIONAL

Continuing Progress at AI Advances Nuclear Technology For Many Tasks, in Many Lands

Highlighting progress in the many and diversified reactor programs at Atomics International are significant developments in the two major power reactor approaches underway by AI for the Atomic Energy Commission—the Sodium Reactor Experiment and the Organic Moderated Reactor Experiment.

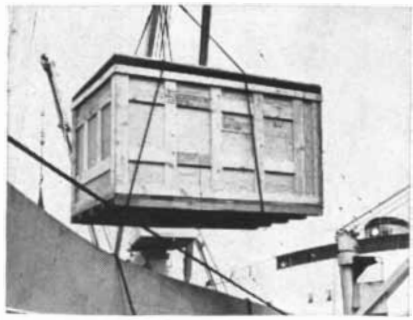
Forecasts Confirmed. On April 25 the 33rd fuel element was introduced into the SRE, and sustained nuclear fission was achieved. The critical loading confirmed earlier calculations. On July 12 heat from the SRE reactor was used by the Southern California Edison Company to generate electricity. This power was fed over utility lines to Edison consumers. Data obtained from the SRE will be used in the design of a 75,000 kw Sodium Reactor power plant proposed for the Consumers Public Power District of Nebraska.

Power Ashore, Propulsion Afloat. Similar studies are starting on the OMRE, recently constructed at the AEC's National Reactor Testing Station in Idaho Falls. This program will assist in the design of two 12,500 kw power stations, one in Piqua, Ohio, and another in a Latin American country. At the same time, the Organic Moderated Reactor is under study as a most promising nuclear propulsion system for the special needs of supertankers.

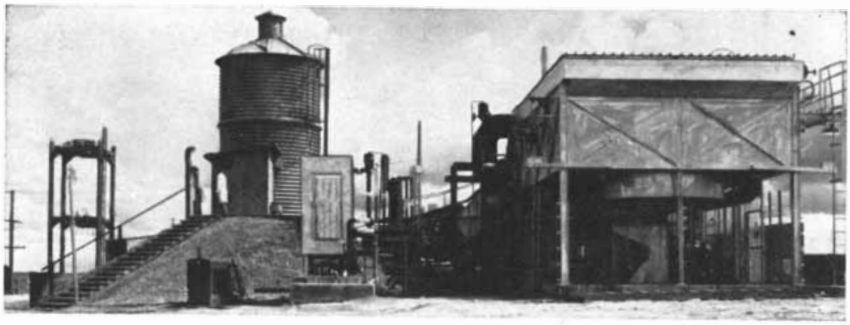
Reactors for the World. The Armour Research Reactor, first private industrial nuclear facility, is now being followed by a stream of similar research reactors—for Japan, Denmark, West Germany, West Berlin and Italy—constructed, shipped, and installed by Atomics International. AI's latest development is the compact Laboratory Reactor, available on a short delivery schedule at very low cost to meet the need for nuclear training and research in universities and industrial laboratories.

ATOMICS INTERNATIONAL is a leading designer and builder of reactors for America and for the world. For help on your reactor plans, write: Director of Technical Sales, Department SA-74, ATOMICS INTERNATIONAL, P. O. Box 309, Canoga Park, California. Cable Address: ATOMICS.

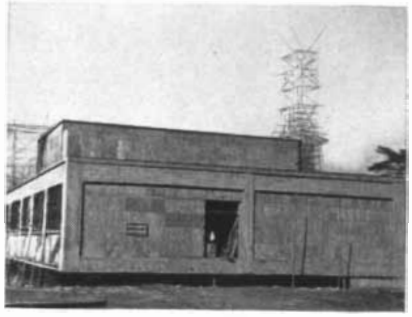
Critical Moment: On April 25, the SRE achieved sustained nuclear fission. Electricity was generated on July 12.



Destination—Denmark: Nuclear reactor components from AI are hoisted aboard a freighter for Copenhagen.

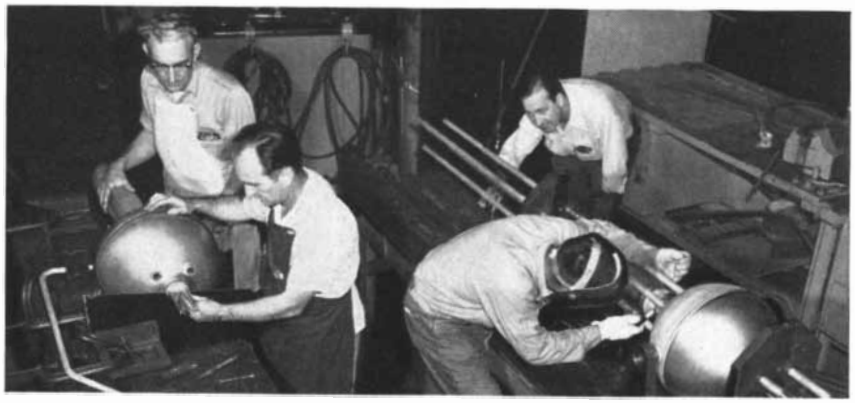


For Land and Sea: A versatile nuclear reactor concept—the OMRE.



Nuclear Research in Japan: Home of Far East's first reactor will be Japan's Atomic Energy Research Institute.

New Laboratory Reactor: Eight-foot-high tank contains fully functional core, coolant and moderator.



Reactor Hardware for Germany: Components for two German reactors in work at ATOMICS INTERNATIONAL.

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.
PIONEERS IN THE CREATIVE USE OF THE ATOM

WHAT IS YOUR APPLICATION FOR SYNTHAMICA* (Synthetic mica) ?

SYN'THE-MI'CA (SIN-THA-MI-KA) *n.* [*Synthetic mica*]

Trade-mark of Synthetic Mica Corporation for synthetic mica. **Chem:** Synthetic mica is a fusion of silica, alumina, magnesia and alkali fluorides — it can be made chemically pure with a wide range of properties for special applications. **Physical:** *(example: Synthamica 202)* melting point 1365°C; Specific heat 0.2; specific gravity 2.9; Hardness (MOH's) 3.4; transparency — excellent; Gassing in vacuum at high temperatures — far superior to natural muscovite mica; maximum continuous operating temp — 1000°C. **Mechanical:** SYNTHAMICA is available in crystals, powder, sheets and paper-like mats. **Potentialities:** Taking advantage of the controlability of synthetic mica properties, high purity and refractoriness Mycalex Corporation of America has developed SUPRAMICA* ceramoplastics, made with SYNTHAMICA synthetic mica to produce superior electrical insulators with dimensional stability, ability to retain metal inserts molded in place, and outstanding dielectric and thermal properties.

Other possible applications include: fillers for brake linings and plastics; welding rod coatings; potting compounds; oxygen valves; reflective coatings; high-temperature furnace window; very-high-temperature connectors, high energy nuclear applications.

Because it is possible to make a wide range and variety of synthetic micas, properties can be "tailor-made" to fit applications.

Write today for complete technical information — please mention your proposed application — our engineering department will supply samples for your inspection.

* SYNTHAMICA is a trade-mark of SYNTHETIC MICA CORPORATION, a subsidiary of MYCALEX CORPORATION OF AMERICA
SUPRAMICA is a registered trade-mark of MYCALEX CORPORATION OF AMERICA

THE FIRST SYNTHAMICA SYNTHETIC MICA

SYNTHETIC MICA CORPORATION
a subsidiary of
MYCALEX CORPORATION OF AMERICA
CLIFTON BOULEVARD CLIFTON NEW JERSEY

Avco makes things better for America...

Avco

Avco today

Avco makes the "business end" of the ICBM

How to keep the intercontinental ballistic nose cone from blazing into white heat and vaporizing completely, as it re-enters the earth's lower atmosphere, has been one of the biggest problems facing missile developers. Avco Research and Advanced Development scientists have solved this problem in the laboratory. With a device called a "shock tube," they have simulated 18,000 mph speeds and 15,000 degree temperatures to study what happens to a missile during re-entry. They have produced re-entry information which has enabled Avco engineers to design and construct an experimental nose cone for the Air Force Titan missile. Another *breakthrough* by the Research and Advanced Development Division of Avco! What is Avco?

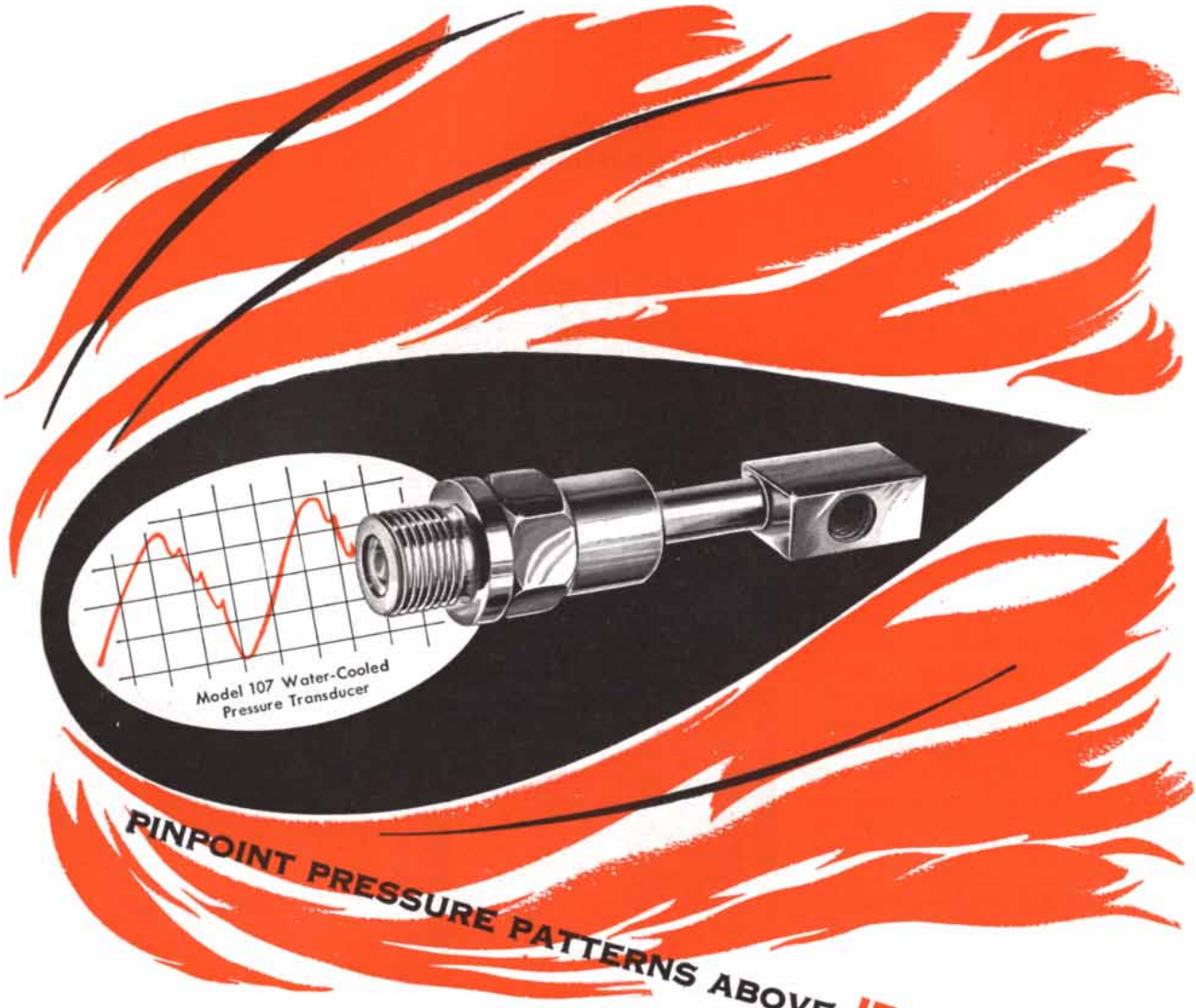
THIS IS AVCO

Avco today is a diversified organization whose products include aircraft power plants and structures, electronics for defense and industry, and specialized home and farm equipment. Avco's divisions and subsidiaries are:

Crosley—electronics and aircraft structures . . . American Kitchens . . . Lycoming—reciprocating engines and gas turbines . . . New Idea and Ezee Flow—specialized farm equipment . . . Research and Advanced Development . . . Crosley Broadcasting Corporation . . . Moffats, Ltd. (Canada)—commercial gas and heating equipment.

Scientists interested in unusual opportunities for advancement can grow with Avco.

Avco Manufacturing Corporation
420 Lexington Avenue, New York, N. Y.



PINPOINT PRESSURE PATTERNS ABOVE 5000°F

Proven Design — new, high temperature pressure transducer uses same catenary diaphragm and tubular strain cylinder as NORWOOD CONTROLS' highly successful air-cooled models. Immune to external vibration; mounts flush with negligible change in volume of pressure chamber; extremely high frequency response, flat to 10,000 cps.

Withstands ultra-high temperatures — designed for use in rocket and jet engines, high temperature chemical reactions, etc. Efficient water-cooling system enables diaphragm to withstand gas temperatures above 5000°F. Heat transfer rate 11 BTU/sq. in./sec. with 85°F temperature rise of cooling water.

Corrosion resistant — All exposed parts of stainless steel, can safely be exposed to highly oxidizing conditions.

Full Scale Pressures — 0–1000 and 2000 psi ranges with 1% of full scale accuracy and excellent temperature compensation. (Other ranges available on request.)

Write for Data Sheet A157-2 on Model 107 and Data Sheet A257 covering Norwood Controls' air-cooled transducers, which have recently been substantially reduced in price.

NC NORWOOD CONTROLS

NORWOOD CONTROLS
UNIT OF DETROIT CONTROLS CORPORATION

933 Washington Street, Norwood, Mass.

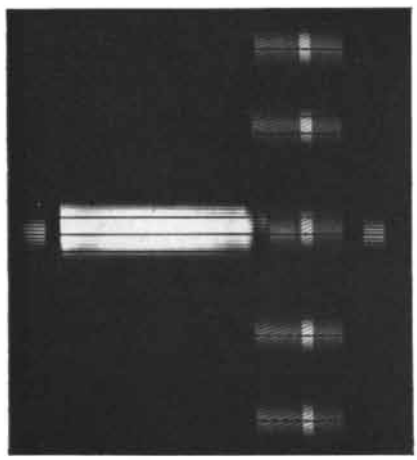
Better Ways to

New Measurements on Polymers with the Ultracentrifuge

By photographing molecules while they are under centrifugal force, the Analytical Ultracentrifuge allows direct measurement of molecular weight, sedimentation constant, purity – and gives information on homogeneity, molecular weight distribution, molecular shape and size.

Proteins

New developments in equipment and technique have extended the classic biochemical uses of the Ultracentrifuge to more precise measurements, to smaller molecules, and to a variety of different molecular studies. *Synthetic-boundary cells* allow sedimentation measurements of molecules to molecular weights as low as a few hundred. *Interference optics* permit direct calculation of molecular weight without additional data. *Absorption optics* accurately measure nucleic acid concentrations to 0.001% ("Ultracentrifugal Analysis of Dilute Solutions," Schumaker and Schachman, *Biochimica et Biophysica Acta,* 23,628, 1957).

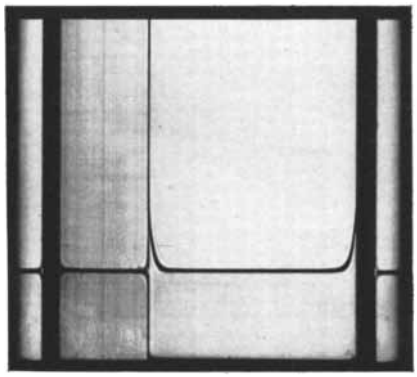


INTERFERENCE FRINGE PATTERN of 5 cells run simultaneously in An-G type rotor.

Plastics

The addition of high temperature equipment now enables Ultracentrifuge runs on plastics and other materials which are insoluble at lower temperatures. Control is better than 0.1 degree at temperatures to above 100° C.

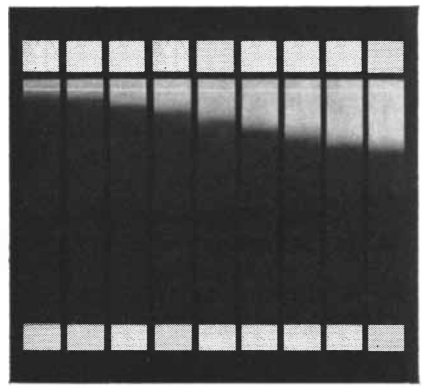
New theoretical developments permit direct measurement of weight-average-molecular weights in polydisperse systems ("Direct Ultracentrifuge Molecular Weights of Synthetic High Polymers," Kegeles, Klainer and Salem, presented at 31st National Colloid Symposium, New York, June 27-29, 1957).



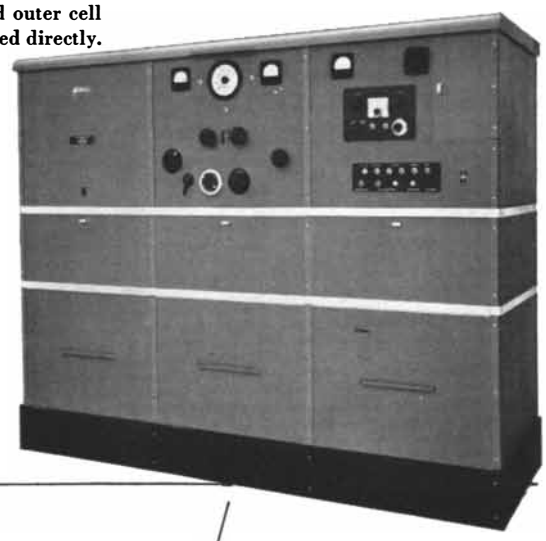
CONCENTRATION IS MEASURED early in low-speed run at meniscus and outer cell edge, and weight average calculated directly.

Petroleum

Both "Preparative" and "Analytical" Spinco Ultracentrifuges have been found to offer new information in studying crude oils and petroleum fractions ("A Study of the Colloidal Characteristics of Petroleum Using the Ultracentrifuge," Ray, Witherspoon and Grim, presented at 31st National Colloid Symposium, New York, June 27-29, 1957).



ABSORPTION PATTERNS showing sedimentation of petroleum dispersed in benzene.



BECKMAN/SPINCO Analytical Ultracentrifuge, Model "E." Speeds to 60,000 rpm, centrifugal forces to 260,000 G. Available with refrigeration, heating and vacuum systems; interchangeable analytical and preparative rotors; absorption, schlieren and Rayleigh fringe optical systems.

Our Technical Sales Department will be happy to correspond with you on Ultracentrifuges or ultracentrifuge applications. Address Beckman/Spinco Division, Stanford Industrial Park, Palo Alto 3, California.

Beckman

Spinco Division

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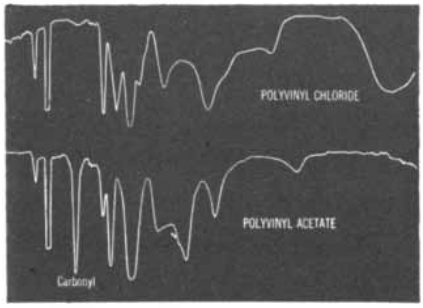
Measure Giants

Analytical Instruments Fingerprint Giant Molecules

By probing a chemical substance with infrared or ultraviolet radiation in a spectrophotometer, that chemical's absorption curve — a nearly absolute measure and often a distinct and exclusive fingerprint of the sample is obtained. This provides a degree of specificity not found in any other analytical technique.

The Infrared Fingerprint

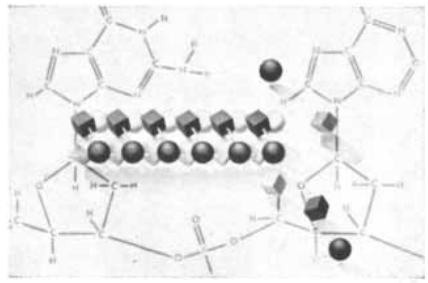
In the chemistry of giant molecules, the infrared absorption curve identifies and determines the building blocks or raw materials of high polymers, reveals molecular structure, helps monitor and control molecular composition during synthesis and fingerprints the giant molecules themselves.



STRUCTURAL DIFFERENCES in these two similar plastics are immediately apparent when their infrared spectra are compared. Note presence of carbonyl group — a basic chemical building block.

Versatile Ultraviolet

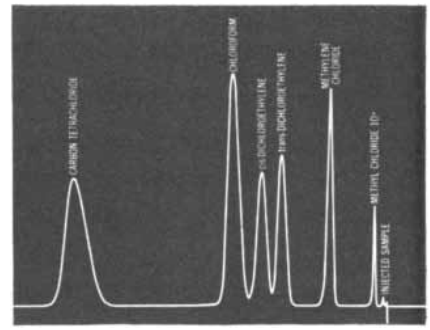
Beyond its use in determination of molecular structures, the versatile ultraviolet spectrophotometer has wide application in polymer chemistry — determination of monomer in polymer; determination of plasticizers in plastics; analysis and control of color in plastics (with spectroreflectometer); quality control of solvents. More than 15,000 Beckman DU spectrophotometers — the acknowledged standard for spectrochemical analysis — are in use today, and the field has been greatly extended with the DK automatic recording instruments.



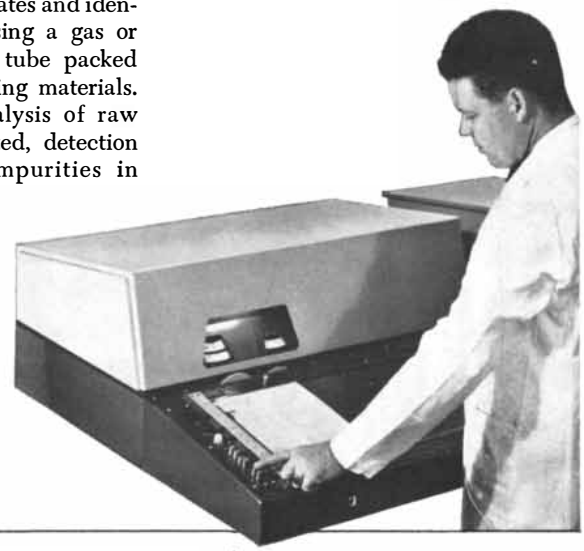
A MODULAR REPRESENTATION of nucleic acid, one of the most complex polymers. A Beckman DK-2 automatic recording spectrophotometer is accelerating an important investigation today by rapidly and reliably measuring the progress of researchers in their efforts to synthesize nucleic acids, believed to be deeply involved in key phases of the life process itself.

Gas Chromatography

Gas chromatography separates and identifies components by passing a gas or liquid sample through a tube packed with absorbing or adsorbing materials. Applications include analysis of raw materials to be polymerized, detection and identification of impurities in styrene, butadiene, chloroprene, acrylonitrile and other chemical building blocks; detection and identification of impurities in plasticizers and analysis of other gases or liquids with boiling points up to 350° C.



HERE'S AN ANALYSIS that by ordinary methods could take as much as *8 hours* of the chemist's productive time. *Twenty minutes* after mixture of six chlorinated hydrocarbons was injected into Beckman Gas Chromatograph, this chromatogram appeared on recorder. The six components — raw materials of synthesis as well as solvents for complex substances — were separated and identified, with the concentration of each clearly indicated.



BECKMAN IR-4 Automatic Recording Infrared Spectrophotometer. Also available are the low-cost IR-5 and IR-6 instruments which bring infrared within reach of every laboratory.

For more information about these instruments, write for Data File L-35-98. Address Beckman / Scientific Instruments Division, Fullerton, California. You will hear from us promptly.

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Scientific Instruments Division
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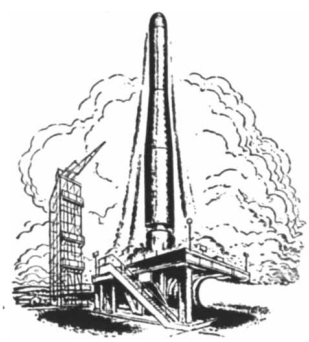
Who's top dog in inertial navigation?

Precision inertial navigation is the most exciting and technically advanced way to keep a moving air, land or sea vehicle on course. It does not use radio, radar, the stars, heat or magnetic reference. Highly accurate, its military use in missiles and aircraft may be the key to an effective deterrent weapon.

American Bosch Arma Corporation, through its ***ARMA*** Division, is a leader among companies making contributions to inertial navigation. As a result, ***ARMA*** was selected to design and produce the inertial guidance system for America's newest intercontinental ballistic missile: Titan. ***ARMA*** . . . Garden City, N. Y. A Division of American Bosch Arma Corporation.



There are unlimited employment opportunities in inertial navigation at ***ARMA***.

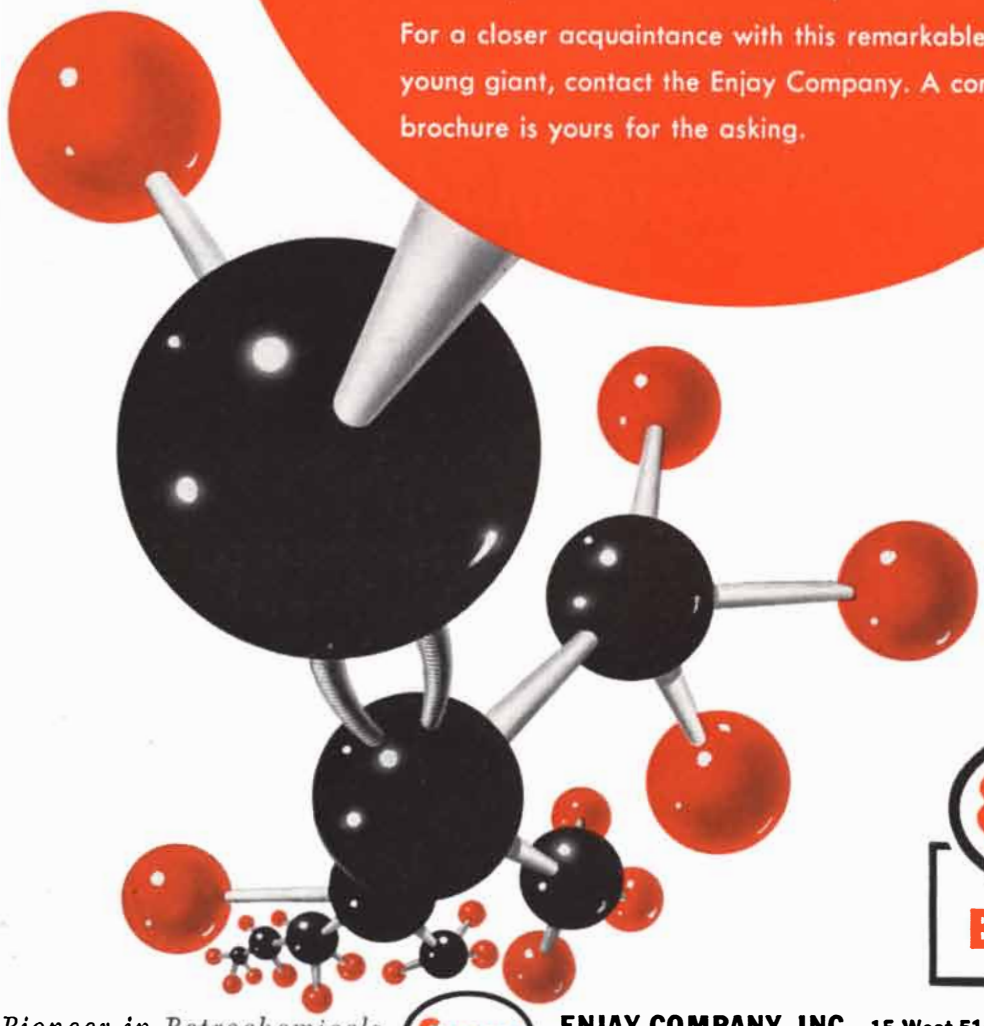
AMERICAN BOSCH ARMA CORPORATION

the growth of a giant...

. . . Enjay Butyl rubber, a man-made giant molecule. Invented in 1937, first produced in 1943, Butyl went immediately to war, replacing natural rubber for the manufacture of inner tubes.

Since the war, Butyl has been applied to many other exciting uses. Its wide variety of outstanding physical, chemical and dielectric properties give it a versatility unmatched by any other rubber, natural or synthetic. Today Butyl makes possible better quality automotive, electrical, industrial and domestic products.

For a closer acquaintance with this remarkable young giant, contact the Enjay Company. A complete brochure is yours for the asking.



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Pioneer in Petrochemicals

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You can't count on shooting down a guided missile. The only effective defense against it is some form of Electronic Counter Measures...devices that deceive or destroy enemy missiles short of their targets.

Admiral has taken the lead in furthering the high priority program to develop ECM. Advanced ECM developments now in progress at Admiral will serve many defense purposes. Resulting equipments will be carried by aircraft for protection in hostile territory. At ground installations, ECM will confuse enemy missiles.

Inquiries are invited regarding Admiral's capabilities in ECM and other forms of military electronics.

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ENGINEERS. The wide scope of work in progress at Admiral creates challenging opportunities in the field of your choice. Write Director of Engineering and Research, Admiral Corporation, Chicago 47, Illinois.

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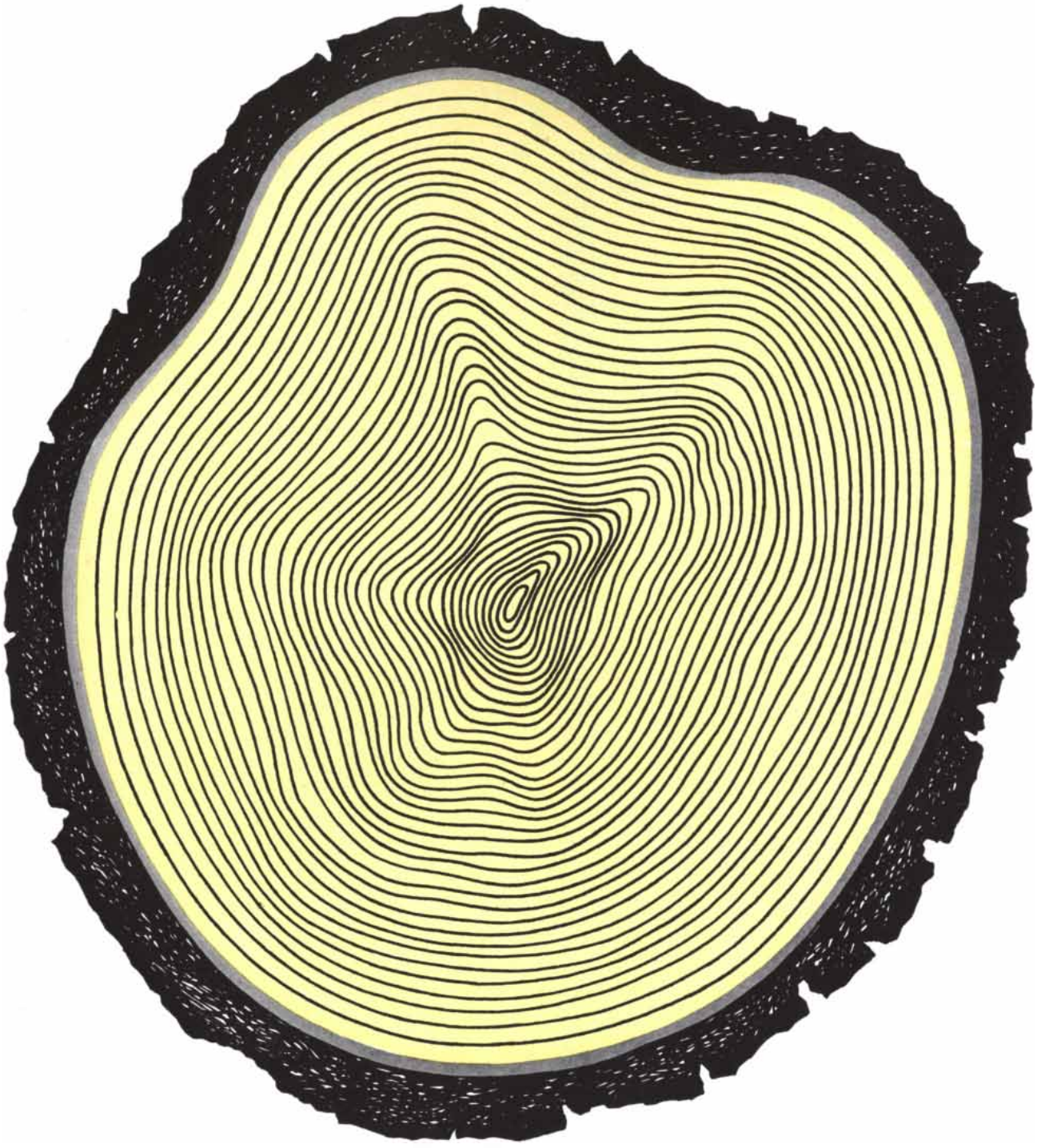

GIANT MOLECULES from wood are Rayonier's business. As chemical cellulose and silvichemicals, we can produce upwards of 2,000,000,000 lbs. of them each year at our mills in the USA and Canada. World industries convert these high polymers into some 500 uses. Among them: rayon, cellophane, tire cord, sausage casings, photographic films and papers, sponges, many plastics, lacquers, acetate and dispersants.

RAYONIER

CELLULOSE CHEMISTRY
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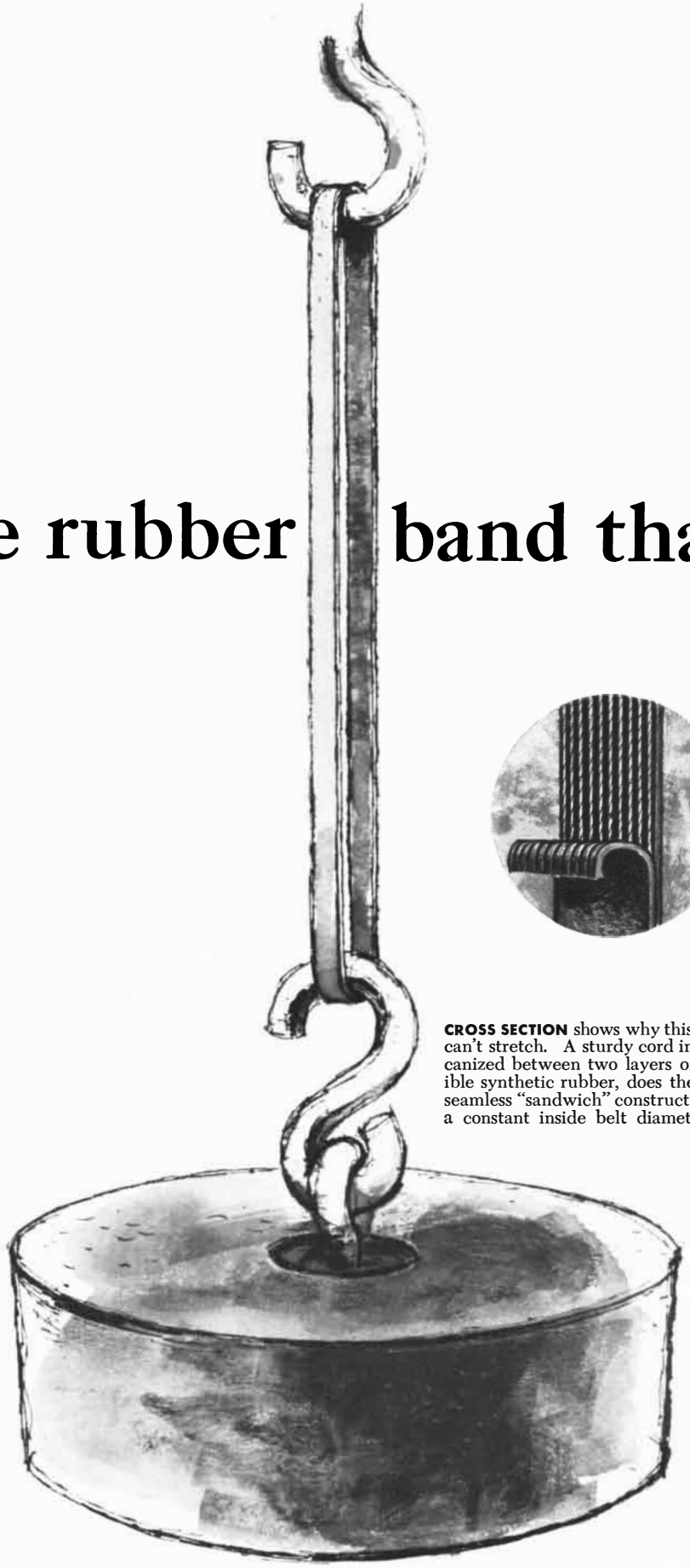
Research Centers at Shelton, Wash.; Vancouver, B.C.; Whippany, N.J.

The rubber band that won't



CROSS SECTION shows why this rubber band can't stretch. A sturdy cord interliner, vulcanized between two layers of tough, flexible synthetic rubber, does the trick. This seamless "sandwich" construction maintains a constant inside belt diameter for years.

stretch

Originally created to help spin better yarn, unique material now solves many drive-belt problems

It looks like an ordinary rubber band. Feels like one, too. But there the similarity ends, because this rubber band won't stretch . . . which is one of the big reasons why it's so useful.

Its story starts back in the middle thirties, when Armstrong research chemists began development work on a new kind of apron for the textile industry. (Aprons look much like two-inch-wide rubber bands, but they actually help to control fibers on a yarn-spinning frame.)

The researchers knew what they wanted in an apron—flexibility, oil resistance, proper frictional "grip," freedom from seams, precise dimensions—all this with absolutely no stretch. But they also knew there was no existing material that combined all these qualities. The problem, then, was to create such a material.

Armstrong chemists felt that synthetic rubber, with its great flexibility and oil resistance, would probably be a good basic material—if they could keep it from stretching. After much experimentation, they found the answer by vulcanizing a sturdy cord interliner between two layers of tough synthetic rubber. The result: a rubber band that didn't stretch. And since the vulcanization literally fused the layers of this "sandwich" together, there were no seams to worry about, either.

The next—and last—step was to make sure that this unusual rubber band had exactly the right frictional grip. This presented a knotty problem because normally synthetic rubber has too much surface friction to serve as an apron . . . it grabs too hard. A controlled reduction of the friction was finally achieved, though, by giving the bands a series of special chemical baths which changed the character of the surface molecules.

These synthetic rubber aprons soon became the standard in the textile field. And as their reputation grew, other applications began to appear. A dictating machine manufacturer, for example, realized that the same qualities which made for good apron performance were just what he had been looking for in a small power transmission belt. And so this very special rubber band—in this case only 3/8 of an inch wide—went to work driving an electronic dictating machine.

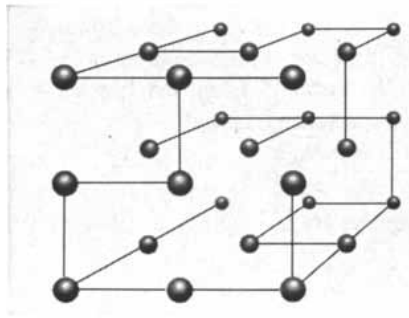
Still another application for these bands was found by a package machinery builder who uses much wider ones as conveyor belts. Right now, these bands are being tested for postage meters, automatic duplicating equipment, and tape recorders. The future? It looks bright for this rubber band that won't stretch.

If you manufacture equipment that uses—or could use—flat belt drives, these non-stretch seamless belts may open the way to lower costs or improved performance. They're available in many different sizes. For suggestions concerning specific applications, write to Armstrong Cork Company, Industrial Division, 8209 Inland Road, Lancaster, Penna.

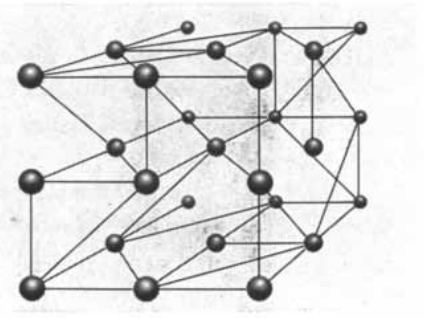
Armstrong Industrial Products

. . . USED WHEREVER PERFORMANCE COUNTS

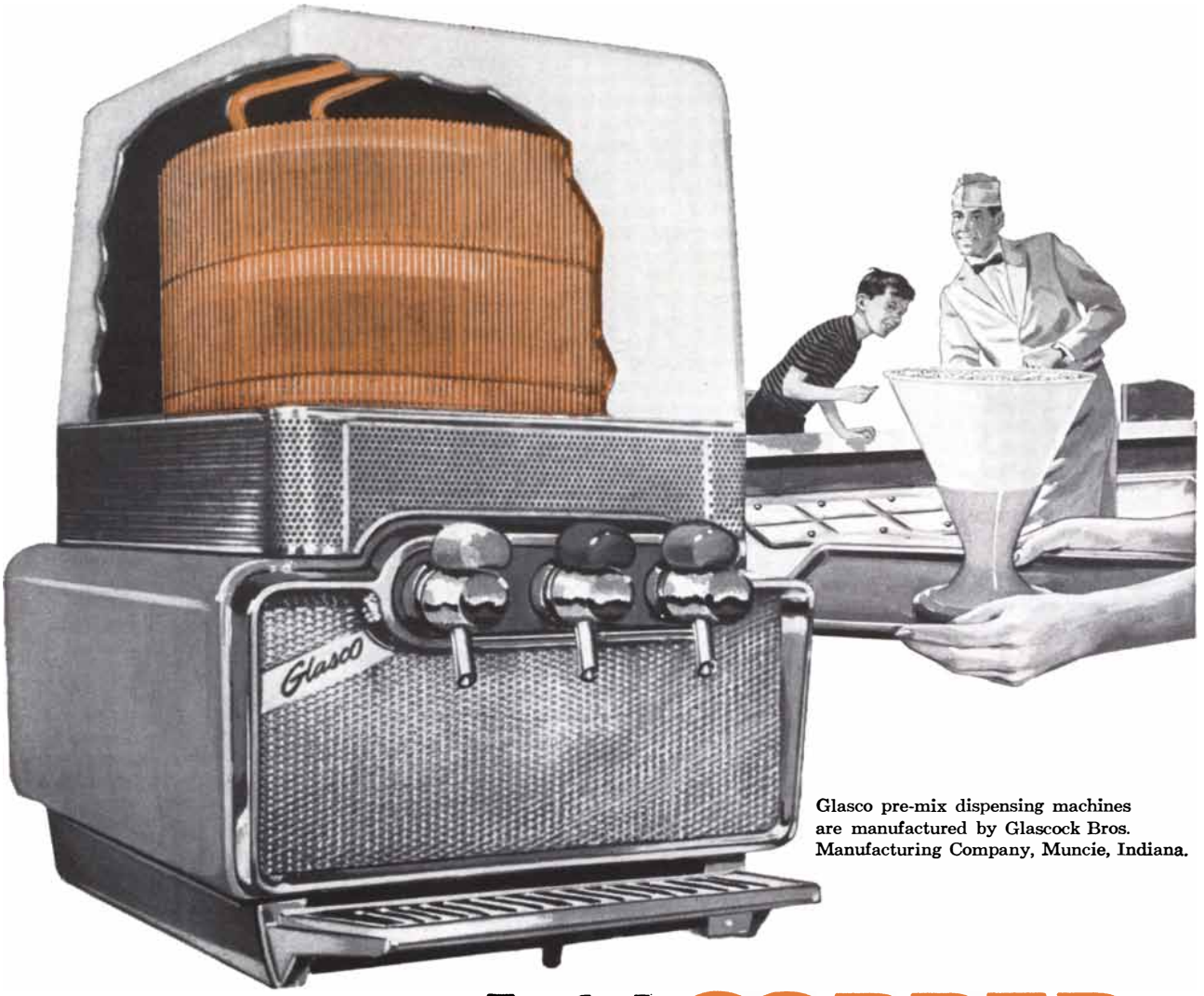
ADHESIVES • CORK COMPOSITION • CORK-AND-RUBBER • FELT PAPERS • FRICTION MATERIALS



THE MOLECULES in resilient synthetic rubber are not completely cross-linked. Although the surface is smooth, its coefficient of friction is relatively high—a desirable characteristic for many drive belt applications.



FOR TEXTILE APRONS, a lower coefficient of friction is desired. To get it, Armstrong chemists developed a special chemical bath that oxidizes the rubber, creating a denser surface with considerably lower friction.



Glasco pre-mix dispensing machines are manufactured by Glascock Bros. Manufacturing Company, Muncie, Indiana.

Add COPPER

...and it serves your drink cold!

Your soft drink from a dispensing machine is served *ice cold* because of Copper. For Copper is the *best* heat-transfer material commercially available. *Copper dissipates heat faster.* That's why the coolant-carrying tubes . . . and fins . . . inside the dispenser are Copper.

And that's why Copper is the metal preferred for air-conditioners to keep you cool at home or at work.

Even the big, new liquid-cooled generators are kept cool with Copper.

Copper has other invaluable properties, too. Because it is the best practical conductor of electricity, wiring and motor-windings are made of Copper. Copper resists corrosion. (It simply won't rust!)

In manufacturing processes, Copper has always been a great metal to *work* with. It proves easy to machine, form, draw, stamp, polish, plate. It welds readily . . . is excellent for soldering and brazing. Besides, you recover a higher portion of your materials cost from the higher-cash-value of your manufacturing scrap!

And today, you can plan with Copper . . . confident that the Copper Industry will keep Copper in ample supply to meet your future needs.

COPPER • BRASS • BRONZE

in over 40 Standard Alloys!

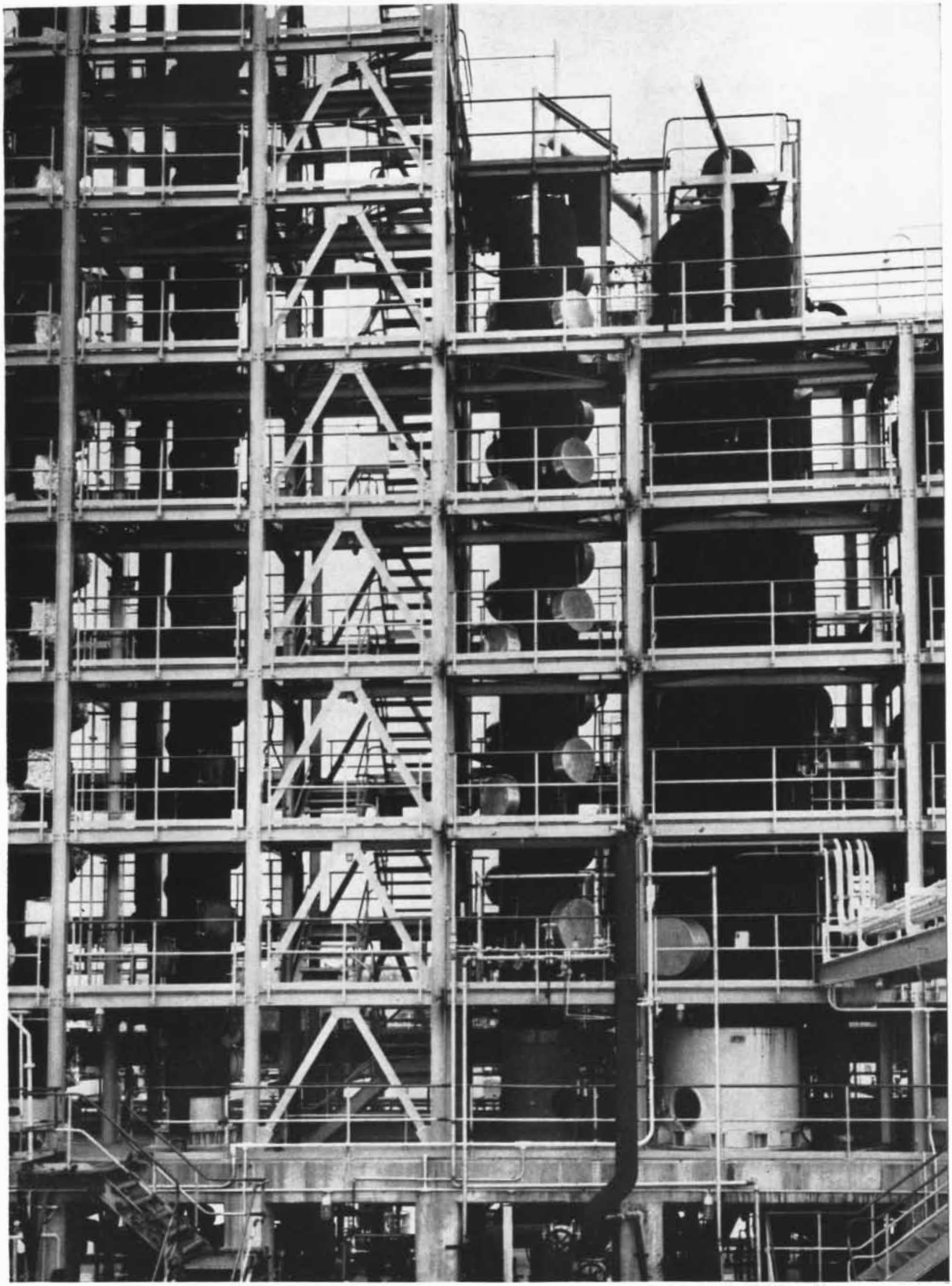
For information on cooling or any other application of Copper, write to the Copper & Brass Research Association, 420 Lexington Ave., New York 17, N. Y.

Henri Poincaré...on disinterested fools

"But scientists believe that there is a hierarchy of facts, and that we may make a judicious choice among them. They are right, for otherwise there would be no science, and science does exist. One has only to open one's eyes to see that the triumphs of industry, which have enriched so many practical men, would never have seen the light if only these practical men had existed, and if they had not been preceded by disinterested fools who died poor, who never thought of the useful, and who were not guided by their own caprice.

What these fools did, as Mach has said, was to save their successors the trouble of thinking. If they had worked solely with a view to immediate application, they would have left nothing behind them, and in face of a new requirement, all would have had to be done again."

—*Science et méthode, 1912.*



MONOMERS are purified in these towers at the American Cyanamid Company's Fortier Plant near New Orleans, La. In this case the monomer is acrylonitrile made from acetylene and hydrocyanic acid gas. These latter substances are here obtained from natural gas.

Established 1845 SCIENTIFIC AMERICAN September, 1957 Volume 197 Number 3

GIANT MOLECULES

Presenting an issue on polymers: huge chains of atoms assembled from simpler molecules. These chains, which comprise the fabric of living matter, are now made by man in forms unknown in nature

by Herman F. Mark

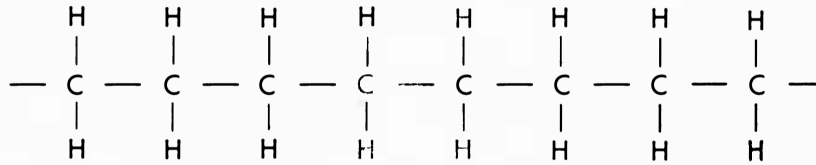
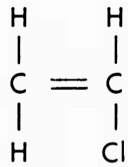
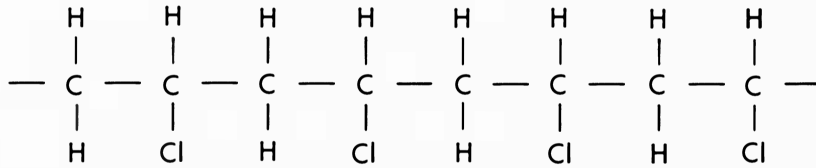
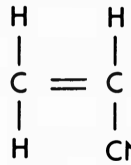
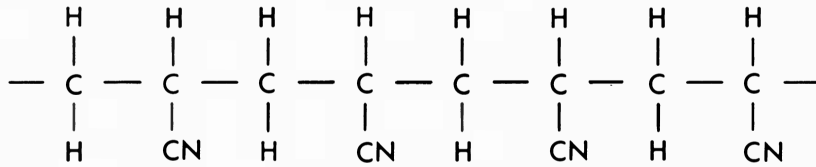
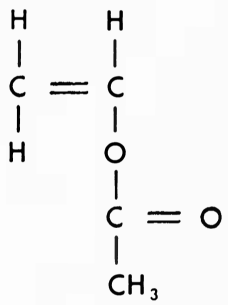
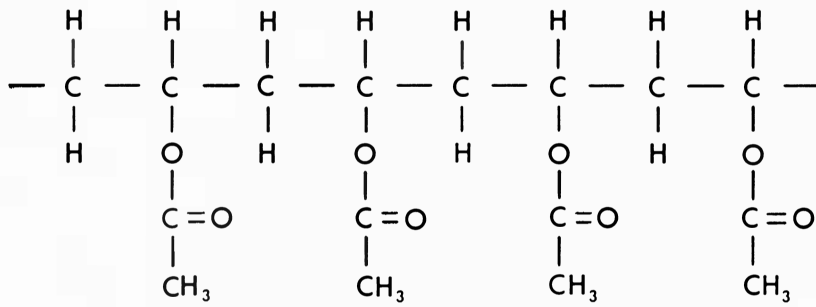
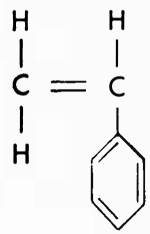
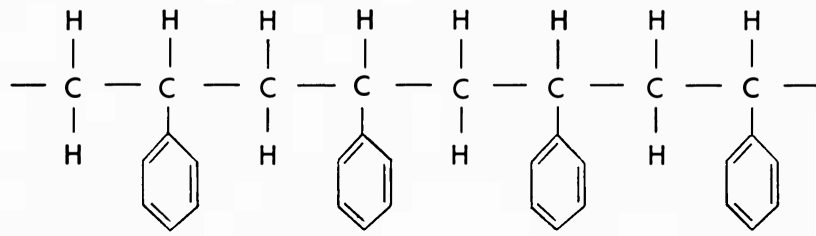
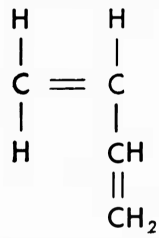
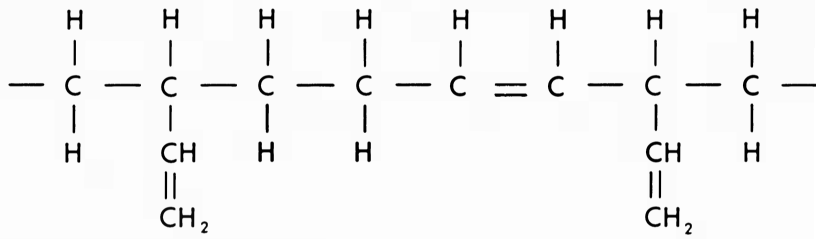
Giant molecules—or high polymers, as the chemist calls them—have been feeding, clothing and housing man ever since he began to manipulate nature. Wood is a high polymer; so are meat, starch, cotton, wool and silk. They are among our oldest and most familiar materials, yet until this century they were a complete chemical mystery. As products of living things, they partake of the prejudice of nature for doing things in an elaborate way. The substances of life are made of the most complicated molecules we know. But their very complexity endows them with wonderfully versatile and powerful properties. The giant molecules therefore present a great challenge to chemists—not only to learn the secrets of their construction but also to devise new materials which nature has neglected to create. And within the past decade the chemistry of high polymers—living and nonliving—has made such rapid strides that it is today one of the most exciting fields in all science.

This development caps a century of remarkable advance in organic chemistry. Chemical understanding of living matter did not begin until 1828, when Friedrich Wöhler of Germany achieved the first test-tube synthesis of an organic substance—urea, a product of animal metabolism. His successors in the new science proceeded to work out the chemical structure and activity of a host of comparatively simple organic molecules: sugars, fats, fruit acids, soaps, alcohols, the coal and petroleum hydrocarbons, and so on. Over the past century many thousands of scientists all over the world became absorbed in organic chemistry, developing ingenious techniques of investigation and constructing a clear theory of the behavior of the simpler organic substances, based on the behavior of the four-valent carbon atom. The theory made it possible to classify the properties of hundreds of thousands of substances, from the exhalations of gas wells to the pigments of flowers and the poisons of snakes. Organic chemistry gave birth to new synthetic products, such as dyes, perfumes, drugs, fuels, etc. Indeed, much of our present civilization—medical care, sanitation, printing, painting, photography, motor transportation, aviation—relies heavily on materials provided by "classical" organic chemistry.

All these substances were comparatively simple members of the organic family. Their bigger, more complicated relatives—proteins and the rest—got only desultory attention from chemists, mainly because they were too difficult to deal with. The methods on which organic chemists relied for separation and analysis of organic substances—solution, melting, crystallization and the like—did not work with giant molecules. For example, cellulose, the chief component of wood, does not melt when heated; instead it hardens and decomposes. Nor can it be dissolved, except in chemicals which change it irreversibly to something different. The same is true of other organic high polymers, such as wool, silk, starch and rubber.

When chemists had the misfortune to produce large organic molecules accidentally during their experiments, they were generally crestfallen. The early literature of organic chemists is full of exasperated references to reactions which "resinified" and covered their glassware with waxy, gluey or sticky messes. These

THIS ARTICLE IS CONTINUED on page 86. **On the next four pages is a chart listing the principal polymers made by man. At the left side of the chart are the structural formulas of monomers, the simple molecules which are strung together to form polymers. In the middle of the chart is a short section of the characteristic chain of each polymer. The complete chain is made up of hundreds or even thousands of monomeric units. Some of the chains are linked to other chains, as indicated in the formulas of the phenol formaldehyde and urea formaldehyde resins. The polymers in the chart are divided into two classes: addition polymers and condensation polymers. The basis of this division is given in the illustrations on pages 86 and 87. There are only nine atoms in the chart: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), chlorine (Cl), fluorine (F), silicon (Si) and sodium (Na). In most cases each atom is represented by its letter symbol. In some cases groups of atoms are abbreviated, for example, CH_3 and the benzene ring. The latter structure, containing six carbon atoms to which other atoms are attached, is represented by a hexagon. A single line between two atoms represents a single chemical bond; a double line, a double bond.**

MONOMER	POLYMER
ETHYLENE 	POLYETHYLENE 
VINYL CHLORIDE 	POLYVINYL CHLORIDE 
ACRYLONITRILE 	POLYACRYLONITRILE 
VINYL ACETATE 	POLYVINYL ACETATE 
STYRENE 	POLYSTYRENE 
BUTADIENE 	POLYBUTADIENE 

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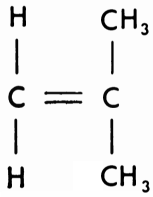

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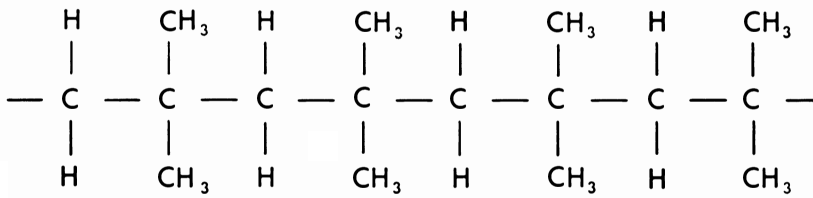

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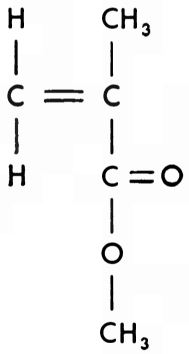

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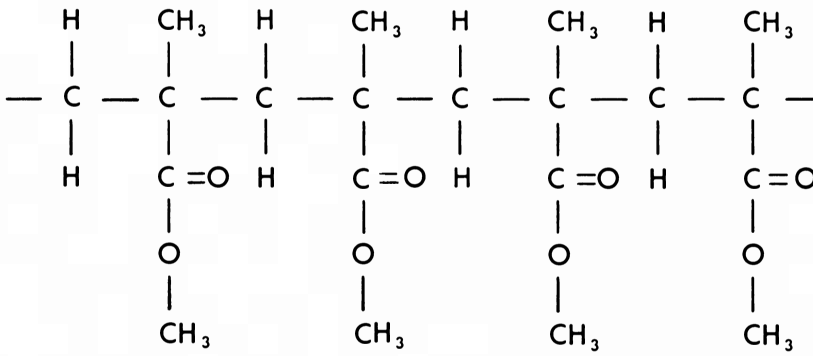

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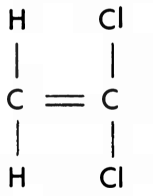

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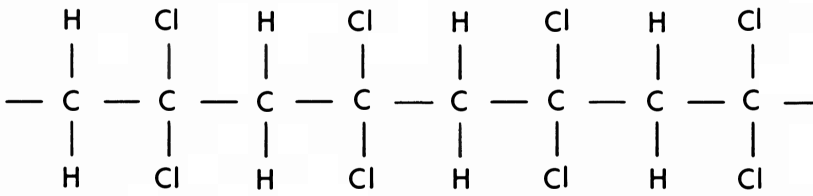

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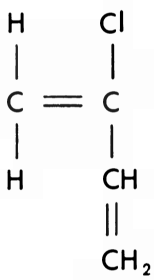

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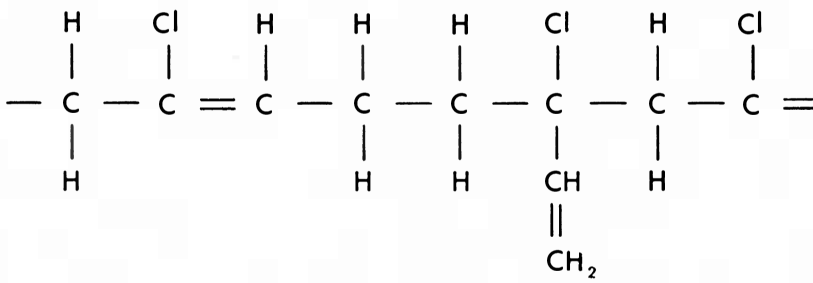

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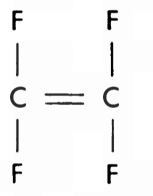

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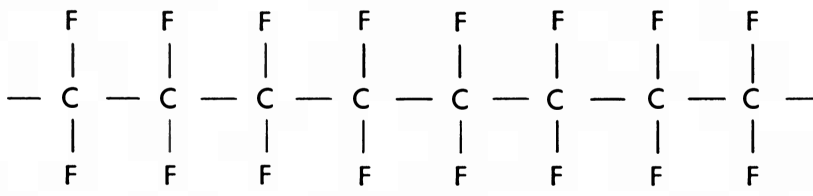

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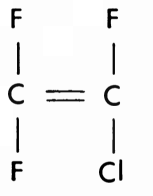

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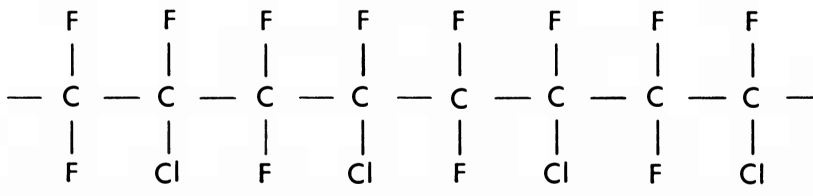
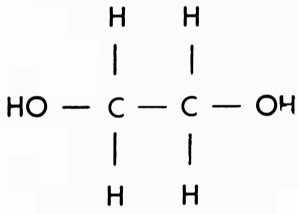


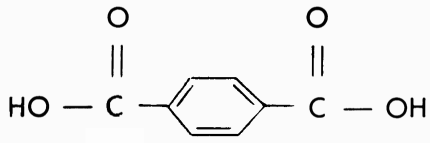
MONOMERS

POLYMER

ETHYLENE GLYCOL



TEREPHTHALIC ACID



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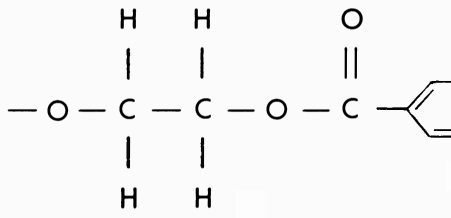

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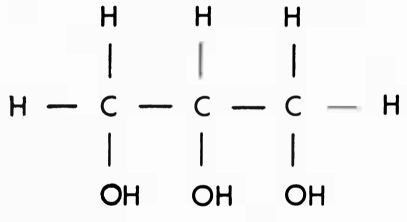

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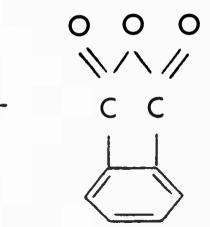

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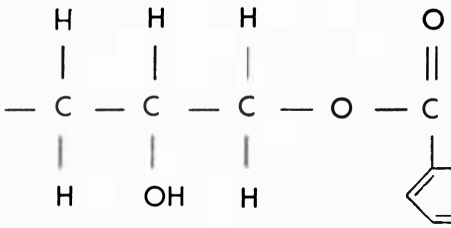

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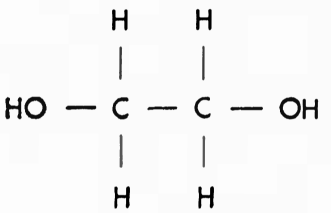

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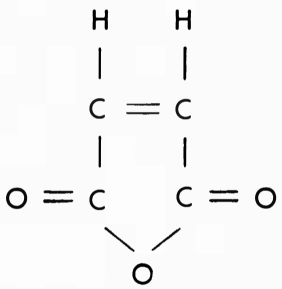

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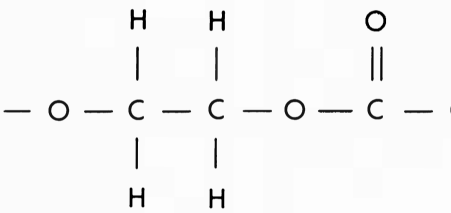

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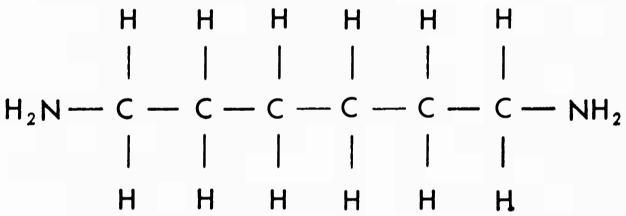

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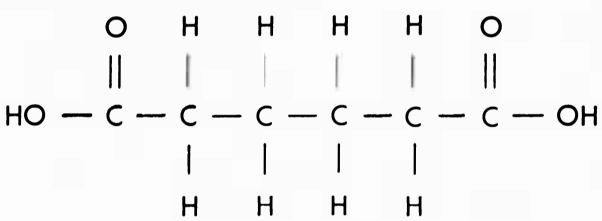

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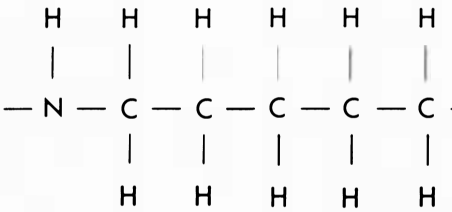

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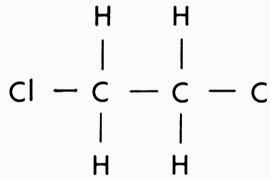
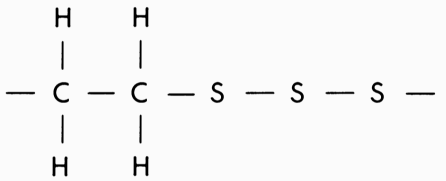


SODIUM POLYSULFIDE

POLYSULFIDE RUBBER



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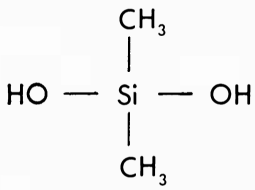

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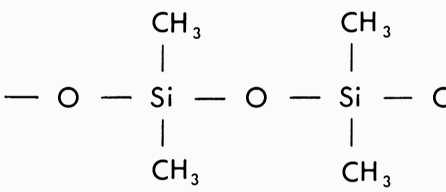
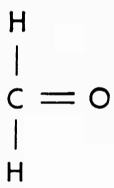
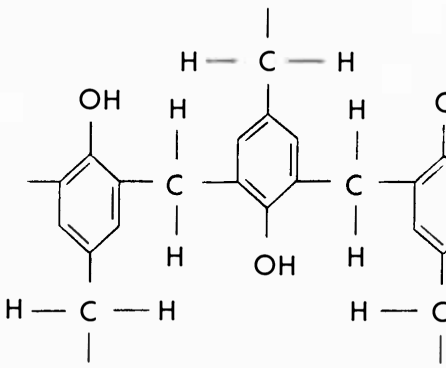


PHENOL

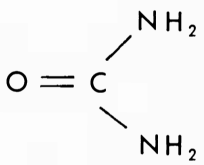
FORMALDEHYDE



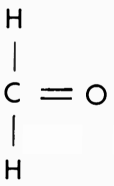
PHENOL-FORMALDEHYDE RESIN



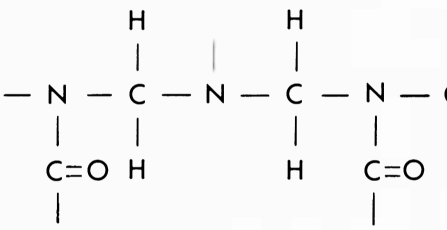
UREA



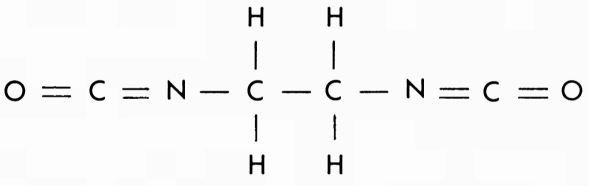
FORMALDEHYDE



UREA-FORMALDEHYDE RESIN

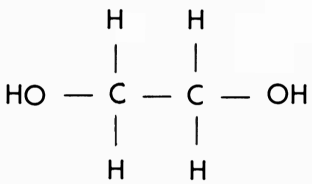


ETHYLENE DIISOCYANATE

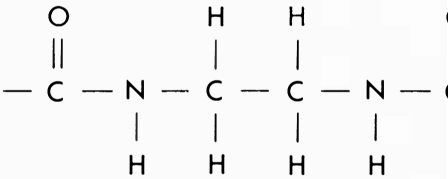


+

ETHYLENE GLYCOL



POLYURETHANE



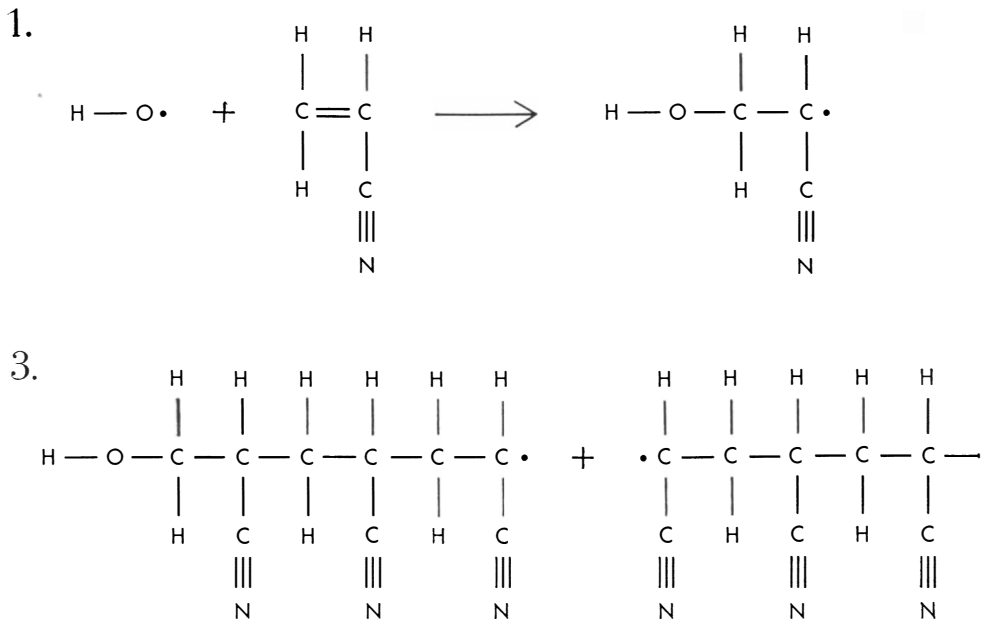
unexpected products were always a disappointment to the chemist, seeking to purify a substance in nice crystalline form, and were an unalloyed nuisance to the bottle-washer who had to clean the glassware.

In short, up to about 30 or 40 years ago the big organic molecules offered little attraction to chemists. Classical organic chemistry was full of interesting and important problems. With so many green pastures around, why should a chemist invest his career in the risky and sticky business of investigating the macromolecules?

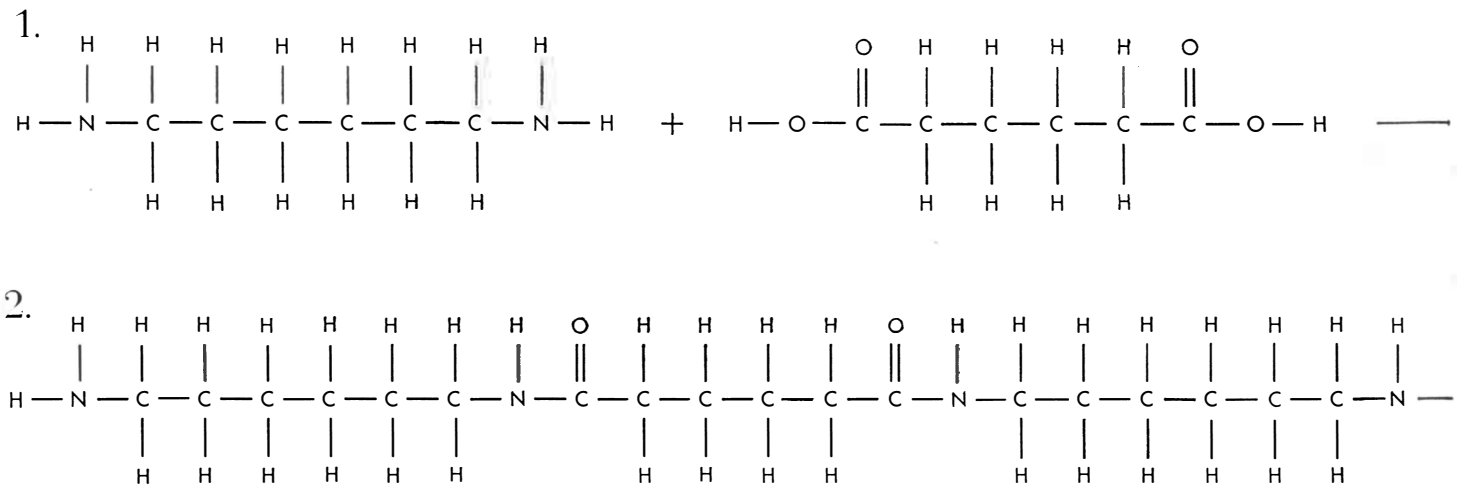
Nevertheless, in the 1920s the study of large molecules such as cellulose and rubber had already begun to look intriguing. In 1923 the writer of these lines (then 28 years old) confessed to his professor at Berlin, Wilhelm Schlenk, that he was strongly tempted to work in this new field. Schlenk, who had long been regarded as one of the most ingenious experimenters in organic chemistry, said: "If I were 20 years younger" (he was 55), "I might be very much attracted myself. Wait until you are 10 years older, and meanwhile demonstrate with 'classical' investigations that you are capable of tackling a problem of such proportions." It proved to be excellent advice.

Attempts to analyze the chemical composition of cellulose, rubber, starch and proteins had begun in the 1880s. Chemists had established that these substances, like all organic compounds, were composed mainly of carbon, hydrogen and oxygen; that cellulose was essentially a sugar compound; that starch was another carbohydrate; that natural rubber was basically a hydrocarbon; that proteins contained considerable amounts of nitrogen and sometimes a little sulfur or phosphorus. The investigators soon decided that the main distinguishing feature of all these substances—what made their properties so different from other organic materials—must be the size of their molecules. The insolubility of the substances and their resistance to melting argued for large molecular size, because it had been found that ordinary organic compounds such as petroleum hydrocarbons became less and less soluble and acquired higher and higher melting points as they were combined into larger and larger molecules. The mechanical strength of cotton, wool and silk also suggested that they were made of very large, strongly coherent molecules.

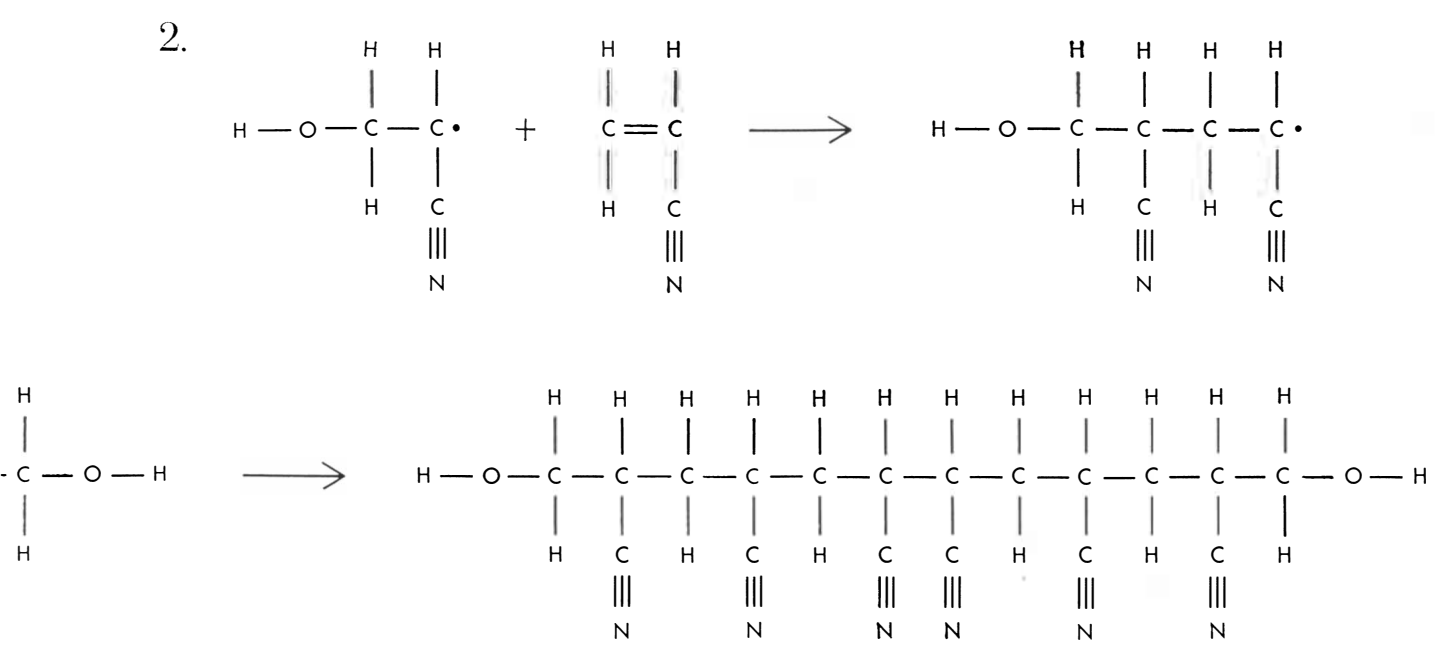
It was a logical deduction that each of the big molecules was made of certain building blocks—glucose in the cases of cellulose and starch, isoprene in the case of rubber and amino acids in the case of proteins. Chemists therefore began to call these compounds "poly" something: starch, for instance, was identified as a polysaccharide, meaning that it was composed of many sugar units. This is the basis of the present general terminology for the classes of compounds with which we are concerned: a monomer is a substance which can serve as a build-



ADDITION POLYMERIZATION is explained by example. A free radical (H-O) combines with a monomer (acrylonitrile) in such a way that the unsatisfied valence (*dot*) of the free



CONDENSATION POLYMERIZATION is a different process. Two molecules combine, usually with the elimination of water (H-O-H), to form the repeating unit of the chain (1). The repeating units then combine in the same manner (2). In this example

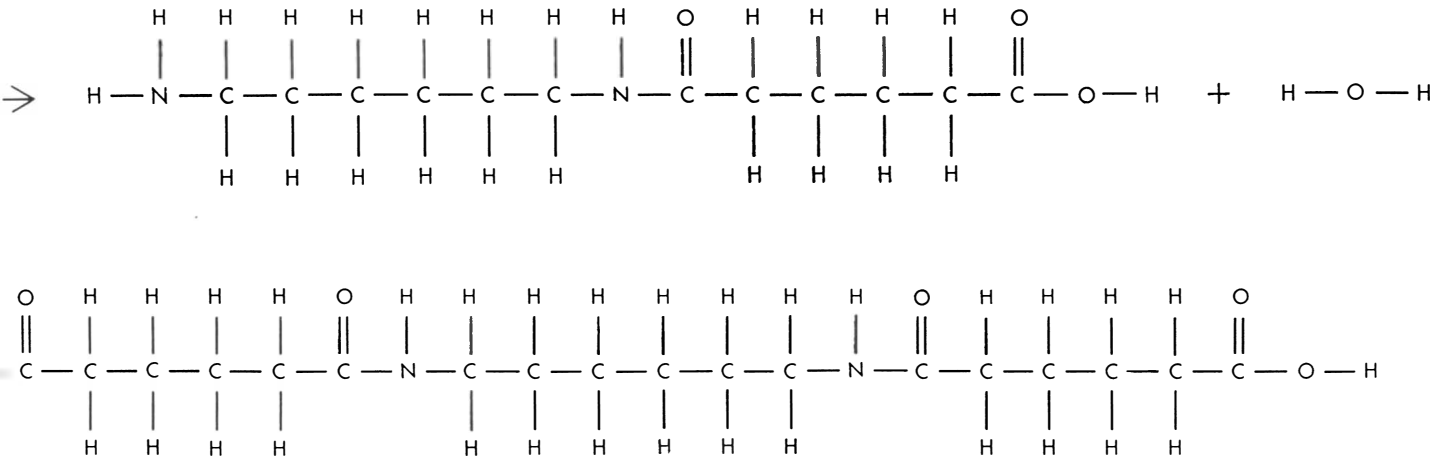


radical is transferred to the end of the monomer (1). The monomer now combines with another monomer (2). The process stops when two growing chains come together (3). In this case the free radical is obtained from the decomposition of hydrogen peroxide.

ing unit (*e.g.*, glucose); a polymer (from the Greek, meaning "many parts") is a combination of such units; a high polymer is a very large aggregation of units, *i.e.*, a compound of high molecular weight.

The spiritual father of high-polymer chemistry was Emil Fischer of Berlin, the great organic chemist of the late 19th and early 20th century. In his later years Fischer became fascinated by the mysterious chemistry of the organic macromolecules. Although loaded down with administrative duties for the German Academy of Sciences, Ministry of Education and National Research Council, he would retire to his private laboratory early every morning to experiment with new compounds. Sitting on a stool and watching thoughtfully as faint precipitates appeared in his reaction flasks, or white powders reluctantly crystallized out of solution, he saw visions of the chemistry which was to come 20 years later. Fischer induced some of his ablest co-workers to study rubber, starch, polypeptides, cellulose and lignin (the other major component of wood). At about the same time the great organic chemist Richard Willstätter was beginning to synthesize polysaccharides and to discover new methods for isolating lignin and enzymes. These pioneers worked largely by intuition. Willstätter was once asked, at a seminar where he reported a certain experiment, how he had happened to choose acetonitrile as the solvent, cobalt acetate as the catalyst and 75 degrees centigrade as the temperature. His answer was: "Just a thought, sir, just an idea."

Ignorance of the chemical structure of the high polymers did not, of course, debar their exploitation at the empirical level. Inventors discovered ways to convert cellulose into acetate fibers, films and coatings, into nitrated explosives and into many other useful products. Between 1870 and 1920 enterprising men (including Alfred Nobel) developed



the original two molecules are those of hexamethylenediamine (*left*) and adipic acid (*right*). The polymer is nylon 66. The polymer in the example of addition polymerization is polyacrylonitrile. In both examples only a very short section of the chain is shown.

large industries based on cellulose derivatives. Meanwhile rubber also became a prominent article of commerce (and financial prosperity), thanks to Charles Goodyear's discovery, early in the 19th century, of the fact that heating it with sulfur (vulcanization) gave it useful properties. And proteins and starches likewise served as raw materials of other substantial manufacturing industries—leather, sizings, glues, adhesives, casein plastics and so on.

At the turn of the century there came an event which was to prove very significant in the development of high polymers. Leo H. Baekeland, a young Belgian chemist who had come to the U. S., took a deep interest in the sticky, resinous by-products which were such a bother to other chemists. He gave up a project on which he had been working and devoted himself to investigating the material that had fouled up his glassware. It was a gummy liquid, formed by a reaction between the common chemicals phenol and formaldehyde in solution in water. Baekeland found that by applying heat and pressure he could turn the liquid into a hard, transparent resin, which proved to be an excellent electrical insulator and to have good resistance to heat, moisture, chemicals and mechanical wear. So the synthetic plastics industry was born; other chemists went on to synthesize many other useful plastics of a similar (thermosetting) type, using formaldehyde with urea or aniline instead of phenol.

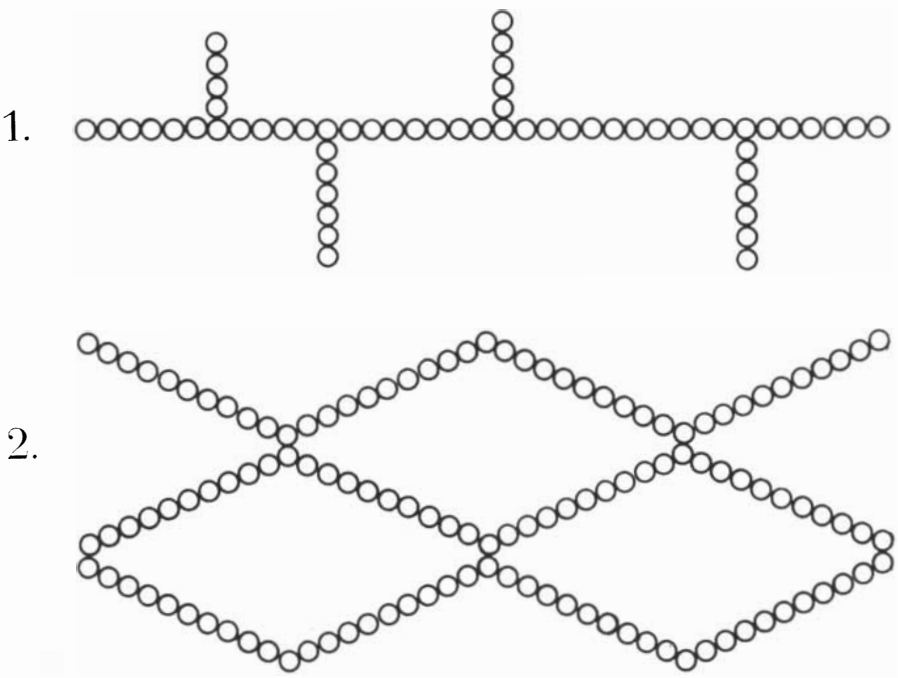
Thus by the second decade of this century factories all over the world were producing polymers in the forms of fibers, films, plastics, lacquers, coatings, adhesives and so on. Most of these were mere modifications of natural high polymers—conversions which transformed nature's substances (*e.g.*, cellulose) into new materials of somewhat different properties. Baekeland's demonstration, on the other hand, paved the way for actual synthesis of polymers from simple materials. But all this was empirical; the basic principles governing the structure and behavior of polymers were still unknown. Chemists knew something about the "how" but not the "why."

It became increasingly important to know the why, in order to improve the products, to standarize the manufacturing processes and to reduce costs. Whenever, in such cases, the chemists of the factories tried to find out how they should best handle their systems and why they behaved as they did, they were disappointed by the lack of fundamental knowledge about polymers. Their academic colleagues in the universities had to confess that the exploration of large molecules was still in a state of infancy.

Soon after World War I a number of far-seeing leaders in science and industry recognized that a systematic exploration of polymer chemistry would pay large returns, industrially and in basic knowledge. Several of the leading organic chemists in the U. S. abandoned their successful careers in industry to gamble on full-time basic study of large molecules. Their studies were richly rewarded. One of the most fertile investigations was the memorable work of Wallace H. Carothers in the laboratories of E. I. du Pont de Nemours & Company. Supported by the vast resources of that organization and by a large group of brilliant collaborators, he developed a systematic knowledge of the chemistry of polymerization and synthesized many hundreds of polymers. This campaign produced, among other things, nylon and the synthetic rubber neoprene. While the scientific world was fascinated by the wealth and clarity of the fundamental results of the research, the du Pont Company drew great satisfaction and profit from its practical applicability. Rarely in the history of chemistry has basic research paid off so rapidly and so handsomely.

These events of the 1920s and 1930s encouraged many academic scientists and industrial researchers to turn to the large molecules. After having been a stepchild for many years, polymer chemistry became fashionable. Under the leadership of Hermann Staudinger in Germany, Thé Svedberg in Sweden and Kurt H. Meyer and Carl S. Marvel in the U. S., it moved rapidly ahead on a broad front—in experiments and in theory. Polymerization processes were developed and refined, their mechanisms explored, their products meticulously described (after having synthesized a new molecule one is naturally curious to know exactly what he has made). Very precise methods of describing the properties and behavior of polymers were developed, based on measurements of osmotic pressure, diffusion, sedimentation, light-scattering and viscosity.

Chemists could now discern a general pattern in the formation of giant molecules. Basically the high polymers were built by the linking of monomers end to end in chains, sometimes several thousand units long. But the chains then grouped themselves in two distinctly different ways. They either (1) coiled up to form a ball-shaped molecule (like a mass of intertwined spaghetti), or (2) lined up in straight, more or less rigid bundles (like wires in a cable). In general the coiled polymers had the characteristics of a rubber, while the straight-bundle type formed fibers or rigid plastics. The chemical character of the



POLYMER CHAINS CAN GROW by branching (1) or can be connected by cross-linking (2). The balls in this drawing and the one on the opposite page are not atoms but monomers.

chains determined whether they would coil up at random or align themselves in bundles: if the chains were relatively rigid and contained chemically attracting groups along their length, they would attach themselves to one another side by side in bundles.

As the principles governing the properties of polymers began to shape up in the minds of the investigators, an exciting new prospect emerged. It was a matter of great intellectual satisfaction to be able to reduce the behavior of these substances to orderly laws and predict it with mathematical precision. But no less stirring was the new creative power made possible by this knowledge. The technological progress of mankind has been largely a history of putting available materials to use. It is a considerable step forward to invent the materials themselves on order. And this is the stage we have now reached in polymer chemistry. Starting from a need for some material of specified properties, we are in a position to create a new material tailored to fill that need.

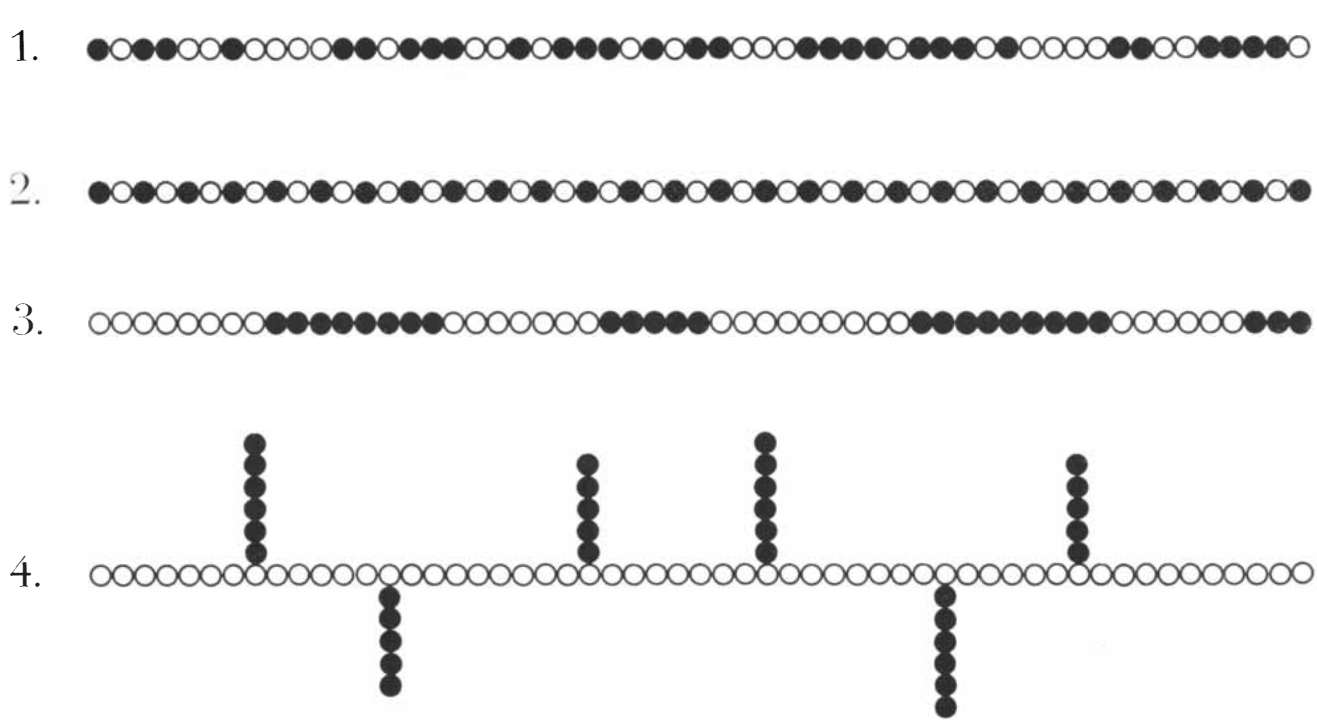
As the building stones for this enterprise we now have some 40 readily available organic monomers, largely derived from coal and oil. These 40 building units can produce an almost limitless number of combinations. Already they have given us scores of important new man-made materials: all the synthetic fibers, rubbers and plastics. The production of these monomers in the U. S. now amounts to about $2 billion a year.

Polymer chemists in the U. S. and abroad are engaged in a vast effort to develop processes which will facilitate the creation of new products and reduce the cost of the present ones. They are exploring various polymerization methods, catalysts, continuous processes, and conditions which will control reactions such as very high pressures, high and low temperatures, irradiation. Knowledge of the principles underlying the chemical properties is sufficiently advanced so that the chemists can introduce into a giant molecule a monomer which will endow it with a high melting point or great resistance to solvents or high tensile strength or some other desired quality.

The products made so far can be considered only a foretaste of more spectacular ones to come. There are several frontiers inviting exploration. For example, the largest high polymers now in production have molecular weights in the neighborhood of 200,000. There is reason to believe that larger molecules would be much stronger. Consequently several industrial laboratories are looking into the possibilities for producing "super high polymers" with molecular weights in the millions. Another active frontier is the investigation of ways to raise the resistance of polymers to heat. The plastics, fibers, rubbers and coatings now made break down at temperatures of 600 degrees Fahrenheit or less. But the prospects for making high polymers which will be able to withstand substantially higher temperatures look promising: they may be based on certain highly stable organic molecules such as diphenyl oxide or diphenylmethylene, with additions of resistant elements such as fluorine, boron or silicon.

Looking much farther into the future, we can even see possibilities for synthesizing biological molecules—not to create life but to furnish aids to or substitutes for living tissues. Already we have a synthetic polymer which can serve some of the functions of blood serum. Although our chemical laboratories do not begin to approach the orderliness or perfection with which a living organism builds its high polymers, we can take hope from the fact that we have a vastly larger number of monomers at our disposal than any living system has, and therefore can make an even greater variety of products.

The articles that follow this introduction and brief historical survey of high-polymer chemistry give a comprehensive view of the current ferment in this immensely important new science, from the explorations in the laboratories to the giant living molecules, which we are beginning to understand as we never have before.



COPOLYMERS are polymer chains in which more than one kind of monomeric unit occurs. Here one kind of monomer is represented by a white ball; the other, by a black. The form of such copolymers may be random (1), alternating (2), "block" (3) or "graft" (4).

How Giant Molecules Are Measured

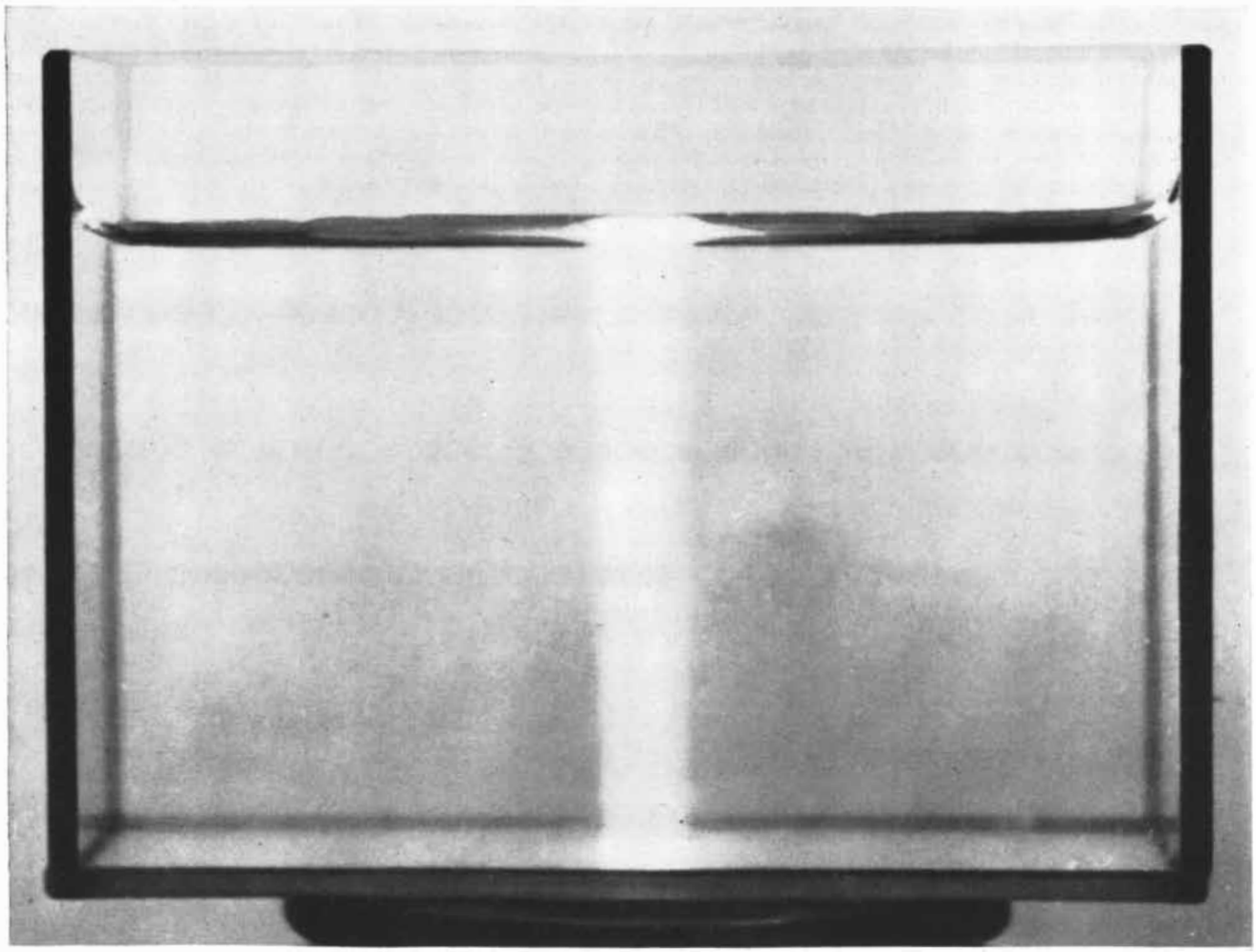
When light passes through such molecules in solution, some of it is scattered. From this and other effects it is possible to determine the weight of the molecules and the degree to which they are folded

by Peter J. W. Debye

The first requirement in attempting to understand the properties of giant molecules is to determine their size and form. Indeed it is the great size of these molecules, resulting in very complicated structures, that is primarily responsible for their extraordinary behavior. A chemist seeking to describe or identify a high polymer therefore begins by measuring its molecular weight.

It is not a simple task. Most of the customary chemical or physical procedures for weighing small molecules do not avail with the macromolecules. They require special methods. We shall consider in this article the principal techniques that have been employed.

First, what do we mean by the molecular weight of a substance? Consider glucose, a sugar molecule. Its formula is $C_6H_{12}O_6$, meaning that it has six carbon



SCATTERED LIGHT makes a vertical beam of light visible when viewed from the side. Even pure liquids scatter a certain amount of light, but the scattering is greatly increased when they contain dissolved polymer molecules, as in the experiment shown here.

atoms, 12 hydrogen and six oxygen. The atomic weight of a hydrogen atom is taken as 1, of carbon 12 and of oxygen 16. Hence the atoms composing glucose add up to a weight of 180 units for the molecule. The molecular weight of glucose, as of most other monomers, is known precisely. It is also known that the giant molecule of cellulose is made up of many glucose molecules linked together. But how many? The number runs into the thousands. The task of the polymer investigator is to weigh molecules composed of unnumbered thousands of monomers, with total molecular weights running into the hundreds of thousands or the millions.

A method of estimating the weight of giant molecules was worked out many years ago by Hermann Staudinger of Germany, a pioneer in the chemistry of high polymers. It is based upon the effect of the molecules on the viscosity of a liquid in which they are dissolved. Let us suppose that we have measured the viscosity of the solvent by its rate of flow in a capillary tube. If we now dissolve a substance in the liquid, the dissolved molecules, acting like mud particles suspended in a stream, will increase the viscosity of the fluid. Albert Einstein, who first studied this problem theoretically, calculated how much the viscosity would increase if a number of solid little spheres were suspended in a liquid and drifted along with it, turning and tumbling in the stream. Staudinger derived a formula for molecules in solution, relating the percentage of increase in the viscosity of the fluid to the molecular weight of the dissolved molecules. He used this rule to calculate molecular weights.

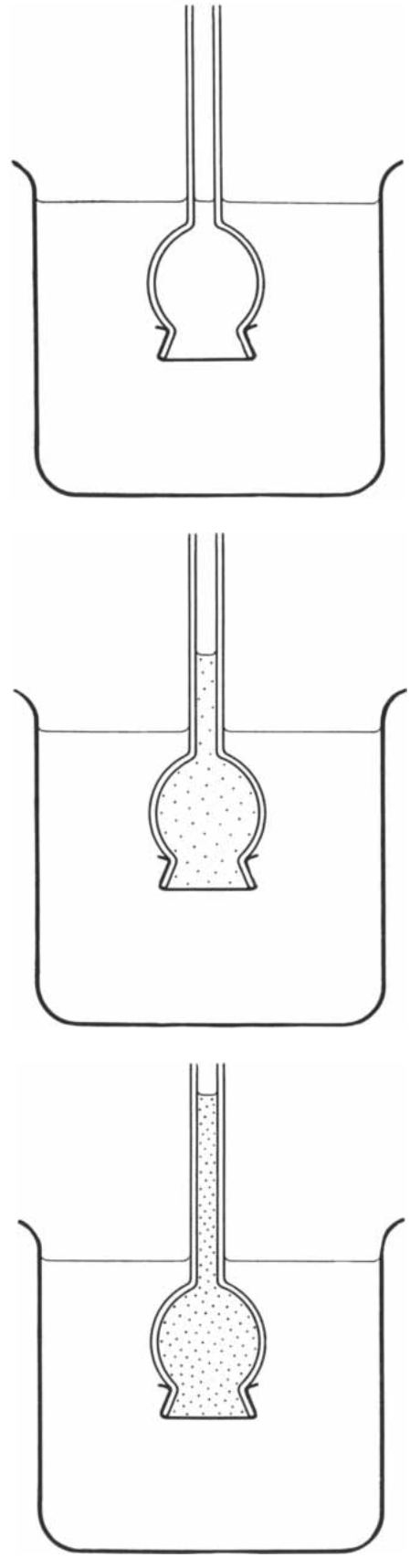
However, reliable measurements by other methods later showed that the relative increase of viscosity is not directly proportional to molecular weight in the case of large molecules. The actual situation is that, at a rough approximation, when the weight of the dissolved molecules is quadrupled, the viscosity only doubles. We can account for this theoretically by assuming that with increasing molecular weight molecules capable of coiling up do not, on the average, enlarge in diameter in direct proportion to their gain in weight. Furthermore, other complications arise, having to do with interactions between parts of the molecular chain. We cannot say yet that viscosity measurements are a reliable guide to the molecular weight of large molecules of unknown structure. Nevertheless, they are useful for estimating the weight of a molecule structured like one whose weight has already been determined, and also for indicating whether a molecule is tightly coiled or spread out. Viscometers are standard equipment in every high-polymer laboratory.

A second instrument for weighing large molecules, invented by Thé Svedberg of Sweden, is the ultracentrifuge, which has become an invaluable aid in studying proteins and other biological substances. The weight of the molecules is calculated from the rate at which they move out to the rim of the whirling centrifuge—the larger the molecule, the faster it migrates. However, because of the unknown magnitude of frictional effects and the fact that very large molecules tend to get in one another's way, the ultracentrifuge becomes ineffective as a weighing instrument for giant molecules.

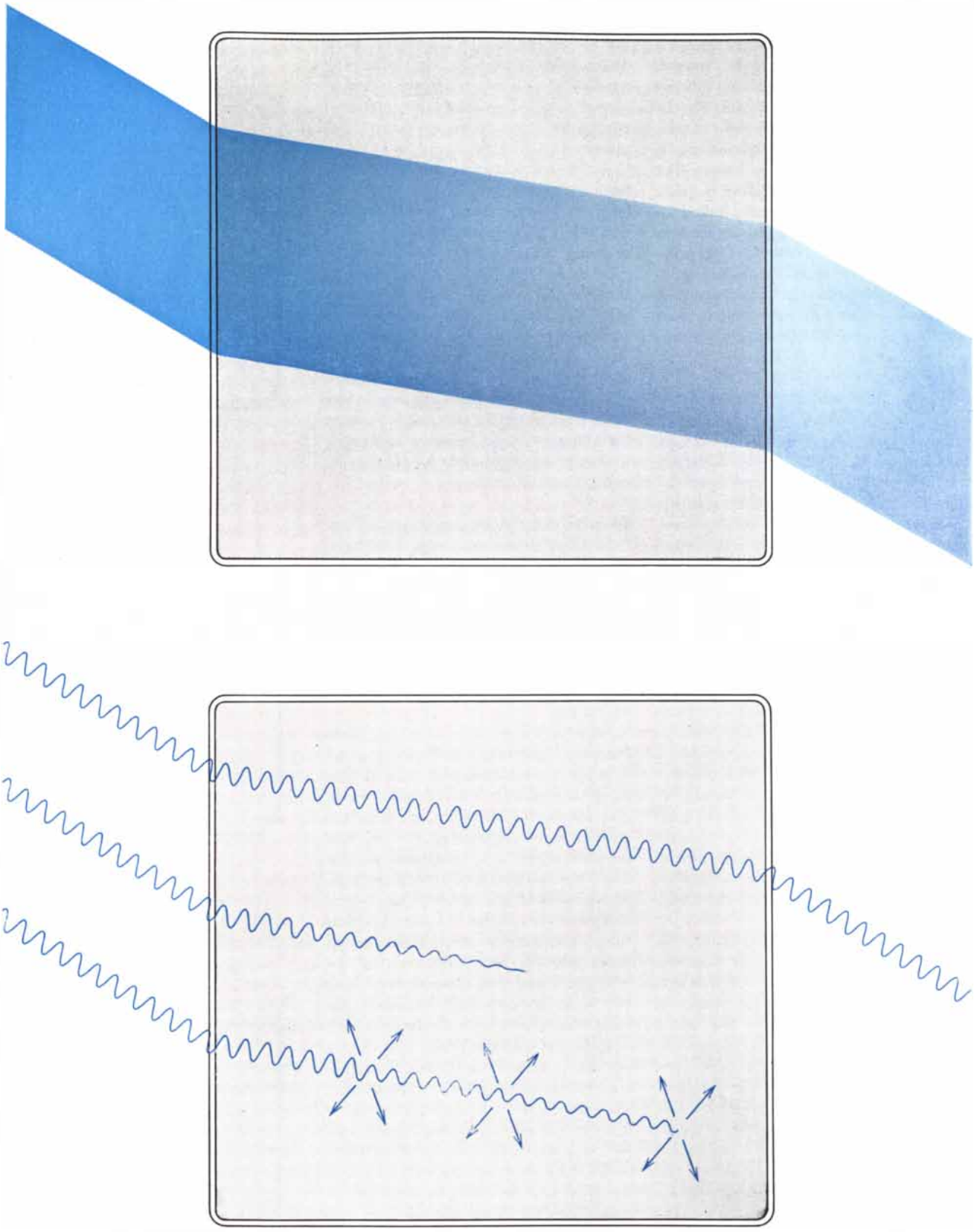
If we wish to obtain a precise measurement of molecular weight, the most straightforward procedure is to take a weighed amount of a substance, count the number of molecules in the sample, and then compute the average weight of the molecules. This can be done in two ways, and these are the principal means employed for the measurement of macromolecules.

As we learned many years ago from J. H. van't Hoff of the Netherlands, if we dissolve a measured amount of a substance in a given volume of a solvent, we can count the number of dissolved molecules by measuring the osmotic pressure of the solution. Recall the familiar demonstration of osmotic pressure in high-school chemistry class. Into a beaker of pure water is lowered a glass tube containing a certain amount of sugar solution. The bottom end of the tube is covered with a membrane which lets water pass through but not sugar molecules. Water from the beaker slowly infiltrates into the tube (as it always does from a less concentrated to a more concentrated solution), and the level of the liquid in the tube rises [*see diagram at right*]. Eventually it stops rising, and the height of the column of solution in the tube then represents the osmotic pressure—*i.e.*, the pressure necessary to counteract the tendency of water to move into the tube.

In a solution dilute enough to avoid any appreciable interactions among the sugar molecules the osmotic pressure is proportional to the number of sugar molecules per cubic centimeter of solution. Thus the height of the liquid in the



OSMOTIC PRESSURE apparatus is a tube sealed at bottom with semipermeable membrane. At top tube contains pure solvent. Dots in lower drawings are large molecules.



LIGHT BEAM transmitted through a tank of liquid is shown schematically in the top drawing. The tank is seen from above. As the beam passes from left to right it is refracted and attenuated. In an actual experiment some energy would also be reflected each time the light struck a new material, but the reflected beams are not shown here. The lower drawing indicates the fate of the transmitted beam symbolically. The top wave represents energy that is refracted but that gets through the liquid. The center wave shows energy that is absorbed and converted to heat. The bottom wave represents light that is scattered by molecules in the solution.

tube tells us how many sugar molecules it contains. Knowing the weight of the sugar that we put in the tube, we can compute the weight of a sugar molecule.

We have in this case a large effect: even at a dilution of about one ounce of glucose (molecular weight 180) per quart of water in the tube, the osmotic pressure amounts to one atmosphere, equivalent to a column of water 32 feet high. The osmotic pressure falls with increasing size of molecules, because there are fewer molecules in a given concentration of solution by weight. Thus if the molecules are 1,000 times heavier than glucose, a one-ounce-per-quart concentration gives an osmotic pressure of one thousandth of an atmosphere. This still corresponds to a column of water one centimeter high. But by the time we reach molecules with a molecular weight of the order of one million, the effect becomes inconveniently small: a 1 per cent solution of such a substance yields an osmotic pressure amounting only to a water column a few millimeters high. In short, the osmotic method is a simple and effective measure but declines in efficiency as we approach the giant molecules.

The second method of counting molecules improves in efficiency with increasing molecular weight. Developed in the last few years, it has become a useful instrument not only for weighing molecules but also for picturing their size and structure. The method is founded upon the phenomenon that molecules scatter light.

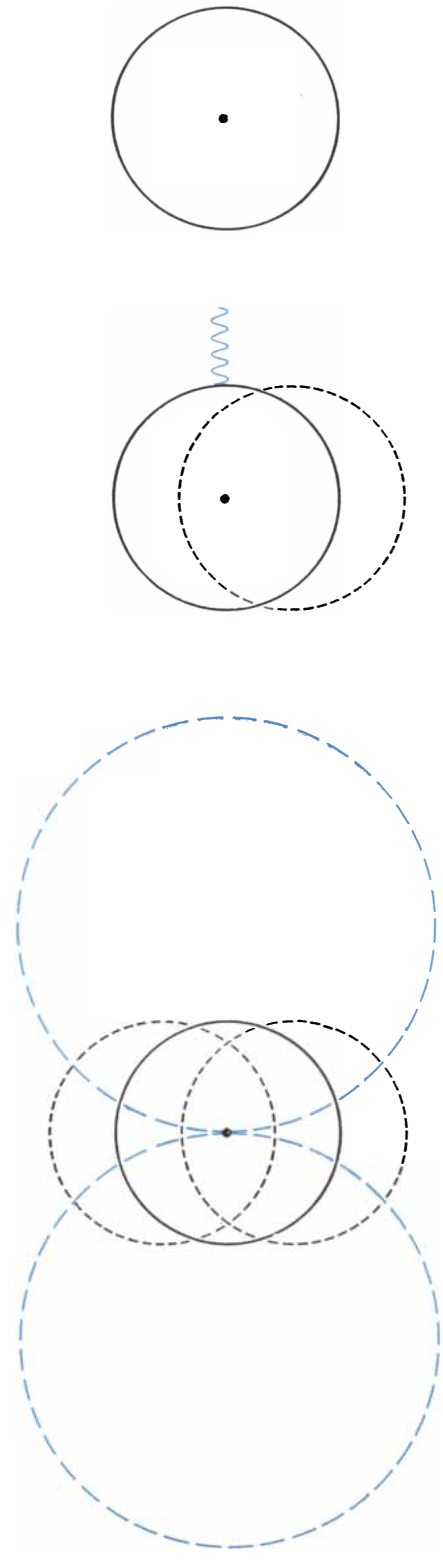
As light passes through any material medium, it loses energy. The distance we can see through the clearest waters is measured in feet, and even air is not perfectly transparent. If it were completely clean of dust particles and water droplets, it would still weaken light. The air molecules themselves (oxygen, nitrogen and so on) extract energy from a light beam. Part of this effect is due simply to absorption and conversion of the light energy into heat. But usually a much larger proportion of the beam's loss of energy is due to scattering of the light by the air molecules. It is the scattering of sunlight by air molecules, as Lord Rayleigh deduced many years ago, that gives the sky its blue color.

The molecules of a gas or liquid give it a certain graininess. Each molecule excited by a beam of light acts like a tiny antenna, picking up the energy and reradiating secondary light waves of the same frequency in all directions. Suppose, then, we start with a certain liquid, a pure solvent, and measure its scattering, or weakening, of a light beam per centimeter of distance—this we call the turbidity of the liquid. If we now dissolve some foreign molecules in the liquid, each molecule constitutes an additional antenna which scatters light. Consequently the increase in turbidity of the solution should be a measure of the number of molecules added. However, there is a complication. The amount of light scattered by dissolved molecules depends not only on their number but also on the size or amplitude of the oscillations of their electrons. Different molecules respond differently to the light waves of a given frequency. Hence in order to count the molecules we must find a way to calculate the unknown amplitude factor.

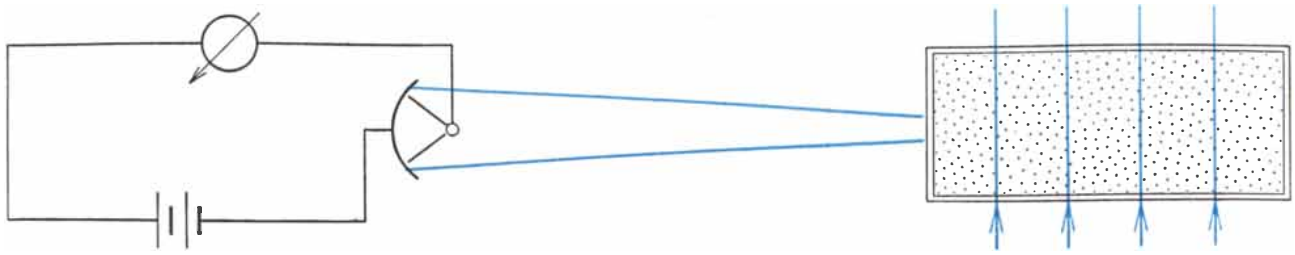
Fortunately this can be done by taking account of another property of the solution which also involves its effect upon light. A liquid refracts (bends) a beam of light entering it from the air. When a substance is dissolved in the liquid, it changes the index of refraction. The amount of change again depends upon the number of dissolved molecules and the amplitude of the electronic vibrations. But this change is directly proportional to the amplitude, whereas the increase in the scattering of light is proportional to the *square* of the amplitude.

The change in refraction represents the number of molecules times the amplitude; the increase in turbidity indicates the number of molecules times the square of the amplitude. Therefore if we make both measurements, we obtain two equations which can be solved to give the number of molecules.

A 1 per cent solution of large molecules is about 100 times more turbid than the solvent itself. This increase in scattering of light can easily be measured with a photocell. Moreover, the efficiency of the turbidity method for counting molecules increases with the size of the molecules. The following thought experiment illustrates why. Let us say we have dissolved a certain number of molecules in a given volume of solvent. If we were now to hook pairs of these molecules together to double the size of the molecules, what would be the effect on the turbidity of the solution? There would only be half as many scattering centers as before. But by doubling the size of the molecules we would have doubled the amplitude of the oscillations; since the scattering of light increases in proportion to the square of the amplitude, we would have increased the scattering by each center fourfold. Thus



SCATTERING is produced by particles acting as antennas. The simplest scattering center is a hydrogen atom, shown schematically at top. The dot represents the nucleus, and the circle the electron cloud. In the center the electric field of an incoming light wave displaces the electron cloud. The cloud then oscillates (*bottom*), radiating light in the pattern indicated by colored circles.

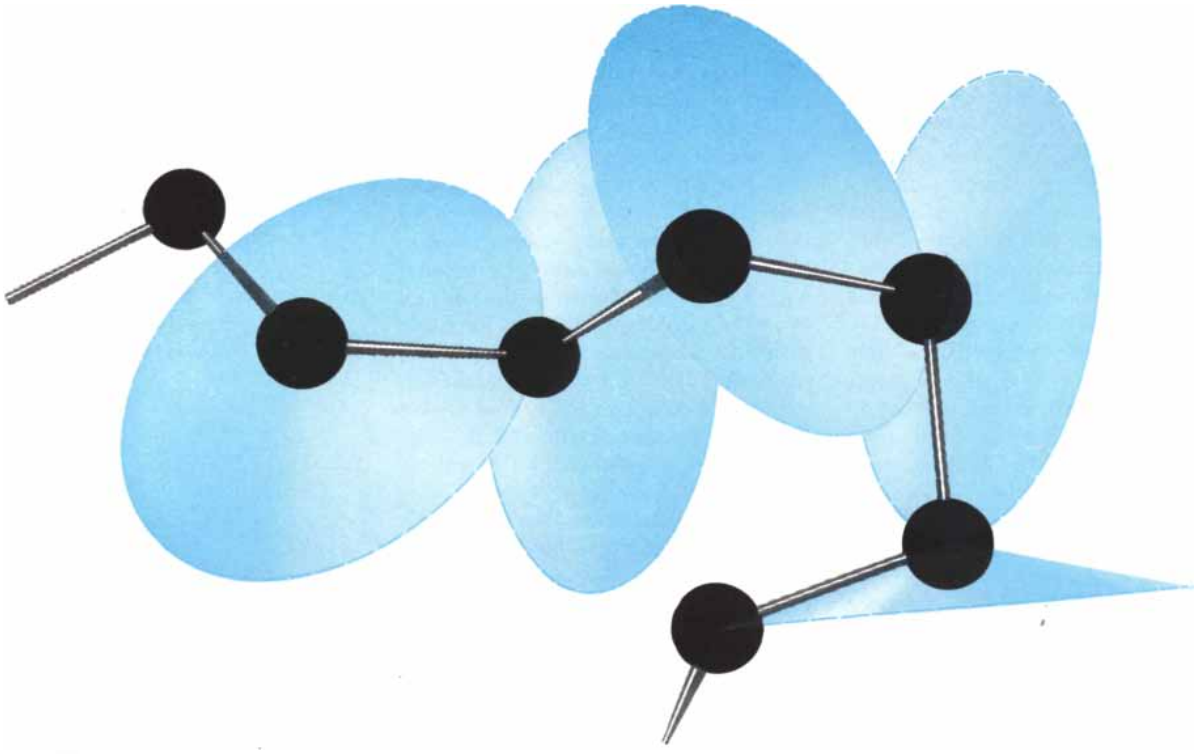


SCATTERING IS MEASURED by photocell. Light, indicated by colored lines, passes up through tank at right. Scattered energy strikes the cell, releasing electrons (*black lines*). The resulting current is then measured by the meter at top of photocell circuit.

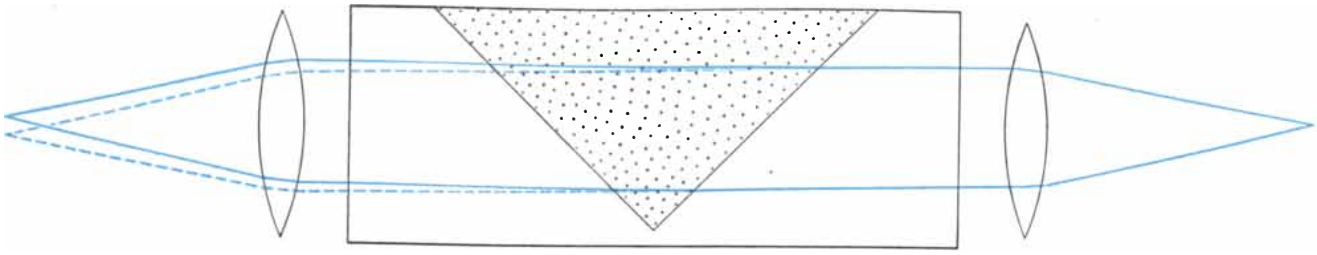
the net result is that large molecules in solution have twice as strong a scattering effect as an equal weight of molecules half their size.

So far we have assumed that the molecules we are counting in a given experiment to arrive at the molecular weight are all of the same size. But of course this is not usually the case in a batch of a polymerized substance. The stringlike molecules do not necessarily grow to one uniform length; the molecular chains in the batch may vary widely in weight. Consequently the molecular weight we obtain is only an average, both in the osmotic and the light-scattering methods. The interesting fact is that one average differs from the other!

In the osmosis experiment every dissolved macromolecule contributes equally to the osmotic pressure, whatever its weight. Therefore the count of molecules, divided into the combined weight of the molecules, gives an average molecular weight in the usual sense of the word average: for example, if the sample is a mixture in which half the molecules have a molecular weight of 10,000 and half 30,000, the average will come out to 20,000. But the light-scattering method will give a different result, because the larger molecules scatter light more strongly—in this case in the ratio of 3 to 1. The smaller molecules contribute one fourth to the total effect, the larger molecules three fourths. Therefore the computed average molecular weight will be one fourth of 10,000 plus three fourths of 30,000, or 25,000. It is easy to see that we can obtain extra information by making both measurements on a given sample of material. If both methods yield the same average, we know that all the molecules in the sample have the same



POSSIBLE CONFIGURATIONS of a chain of carbon atoms are illustrated in the drawings at the bottom of these two pages. The black balls represent carbon atoms; the gray lines, the bonds which join them. The colored cones show, for each bond, all the pos-



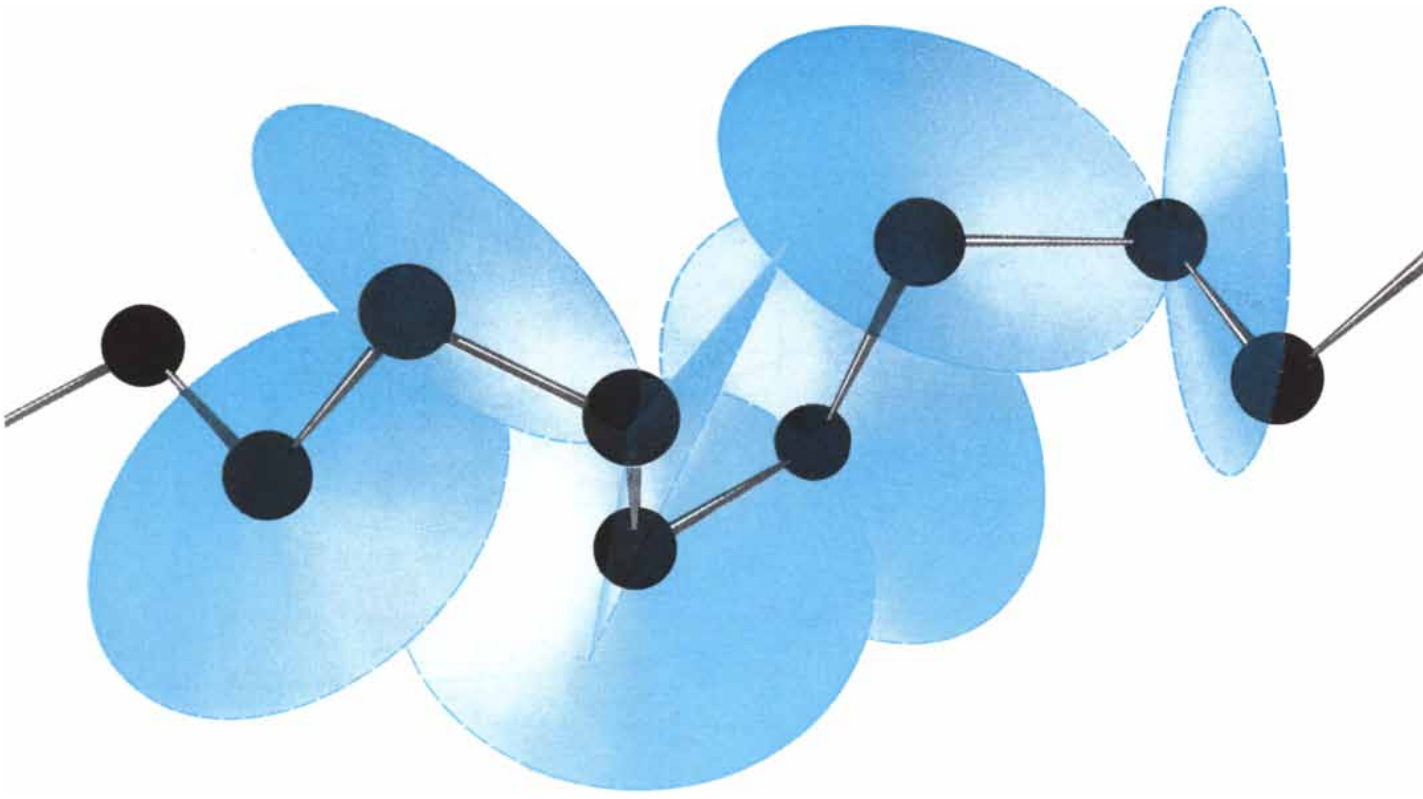
REFRACTOMETER measures changes in refraction. Hollow prism (*triangle*) containing solution of giant molecules (*dots*) is immersed in vessel of pure solvent. Colored lines show light paths, the broken lines giving the path when prism contains pure solvent.

weight. If the averages differ, the difference indicates roughly the spread of their weights.

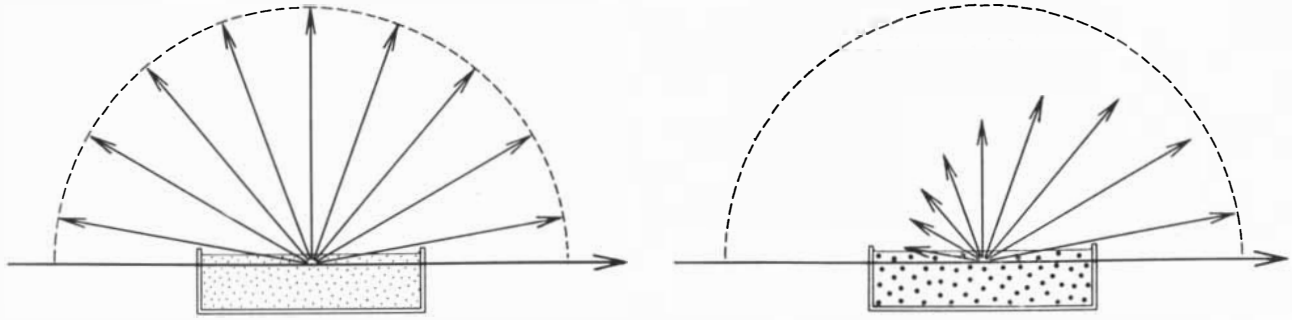
Let us now give thought to what the scattering of light may tell us about the structure or configuration of giant molecules. We think of a long, flexible molecule which can coil up or stretch out into a great number of different shapes. Considering all its possible convolutions, what is its average size (the volume it occupies) likely to be? We can make a rough estimate by considering the distance between one end of the molecule and the other in all of the molecule's possible configurations.

The problem is reminiscent of the "random walk" problem in mathematics. Suppose a person takes a step in some random direction, forgets what he has done and takes a step in another direction, turns and steps again, and so on. Assuming that the turns are made completely at random, how far will he move from his starting point, on the average, in a given number of steps of the same length? It turns out that the average distance is proportional to the square root of the number of steps. If he takes four times as many steps, he will wind up only twice as far from his starting point.

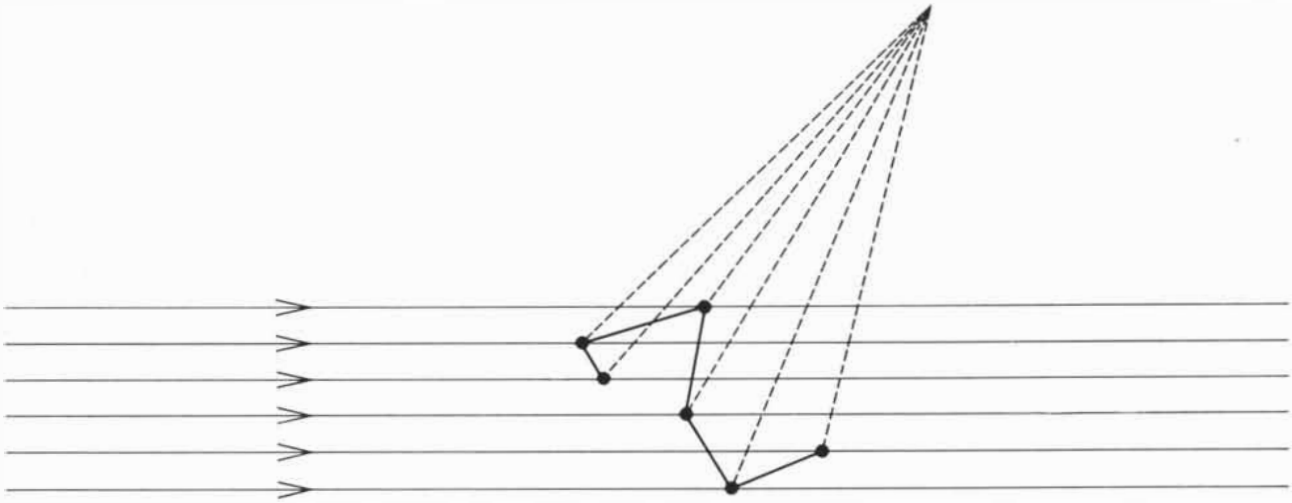
In a similar way we examine the possible twists and turns of a long chain molecule. Here the distance between one carbon atom and the next corresponds to a step. The molecule can rotate more or less freely around each C-C bond, but the bonds are restricted to an angle of 109.5 degrees to one another. Knowing the length of the step and the angle of the permitted turns, we can calculate the distance from one end of the molecule to the other in all its allowed configurations. Now the square root of the



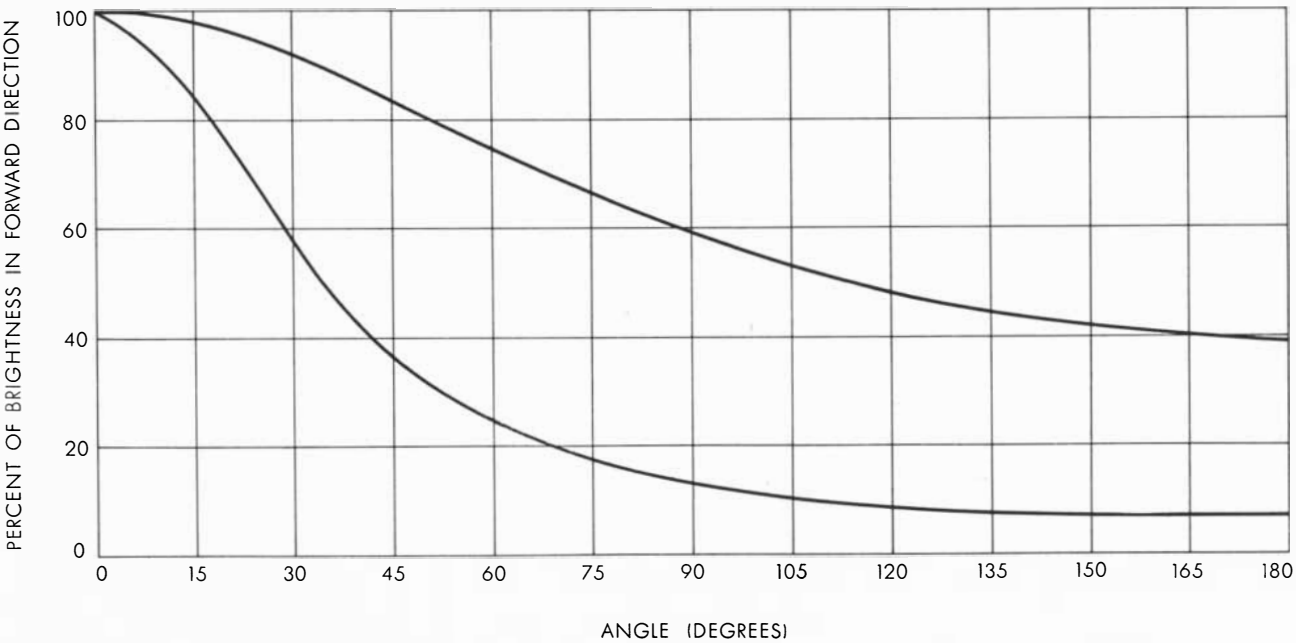
sible positions through which it could move, assuming that the bond to its left is fixed. Any two successive bonds must make an angle of 109.5 degrees, but the bonds are free to move with respect to one another as long as the size of the angle is maintained.



SCATTERING PATTERN for solution of small molecules is at left; for solution of large molecules, at right. Horizontal arrows give direction of beam. Other arrows, by their relative lengths, indicate the relative intensity of light scattered at various angles.



LARGE MOLECULE scatters light asymmetrically because each point on the molecule acts as a separate antenna. Light received at any outside point depends on the amount of interference among trains of energy (*broken lines*) from different radiating centers.



LIGHT CURVES give scattering pattern for polystyrene in benzene. Upper curve is for molecules of weight one million; lower curve, for molecules of weight nine million. Vertical scale compares intensity at any angle with the intensity scattered forward.

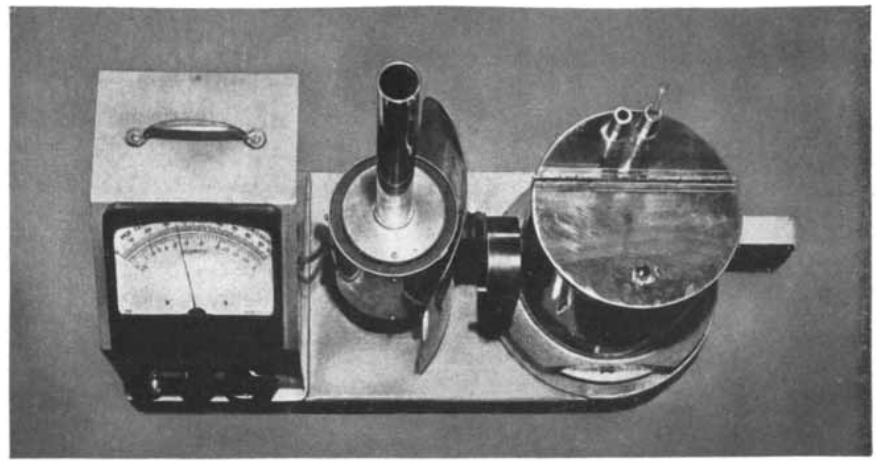
average of the squares of all these distances is taken to define the average size of the molecule.

As a specific example let us take the molecule of polystyrene in solution in benzene. A polystyrene molecule of molecular weight one million has about 20,000 C-C links, each 1.5 Angstrom units long (one Angstrom is a hundred millionth of a centimeter). From the information aforementioned, we compute that the average end-to-end distance, or diameter, of the molecule is about 300 Angstroms.

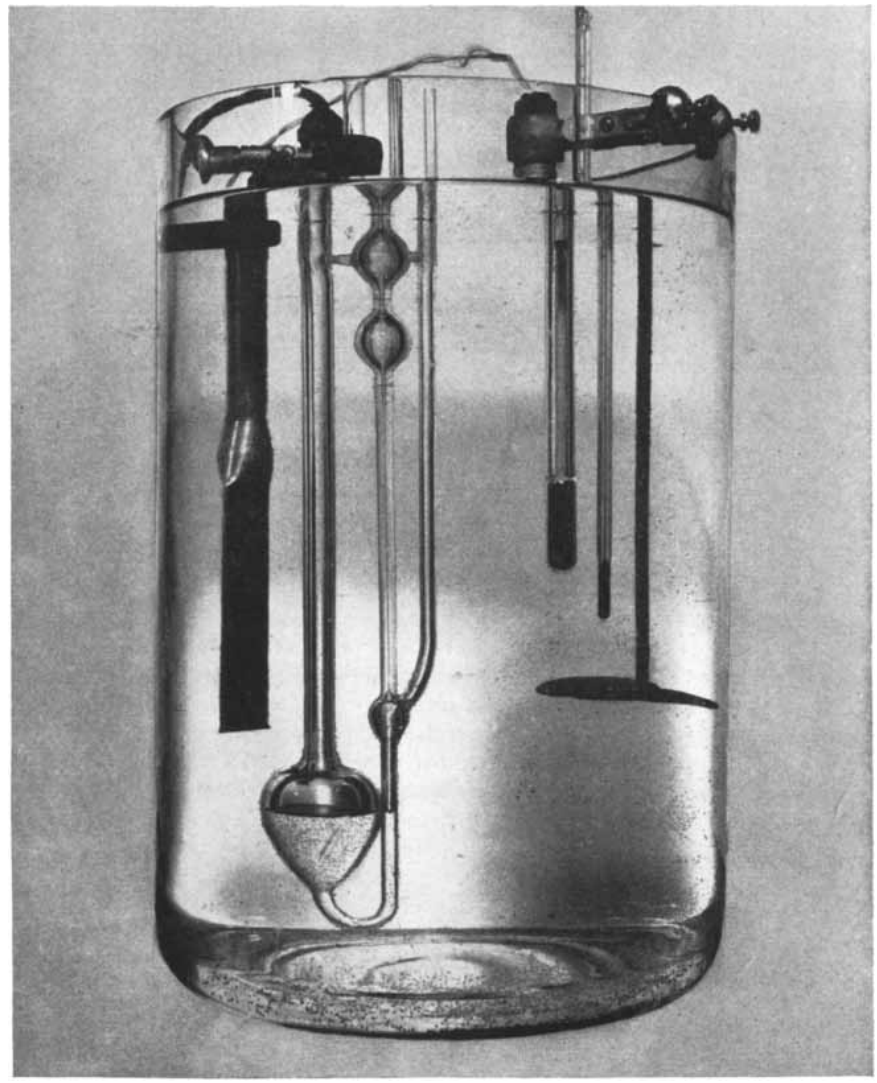
Now this size begins to be comparable with the wavelengths of visible light (which are in the neighborhood of 5,000 Angstroms). A molecule of such a size no longer acts like a single point in intercepting and reradiating light; instead, light comes from various points on the molecule, and as a result we have interference effects because of phase differences in the scattered light waves. The intensity of light-scattering now depends on the angle from which we view the beam [*see diagrams on opposite page*]. On the average a solution of large molecules scatters more energy forward, in the direction of the beam, than backward. What is most important, the larger the molecule, the higher the proportion of light scattered in the forward direction.

We can consult this scattering pattern, then, as a guide to the size of molecules. Polystyrene has been so studied, and it has confirmed the prediction that the size of a molecule is proportional to the square root of the number of C-C links. However, the size in each case is substantially larger than had been calculated theoretically: polystyrene of molecular weight one million has an average "diameter" (end-to-end distance) of 1,100 Angstroms instead of 300. The chief reason for the discrepancy is that in considering the possible configurations the calculation failed to take account of such factors as the impossibility of two monomers in the chain simultaneously occupying the same position in space. Naturally the molecules cannot be as compact, on the average, as such a calculation predicts.

The mathematical difficulties in dealing with these enormously complex molecules are so formidable that we are far from any fully satisfactory quantitative description of them. But all in all, the combined information from the various measurements—of viscosity, osmotic pressure and scattering of light—is beginning to give us a clear picture of their size and structure.



PHOTOMETER measures light scattering. Light source is a mercury arc in the cylinder in the center. The beam passes through a shutter to the dark chamber at right. This contains the scattering solution and a photocell which can be rotated by means of the graduated dial at the bottom of the chamber. The meter at the right indicates the current in the photocell.



VISCOMETER is essentially a capillary tube. In this photograph the capillary is the center tube in the assembly of glass at left in the large vessel. Liquid drawn up from the bottom bulb fills the two small bulbs above the capillary. It is then timed as it flows out. The rest of the apparatus in the vessel is for the purpose of maintaining constant temperature.

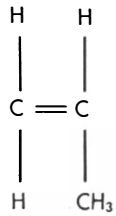
How Giant Molecules Are Made

New catalysts control the orientation of monomers as they are linked in chains. This greatly increases the range of properties that can be built into synthetic polymers

by Giulio Natta

A chemist setting out to build a giant molecule is in the same position as an architect designing a building. He has a number of building blocks of certain shapes and sizes, and his task is to put them together in a structure to serve a particular purpose. The chemist works under the awkward handicap that his building blocks are invisible, because they are submicroscopically small, but on the other hand he enjoys the happy advantage that nature has provided models to guide him. By studying the giant molecules made by living organisms, chemists have learned to construct molecules like them. What makes high-polymer chemistry still more exciting just now is that almost overnight, within the last few years, there have come discoveries of new ways to put the building blocks together—discoveries which promise a great harvest of new materials that have never existed on the earth.

We can hardly begin to conceive how profoundly this new chemistry will affect man's life. Giant molecules occupy a very large place in our material economy. Tens of millions of men and women, and immense areas of the earth's surface, are devoted to production of natural high polymers, such as cellulose, rubber and wool. Now it appears that synthetic materials of equivalent or perhaps even better properties can be made rapidly and economically from coal or petroleum. Among other things, this holds forth the prospect that we shall be able to turn much of the land now used for the production of fiber to the production of food for the world's growing population.



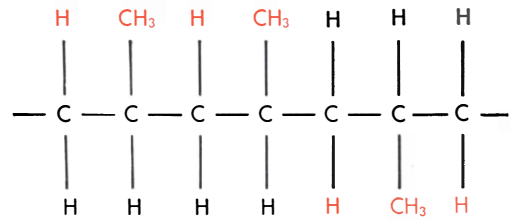
PROPYLENE is the monomer of the polymer chains depicted in formulas at right.

In this article I shall explain how the synthetic giant molecules are made. The molecules with which we are here concerned are the chainlike structures made of organic building blocks. They are formed by linking together hundreds or thousands of these units, called monomers. Let us consider the monomers first.

A monomer whose structure consists simply of a backbone of carbon atoms with hydrogen atoms ranged along the sides lends itself to the formation of a neat, straight chain of links hooked end to end, though it may also grow branches. Chain molecules of this type readily align themselves alongside one another and can be oriented to form fibers. The structure becomes more complex when, in place of hydrogen atoms, the monomer has side groups—for example, the methyl group (CH_3). A chain formed of such monomers may have one of three arrangements [*see diagrams at right*]. (1) The side groups may occur at random on either side of the chain; this type of polymer is called "atactic," meaning lacking in order (tactic comes from the Greek word for order). (2) The groups may all lie on one side of the chain; this arrangement is called "isotactic." (3) They may alternate from one side to the other in regular order; this type is called "syndiotactic."

These elements of structure lead to a great variety of formations. Isotactic chains easily line up side by side and form crystalline structures, whereas atactic chains tend to make an amorphous material. Blocks of different polymers may be joined end to end, or one polymer may be grafted onto another as a branch on the main chain [*see diagram on page 89*]. In each case the structure confers certain mechanical

1.



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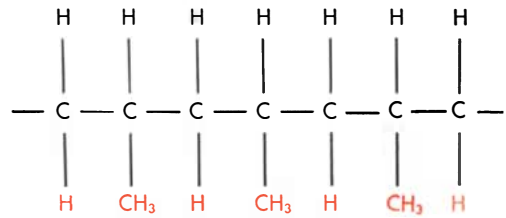

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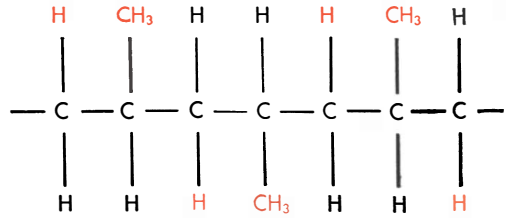


POLYPROPYLENE can now be prepared in various forms. If the CH_3 side groups (*in*

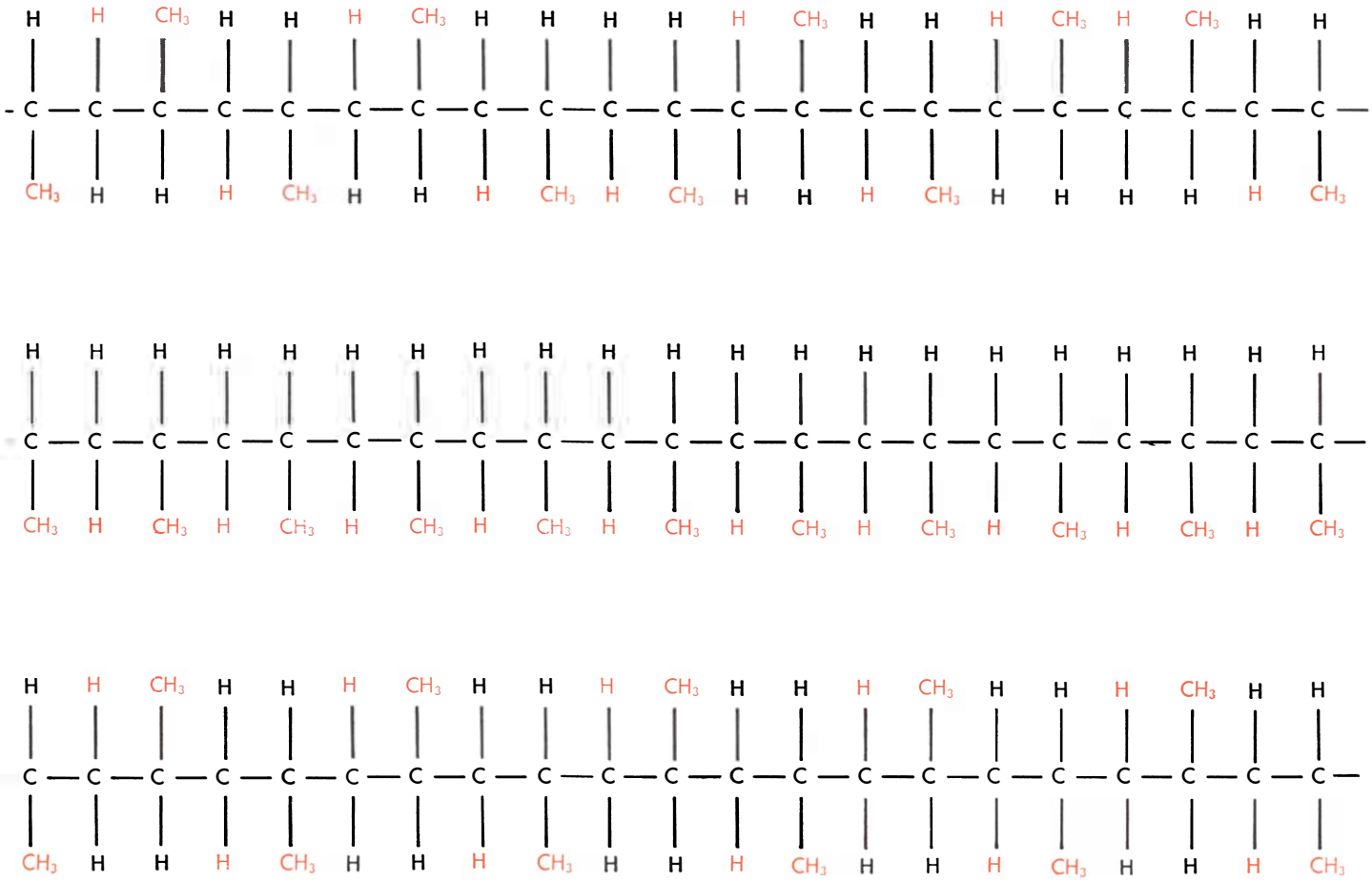
properties on the polymer, as Arthur V. Tobolsky explains in the following article [*page 120*]. For example, crystallinity gives a polymer strength and a high melting point, side-by-side alignment of the chains in bundles allows formation of a fiber, and so on.

How do monomers grow into a chain; that is, how do they link themselves together? There are two ways, called condensation and addition. In the condensation process, monomers or groups of monomers, upon being heated, unite spontaneously and at random by chemically active hooks at their ends—like skaters or groups of skaters linking arms. In the addition process the polymer builds up, one monomer at a time, by a chain reaction, very much as if one person grasped a live wire and was fixed to it, a second seized the first and was himself held fast by the electricity, a third person similarly was added to the chain by seizing the second, and so on.

Let us follow through the condensation process. Suppose we dump a mixture of monomers into solution and heat the mixture. If the monomers are equipped with chemically active hooks, we can expect them to link up into polymers. But the product we get will be strictly accidental. Like a tile floor in which tiles of different colors are put together at random, the polymer will have no predictable pattern, because the monomers, having no preference for any particular configuration, will have linked up by chance.

If, however, we use monomers which join only in one way, we can predict what kind of chain they will form. We take, let us say, two monomers: one has a basic group, the amino group (NH_2), at each end, the other has an acid group, carboxyl (COOH), at each end. The two monomers will hook up end to end, the basic end of one linking up with the acid end of the other and splitting off a molecule of water in the chemical reaction [*see diagrams at the bottom of pages 86 and 87*]. This is the classical reaction by which, in nature, amino acids are linked to form proteins, as Paul Doty explains in the article on page 173. It has been adapted by man to make synthetic fibers such as nylon. The monomers may have a basic group at one end and an acid at the other, or basic groups at both ends, or acids at both ends; in all cases it is the inherent chemical affinity between the end groups that causes the monomers to grow into a linear polymer.

This building plan, upon which Wallace H. Carothers of du Pont based his synthesis of nylon, is derived from the design of the natural fibers of wool and silk. They too are made by condensation of simple, regular monomers, all of the same configuration (levorotatory). Their monomers are amino acids, with an amino group at one end and a carboxyl at the other; they link up into long chains; the chains in turn are spun into strong fibers. All these lessons from the natural models have been followed by the creators of synthetic fibers. We do not know very much about how living organisms carry out their building and spinning processes,



color with adjacent hydrogen) **are located at random on either side of the carbon chain, the polymer is called atactic (1). If they are on the same side, the material is isotactic (2); if the groups are distributed from side to side in a regular way, it is syndiotactic (3).**

but the chemist has his own methods.

The construction of polymers by the condensation method is rather slow and tends to come to an almost complete stop before the molecules have attained a truly giant size, because as the chains grow they become less mobile and less numerous and therefore less likely to encounter free building blocks in the solution. Fortunately products such as nylon have acquired their valuable properties when they reach a molecular weight of 10,000 to 20,000. But to build molecules with molecular weights in the hundreds of thousands or millions by condensation is very difficult.

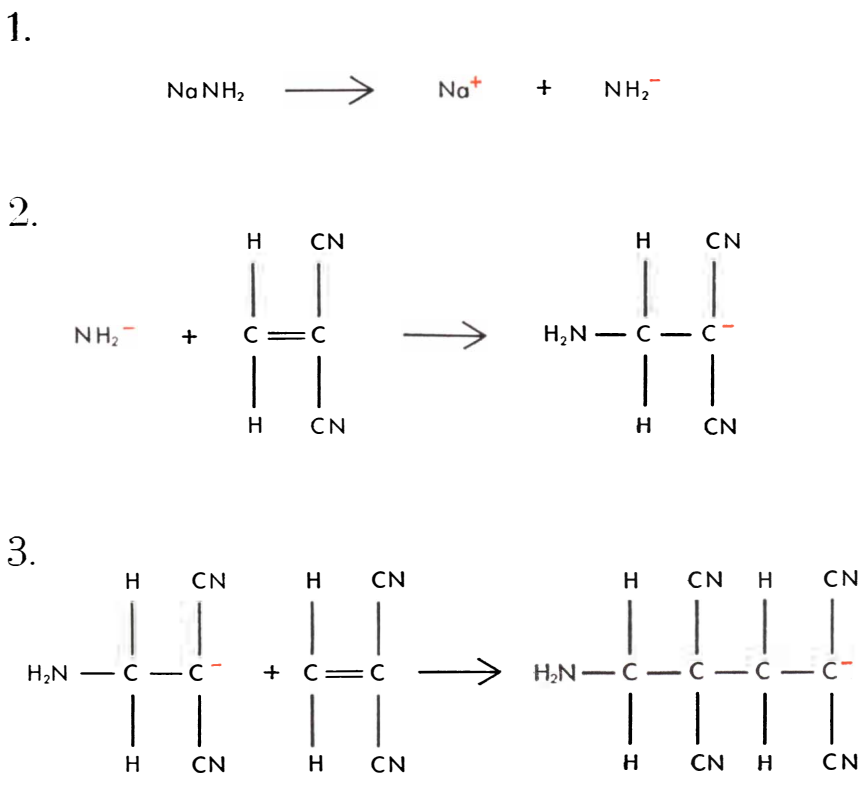
The addition method, on the other hand, can produce giant molecules of almost unlimited size. Starting from an active center (an activated monomer which serves as a kind of seed), it adds one monomer at a time and rapidly builds a chain which in theory can go on growing indefinitely as long as the supply of building blocks holds out. The process is comparatively simple but difficult to control. As I mentioned, the monomers here employed do not start with built-in chemical hooks, as condensing monomers do: instead the hooks have to be generated. Each monomer, upon joining the chain, thereby acquires a hook to seize another. There are various ways of generating such a hook, or bond; each requires a catalyst.

One method employs free radicals as the catalyst. (Actually they differ from true catalysts in that they are consumed in the polymerization reaction.) A free radical is a compound with an unpaired electron—usually a fragment of a larger molecule which has been split by heating. The unpaired electron makes the radical very reactive: it readily hooks itself to another molecule by its odd electron. Suppose it encounters a monomer. In an organic monomer the carbon and hydrogen atoms are held together by covalent bonds, meaning that the bond consists of a pair of electrons shared between a pair of atoms. The conventional symbol C-C represents two carbon atoms linked by an electron pair. Frequently the carbon atoms are joined by a double bond (C=C)—that is, two pairs of electrons. Now when a free radical encounters a double bond, it may pair with one of the electrons in the extra bond, leaving the other member of the pair without a partner. Thus the monomer itself becomes a radical: it now has an unpaired electron at one end [*see diagrams at top of pages 86 and 87*]. It promptly reacts with a second monomer; the newly released electron at the end of the second seizes a third monomer; the third grasps a fourth, and so the chain grows. It can grow to giant size and might increase without limit but for the fact that the reactive end of the chain is not restricted to reacting with monomers: it may combine with other molecules in the solution, or two chains may join head on (*i.e.*, at their free-radical ends), thus closing the growing points of both.

Among the polymers that can be made by the free-radical method are polyethylene [*see article on page 139*], polystyrene and polyvinyl chloride. Some of these giant molecules are perfectly linear, like a long snake; some are branched, like a tree. Branches develop when free radicals start side growths at points along the chain. This is particularly likely to happen when a polymer is produced at high temperature. For example, polyethylene made by the high-pressure process (at pressures above 1,000 atmospheres and temperatures above 212 degrees Fahrenheit) is highly branched: it may have several long branches and hundreds of small ones. The branches interfere with packing of the chains in crystalline (*i.e.*, regular) arrangements, and as a result polyethylene synthesized by this method has a comparatively low crystallinity—30 to 60 per cent. With low crystallinity go low strength and a low melting point.

Free radicals are one type of catalyst that can grow polymers by addition; another method involves the use of ions as catalysts. The latter is a very recent development, and to my mind it portends a revolution in the synthesis of giant molecules, opening up large new horizons.

Under certain circumstances the electrons of a double bond between the carbon atoms in a monomer can be so displaced that one of the carbon atoms in effect has a positive charge while the other end of the molecule is negative. The carbon atoms are "polarized," so to speak. If we now neutralize the positively charged carbon atom by causing it to react with a negative ion, the other end of the monomer becomes negatively charged, because of its unneutralized negative carbon atom. It will then act as a negative ion and attach itself to the positively charged end of a second "polarized" monomer [*see diagram at the left*]. This again leaves a negative charge at the growing end of the molecule. Thus, by a chain reaction like the one



IONIC ADDITION is illustrated by example. Sodium amide splits into ions (1). A negative NH_2 ion combines with the positive end of a vinylidene nitrile monomer (2). The negative end of this monomer then combines with the positive end of a second (3), and so on.

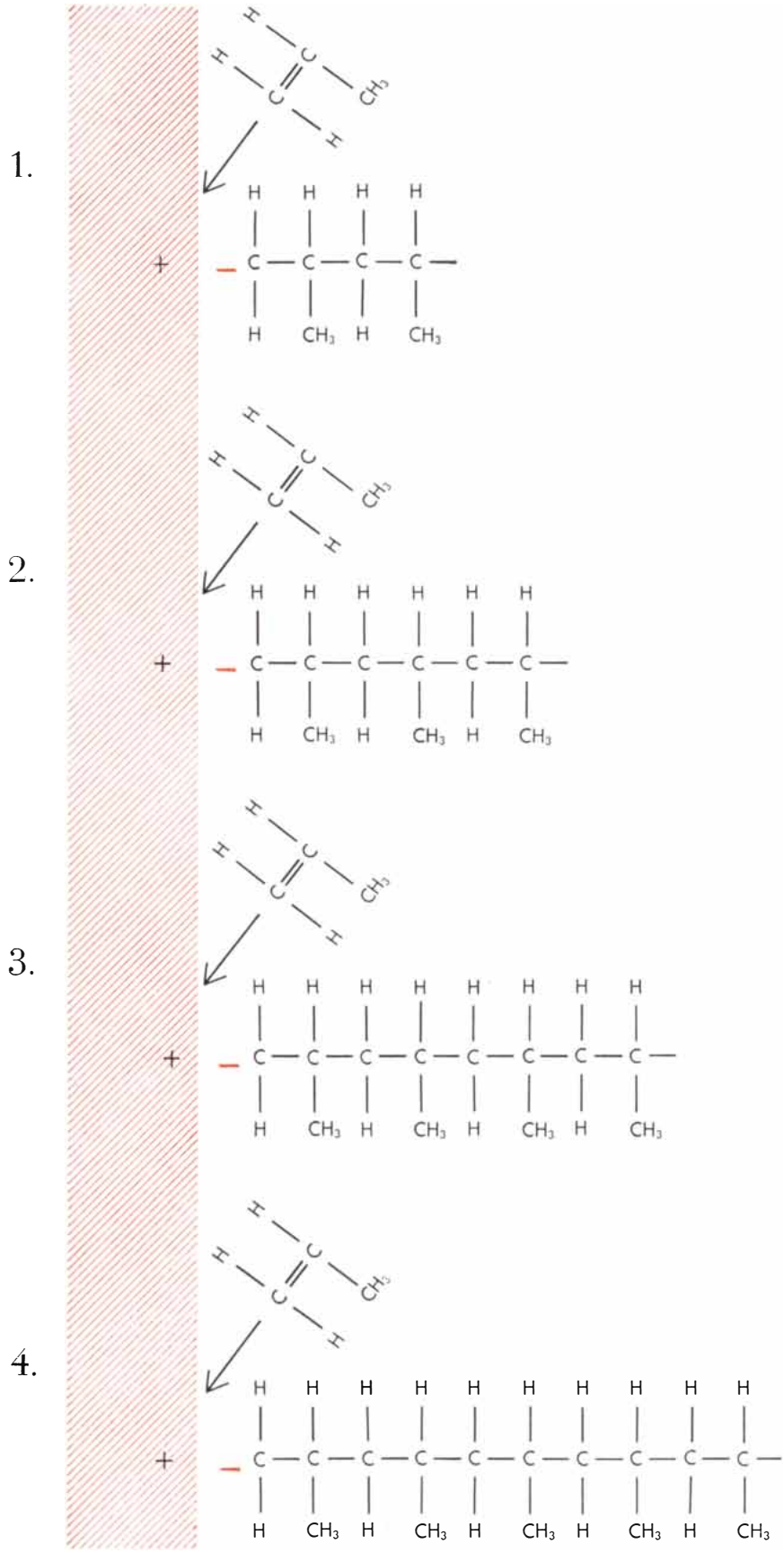
catalyzed by free radicals, the molecule grows to a high polymer. This version of the ionic process uses negative ions (anions) as the catalysts. The process also works in reverse: if positive ions (cations) react with the negatively charged end of a polarized monomer, it will grow from the positively charged end.

The cationic method has produced some very interesting high polymers: for instance, butyl rubber, the synthetic rubber used for tire inner tubes. But the anionic catalysts, a more recent development, have proved far more powerful. They yield huge, made-to-order molecules with extraordinary properties.

Experiments with anionic catalysts had been carried on for a number of years. Before World War II Russian chemists, by a process using sodium as the catalyst, had produced a synthetic rubber from butadiene, but the rubber was of rather poor quality. In the U. S. the polymer chemist Avery Morton had obtained very large polymers of butadiene and styrene with an ionic process. And Michael Szwarc had generated tremendous chains of polystyrene which he called "living molecules," because even after they had stopped growing, having used up the available styrene, they would start growing again if more styrene was supplied later.

Only in the last four years, however, have the great possibilities of ionic catalysis begun to take shape. In 1953 Karl Ziegler in Germany, and less than a year later the du Pont Company in the U. S., patented new ionic processes for making polyethylene. These processes made it possible to synthesize polyethylene at atmospheric pressure and temperatures as low as 90 degrees F., instead of the very high pressures and temperatures previously required. For the first time the molecule could be polymerized in a regular, unbranched form, producing a strong, crystalline material with high resistance to heat.

Early in 1954 our group in the Institute of Industrial Chemistry of the Polytechnic Institute of Milan, using certain special catalysts, succeeded in polymerizing more complex monomers of the vinyl family (of which ethylene is a member). We were able to generate chains of very great length, running to molecular weights in the millions (up to 10 million in one case), and to produce at will either isotactic or syndiotactic or atactic forms of the chains. In other words, we found that it was possible, by a

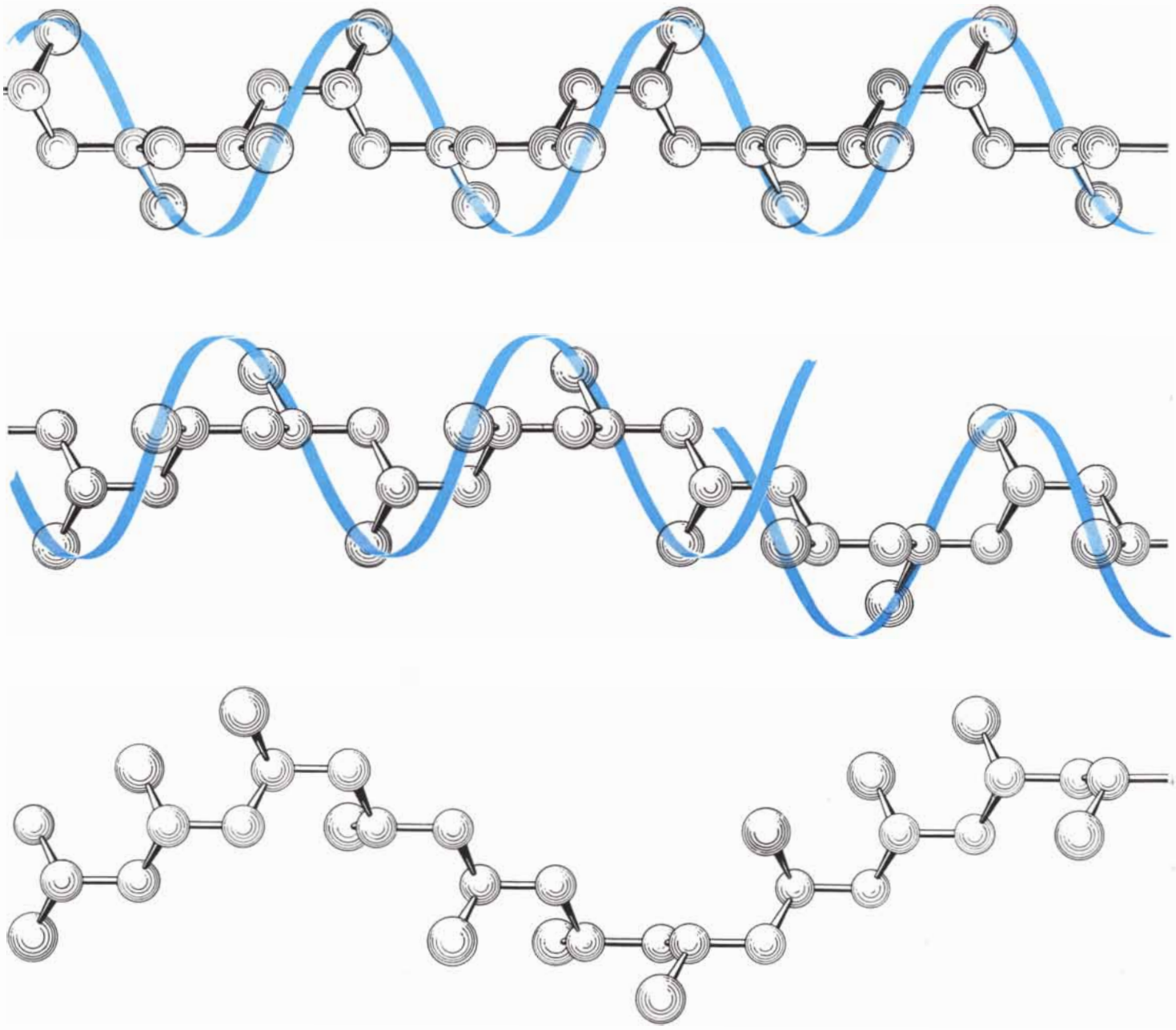


NEW IONIC CATALYST is a solid material (*colored band*) containing complex positive ions. It grows ordered polymers, in which new units add themselves at the inside end of the growing chain. Shown here are four stages in the growth of isotactic polypropylene.

proper choice of catalysts, to control the growth of chains according to predetermined specifications.

Among the monomers we have polymerized in this way are styrene and propylene, both hydrocarbons derived from petroleum. The polypropylenes we have made illustrate the versatility of the method. We can synthesize them in three forms: isotactic, atactic or "block isotactic," that is, a chain consisting of blocks, one having all the side groups aligned on one side, the other on the opposite side [*see diagrams below*]. The isotactic polypropylene is a highly crystalline substance with a high melting point (346 degrees F.); it makes very strong fibers, like those of natural silk or nylon. The atactic product, in contrast, is amorphous and has the elastic properties of rubber. The block versions of polypropylene have the intermediate characteristics of a plastic, with more or less rigidity or elasticity.

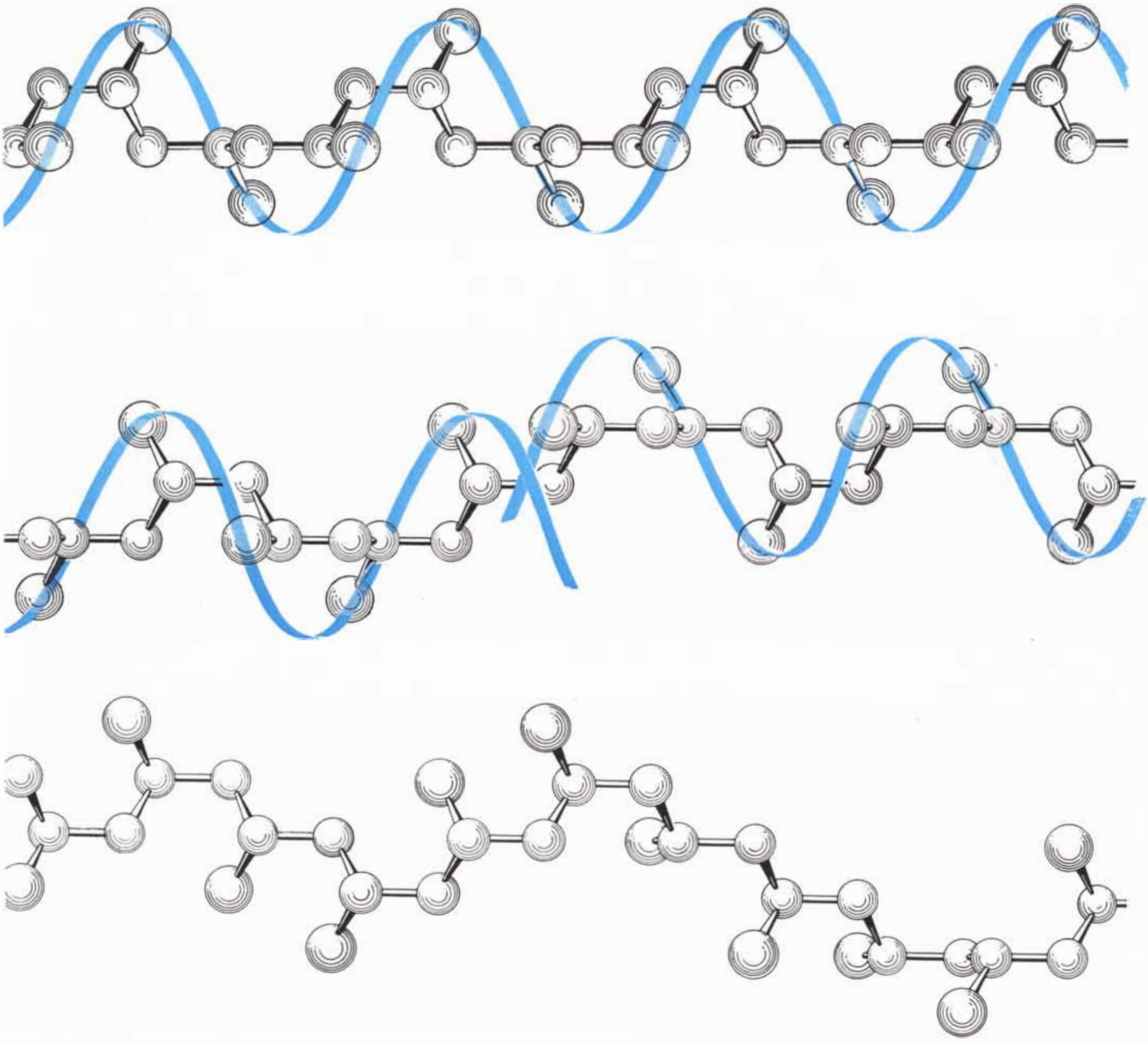
The possibility of obtaining such a wide array of different products from the same raw material naturally aroused great interest. Furthermore, the new controlled processes created properties not attainable before: for example, polystyrene, which had been known only as a glassy material with a low softening point (under 200 degrees F.), now could be prepared as a strong, crystalline plastic with a melting point near 460 degrees. The new-found power of the anionic catalysts stimulated great activity in polymer research, both in Europe



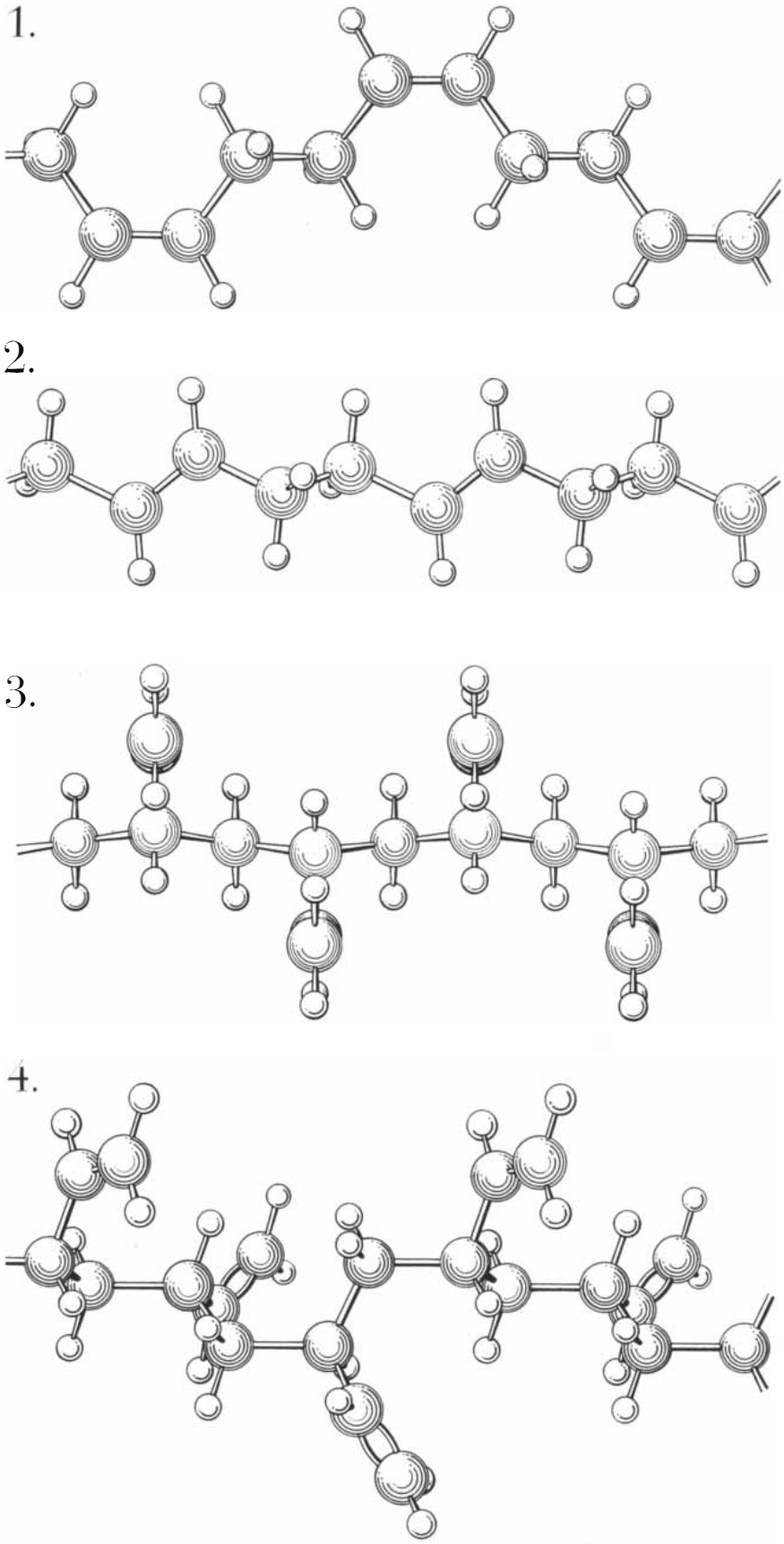
DEGREES OF ORDER in polypropylene molecules can be varied. Isotactic molecule (*top*) has CH_3 side groups (*the balls through which the imaginary colored ribbon passes*) in a regular helical sequence around the central chain. It forms crystalline fibers. The

and in the U. S. New polymers were made from various monomers. In our own laboratory we synthesized all of the regular polymers, and some amorphous ones, that can be made from butadiene; some of the products are rubber-like, others not. At about the same time the B. F. Goodrich Company and the Firestone Tire and Rubber Company both announced that they had synthesized, from isoprene, a rubber identical to natural rubber—a problem on which chemists throughout the world had worked in vain for more than half a century.

What are the magical new catalysts that have shown such remarkable powers? Most of them are complexes consisting of several substances: for instance, the chloride of a metal with an unfilled electron shell (*e.g.*, titanium) and an "organometallic" compound (*e.g.*, aluminum linked to an alkyl group). Groups of ions of these substances serve as the active centers from which giant molecules grow. The character of the growing molecule is controlled by the nature of the generating complex and by temperature. When the catalytic complex is firmly fixed on solid crystals with a layer structure and the reaction proceeds at low temperature, it generates a perfectly regular, isotactic molecule of tremendous length. When the generating complex is less firmly rooted in the crystals, or when the process is carried out at high temperatures, the chain changes its pattern of growth from time



middle diagram shows a section of a block polymer with three isotactic parts. It forms a less crystalline, leathery material. A random molecule (*bottom*) forms an amorphous, rubbery substance. The balls in the backbone represent, alternately, CH_2 and CH groups.



POLYBUTADIENE has recently been prepared in all four possible stereoisomeric forms by Natta and his colleagues in Milan. In these diagrams the large balls represent carbon atoms; the small balls, hydrogen atoms. Form 1 is a rubbery substance; form 2 is fibrous.

to time and we get a molecule of the block type. When the catalysts are embedded in an amorphous support, we get atactic, or irregular, molecules.

The giant molecules themselves do not suggest life, but the catalytic complexes that generate them do. We should speak not of "living molecules," as Szwarc did, but of "living complexes." A molecule growing from the catalytic complex on the surface of a crystal is like a hair growing from its root: that is, the monomers are added at the root. The long molecule is very thin and very delicate—far more easily torn loose than an actual hair. Even eddies produced by stirring the liquid will tear the molecule from its generating complex, as a windstorm can tear a slender plant stem from its roots. But the generating complex, like a root, does not die; it retains the ability to send forth new shoots. It is, however, subject to a number of mortal dangers: certain poisons will kill its ability to generate molecules, freezing or lack of nourishment will render it inactive, and so on.

No one will be misled into supposing that these complexes bear any basic resemblance to a living organism. Nevertheless the analogies between the way they build giant molecules and the way an organism does are striking, and very hopeful for the future of polymer chemistry. A living creature builds its high polymers, precisely tailored according to a set design, by means of catalysts (enzymes). We are now in a position to hope that, with man-made catalysts, we shall be able to produce predesigned giant molecules in the same controlled and orderly way.

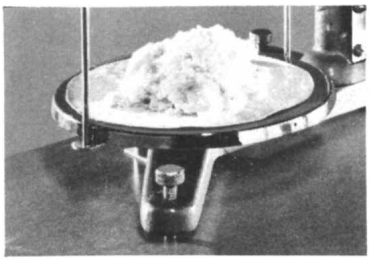
In some respects we can improve on nature. As I have mentioned, we shall probably be able to create many new molecules which do not exist in living matter. They can be made from simple, inexpensive materials. And we can manufacture giant molecules more rapidly than an organism usually does. For example, a single active center in a catalyst can generate more than 10,000 polypropylene molecules of molecular weight 200,000 in 20 hours—polymerizing monomers at the rate of 250,000 per hour!

Although it is less than four years since the new methods for controlled synthesis of macromolecules were discovered, already many new synthetic substances—potential fibers, rubbers and plastics—have been made. Thousands of chemists are now devoting themselves to this new field of research, and unlimited possibilities have been opened to their imagination.

Kodak reports on:

what may become a standard anion-exchange packing . . . film for cases where no other film will do . . . learning to synchronize

A fluff of good resolution



With one of the lowest bulk densities among Eastman Organic solids, regard these five grams of fluff. Familiarize yourself with the look of *N,N-Diethylaminoethylcellulose* (Eastman 7392; 25 g. for $4.60, 100 g. for $15.90). It looms as the standard anion-exchange packing for chromatographic columns set up to resolve proteins.

Despite our many years in cellulose chemistry, and despite our having invented and manufactured oxycellulose for the purification of ACTH by ion exchange, the idea for DEAE-cellulose seems to have entered the heads of some folks at the National Institutes of Health instead of ours (*J.A.C.S.*, *78*, 751). We are not crestfallen, though, for we recognize that our lot is to make and sell Eastman Organic Chemicals and invent only when we can.

A gentleman in Philadelphia named Earl Usdin has been so grateful at being spared the mess of preparing his own DEAE-cellulose that he has shared with us his experience here and in Sweden with a further elaboration of the idea, N,N,N-triethylaminoethylcellulose. This is a quaternary compound, with a charged nitrogen ready to attract anions as soon as the coating of hydroxyls that preserve its electrical neutrality has been removed. With that kind of attractive force in play, the casual bystander would expect to find TEAE-cellulose much more anion-avid than DEAE-cellulose, which depends on the mere general basicity of amine nitrogen. Doctor Usdin, no casual bystander in this area, reports that actually the effective difference between the two is small.

Certain folic acid derivatives that interest him come off the TEAE-cellulose with phosphate developers at pH 6.1, as compared with the rather destructive pH 1 to 2 levels which the older-fashioned, ante-cellulosic ion-exchange resins need to make them let go. He claims that once you have the DEAE-cellulose it's a breeze to convert to TEAE-cellulose. Just reflux with *Bromoethane* (Eastman 114).

We'll give this some time to sink in. Then, if demand should develop for TEAE-cellulose, we might be moved to offer that too. Meanwhile you are welcome to an abstract of the procedures for chromatography with these fluffs. Also to a copy of our catalog of some 3600 organic chemicals we stock, "Eastman Organic Chemicals List No. 40." Write Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y. (Division of Eastman Kodak Company).

For your own good

It is now possible to walk up to an ordinary film counter and buy a roll of 120 or 620 roll film that is just too fast for your own good. We do *not* recommend the new *Kodak Royal-X Pan Film*, except for special cases involving very poor light conditions, very high shutter speeds, or very small lens openings. Processing it by current commercial photofinishing techniques will lead to unsatisfactory results; instead, one must follow the special processing instructions packed with the film. Measured by the official ASA method, the Exposure Index is 650, but we think you will get along better handling it on the assumption of a 1600 exposure index.

Semi-pro sound movies

Four hundred feet of unexposed 16mm *Kodachrome Film* can be purchased for $24. $14 more gets it processed (and by *us* at that). $10 more puts a *Kodak Sonotrack Coating* along the edge. Now sound can be magnetically recorded on the film by merely projecting it with the *Kodak Pageant Sound Projector, Magnetic-Optical*, while commentary, sound effects, and/or musical background are applied via the handy microphone. Now, if 10% is enough for wastage, you have 10 minutes of movies with sound. Total outlay, exclusive of equipment amortization and talent—$48. If you have planned well, you can impart much information or persuasion in this way, and more vividly than by ink on paper.

Then ambition sets in. You realize in time that the distinction between a movie with sound and a sound movie can be as noticeable as the distinction between "assistant director" and "assistant to the director."

Synchronization—that's the problem.

If the aforementioned *Pageant* projector could be run at exactly the same speed as the movie camera used, you could take the projector to the scene of photography and with it record lip-synchronized speech and actual sounds. This turns out to be feasible. All you need is a simple braking attachment on the projector and a strobe pattern disk, both of which we can supply, and a little neon or argon lamp.

Still, you are not yet in a good position to compete for the top awards of the Motion Picture Academy of Arts and Sciences. On the other hand, you have paid the Kodak Audio-Visual Dealer only $12.50 for synchronizing equipment.

By now when watching movies at the theater or on television, you are aware of how the film editor keeps switching back and forth between the camera angles and auxiliary shots at his disposal while the sound track flows smoothly on. So back you go to the Audio-Visual Dealer. He has been fully indoctrinated by us in a new technique of great utility to organizations who would like to turn out sound films that rise up and out of the amateur class yet require too few release prints over which to distribute the costs involved in professional production. This new re-recording technique is built around a few extremely inexpensive magnetic recording aids and certain unique design features of the *Pageant Sound Projector, Models MK4* and *AV-104M*. He is eager to teach it to you.

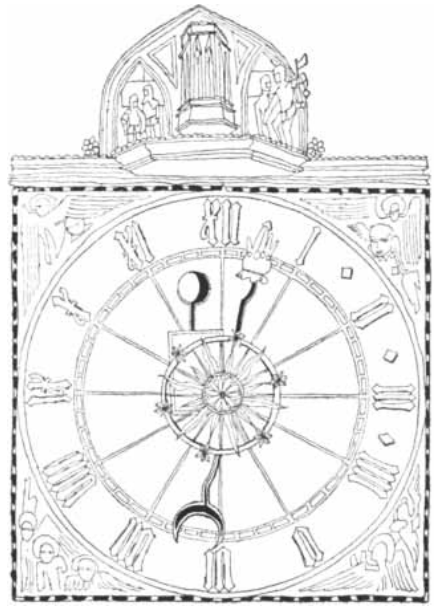
If you can't remember the fellow's name, a note to Eastman Kodak Company, Audio-Visual Sales, Rochester 4, N. Y., will bring a quick reminder.

Prices quoted are subject to change without notice.

Kodak
TRADEMARK

This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science

SCIENCE AND



Enough Engineers

Notwithstanding the feverish recruiting of engineering college graduates and the spate of want ads in Sunday papers, there is no shortage of engineers in the U. S., according to a study by two economists, David M. Blank and George J. Stigler, which was financed by the National Science Foundation. Their report, titled *The Demand and Supply of Scientific Personnel*, was published last month.

Considering the problem in economic terms—price as a reflection of the relation between supply and demand—the economists observed that during the past 30 years the salaries of engineers have lagged behind the pay of the general labor force and of professional groups such as doctors and lawyers. (The trend was briefly reversed at the time of the Korean War, when there was a shortage of engineers for about a year.) While starting salaries for engineers have jumped, they have not risen more than in business and other professions. The pay of experienced engineers has not kept pace, so the differential between them and beginners has narrowed. In 1953, the latest year for which the study obtained figures, the average salary of engineers was $6,216.

The economists conclude that the increase in the supply of engineers from 11,000 graduates per year in the early 1930s to 29,000 in the 1950s has more than kept pace with the demand, and that if engineers are in short supply, they must be considered so on non-economic criteria, for example, that "we should have 10 per cent more engineers than a hostile power is believed to have."

The report discounts the significance of help-wanted advertising. It is used almost exclusively in connection with military contracts, where the cost is reimbursed by the government.

Blank is an economist with the Columbia Broadcasting System. Stigler is a professor of economics at Columbia University. Their study was made under the auspices of the National Bureau of Economic Research.

A story in *The Wall Street Journal* last month tended to bear out the economists' argument. The paper said that engineers laid off by the recent closing of a missiles plant of North American Aviation were having great trouble in finding new jobs. Some were accepting "insulting" offers of $600 per month. The U. S. as a whole seems to be exhibiting a diminishing "thirst for engineering skill," said the *Journal.*

Meeting at Pugwash

For six days last July, 22 scientists from 10 countries met in the hamlet of Pugwash in Nova Scotia to talk about "the perils to humanity posed by the development of weapons of mass destruction." Financed by the Cleveland industrialist Cyrus Eaton, a native of Pugwash, the conference was the culmination of an appeal for such a meeting made two years ago by Albert Einstein and Bertrand Russell.

The group included scientists from the U. S., the U.S.S.R., China and Japan. They began by agreeing to "say nothing which might seem to favor one rather than the other of the two great groups of powers into which the world is divided"; then they split into three committees, which considered (1) the hazards of the peaceful and military uses of atomic energy, (2) the problems in the control of nuclear weapons, (3) the social responsibility of scientists. The conference produced a general statement emphasizing that every possible effort should be expended to prevent war and recommending suspension of nuclear bomb tests, special attention to disagreements between small nations, which could lead to global war, and education in each country on the necessity for international cooperation.

Present at the conference, by invitation of Lord Russell, were: M. L. E.

THE CITIZEN

Oliphant of Australia; H. Thirring of Austria; G. Brock Chisholm and John Stewart Foster of Canada; Chou Pei Yuan of China; A. M. B. Lacassagne of France; C. F. Powell and J. Rotblat of Great Britain; I. Ogawa, H. Yukawa and S. Tomonaga of Japan; M. Danysz of Poland; D. F. Cavers, H. J. Muller, P. Doty, E. I. Rabinowitch, W. Selove, L. Szilard and V. F. Weisskopf of the U. S.; A. M. Kuzin, D. F. Skobeltzyn and A. V. Topchiev of the U.S.S.R.

Airborne Observatory

Astronomers are about to get a new view of the sun, three times clearer than they have ever had before. It will be provided by photographs made 80,000 feet above the ground by a 12-inch telescope suspended from a giant balloon. At this height the telescope will be above the turbulence of the earth's atmosphere, which limits the sharpness of pictures taken from the ground.

Astronomy at 80,000 feet poses a number of peculiar problems. The telescope will be pointed at the sun by an automatic light-seeking device developed for rocket work. Even if an astronomer wanted to go along for the ride, his breathing would cause the platform to swing too much. Against the extreme and uncertain temperatures that will be encountered, the telescope will have heat-resistant quartz mirrors and a barrel made of Invar, an alloy with a very low coefficient of expansion. Its secondary mirror, collecting the focused beam from the primary mirror, will rotate continuously so that its aluminized reflecting surface will be exposed to the concentrated heat of the sun's image only once a second. Because of the uncertainty about the temperature at 80,000 feet, which will affect the focal length of the telescope, the camera lens will shift over a range of 20 different positions; thus only one picture in 20 can be expected to be in focus. The apparatus is designed to make 8,000 photographs at one-second intervals. After it has run through this number, the telescope, camera and guiding equipment will be released from the balloon and parachute to the earth.

The main features of the sun that the astronomers hope to photograph are turbulent eddies in its outer gases. At present the smallest such storms that can

be distinguished appear to be 600 miles across. Sharper pictures should define their size more closely and make visible smaller eddies, giving a more detailed view of the solar atmosphere. Flares and prominences, which cause magnetic storms and other disturbances on the earth, are thought to grow out of eddies in the sun.

The project, sponsored jointly by the Office of Naval Research and the Air Force, is directed by Martin Schwarzschild of Princeton University. The telescope was made by the Perkin-Elmer Corporation; the balloon suspension, by General Mills, Inc.

Weather by Machine

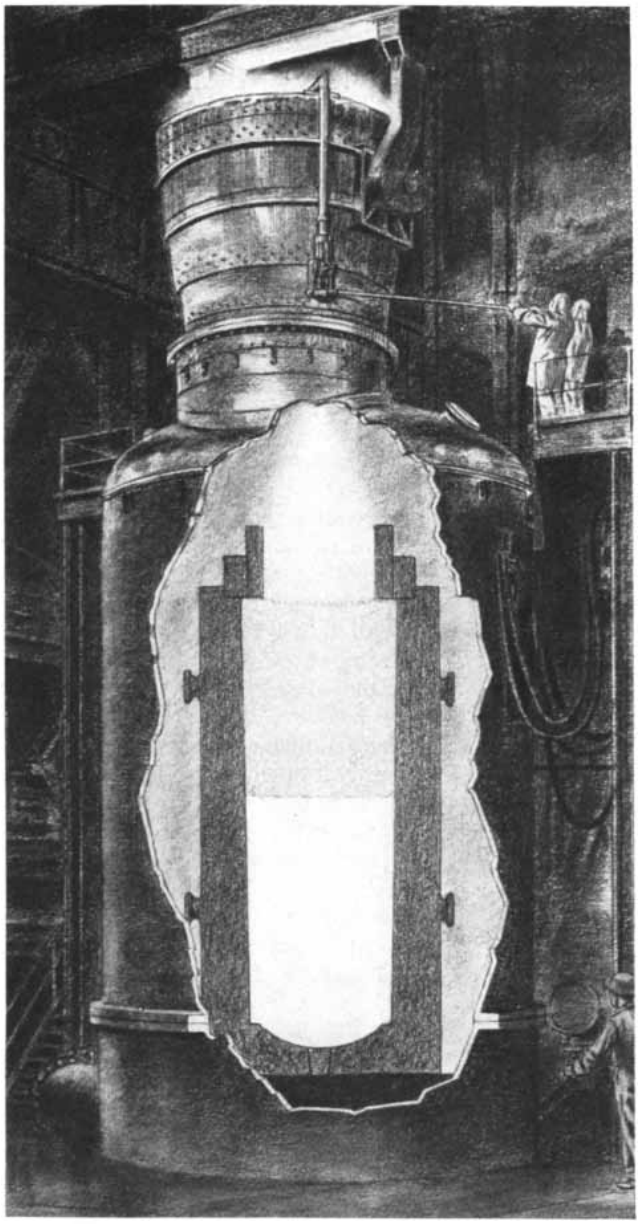
With the aid of high-speed computers, meteorologists are now grinding out mathematical weather predictions as good as, or better than, those produced by the most skillful "subjective" forecasters. For the past year and a half a Joint Numerical Weather Prediction Unit in Washington, D.C., has been furnishing daily machine forecasts to its sponsoring agencies, the U. S. Weather Bureau, the Navy and the Air Force. The program was reviewed recently in the *Bulletin of the American Meteorological Society*.

The system is an attempt to compute the detailed motions of the atmosphere by means of the basic equations of fluid dynamics, starting from observed initial conditions. In practice these conditions are the temperature and wind velocity at a number of sample points in the atmosphere. The points may be taken at a single altitude, or, for more accurate predictions, at several.

The Joint Unit has dealt with a roughly square region of air above North America, the Arctic Circle and adjoining portions of the Atlantic and Pacific oceans. The atmosphere at 18,000 feet is divided by a grid which gives almost 500 equally spaced points. Winds and temperatures reported by observing stations near these points are fed into the computer, which then proceeds to solve the equations of motion. It presents its answers in the form of the predicted wind and temperature for each point at a specified future time. Conditions at the 18,000-foot level are predicted for 24, 48 and 72 hours in the future. Three-level computations, covering smaller areas, are made for 12, 24 and 36 hours.

The machine forecasts for the levels at 18,000 feet and above are consistently better than those made by conventional methods. But the sea-level predictions are not quite as good. The Joint Unit has

Better Metals for Better Products



through Stokes Vacuum Stream Degassing Systems

VACUUM STREAM DEGASSING is an economical method for the refinement of steel through removal of gaseous impurities while the metal is in the molten state. Among other benefits, this eliminates hydrogen flaking and increases ingot yields. Ductility is increased . . . alloy uniformity and homogeneity are improved to give a significantly better steel.

Stokes Vacuum Stream Degassing Systems are another practical demonstration of the engineering and design leadership in the field of high vacuum which Stokes has achieved during the past 30 years. Stokes was the first American supplier to install a major stream degassing system . . . to engineer a completely practical plant of proved production equipment.

Stream degassing is not only an asset to the steel industries, but may also become a significant factor in the production of non-ferrous metals, especially copper and aluminum.

Stokes can provide a complete analysis of your specific needs . . . supply your vacuum component requirements . . . or fabricate and erect a complete vacuum system on a turnkey contract, with undivided responsibility for delivery and performance. Write for additional information on this and other Stokes high vacuum equipment and systems—call on the Stokes Advisory Service for consultation.

Vacuum Equipment Division
F. J. STOKES CORPORATION
5500 Tabor Road, Philadelphia 20, Pa.

STOKES

just installed a larger computer and is extending its region of coverage to the entire Northern Hemisphere. This bigger network is expected to give substantially better results at all levels, and numerical methods may soon entirely supplant conventional techniques of weather forecasting.

Nearer Zero

A record descent on the temperature scale, to about a hundred-thousandth of a degree above absolute zero, has been made at the University of Oxford. N. Kurti and a group of co-workers at the Clarendon Laboratory cooled a small piece of copper to this temperature, using the phenomenon of nuclear magnetism. Discussing the experiment in the magazine *Science Progress*, Kurti predicted that refinements in technique should make it possible to reach a millionth of a degree or less.

A standard process for producing very low temperature lines up the molecules of a cold magnetic salt in a magnetic field, then removes the field and allows the molecules to go back to a random arrangement: the work performed in this return reduces the thermal energy of the material. If the molecular magnets could attain complete disorder, they could be cooled to absolute zero. Actually their own magnetism produces an over-all field, so that there is an unavoidable ordering effect. Kurti applied the method to the nuclei of copper atoms instead of to molecules. Since nuclei are weaker magnets than molecules, the residual ordering is reduced and greater cooling is possible.

According to Kurti, matter may exhibit some entirely new properties in the microdegree temperature range. Among the properties he plans to investigate are specific heats and electric and magnetic behavior.

Spacistor

A new type of semiconductor amplifying device which, according to its inventors, may be superior to transistors for certain purposes was announced last month by the Raytheon Manufacturing Company. Among its expected advantages are operation at higher frequencies and higher temperatures.

The device, which is still in the laboratory stage of development, is called the "spacistor." It consists of a semiconductor to which is applied a high, steady voltage. The voltage produces a "space charge" region in the semiconductor and accelerates electrons passing

DOW CORNING

SILICONE NEWS

Task Force: Silicones

- Help deliver the Hustler's punch
- Protect vital communications
- Keep the DEW line lighted

DEPENDABLE ALLIES *in the constant battle to preserve peace are silicones—the same Dow Corning Silicones that help production men mop up trouble spots . . . that help designers engineer better consumer products. While the detailed story of how silicones aid our defense program is under security wraps, some information about the vital role silicones play in strengthening our defense arm can now be revealed.*

STRIKING STRENGTH — The Convair B58 Hustler, spectacular new addition to our air arm, delivers an extremely accurate and lethal "punch". One of the reasons for its superior fire power efficiency is Silastic,* the Dow Corning silicone rubber.

The B58's electronic fire control centers need protection against jolting and electrical leakage. Silastic provides for that need. Silastic cushions and insulates the fire control "brains" against the roughest flight, despite the sub-zero temperatures encountered aloft. Silastic also remains resilient when subjected — as often occurs in this equipment — to temperatures of 350 F. Designed and produced for the Convair B58 by Emerson Electric Manufacturing, these electronic packages, cushioned in Silastic, assure the Hustler's ability to deliver.

On the civilian front, products ranging from "fry pans" to electric motors —from portable TV's to automobile transmissions — have been improved with Silastic, the silicone rubber that retains superior electrical and physical properties from —130 to over 500 F.

NEW SWITCH—Communications are vital in military operation. Stromberg-Carlson solved a major problem of reliability in field-type telephone switches by adopting coil spacers and insulators of silicone resin-bonded glass laminate. While the spacers and insulators formerly used would melt under unusual stress, the silicone-glass parts are unaffected even if trouble on the circuit should force temperatures to 680 F! Here again, as in hundreds of industrial and consumer products, Dow Corning Silicones have helped solve a major dependability problem.

READY RADAR — Strung above the Arctic Circle is a line of Distant Early Warning radar stations. In that remote, deep-freeze area, dependable and maintenance-free power is essential. That's why Western Electric Company, prime contractor for DEW Line installations, specified silicone insulated dry-type transformers to supply station power and lighting requirements.

When insulated with Dow Corning Silicones, dry-type transformers offer exceptionally light weight, maximum reliability, and are unaffected by arctic cold even when idle. In industrial installations, this type of silicone insulated transformer offers exceptionally safe and reliable performance and permits location close to the load.

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

FOR MORE INFORMATION **on any of these silicone products or applications, write Dept. 9821.**

first in silicones

Dow Corning CORPORATION
MIDLAND, MICHIGAN

ATLANTA BOSTON CHICAGO CLEVELAND DALLAS DETROIT LOS ANGELES NEW YORK WASHINGTON, D. C.
CANADA: DOW CORNING SILICONES LTD., TORONTO GREAT BRITAIN: MIDLAND SILICONES LTD., LONDON FRANCE: ST. GOBAIN, PARIS

through it to high speeds. Thus they travel through the solid in a short time. In a transistor the charges move by the slower process of diffusion and have a much longer transit time. The shorter the transit time, the higher the frequency at which an electronic device can operate. Raytheon predicts that the spacistor will work at 10,000 megacycles.

Electrons are supplied to the spacistor from an outside battery circuit. Therefore the current flow does not depend on the availability of mobile charges within the semiconductor, as it does in transistors. Raytheon scientists say this should make possible a wide choice of materials, including silicon carbide, which withstands higher temperatures than silicon or germanium.

A further claimed advantage is that practically no current is required from the signal that is to be amplified; it merely modulates the battery current. This means that spacistors can be used to amplify low-power signals such as electrical waves in the brain and other biological systems.

Live-Virus Polio Vaccine

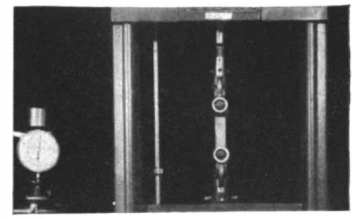
Although the Salk dead-virus vaccine seems to have cut polio cases in the U. S. to less than one third, the live-virus vaccines remain a live issue. An expert committee of the World Health Organization recently urged that they be tested on a large scale to determine whether they can produce long-lasting immunity and wipe out the disease organism. A killed-virus vaccine "is not able to achieve this kind of result," said the committee.

The immunity conferred by the Salk vaccine does not prevent virus from multiplying in the intestinal tract. Thus the germ can be passed from person to person in a disease-free population. If immunity wears off, the virus will be there to attack.

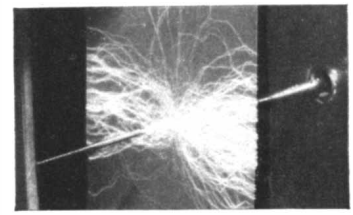
Live-virus vaccine, taken orally, is said to immunize the intestinal tract as natural infections do. This may mean that the immunity it produces is as long lasting. In any case it eliminates the virus's breeding ground. Some authorities are studying the advisability of giving live vaccine to populations already immunized with the Salk preparation.

One of the chief developers of a live-virus vaccine, Albert B. Sabin of the University of Cincinnati, says that tests "on tens or hundreds of thousands of individuals" are required "to establish whether such an orally administered vaccine is absolutely safe for an individual and a community." The possible

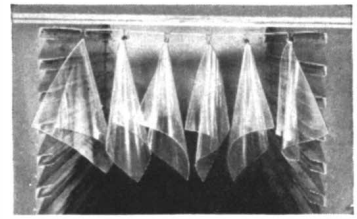
"MYLAR" *offers a unique combination of properties valuable for electrical design*



HIGH TENSILE STRENGTH. "Mylar" is the strongest plastic film. Instron tester shows an average strength of 20,000 lbs. psi.



HIGH DIELECTRIC STRENGTH. Average of 4,000 volts per mil . . . average power factor of 0.003 at 60 cycles . . . dielectric constant above 3.0 at 72°F., 1,000 cycles.



THERMAL STABILITY. Tests prove "Mylar" has an effective operating range, -80°F. to 300°F. . . . won't brittle with age.

TESTS BY REMINGTON RAND PROVE . . .

Du Pont MYLAR® provides greater reliability, longer life for capacitors used in Univac®

PROBLEM: The Remington Rand Division of the Sperry Rand Corp. had to find a capacitor of high reliability that could meet the requirements of extra-sensitive circuits found in UNIVAC* Data Automation Systems.

SOLUTION: In a series of accelerated tests by Remington Rand, various types of capacitors were exposed to conditions more exacting than those found in normal operation of UNIVAC Systems. These tests proved that capacitors made with "Mylar"† polyester film offered greater reliability and longer life, with an extra margin of safety in moisture resistance. The tests documented the fact that "Mylar" provides excellent insulation resistance at high temperatures . . . "Mylar" does not deteriorate with age or voltage stresses within normal operating ranges.

RESULTS: By using capacitors made with "Mylar", Remington Rand has improved the performance of another component in UNIVAC Systems . . . has helped improve the performance of UNIVAC Systems themselves.

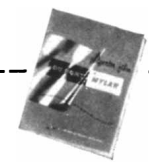
HOW CAN "MYLAR" HELP YOU? Whether you make guided missiles or tiny components, it will pay you to investigate the unique advantages of using "Mylar" film . . . or products made with "Mylar". Send for a copy of our new booklet containing detailed information on properties and applications.

DU PONT
REG. U. S. PAT. OFF

BETTER THINGS FOR BETTER LIVING
. . . THROUGH CHEMISTRY

DU PONT **MYLAR®** POLYESTER FILM

*UNIVAC *is a registered trademark of Sperry Rand Corporation.*
†"MYLAR" *is Du Pont's registered trademark for its brand of polyester film.*



E. I. du Pont de Nemours & Co. (Inc.)
Film Dept., Room S-9, Wilmington 98, Del.
Please send your booklet listing properties, applications and types of "Mylar" polyester film available (MB-11).

Application_____
Name_____ Title_____
Company_____
Address_____
City_____ State_____

dangers are twofold: (1) the vaccine may cause disease in the persons who receive it, (2) the "attenuated" or harmless virus used in the vaccine may mutate as it breeds in the vaccinated individual, who may then pass it on to others in a more virulent form. In a paper in *The Journal of the American Medical Association* Sabin explains that virus excreted by vaccinated test subjects has proved slightly more effective in attacking monkey nerve tissues than the virus used in the vaccine. He believes, however, that the altered virus would still be harmless to human beings.

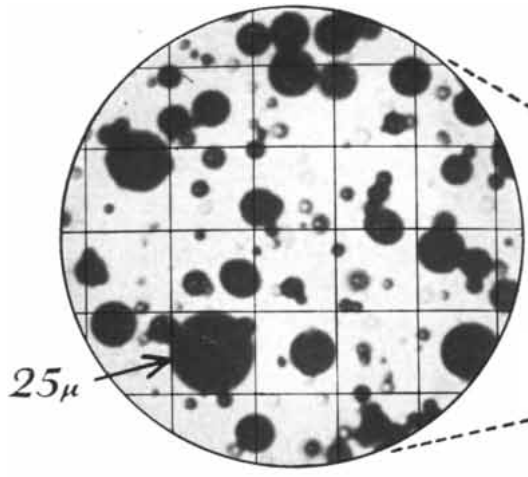
Sabin has tested his vaccine on 243 subjects, "all without harmful effects." Other investigators, including Hilary Koprowski of the Wistar Institute, also have used live-virus vaccines without mishap.

Live Fossil Mollusk

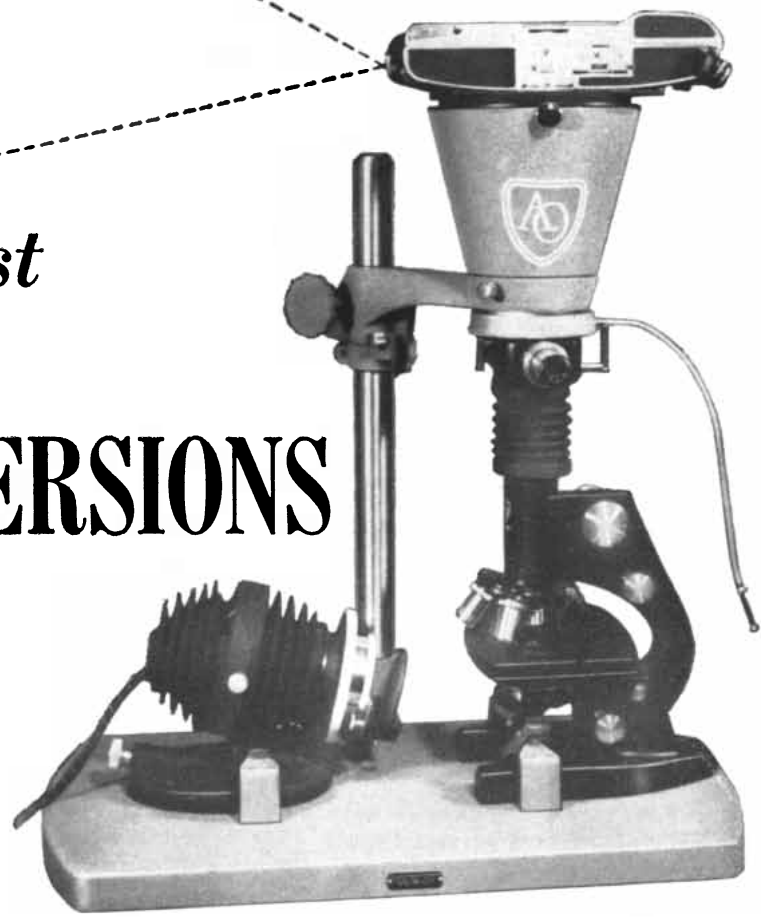
An extraordinary upside-down mollusk 280 million years behind the times has been dredged up off the coast of Mexico. The living fossil is described in a recent issue of *Nature* by Henning Lemche, one of the Danish zoologists analyzing the material from the sea's depths gathered by the *Galathea* expedition. Ten living specimens and three shells of the inch-long animal, named *Neopilina galatheae*, were part of a rich haul brought up May 6, 1952, from more than two miles under the sea.

The mollusk, which has a fragile shell somewhat like a limpet shell, is unlike any modern type. According to Lemche, the shellfish probably lies on its back and uses its weak foot and feathery appendages to obtain food from the water. The stomach contents of the specimens found indicated that tiny one-celled radiolarians formed the staple of their diet. Neopilina's body is divided into five segments, each with a pair of gills, excretory organs and other internal structures. This segmentation violates the general criterion that mollusks are unsegmented. Some fossil relatives of the living form evidently had six or more segments and may well have been the link between arthropods and segmented worms. Lemche conjectures that Neopilina itself might represent a link between single-footed shellfish and the many-legged mollusks such as squid.

Bentley Glass of Johns Hopkins University considers the antique mollusk a more amazing find than the coelacanth, the living-fossil fish [see "The Coelacanth" by Jacques Millot; SCIENTIFIC AMERICAN, December, 1955]. He points out in *Science* that the new-found mol-



Here's the *latest* on Lithium METAL DISPERSIONS



Microscope and Illuminator by American Optical Company, Instrument Division, Buffalo, New York. Polaroid® Land Camera by Polaroid Corporation, Cambridge, Massachusetts.

Got a catalyst problem?

Interest sparked by the discovery that lithium metal dispersions make unique polymerization catalysts (the polymerization of isoprene to a "natural" rubber) indicates a heretofore unexploited instrument of research.

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lusk represents a much older class which was already on the road to extinction "when the coelacanths were just beginning to branch off as a special side-group of the other lobe-finned fishes."

Battle of Jericho

A spirited, if decorous, battle was recently fought in the pages of the British journal *Antiquity*. It concerns the rival claims of two archaeologists to discovery of the oldest center of civilization. Kathleen M. Kenyon, director of the British School of Archaeology in Jerusalem, maintains that the most ancient town so far unearthed is at Jericho, while Robert J. Braidwood of the University of Chicago holds that a village at Jarmo in Iraq is older [see "From Cave to Village," by Braidwood; SCIENTIFIC AMERICAN, October, 1952; and "Ancient Jericho," by Kenyon; April, 1954].

Miss Kenyon, excavating a great mound at Jericho, found houses and fortifications far below the walls that Joshua's Israelites are alleged to have toppled with their shouts. By radiocarbon dating she estimated the time to have been before 7000 B.C.

In a long letter to *Antiquity*, Braidwood defended his own previous claim that the earliest villages arose in the Tigris-Euphrates region around 5000 B.C. He began wryly: "People have begun looking at me—as the excavator of Jarmo—with that look which I suppose is usually reserved for bridegrooms left waiting at the church. My reaction, both in terms of what I know of the comparative archaeology of the Near East and of cultural process in general is—in pure Americanese—that it doesn't figure!" Braidwood questioned the radiocarbon dates for ancient Jericho, doubted that an oasis was a likely site for the earliest civilization, took issue with Miss Kenyon's definition of civilization and argued that the Jericho excavation showed only "an incipient town in a somewhat marginal region." He contended that agriculture and a civilized way of life were more likely to have originated on rainy slopes like those near Jarmo.

Miss Kenyon, in reply, remarked that Professor Braidwood "was suffering from jaundice when he visited Jericho," that his arguments about the dates were based on misconceptions about the evidence, that at the time of his visit "we had not made our most exciting discoveries" and that even if the correct date was about the same as that of Jarmo, "an incipient town of 5000 B.C. would still be a remarkable development."

How to cope with an avalanche of urgent data

Tape keeps ballistic missile tests in manageable form

Four of the twenty-four Ampex FR-100 Tape Transports at the General Electric Missile and Ordnance Systems Department facility in Philadelphia.

Nobody intends to get buried, drowned, suffocated or trampled as the floodgates open on one of the biggest of all data-acquisition programs. For its ballistic missile development contracts, General Electric's Missile and Ordnance Systems Department has installed a data-processing and computation center to match the challenge.

A PREFERENCE FOR TAPE

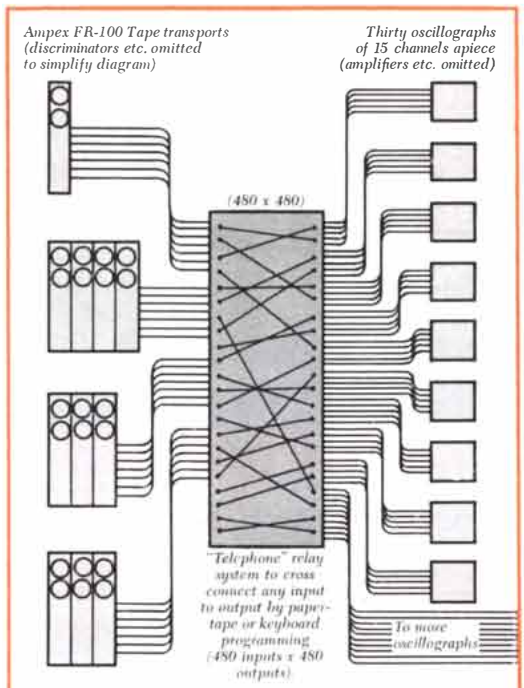
Of the test information received, about 90 percent will be on tape. Two facts about magnetic tape recording help keep the sheer mass of information under control: (1) hundreds of simultaneous parameters are recorded on one tape with a common time base; (2) tape gives live electrical voltages, hence reducing, correlating, computing and handling steps can be done automatically. General Electric's goal is to provide all interested engineering groups with both analog and computed data within three days of receipt of raw tapes.

Tapes from flight test, ground test and component development will be received from sources all over the U.S. These tapes will include quarter, half and one-inch widths. Hence most "tape stations" in the data-reduction system will have three Ampex FR-100 tape transports for the three widths. They will share electronics.

NOVEL USE OF A TELEPHONE TECHNIQUE

The right data must get to each of a large number of research and design groups. No traffic snarls allowed – so General Electric's engineers have made ingenious use of taped data's electrical form. They use a "telephone central station." After the necessary conversion steps, hundreds of channels of data from magnetic tape are fed into an automatic relay switching system. This connects them into 450 channels of oscillographic writeout (30 oscillographs with 15 channels apiece). When desired one input can go through a multiple relay putting the same data trace on two or more of the oscillograph records. Programming is done by a carefully checked paper tape. The end result is visual traces in a desired side-by-side relation. And each oscillograph record contains the data of interest to particular engineering groups.

Magnetic tape comes to life again in computation. The visual records are marked wherever special computer effort is required. Another group



"Telephone" relay switching system from magnetic-tape data to oscillographic writeout.

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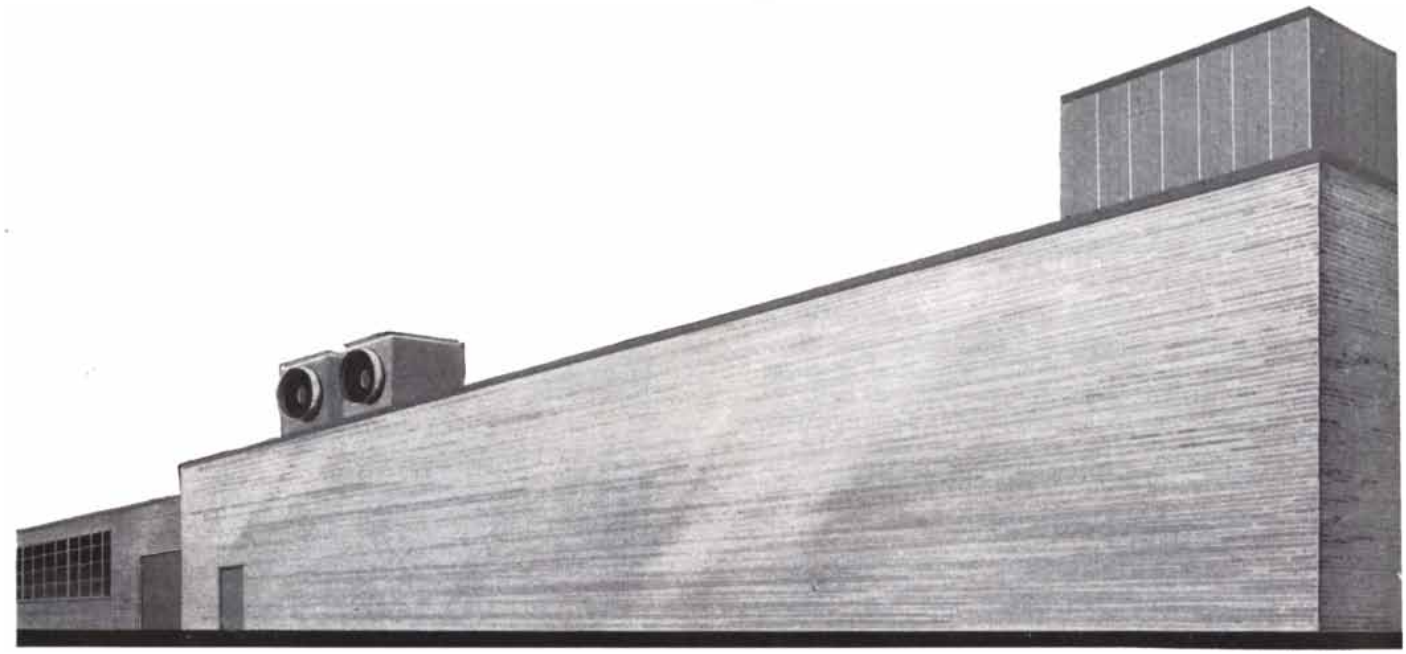
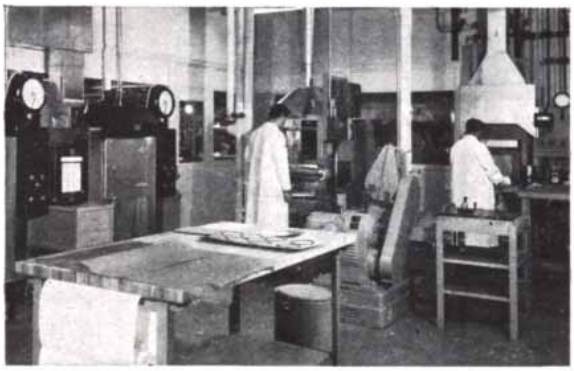


C/R's new Special Elastomer Section at Elgin, Illinois—just recently completed—was created to meet increasingly critical specifications for molded synthetic parts in guided missiles, jet aircraft, automobiles and industrial machines and equipment. There is no other comparable laboratory and production unit in the country.

The latest modern electronic equipment has been installed to assure precise control over temperature, air pressure, humidity and other physical factors that might affect product purity. This plant is virtually dust-free.

The new plant is specialized in the production of custom molded parts from Silicones, Kel-F Elastomers, the fluoro rubbers and Teflon*. Resistance to fuming nitric acid, resistance to temperatures of 600° F., or operation at – 400° F., and low coefficients of friction are just a few of the many special properties now available through these special materials.

To insure rigid, quality-control production under laboratory conditions, the plant was constructed *around* the laboratory. The entire manufacturing process, from origi-



Ovens, mill and press in the Laboratory Section. The entire production of Sirvene parts — from original research to final inspections—is in effect a laboratory process. From the original mixing, through the molding and forming processes and in all final tests, each step is scientifically controlled by Sirvene engineers.

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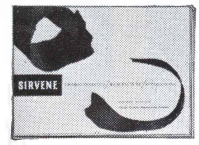

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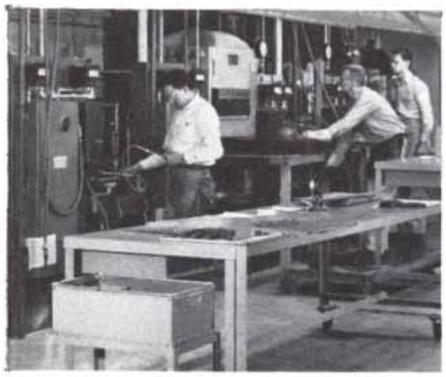

The Elastomer Section presses. Molds made with the greatest accuracy are placed into these automatically controlled curing presses. Here, the Sirvene part is then formed and cured for the pre-determined time and temperature.

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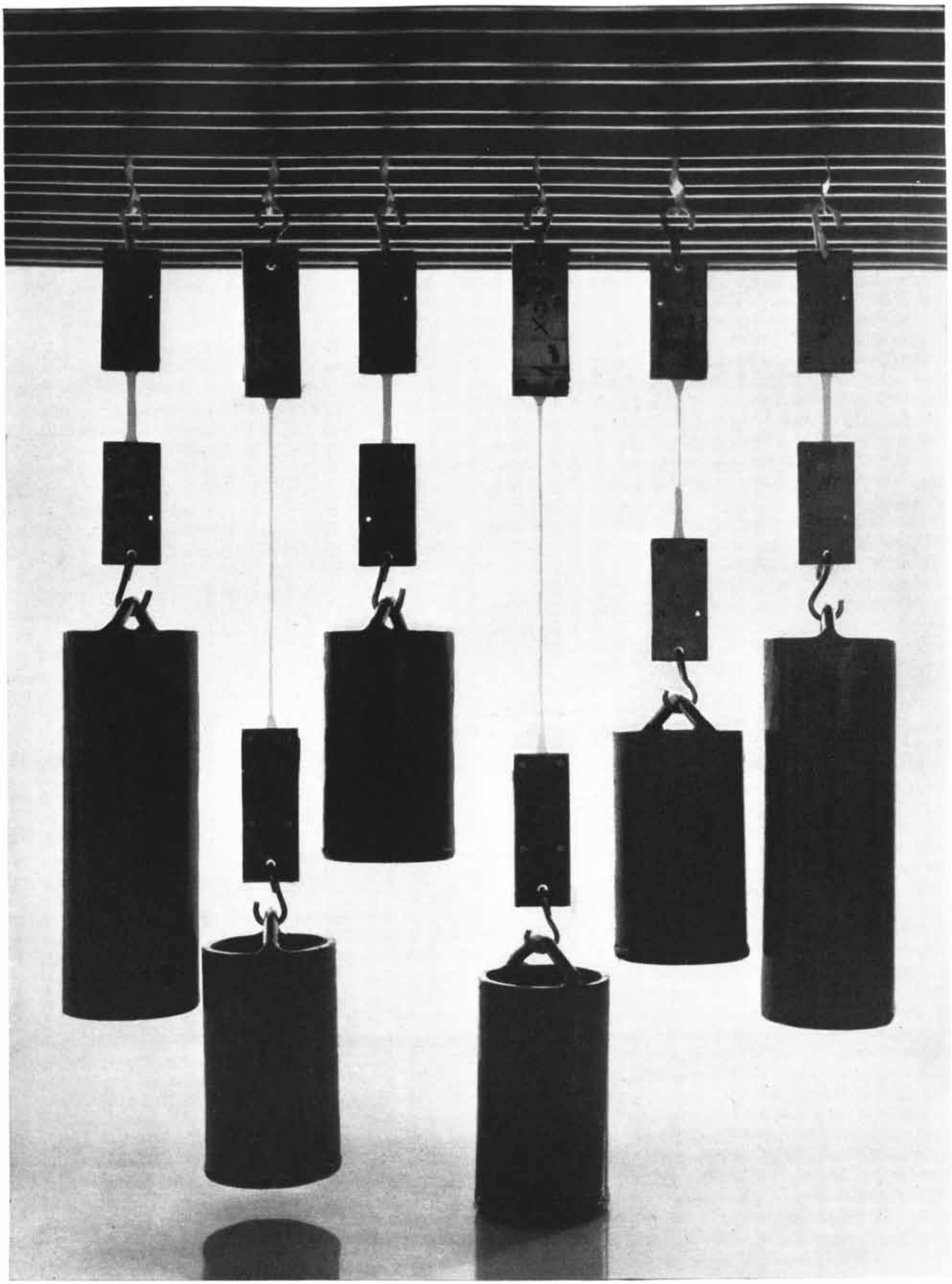


DEAD-LOAD CREEP TEST at the laboratories of the Phillips Chemical Company compares the long-term load-bearing properties of polyethylenes and copolymers containing polyethylene. Creep is the tendency of all materials to yield and extend under prolonged strain. It is inherent in the molecular structure of polymers, and is corrected in part by crystallization and cross-linking.

The Mechanical Properties of Polymers

Solid polymer materials may be glassy, leathery or rubbery. These qualities can be explained in terms of the structure of polymer molecules and how they are organized in solids

by Arthur V. Tobolsky

The products made of giant molecules—rubbers, fibers, films, foams, glues, plastics of all kinds—display a bewildering variety and range of physical properties. They are variously hard or soft, stiff or supple, brittle or tough, leathery or rubbery, glassy or crystalline, meltable or nonmeltable. Obviously this diversity of properties reflects a great variety in the construction of the molecules themselves and the way they are organized in the macroscopic aggregations in which we use them. Just how are the properties of the materials related to their molecular structure? Can we find any system in all this multiplicity of aspects which the giant molecules present to us, any principles that will explain why a given molecular structure endows a substance with the particular qualities it exhibits? As Herman F. Mark points out in his introductory article [*see page 80*], considerable progress has been made in this scientific quest during the past two decades, so that we now understand the principles well enough to begin to create deliberately tailor-made molecules bearing properties we desire.

The polymers fall into two general classes: (1) completely amorphous and (2) partly crystalline (regular) in structure. Let us consider the fully amorphous group first. Amorphousness of structure is common to all polymers and, next to the size of their molecules, is their most important family trait. The molecular chains in an amorphous polymer are coiled together in a disordered tangle, like a bowl of cooked spaghetti, except that the giant molecules are relatively much longer and tend to coil and intertwine with one another in more erratic configurations. In their internal disorder amorphous polymers resemble liquids more than they do solids. As a result, even the most solid-seeming amorphous polymer acts in some ways like a liquid. Under special circumstances, some polymers can even be said to behave like gases. In sum, these materials fit none of the three classical states of matter. The amorphous polymer represents a distinct, fourth state of matter in itself.

We employ amorphous polymers in many different forms. They range from rubber to artificial leather to polystyrene (used in children's toys, kitchen utensils, etc.) to polymethyl methacrylate (airplane windows). That is to say, the amorphous polymers comprise glassy, leathery and rubbery materials. However, the apparent differences among these materials represent simply their different states at room temperature. Any of them can become glassy, leathery or rubbery, depending on the temperature. Rubber will shatter like glass if it is frozen quickly to about 160 degrees below zero Fahrenheit. The glassy plastics turn leathery and then rubbery upon overheating; they are even known, alas, to "melt" down to a viscous liquid.

An amorphous polymer goes through the transition from the glassy to the rubbery state within a range of about 80 degrees on the Fahrenheit scale. Each polymer has its own characteristic "glass transition" temperature—at which it changes from the glassy to the leathery state. This depends upon the architecture of the molecule and the energy binding aggregations of the molecule together. Rubber unfreezes from the brittle to the flexible state at a comparatively low temperature because its molecule is inherently limber, rotating freely around each carbon link, and because the molecules are only weakly held together. On the other hand a polymer made up of inherently stiff molecules, or molecules strongly held together at places along the chains, will leave the glassy state only at a relatively high temperature.

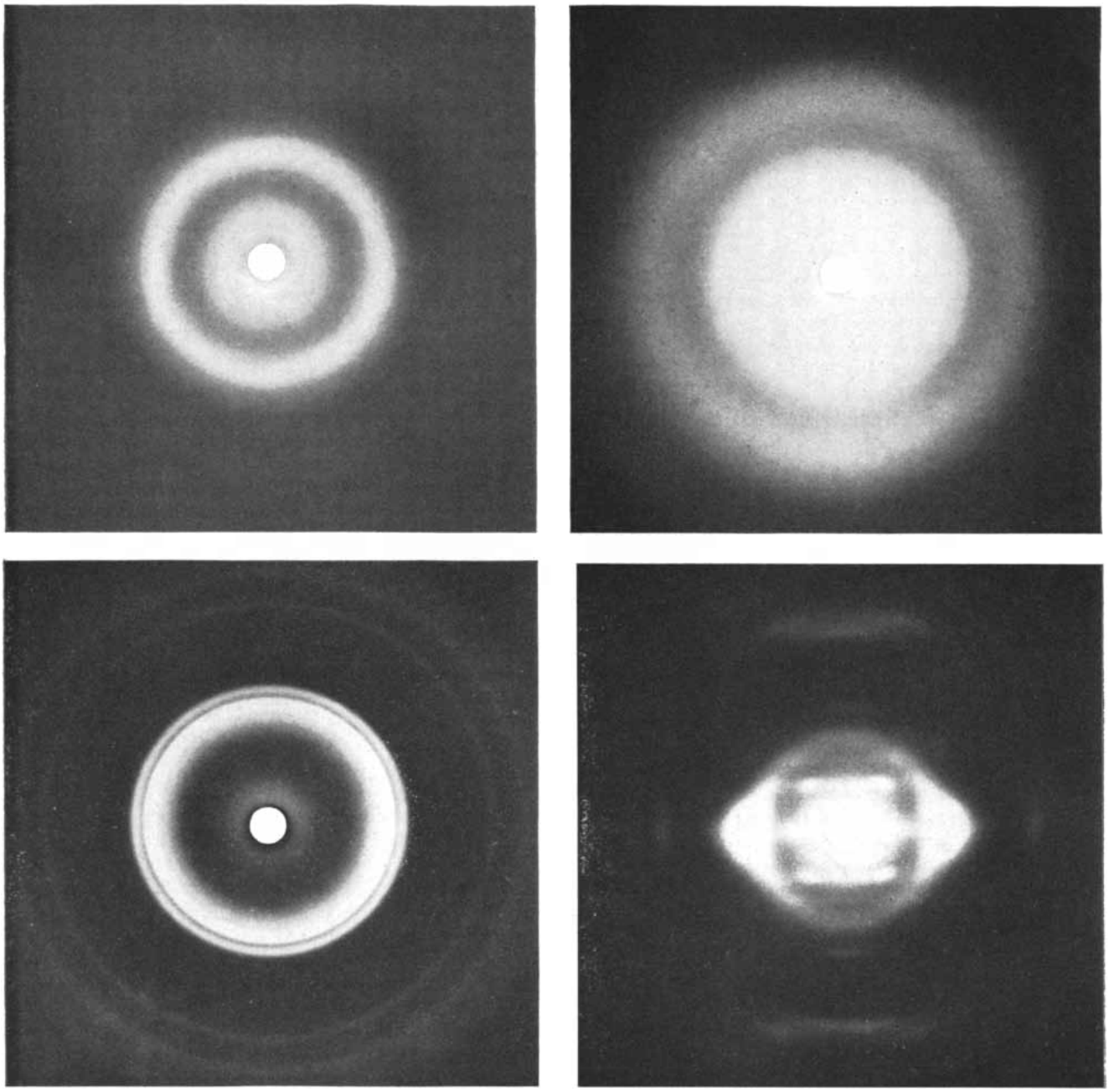
A polymer in the glassy state can be described as a "supercooled liquid" (as can glass itself). Its long chain molecules lie quiet, frozen in their random configurations. In this condition the molecules' atomic groups behave much like the atoms in a crystal lattice: each group vibrates about a certain mean position, embedded in the irregular arrangement set up by the tangle of long molecules. This structure is a respectable enough solid. It has approximately the same resistance to deformation, or modulus of elasticity, that a crystal has. The atomic groups are held together by forces similar to those that bind the atoms in a crystal, and it takes force to push them apart. Glassy polymers resist deformation with a force of about 150,000 to 600,000 pounds per square inch. The resistance of the crystals of steel is approximately 30 million pounds per square inch.

What happens when an amorphous polymer is warmed up and makes the transition from the glassy toward the rubbery state? Events are very different from those that transpire in crystals or even in glass when they are heated. The atoms in a crystal oscillate around their position with increasing agitation as the temperature goes up until they break the bonds holding them in the lattice arrangement; the material then passes abruptly from the solid to the liquid state. Glass, with its amorphous molecular structure, is really an inorganic three-dimensional polymer. It is transformed gradually over a wide temperature range from a solid to a highly viscous liquid and flows by the rupture

and rearrangement of its tenacious silica bonds. On the other hand, when an organic amorphous polymer abandons the frozen state the molecular chains are aroused to disorderly thermal motions: the spaghetti comes alive, so to speak. As the material is warmed, segments of the molecules begin to move—at first short segments about half a dozen atoms in length, then longer ones. They move with the same sort of random Brownian motion that diffuses atoms in a liquid. The segments are restrained in their wandering, however, by cross-links and by centers of simple entanglement between the chains.

At the low end of the transition temperature range, when only the short segments are moving rapidly, the polymer is leathery—flexible but tough and resilient. It becomes less tough and more pliable as the temperature rises. If the material is highly polymerized (*i.e.*, if its molecules are very long) it will go into a phase of rubbery behavior. Here the entire free lengths of the molecules between cross-links and centers of entanglement are in rapid motion, twisting, writhing and rippling in every direction.

Although material in the rubbery state is stretchable, it still retains resistance to deformation. Its modulus of elasticity, however, depends upon forces entirely different from those in a glassy polymer. It is in the rubbery state that the behavior of a polymer may be likened to that of a gas. A gas resists compression because confinement in a smaller volume restricts the random, diffusional motion of the gas molecules. Similarly the stretching of rubber molecules restricts their random diffusional



X-RAY DIFFRACTION PATTERNS of four polymers are compared. To make such pictures, a sample of the polymer is placed in an X-ray beam perpendicular to the film. At top are patterns made by amorphous polystyrene (*left*) and amorphous polymethyl methacrylate (*right*); the patterns have no sharply defined bands. At bottom left is a pattern made by unoriented crystalline polyethylene; its bands are sharply defined. At bottom right is a pattern made by oriented crystalline nylon; it has spots as well as bands.

motions. In both cases we have reduced the entropy. The rubber molecules resist restriction of the randomness of their motion much as a swinging skip-rope resists reduction of the amplitude of its swing when its swingers try to pull it taut.

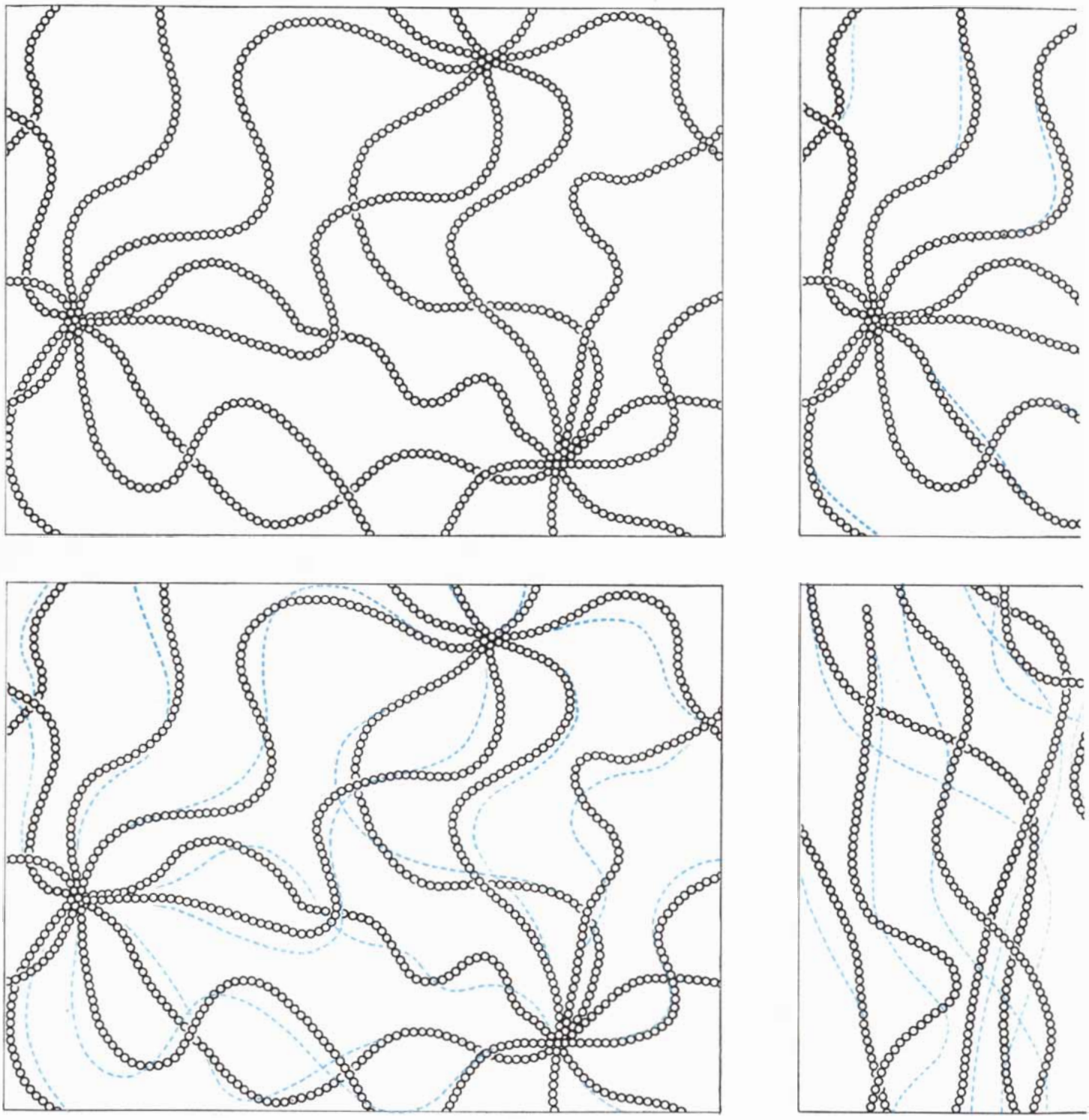
Experiments and common experience bear out this theoretical analogy between a gas and a rubbery polymer. When a gas is compressed, it heats up; similarly, rubber heats up when it is stretched, as anyone can confirm by touching a rubber band to his lips while stretching it. Conversely, the application of heat to a stretched rubber band increases the tension proportionately, just as heat will increase the pressure of the gas in a vessel.

When it is heated at last to a sufficiently high temperature, an amorphous polymer yields its shape and begins to flow like a liquid with a high viscosity. At this point entire molecules flow past one another. But the molten polymer is no ordinary liquid. The viscosity of ordinary liquids is the measure of the relative ease with which individual molecules slide past one another in their constant diffusional motion. In the polymer the unit of diffusional motion is not a single complete molecule but a segment of a long molecule. The flow of the molecule as a whole requires the cooperation of many segments. Viscosity in a polymer thus depends heavily on chain length or the degree of polymerization. This makes a problem for designers. Polymers are fabricated in the liquid state. The most important fabrication processes, injection molding and extrusion, are facilitated by low viscosity, or short chain length. On the other hand long chains make stronger polymers.

The tendency to liquid flow can be entirely suppressed if the somewhat nebulous centers of entanglement are replaced by chemical cross-links between the chains. This is what vulcanization accomplishes in rubber. The same effect can be achieved in rubber and other polymers by high-energy ionizing radiation, which knocks out hydrogens and cross-links the chains in direct carbon-carbon bonds. The resulting three-dimensional network will not flow unless the chemical bonds are actually ruptured. In a rubber band, where extensibility is desired, approximately one cross-link is established for every two hundred atoms along the chain. A very high degree of cross-linking produces a structure that makes no transition from the glassy state and remains

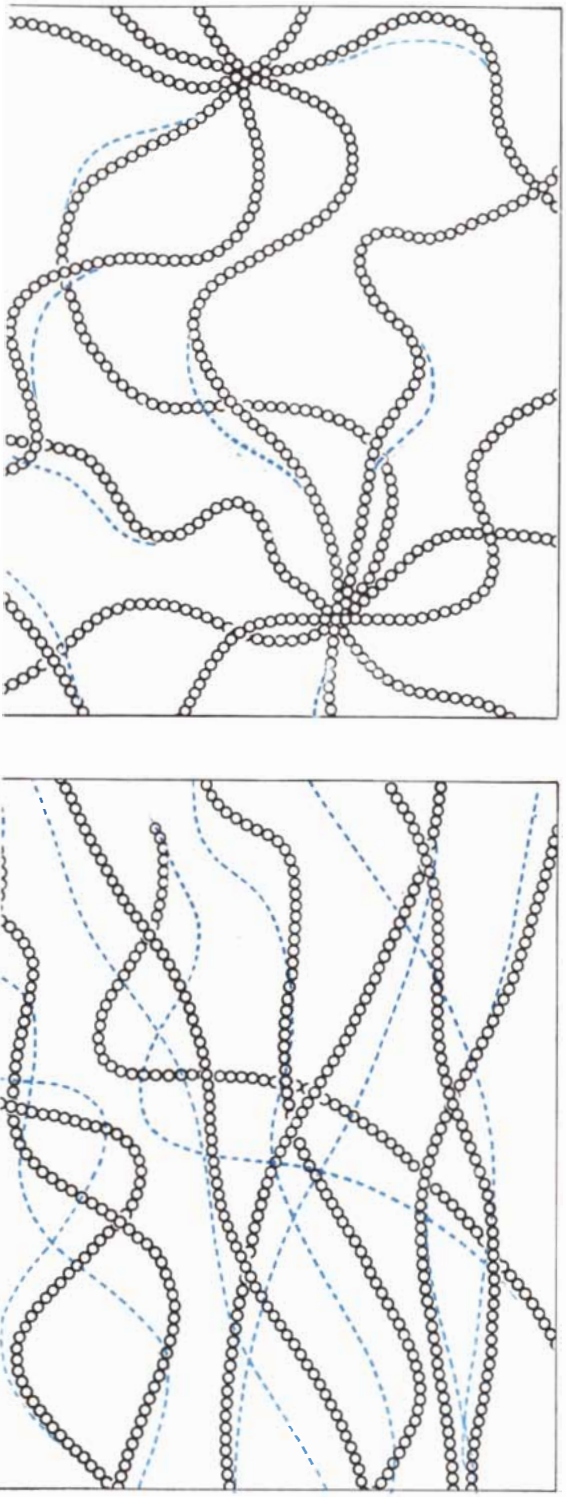
rigid and hard at all temperatures below that of actual chemical decomposition. This is the structure of the so-called thermosetting plastics, like Bakelite, which resemble glass in the completeness of their three-dimensional polymerization.

Polymers are not the only substances with dual personalities, behaving at once as solids and as liquids. No substance ever fulfills completely the theoretical specifications of either of these two states of matter. To qualify as an ideal solid with perfect elasticity, a substance would have to maintain its resistance indefinitely when subjected to a given stress. Even the strongest steels ultimately yield to stress and betray the fluid property of elongation called creep. All substances show a combination of elastic and fluid behavior that is termed viscoelasticity. Creep in crystalline substances takes place, however, along crystal interfaces and fault planes. In a



AMORPHOUS POLYMER is characterized by random arrangement and behavior of its molecules. In the glassy state (*top left*) the molecules are "frozen"; the atomic groups (*small circles*) oscillate like atoms in a crystal. In the leathery state (*top right*) short segments of the molecules go into random motion, like atoms in a liquid. Entire segments of molecules between centers of entangle-

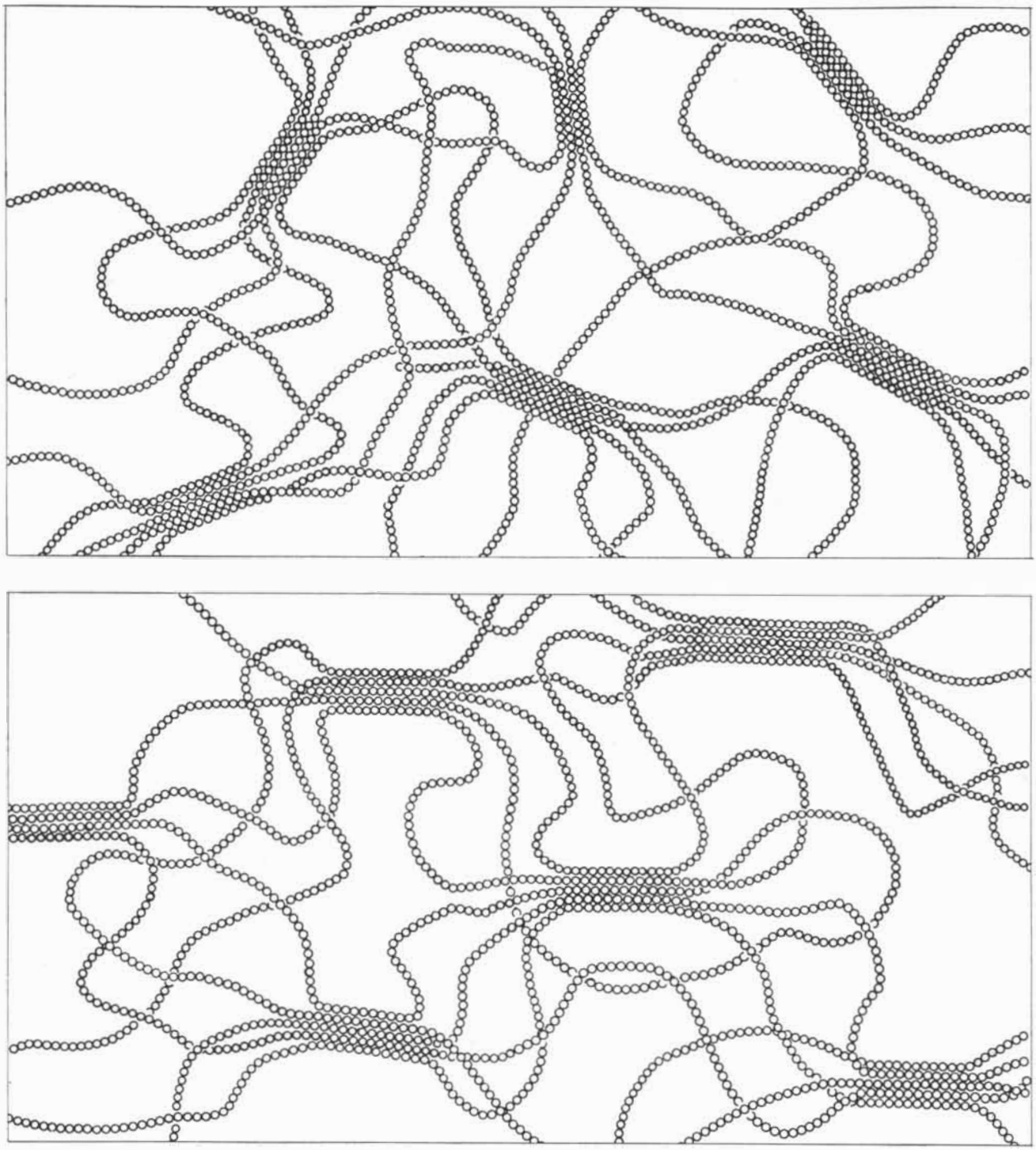
polymer creep is inherent in the very organization and behavior of its constituent molecules. This is one of the basic problems that must be taken into account in the design of polymers, especially for uses in which dimensional stability is a critical specification. Creep afflicts even highly cross-linked poly-



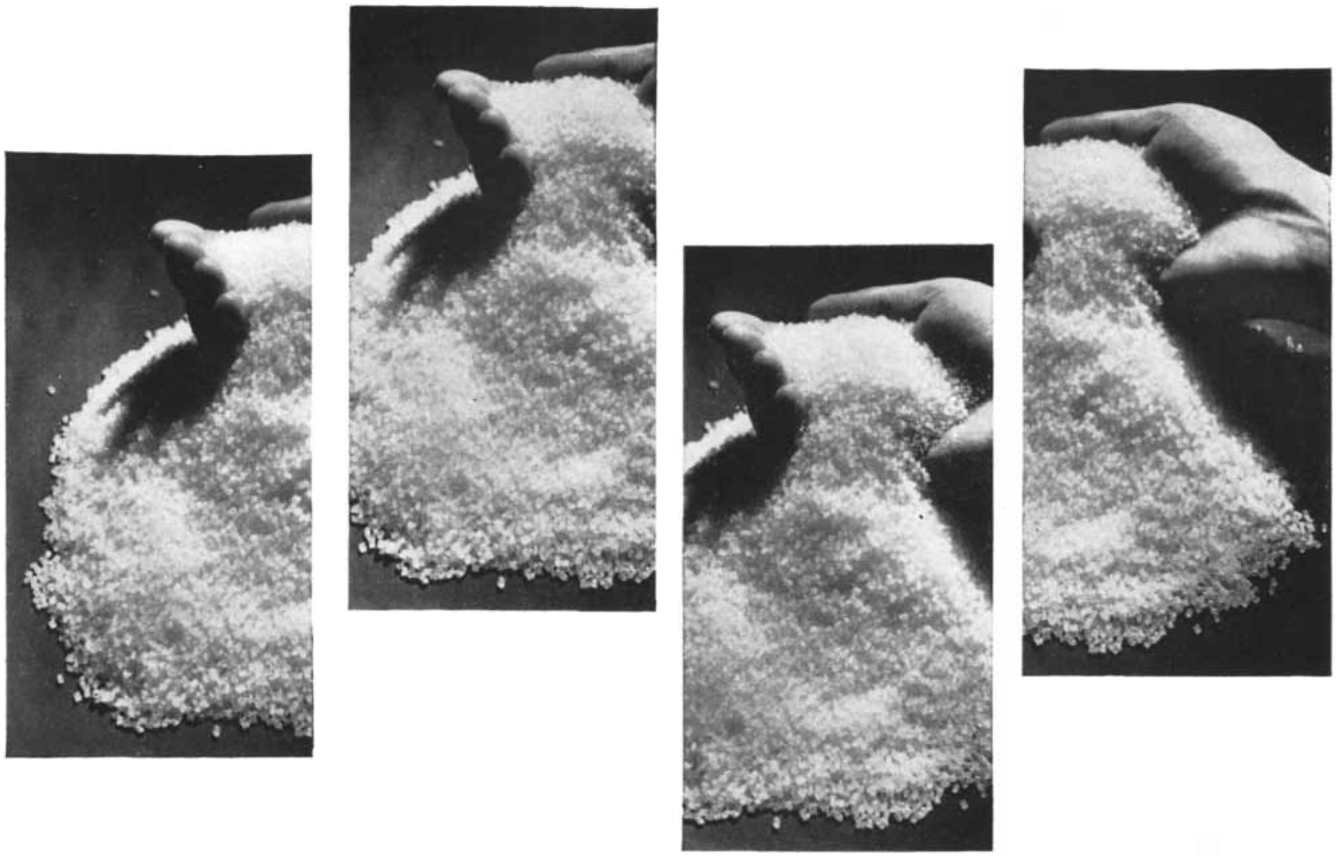
ment are in motion in the rubbery state (*bottom left*). In liquid-flow state (*bottom right*) molecules slide past one another.

mers, due to the instability of the chemical bonds. In our laboratory at Princeton University we have used the viscoelastic behavior of rubbers at high temperatures as a means to investigate the internal chemistry of polymer networks. Relaxation of stress in the material when it is held at constant length provides another sensitive indicator of bond rupture, bond interchange and the formation of new chemical bonds. A number of significant discoveries have been made by use of this simple technique.

Now let us look at the other class of polymers referred to at the beginning of this article—the partly crystalline. The crystals in these polymers are regions where short sections of adjoining chains happen to be lined up parallel to one another and form a regular three-dimensional lattice. The tiny crystallites, not much longer than a millionth of a centimeter, are detectable by X-ray diffraction, and sometimes groups of them are



CRYSTALLINE POLYMERS have tiny regions of crystal structure in which segments of molecules happen to fall together in a regular pattern. Atomic groups form strong bonds with one another. Some portions of each molecule are entangled with others in the amorphous regions between these crystallites; most of the molecules are involved in more than one crystallite. In the oriented crystal structure (*bottom*) the crystallites are lined up in the same direction. Their alignment concentrates their strength in that direction.



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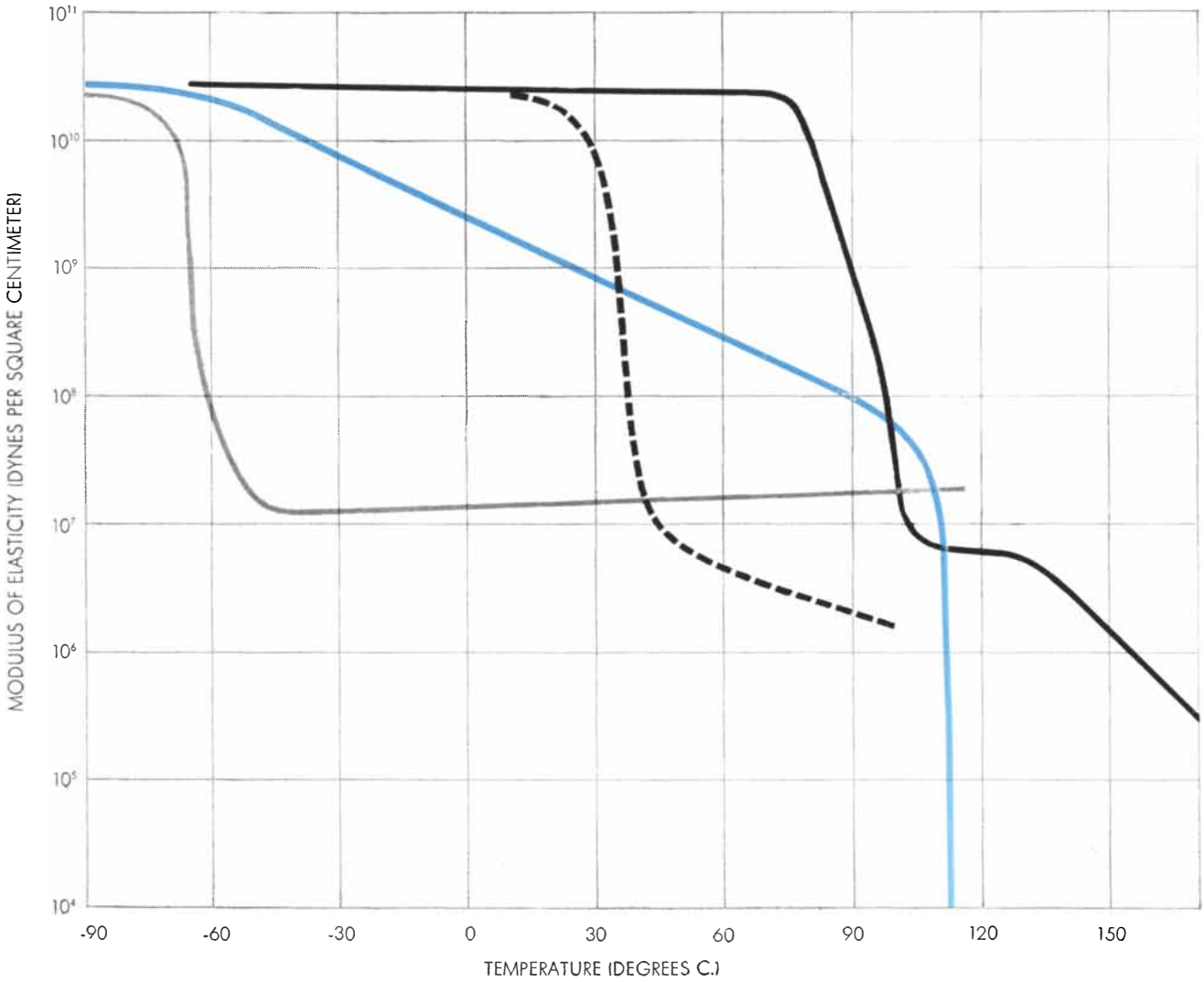
visible to the naked eye in polarized light [*see photograph on page 133*]. Some portions of every molecule in every crystal are tangled with segments of other molecules in the spaces between the crystals. These amorphous regions in the polymer serve as a kind of mortar to hold the crystals together.

We do not understand the behavior of crystalline polymers nearly so well as that of completely amorphous polymers, but certain principles are clear. A crystalline polymer has a glassy state which it abandons at a certain temperature. This change in its characteristics signifies the freeing of the molecular segments involved in amorphous parts of its structure. Unlike amorphous polymers, however, it does not become leathery or rubbery. It loses its brittleness but not its rigidity. The crystallites act like cross-links and suppress the tendency to creep in the same way. The rigidity of these polymers depends upon what percentage of their weight is crystalline. For example, polyethylene that is 80 per cent crystalline is considerably more rigid than a 50 per cent crystalline variety. (The more crystalline type is a new version of polyethylene made by the low-pressure method—see article on page 139.) For impact strength, however, some percentage of amorphous structure is desirable. The amorphous regions provide flexibility to absorb the shock of impact, while the crystallites provide strength.

Crystallites are most likely to occur in polymers whose chain molecules have a comparatively simple and symmetrical structure. The crystallinity of some polymers can be controlled by the method of polymerization. Thus polystyrene, normally amorphous because it has bulky phenyl side groups attached at random, can be produced in a highly crystalline form by means of catalysts which place all of the side groups at regular intervals on one side of the chain. Contrariwise, a crystalline polymer can be made less rigid by introducing a liquid which acts as a "plasticizer." For example, unplasticized polyvinyl chloride makes stiff piping; plasticized, it makes a flexible garden hose (except in cold weather!).

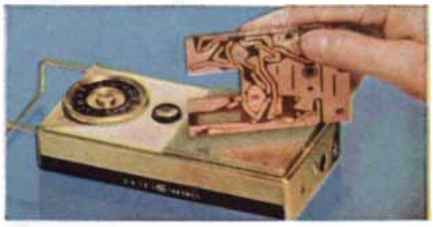
The crystalline polymers maintain



GLASSY TO RUBBERY TRANSITIONS of four polymers are compared. The curves are for the amorphous polymers rubber (*gray*), polyvinyl acetate (*broken black line*) and polystyrene (*solid black line*), and for crystalline polyethylene (*color*). At the top of their curves the polymers have the elastic modulus of the glassy state. In the sloping portions of their curves, the amorphous polymers go through a leathery phase, then enter a rubbery phase and terminate in decomposition (rubber) or liquid flow (polyvinyl acetate and polystyrene). Polyethylene softens gradually to the point at which its crystallites melt and the polymer goes into liquid flow.

"Plated wiring" for all types of circuits—from radios and TV to auto dashboard panels—is deposited on rows of boards like these in an automatic electroplating tank. Anaconda phosphorized-copper anodes, 42 inches long, hang from the busses.

Copper plating replaces wiring in the new small radios



One of G.E.'s smallest all-transistor pocket radios and the midget circuit board with its "plated wiring."

THE PROBLEM: From pocket radios to intercontinental missile controls, the trend is toward *miniaturization*. And one big space-saving help has been the substitution of wafer-thin "printed" circuits for the familiar maze of wiring.

To make these printed circuits by the million, General Electric developed a new automatic system for electroplating the "wiring" on circuit boards. The advantages: Copper can be plated simultaneously on both sides of the board and *inside* the holes. This provides ready-made plug-in connections for parts and, where desired, continuity between circuits.

G.E. prints the wiring diagrams in microscopically thin silver on circuit boards. These pass, thousands at a time, through a 75-foot-long automatic acid-copper plating tank. The copper "wiring" builds up on the silver.

This system calls for copper anodes with superior "throwing power"—even to plate copper inside the holes—and for the least possible interruption for cleaning the tank and correcting the solution.

THE ANSWER: Anaconda's "Plus-4" (Phosphorized Copper) Anodes meet all requirements. The small but precisely controlled amount of phosphorus practically eliminates sludge and copper build-up in solution; helps give the dense, smooth, uniform copper deposit needed.

THE FUTURE: In electrotyping, electroplating, and the rapidly growing business of electroforming, Anaconda "Plus-4" Anodes are helping industry save money, improve products. They illustrate how Anaconda and its manufacturing companies—The American Brass Company and Anaconda Wire & Cable Company—constantly seek better ways of doing things with nonferrous metals and products. For assistance in your special problem, see the *Man from Anaconda*. The Anaconda Company, 25 Broadway, New York 4, N. Y. 57257

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Phillips New Rigid POLYETHYLENE

IMAGINATION HEADQUARTERS

New Sales Service Laboratory

This recently completed laboratory is located at Phillips Research Center, Bartlesville, Oklahoma. Standard production-line machines are backed by a full range of evaluation and research laboratories. Here, scientists and engineers work full time on new product ideas and to develop processing techniques for the hundreds of companies that will convert Marlex 50 into plastic articles. This comprehensive service is available to all plastics processors interested in Marlex 50 polyethylene. Get in touch with your District Sales Office listed below.

MARLEX 50 for film—Outstanding protection because of low permeability and high abrasion resistance. Food can be cooked . . . medical supplies can be sterilized in sealed Marlex packages. Marlex is odorless. It safeguards flavors and fragrances.

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A Subsidiary of Phillips Petroleum Company, Bartlesville, Oklahoma

Plastics Technology

MARLEX* 50

Now Available in Commercial Quantities

MARLEX 50 is the new kind of plastic that is tougher, stronger and more rigid than any commercial polyethylene yet available. Many new and better products can be marketed because of the unique properties of MARLEX 50. Its greater resistance to temperature extremes and chemical attack, lower permeability to liquids and gases, greater rigidity and other unusual properties offer a whole new field of profitable applications for plastics processors everywhere.

Manufacturing economies are yours through the greater strength, toughness and rigidity of MARLEX 50 and its ability to set up at higher temperatures. You can get up to 40% more items per pound of resin. You may get up to 25% faster cycle time, too. Here's a new kind of plastic to help you produce better products more profitably. MARLEX can decrease your costs by replacing more expensive materials. Call your MARLEX sales representative today.

*MARLEX is a trademark for Phillips family of olefin polymers.

MARLEX 50 for injection molding—Rich colors, glossy surfaces, fine details! Marlex 50 moldings withstand up to 250°F without losing shape . . . endure temperatures far below zero without losing toughness and pliability. Ideal for accurate vacuum moldings.

MARLEX 50 for fabrics—Easily processed into fabrics and rope with high tenacity and low elongation. Exceptional oil and chemical resistance. Withstands boiling soapy water, dry cleaning solvents, and prolonged exposure to sun and weather.

MARLEX 50 for blow molding—Rigid, tough, pure! Conforms intimately to mold surfaces. Remarkable resistance to chemicals and heat. Can be sterilized repeatedly. Excellent for bottling foods, drugs, chemicals, oils. Use Marlex 50 for caps and closures, too.

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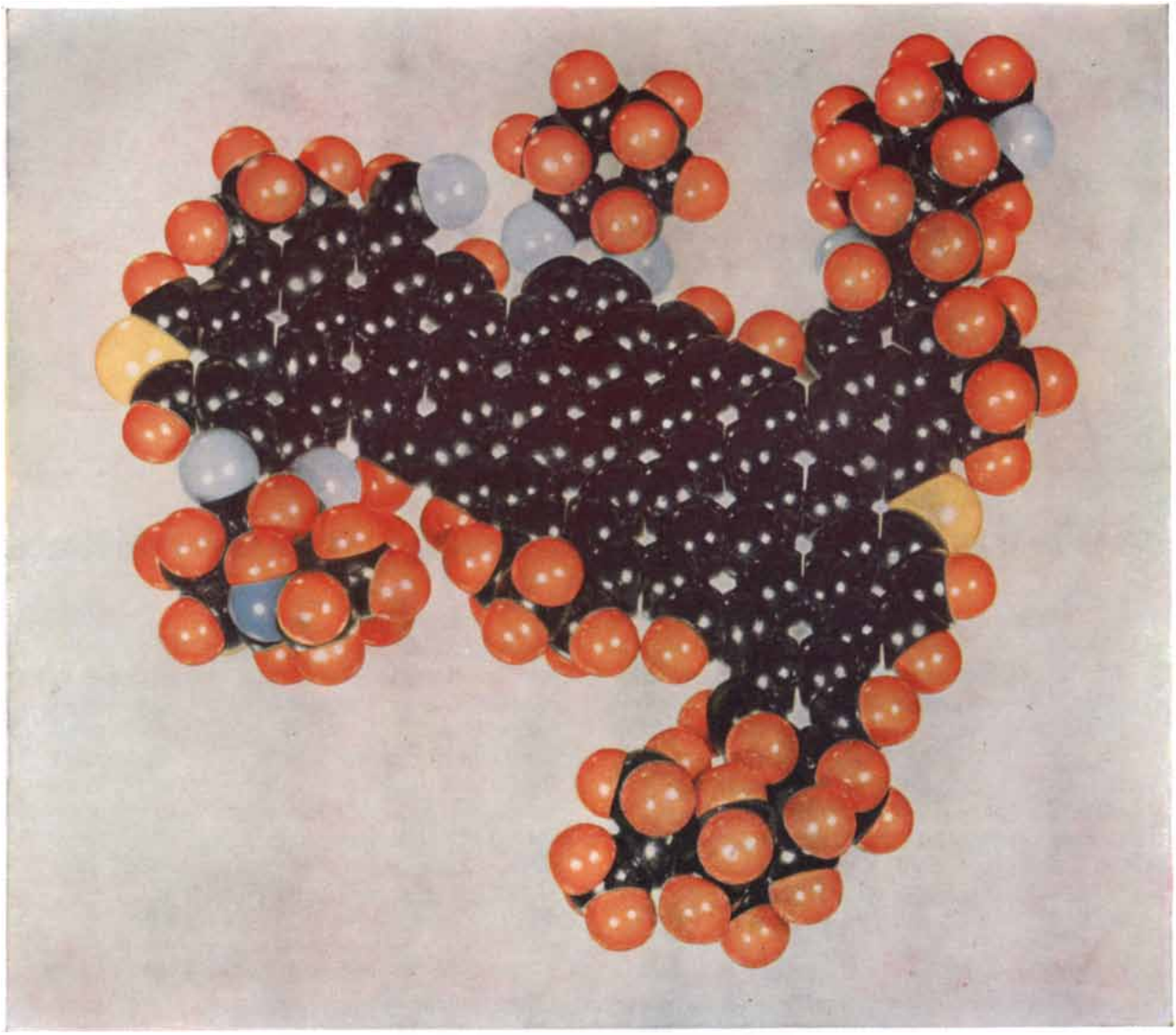


The general configuration of the coal molecule, if such a thing really exists, is believed to be of the type shown above. The black balls represent carbon atoms; the light blue, oxygen; the orange, hydrogen; the dark blue, nitrogen; the yellow, sulfur.

Meet the molecular mother of 200,000 useful products

FROM THIS COMPLEX of carbon, oxygen, hydrogen, nitrogen, and sulfur—which we call *coal*—come many of the basic chemicals used to make the new giant molecules. Plastics, synthetic rubber, synthetic fibers, resins, and a host of other important products—more than 200,000 in all—start with coal.

Over 200,000 products made from coal! Yet only a fraction of the 1900 chemicals obtainable from coal are now being used commercially! That is why United States Steel and other producers of coal chemicals are intensively studying coal, its structure, and its future potential as a source of basic chemicals.

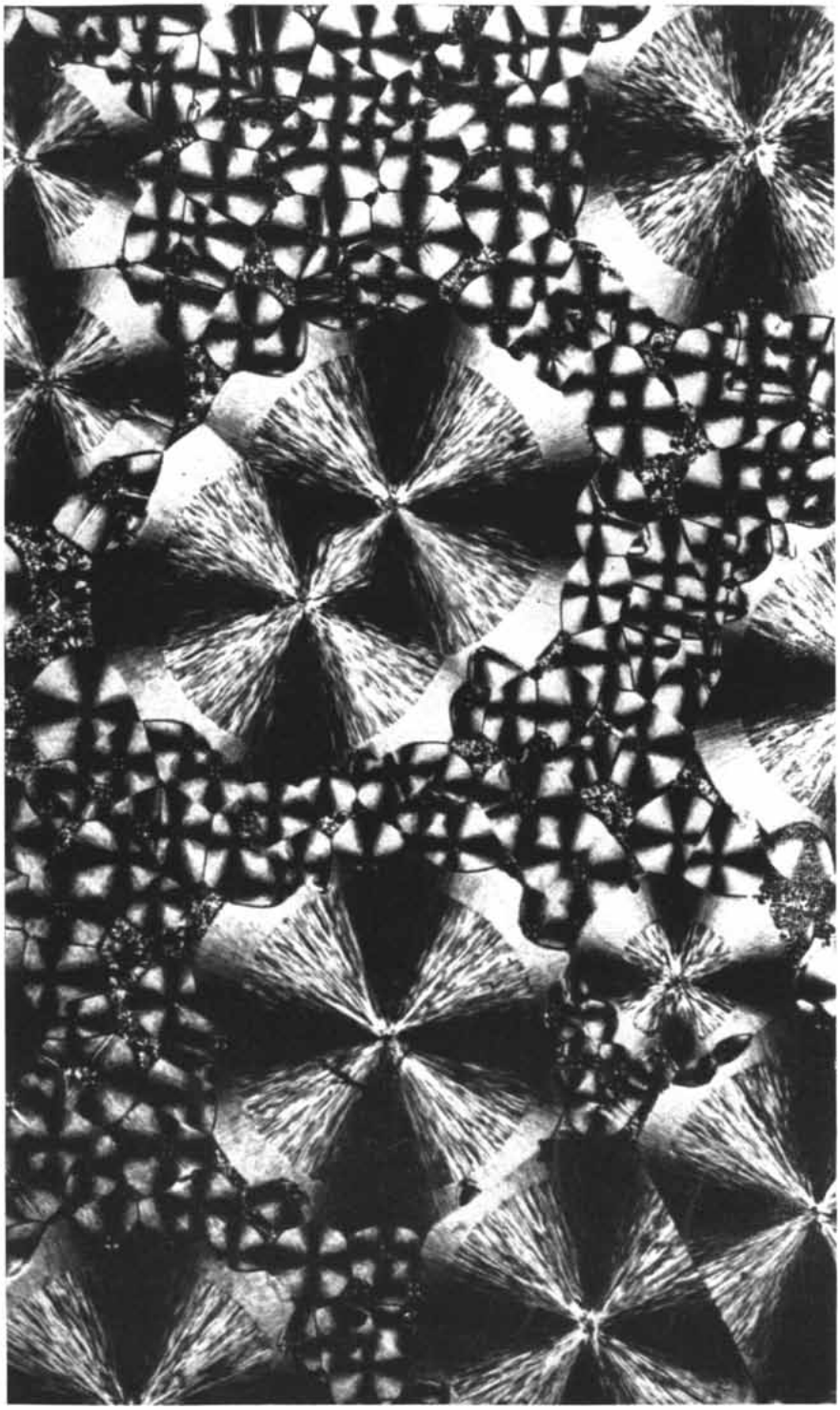
Why, you may ask, are we so interested in chemicals when our principal business is steel? The reason is that in producing coke for our steelmaking operations, we also produce chemicals. Thus we are always interested in anything that will help to advance the technology of these related products, improve their quality, and in general reduce the overall cost of manufacture and provide better products and better service for our customers.

That is why we are so interested in giant molecules—especially the giant *coal* molecule. United States Steel, 525 William Penn Place, Pittsburgh 30, Pennsylvania.

USS

UNITED STATES STEEL

their rigidity over a temperature span of perhaps 200 degrees F. above the glass transition point. The percentage of crystallinity tends to decline as the temperature rises. Then, at a certain critical temperature, all of the crystallites melt and the polymer goes rather abruptly into liquid flow. In general, crystalline polymers have higher temperatures of liquid flow than amorphous polymers. Thus the melting point of a new crystalline polystyrene made with the aid of catalysts [*see article on page 98*] is considerably higher than that of the familiar amorphous polystyrene. The temperature interval between the glassy and liquid-flow states is considerably wider in the more crystalline variety, for both



CRYSTAL STRUCTURE of an experimental polymer made at the General Electric Research Laboratory creates this pattern in polarized light. Each center in the pattern represents a cluster of crystallites. Amorphous structure occurs within centers and between them.

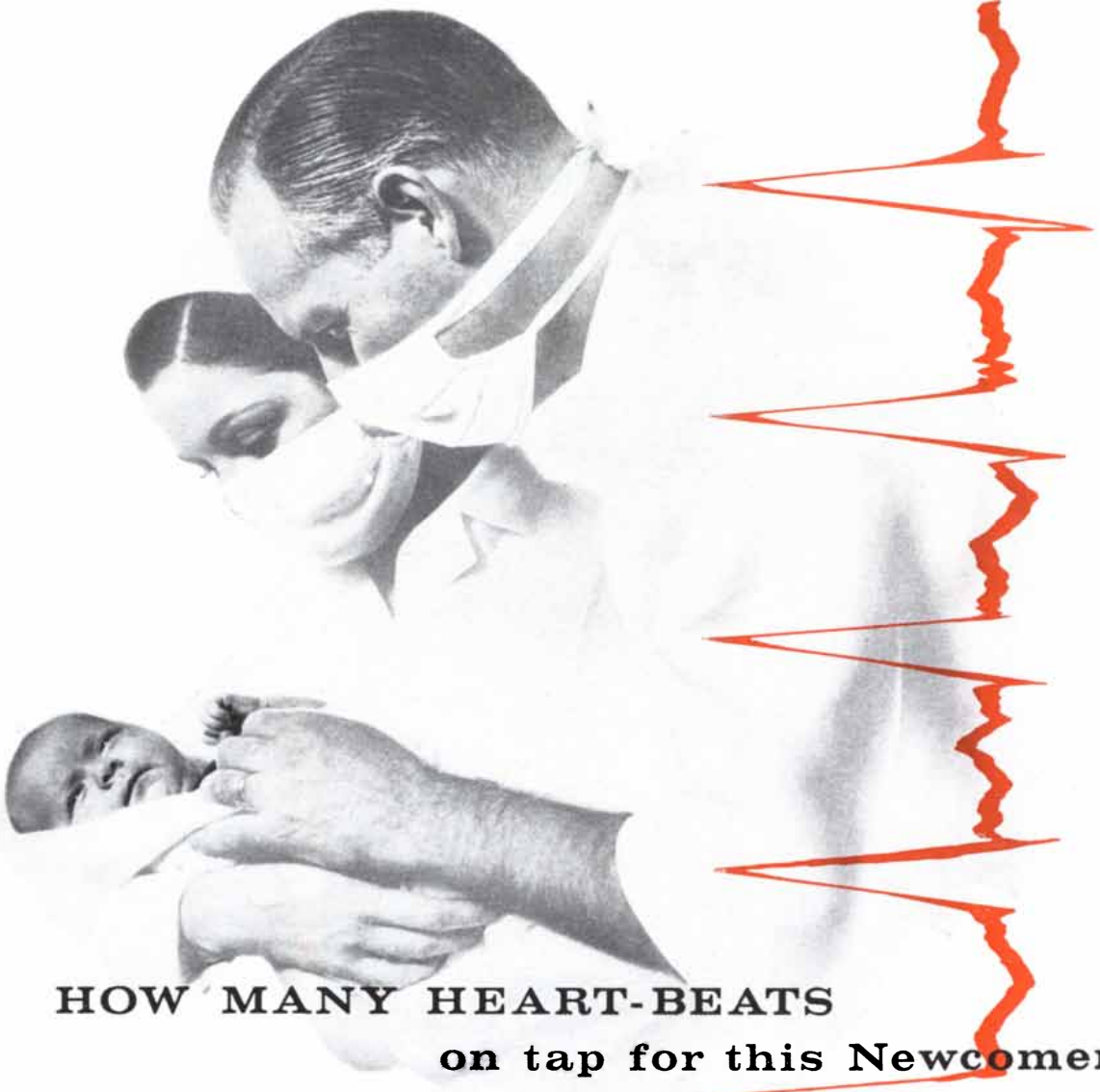
polystyrenes have the same glass transition temperature—namely, about 195 degrees F.

In crystalline polymers the molecules may be unoriented (disposed in random directions) or highly oriented, as in a fiber. Nature produces oriented polymers in the form of cotton, wool and silk fibers. The orientation gives these substances great tensile strength. The same kind of structure gives synthetic fibers their even greater strength, comparable to that of steel. Machines spin these fibers by extruding the polymers as threads and stretching the threads in one direction to orient the molecules. A crystalline polymer can also be oriented in two directions to form a strong film. For example, a polyester polymer (polyethylene terephthalate) can be spun into Dacron fibers or rolled into Mylar sheets.

Natural rubber, ordinarily amorphous at room temperature, becomes oriented and crystalline when stretched. This accounts for its great tensile strength. Most synthetic rubbers, on the other hand, lack this property and need fillers, such as fine particles of carbon black, as reinforcement.

To sum up, we have learned a number of useful things about the relation between the mechanical properties of polymers and their molecular architecture. We understand fairly well why amorphous polymers are glassy, leathery or rubbery, and how to modify their properties by introducing cross-links or by other stratagems. We know that we can make a polymer which is rigid yet tough by giving it a partly crystalline structure. We know what kinds of giant molecules are likely to form crystalline and amorphous structures, respectively. We have some understanding of how the ultimate strengths of polymeric materials—their tensile strength, resistance to frictional wear, resistance to compression—are affected by molecular properties, such as the size of the molecules and their orientation. I think it is fair to say also that we now understand the viscoelastic behavior of polymers much more clearly than that of metals.

However, there are still many things about the strengths and other properties of polymers that we do not understand, and they pose a number of challenging problems for investigators. Among these unsolved problems are the marvelous properties of living tissues. What we learn from synthetic polymers will certainly shed light on the behavior of the giant molecules of living matter.



HOW MANY HEART-BEATS
on tap for this Newcomer?

What will the life span be for this young fellow—will his life be happy or hard, long or short? How many times, actually, will this new heart beat?

Answers to questions like that aren't just guesses any more . . . they can be computed, far in advance, with an amazing degree of accuracy.

Those marvelous electronic mechanisms called *computers* have opened a new volume of information about our world, our life, and ourselves in general. And new chapters keep registering on the computer consoles.

The terrific speed with which complex calculations whip through the computers continues to challenge the comprehension. And the basic principle of the computers—of working with electrical charges that are *exactly* proportional to the figures involved—continues to require a power supply that is uniform, unvarying, and dependable. This demand is increased by the move to miniaturize the computer—get it down to a less cumbersome size by using smaller components all the way through to produce the same, or better, results.

Computer designers had a problem . . . until they called in Sorensen. Sorensen is the authority on *controlled power for research and industry*, the world's leading maker of precision electronic voltage regulators. When Sorensen engineers collaborated with the computer design people, new solutions to the power problem were found. Sorensen "resonant regulators", in special circuitry for computer needs, are now providing surge-free power for leading makes of computers.

If you have problems of devising a "smooth" power source, AC or DC, for "plug in" apparatus or major installations, consult Sorensen, the power specialists.

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Natural and synthetic rubbers are reinforced to super-toughness to take grueling punishment. Both types of elastomers rely heavily on WITCO-CONTINENTAL Carbon Blacks to greatly improve resistance to tear and abrasion.

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High-quality chrome plating—such as the finish of this toaster—depends upon thorough degreasing of the base metal. Emulsol's EMCOL emulsion-degreasing detergents economically remove all oil and grease to leave a spotless surface for plating or spraying. *For details on degreasing with* EMCOLS, *write for Bulletin No. 38.* Emulsol Chemical Division.

CLEANER WASH

Even synthetic fibers need washing. ULTRA's low suds NEOPONE® LO Beads are ideal in automatic washers for synthetic as well as natural fabrics. ULTRA's complete line of detergent beads, flakes, powders and liquids are available in bulk, or in private-label packages, for the whole range of home or industrial cleaning problems. Ultra Chemical Division.

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Mastics	Rubber Chemicals

From Giant Molecules... Products that look better...wear better Because of Witco Chemicals

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As lubricants for plastics, WITCO Metallic Stearates improve performance in injection molding and extrusion operations to insure fine-finish plastics such as this radio case. More effective greases, smoother cosmetics, flatter paints and water-repellent finishes are other Witco Stearate applications.

PLASTIC PADDING

Fine-celled foams are essential to the quality of urethane products such as this safety padding for dashboards. Formulated by Witco specifically for urethane applications, FOMREZ* 50 Polyester Resin produces foams of excellent appearance and performance. A highly effective coupler for all urethane resin foams is Witco 77-86.

*Trade-mark applied for

Easing processing problems and improving product quality for the rubber, plastics, paint and other industries have been prime objectives of Witco for the past 37 years.

Witco manufactures quality industrial chemicals in bulk quantities. Seven research and technical laboratories create new, more useful products—and develop more efficient application techniques for older ones. Fourteen Witco plants, here and abroad, insure that the product needs of rapidly growing industries in the chemical and related fields will be met.

Shown here are but a few of the ways in which Witco chemicals serve industry. Witco's many years of experience may similarly benefit your process or product. An inquiry will bring you information on Witco products designed to serve *your* manufacturing needs.

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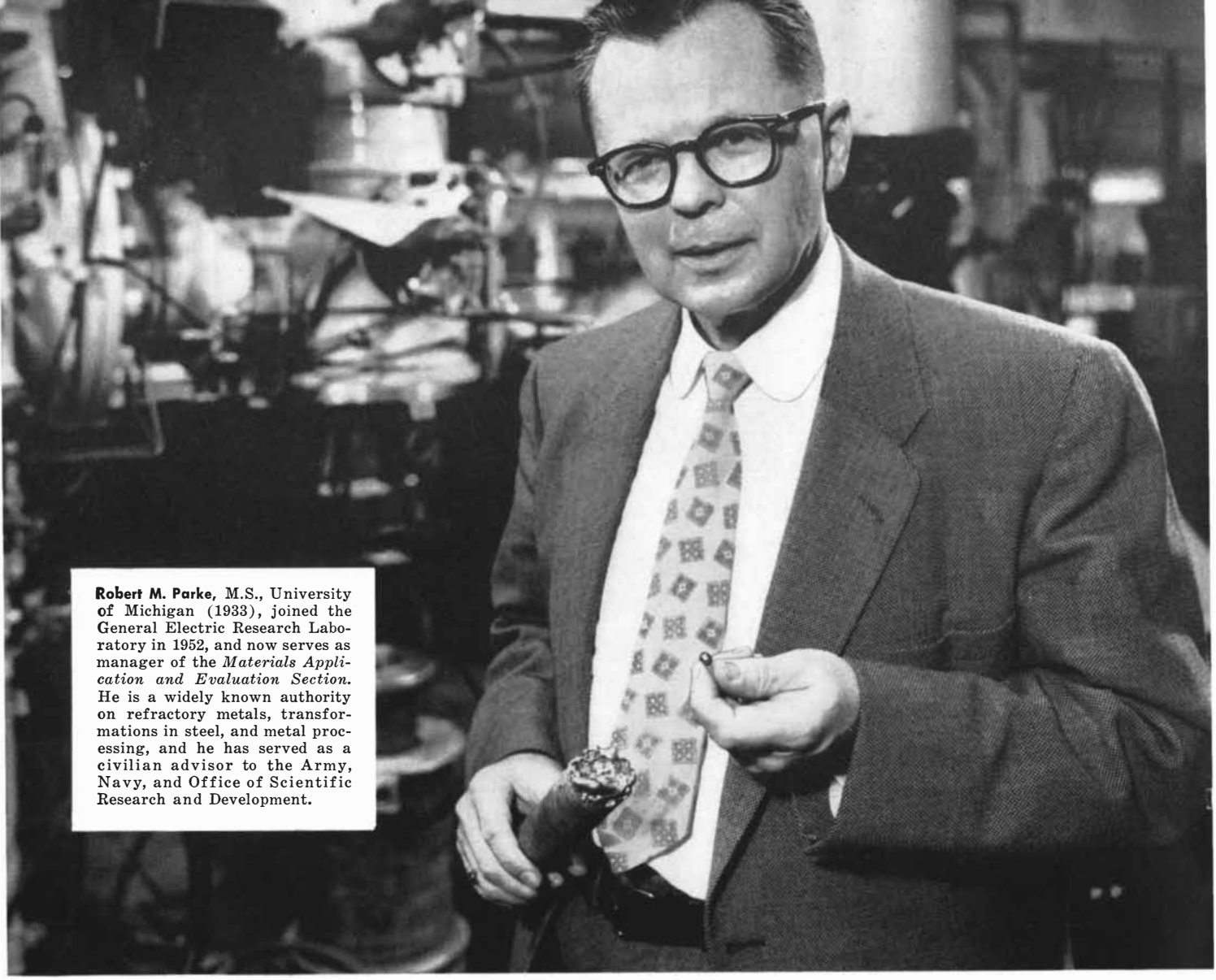


Robert M. Parke, M.S., University of Michigan (1933), joined the General Electric Research Laboratory in 1952, and now serves as manager of the *Materials Application and Evaluation Section.* He is a widely known authority on refractory metals, transformations in steel, and metal processing, and he has served as a civilian advisor to the Army, Navy, and Office of Scientific Research and Development.

"Difficult" metals aid defense

New processing techniques developed by General Electric's Robert M. Parke make casting of refractory metals easier

The word *refractory* implies "difficult." The *refractory metals* — such as tungsten and molybdenum — are very difficult to melt and cast, but their high melting points go hand in hand with their outstanding high-temperature strength. Thus these metals, previously used mostly as wire and thin sheet for electrical and electronic devices, now are needed in large pieces for modern defense equipment such as jet engines and missiles.

Robert M. Parke has helped solve many of the problems associated with casting ingots of "difficult" metals weighing several hundred pounds. He and his associates at the General Electric Research Laboratory have developed new techniques for "growing" electrodes of refractory metals, permitting continuous melting and casting in special arc furnaces. The ingots produced by these processes are extremely pure as well as large. This means improved materials not only for defense, but for products used in the home and industry.

At General Electric, such research is motivated by a belief that providing scientists with the tools, the incentives, and the freedom to seek out new knowledge is the first step toward progress for everyone.

Progress Is Our Most Important Product

GENERAL ELECTRIC

POLYETHYLENE

The simplest polymer bids fair to become the commonest. Until recently it could be synthesized only at very high pressures. Now with the aid of catalysts it can be made at low pressure

by Gerald Oster

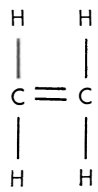
In the early 1930s a group of chemists in the laboratories of Imperial Chemical Industries in England commenced some dangerous experiments. They were studying chemical reactions at high pressures, and they undertook to try to make a giant molecule with ethylene. Ethylene, a gas obtained from the cracking of petroleum, is a comparatively inert substance, difficult to polymerize. To activate its molecules and compress the gas to a density sufficient to create a good chance of the molecules' forming long chains, the English chemists used high temperatures and pressures of more than 1,000 atmospheres. This exotic setup invited explosions, and in fact their apparatus did blow up occasionally. But their hazardous work did not go without reward. They succeeded in combining the molecules of gaseous ethylene into a high polymer which took the form of a solid.

Ethylene had been polymerized before this to smaller chain molecules, forming oils and greases. But the new solid polyethylene was an entirely different order of substance, gifted with some very attractive properties. It was a tough, pliable material with a waxy feel. It shed water like a duck's back, was impervious to chemicals and fungi and made an excellent electrical insulator. Polyethylene was soon put to use as insulation for submarine cables, and also as an insulator in radar equipment, then just being developed. Probably radar would not have played so large a role in World War II if this superbly efficient insulating material had not been available.

A really important new discovery is not like a new toy, whose attractions are quickly explored and quickly exhausted. Major innovations in science and technology usually win appreciation gradually: it takes time to realize the full range of their possibilities. Polyethylene has developed more rapidly than most. In less than two decades it has become a prominent item of commerce and a ubiquitous household article all over the world. Baby bottles and unbreakable toys, water pipes and electrical insulation, potato bags and squeeze bottles, chemical-storage drums and ice cube trays, gun covers and farm crop covers—these and hundreds of other items are now being made of polyethylene. It can be prepared in a number of versions, from thin, transparent films to fairly stiff piping, and it can easily be fabricated into any form desired. And polyethylene is comparatively inexpensive: ethylene is by far the cheapest of all the monomers used to make polymers. (At the moment the price of polyethylene per pound is about the same as that of copper.) Polyethylene is now being manufactured on a large scale in the U. S., England, Germany, Italy, the U.S.S.R. and other countries. In the U. S., where substantial production of polyethylene began only three years ago, it is rapidly becoming the biggest plastic product. By 1960 production is expected to reach one billion pounds—polyethylene will be the first synthetic plastic to attain that level.

Scientifically also polyethylene is one of the most interesting of all the giant molecules. Because it is made of a very simple building block—almost the simplest possible hydrocarbon unit—chemists have been able to correlate polyethylene's properties with its molecular structure very satisfactorily, more satisfactorily than for any other polymer. In fact, ethylene and its polymers serve as

1.



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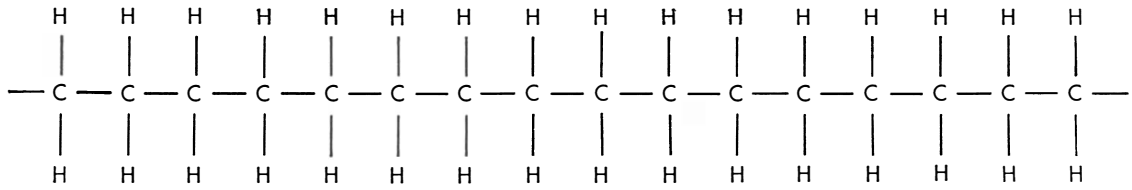
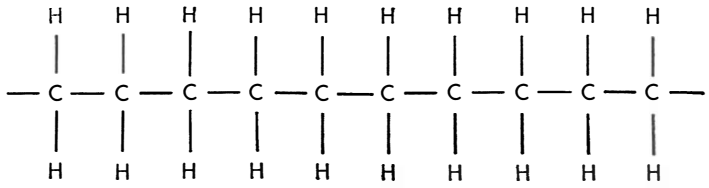


POLYETHYLENE CHAIN (2) consists simply of carbon atoms to which hydrogen atoms are attached. Its monomer is ethylene (1), a gas. The polymer chain shown here is linear; the polyethylene chain is often branched and may also be cross-linked to other chains.



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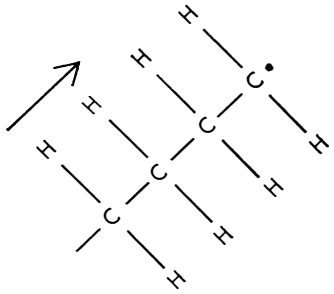

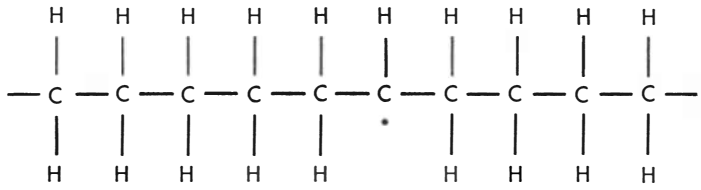

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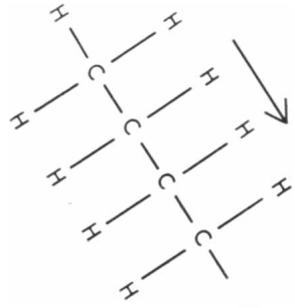
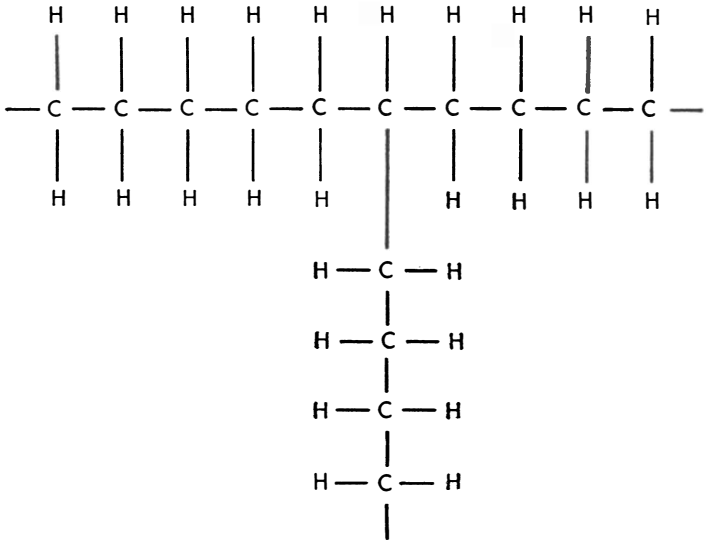




3.

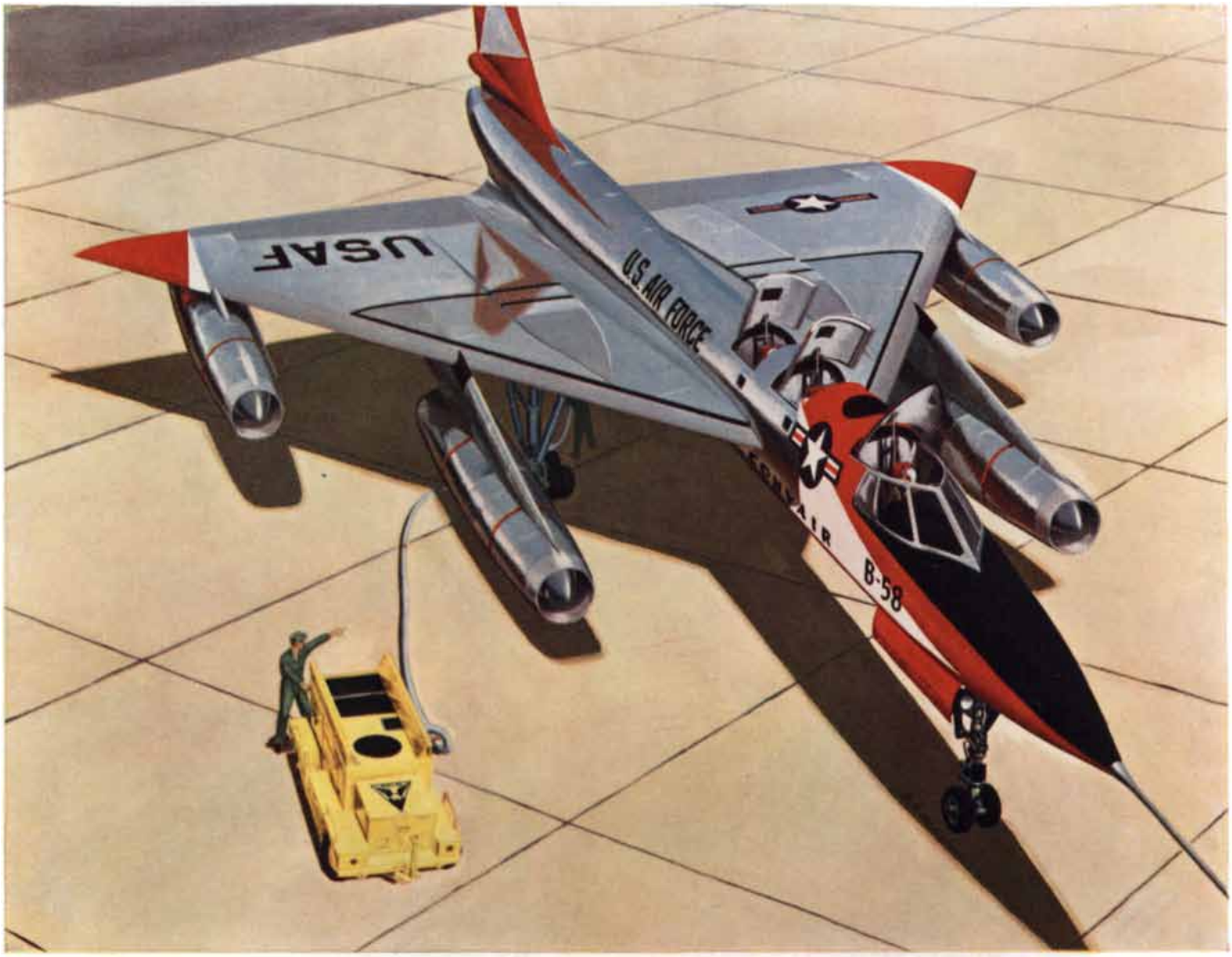
BRANCHING MAY OCCUR by this process. A growing polymer chain with an unsatisfied valence (*dot*) may remove a hydrogen atom from another chain (1 *and* 2). This leaves an unsatisfied valence on the first chain to which monomers may attach in a new chain (3).

elementary models for experiments and deductions that lead to understanding of their more complicated cousins, as has been pointed out in the preceding articles in this issue.

Ethylene is a symmetrical little molecule consisting of two carbon atoms, each guarded by a pair of hydrogen atoms [*see diagram on the preceding page*]. This "saturated" system is highly invulnerable to chemical attack, but heat can compel the ethylene molecules to link together. It is believed that at high temperatures ethylene reacts with oxygen to form a peroxide, which then decomposes into a free radical. The reactive free radical attacks an ethylene molecule, generates a new free radical at its end and so starts a chain reaction by which one monomer after another is added at the active end of the growing molecule [*see article on page 98*]. Since ethylene is a gas that does not liquefy at high temperatures, the gas must be squeezed under high pressure in order to crowd the molecules close enough together so that they will grow to high polymers within a reasonable time. They can build up to chains of enormous length, but sooner or later the free-radical end of a growing chain encounters the active end of another, and when these ends unite the growth stops.

Polyethylene culminates a family of chain molecules long known to petroleum chemists as the paraffins. The family starts with gases (methane, ethane, etc.), and as the molecules get bigger and bigger, the substances become liquids (*e.g.*, gasoline) and then solids. The solid paraffins were known in the past only as soft waxes, but with the synthesis of polyethylene we have the first really solid child of this family—*i.e.*, the first which is coherent enough to form solid objects. It retains the family characteristics. In particular, it is not wetted by water and is practically impermeable to moisture. This makes it attractive as a material for water pipes: not only is it light and non-corrosive, but it allows water to flow much more easily than a metal does, because, being nonwettable, it causes little or no frictional resistance to the flow.

Notwithstanding its many attractions, polyethylene has suffered from two important drawbacks. First, production of the polymer by the high-pressure process remains uncomfortably precarious. Pressures as high as 7,000 atmospheres are used. The reactor in which polyethylene is cooked is sometimes called a cannon, and with good reason:



Solar Advanced Technology

Gas turbine ground support unit starts giant jets in seconds

ADVANCED JET BOMBERS, like this Convair B-58 Hustler, require a powerful source of compressed air to start their high-thrust engines. Solar advanced technology has helped solve this aviation problem with mobile, portable gas turbine units that supply large volumes of compressed air as well as shaft power for electric and hydraulic adaptations.

The new unit, powered by a Solar 500 hp Jupiter® engine, offers many advantages over conventional ground support units. It is portable and lightweight, easy to maintain, starts instantly under severe temperature extremes and can be operated on a variety of fuels—including gasoline, kerosene, diesel fuel, jet fuels and others.

In addition to aircraft ground support, Solar gas turbines can be used for emergency and auxiliary power generation, pumping and mechanical drive, boat propulsion and many other applications requiring a compact, efficient source of power. For more information write to Dept. D-71, Solar Aircraft Company, San Diego 12, California.

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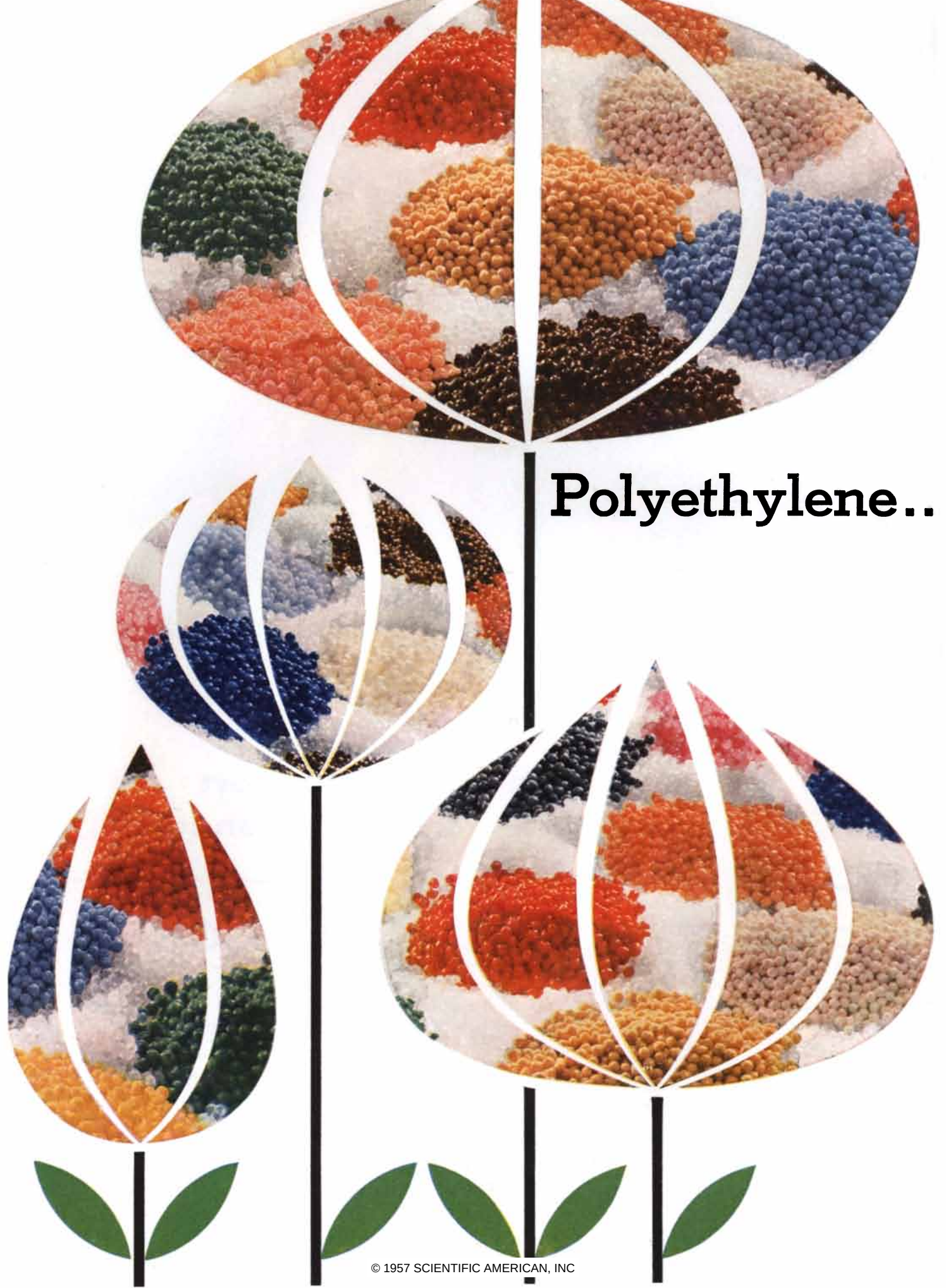


Polyethylene..

fastest growing plastic of all time

The versatility of colorful Tenite Polyethylene means new uses every day for this giant molecule

Tenite Polyethylene is a material formed by polymerizing ethylene gas into giant molecules of solid plastic.

Chemically inert, this plastic has no solvent at room temperatures. It is strong, tough and virtually unbreakable, yet is the lightest of all plastics. It is an excellent dielectric with low thermal conductivity and high resistance to water.

Tenite Polyethylene can be injection molded, or extruded into sheeting which in turn can be vacuum formed. It can be "blown" into bottles. It can be extruded as film or pipe, or as a coating on paper, film or foil.

Originally a dull, milky-white material, polyethylene has been given a colorful new dimension by Eastman. Today, molders and extruders can order pellets of Tenite Polyethylene in almost any color desired. For Tenite Polyethylene has profited by Eastman's long experience in the coloring of Tenite Acetate and Tenite Butyrate—two Eastman plastics based on another giant molecule, cellulose.

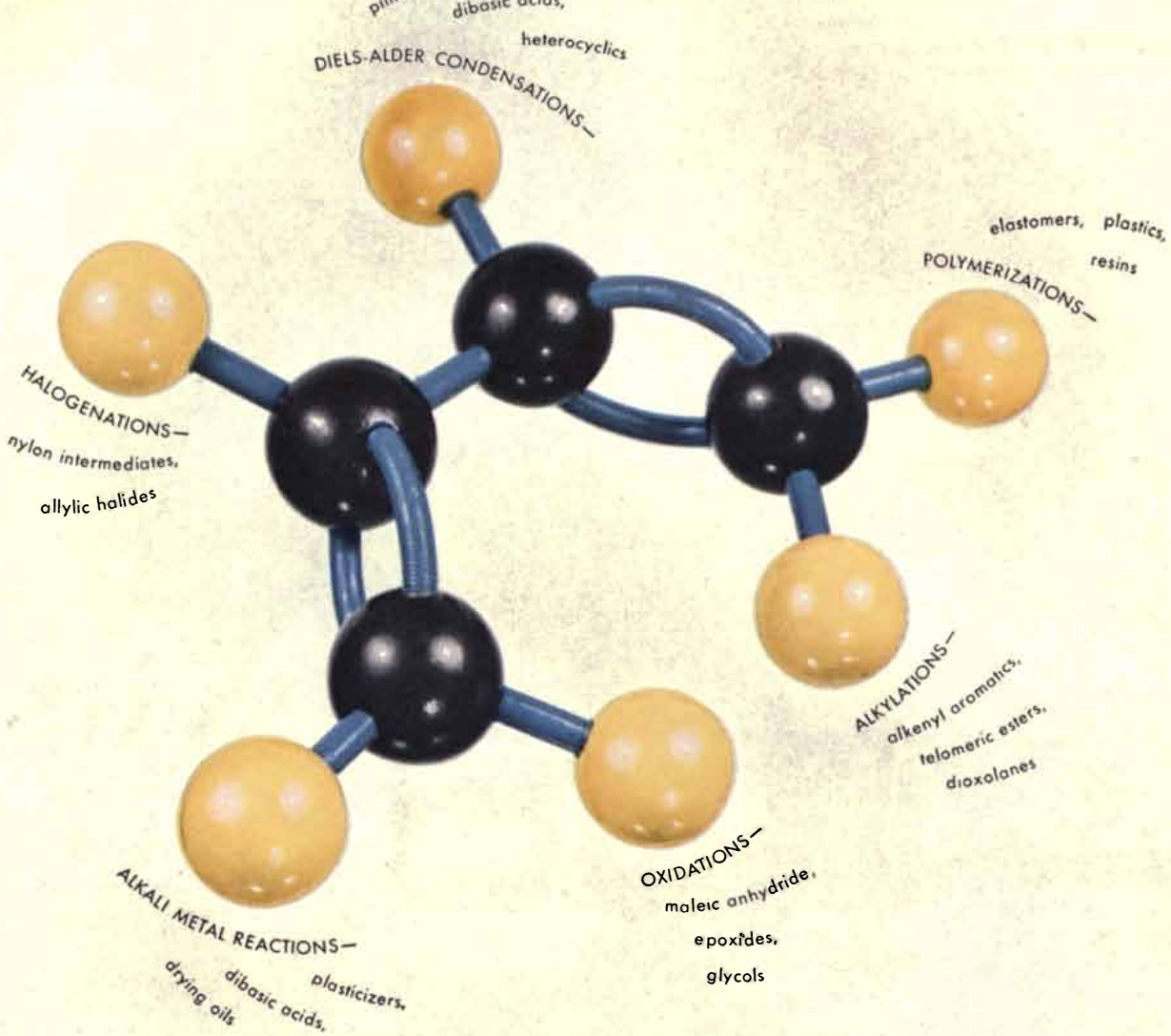
Perhaps Tenite Polyethylene could add longer life, better performance or greater sales appeal to some product you make. For more information on this versatile plastic, write EASTMAN CHEMICAL PRODUCTS, INC., subsidiary of Eastman Kodak Company, KINGSPORT, TENNESSEE.

TENITE

POLYETHYLENE · BUTYRATE · ACETATE

plastics by Eastman

1932—EASTMAN'S 25TH YEAR IN PLASTICS—1957



BUTADIENE . . . four-carbon building block

Though already one of the few billion-pound chemicals, many new significant uses of Butadiene are yet to be realized; the structural opportunities offered by this four-carbon building block are limited only by man's creative imagination.

To further encourage the development and use of Butadiene, TEXUS production facilities have been greatly expanded, assuring the Chemical Industry of sufficient quantities for both current and growth needs.

In addition to providing a dependable source of supply from the world's largest Butadiene plant, TEXUS offers you the benefits accruing from important and expanding research and development programs.

Your inquiry regarding present and prospective uses of Butadiene is sincerely invited . . . and will be held in the strictest confidence. A letter or call to our New York office will bring you the current TEXUS Butadiene Technical Bulletin and also subsequent data as it is published.

TEXUS

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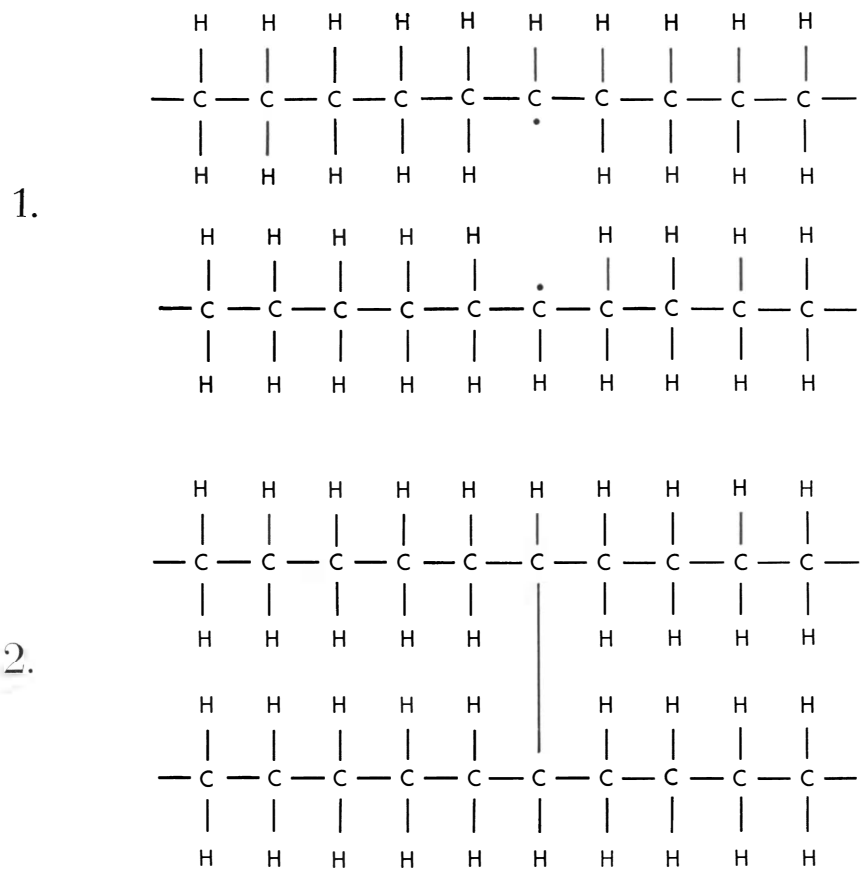
Plants and General Offices: Port Neches, Texas

the pressure in the reactor may be greater than that in a big gun at the moment of firing! Yet these pressures have to be maintained continuously while the polymer is being made. Furthermore, the gas has to be kept at a high temperature, and to make matters worse, the polymerization of ethylene itself generates a considerable amount of heat. To withstand the pressure, the reactor, a cannon-like tower about 40 feet high, must have walls at least 10 inches thick, made of special metal alloys. Thanks to automatic safety controls, polyethylene reactors no longer blow up at the rate of one a month, as they used to, but a factory operating under such extreme conditions is still not calculated to produce peace of mind.

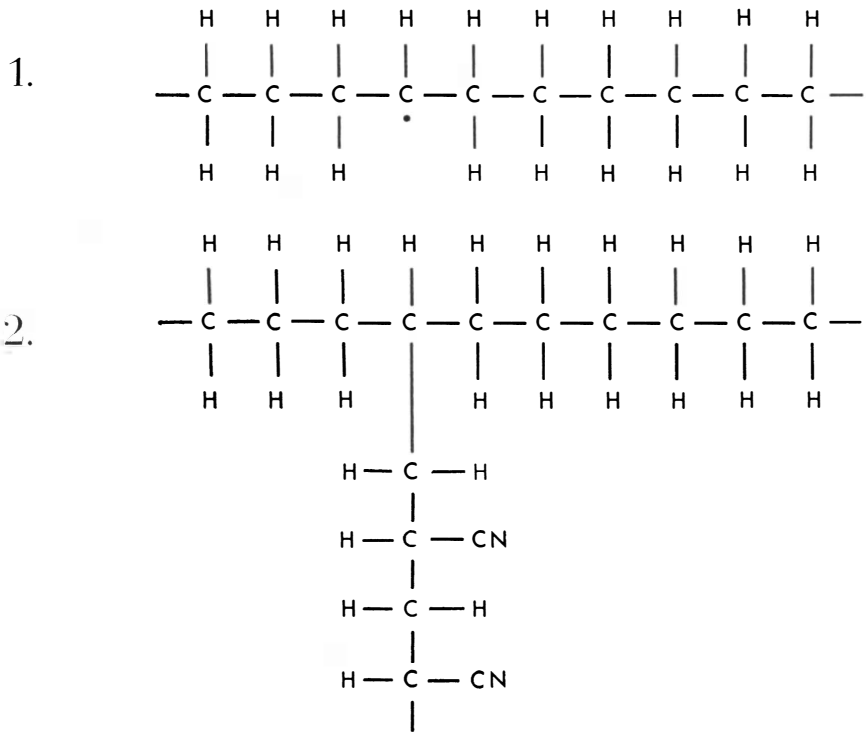
The second, and more important, drawback is a major defect in the product itself. Polyethylene made by the high-pressure process begins to soften at temperatures near the boiling point of water and melts at a few degrees above that. Consequently articles made of polyethylene will not stand heat. A sudden surge of current overloading a circuit will melt away the polyethylene insulation of the wires; a polyethylene bottle put in boiling water becomes a shapeless mass; the material will not do as piping for hot water; and in general it is limited to uses in which it does not have to resist heat.

The melting point of polyethylene produced by the conventional method is lower (by about 50 degrees Fahrenheit) than what we would expect of a paraffin of high molecular weight. The reason for this is now well understood. The high temperature used in the process promotes attachment of many side branches to the main chain of the giant molecule. These branches add a complication which puts a stress upon crystalline portions of the polymer (that is, regions where the chains are aligned in a regular arrangement). As a result the amount of crystallinity that can develop is limited (to about 50 or 60 per cent), and the structure of the substance is easily broken down by heat.

Naturally chemists looked for a way to synthesize polyethylene at reasonable temperatures and pressure. Such a process might overcome both drawbacks of the original method: not only would it eliminate the hazards of the conventional process but it might yield unbranched molecules. A polyethylene consisting of simple linear chains should be more crystalline, stronger and more resistant to heat, though it would lose in pliability. Three years ago a German



CROSS-LINKING MAY OCCUR when radiation removes hydrogen atoms from adjacent polymer chains (1). The two carbon atoms with unsatisfied valences are then bonded (2).

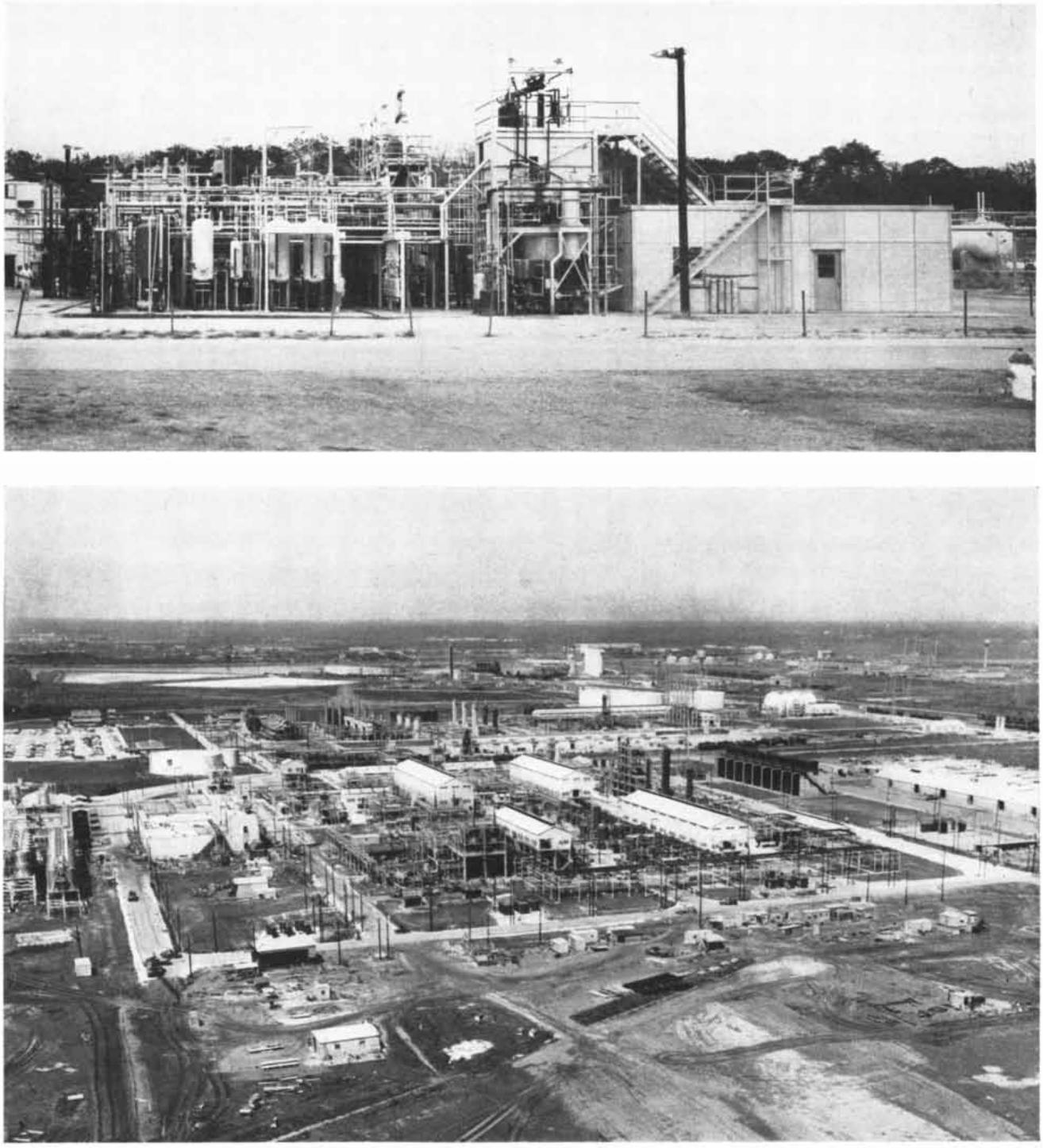


GRAFTING MAY OCCUR when a hydrogen is removed from a polymer chain (1) so that other monomers may grow from it (2). Here polyacrylonitrile is grafted to polyethylene.

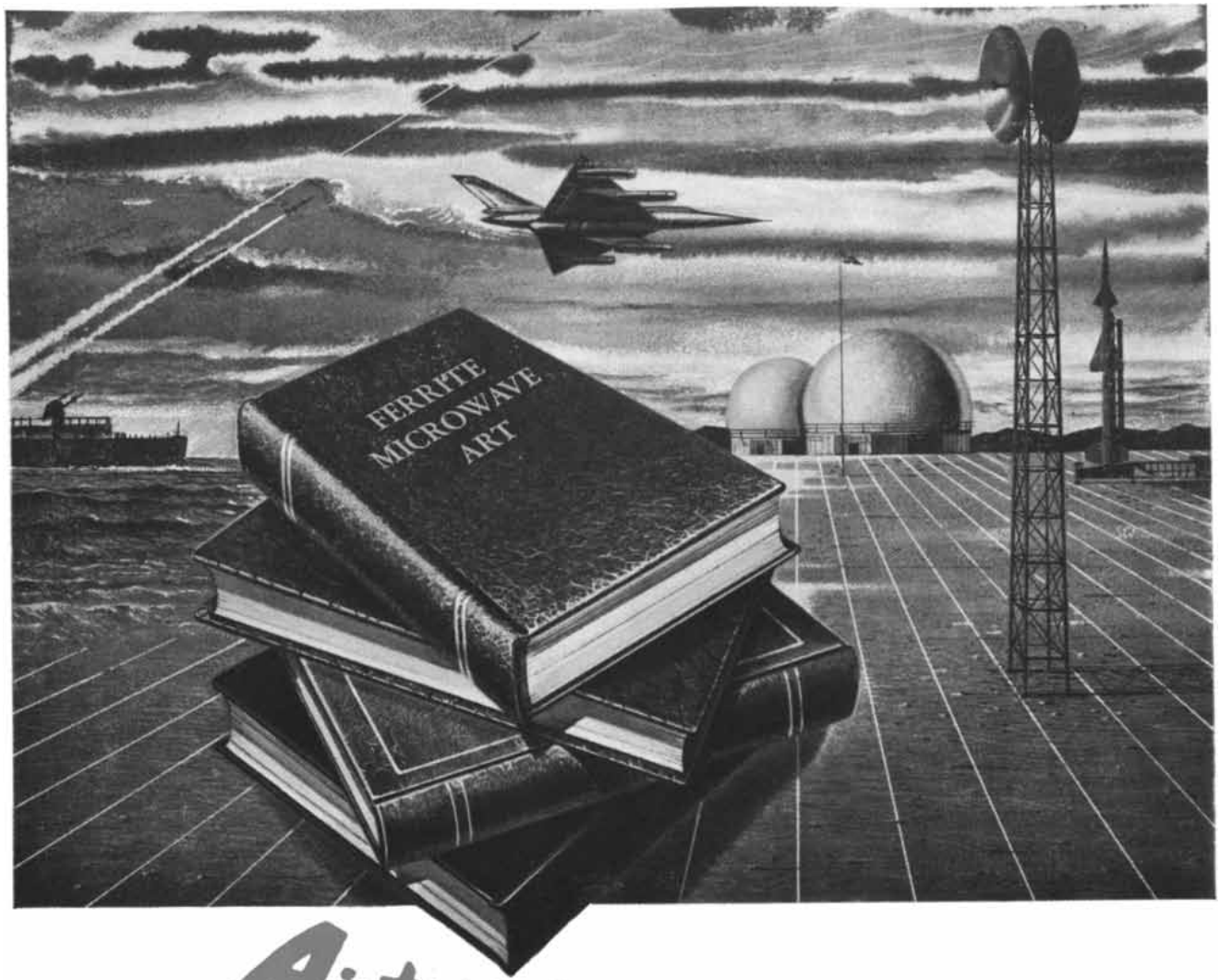
chemist, Karl Ziegler, found a solution to the problem. He discovered that ethylene could be polymerized to polyethylene at normal pressure and comparatively low temperatures with the aid of a catalyst—a complicated combination of metals and organic substances [*see article on page 98*]. Since then the Phillips Chemical Company in the U. S. and others have developed similar processes using different catalysts.

The new polyethylene has several new properties. It is highly crystalline (as much as 90 per cent) and has a considerably higher melting point (about 275 degrees F.). It is stiffer, stronger (able to bear twice as great a load) and denser; the new and old forms of the substance are therefore distinguished by the names high-density and low-density polyethylene.

Production of high-density polyethylene is just emerging from the pilot-plant stage, and the material has not yet been fully tested. There are problems to be worked out, including the separation of the product from the catalysts and im-



LARGE PLANTS are presently going "on stream" for the low-pressure production of polyethylene. At top is a low-pressure semi-works of the Phillips Chemical Company in Bartlesville, Okla. At bottom is the full-scale Phillips plant near Houston, Tex. Parts of this plant are still under construction, but it is scheduled to reach a capacity of 75 million pounds a year by the end of 1957.



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ferrite advances add new chapters to the microwave art

Since the close of World War II the big push has been toward the use of higher and higher frequencies to solve the many problems which threatened to limit modes and extent of radio communication as well as radar and other detection systems.

From LF to HF to VHF to UHF and beyond — from the 50 kilocycles radio band to the 10,000 megacycle weather radar is the distance we have traveled in the past fifteen years. Today our sights are set on the 30,000 to 90,000 megacycle bands.

Airtron, Inc. has been a leading contributor to the extension of the microwave state of the art. It has been Airtron who has written in the **new chapters** on ferrite components and material, double ridge waveguides, and high powered, miniature ferrite and non-ferrite microwave components, to the standard texts that are the only reference source for engineers and users of microwave equipment.

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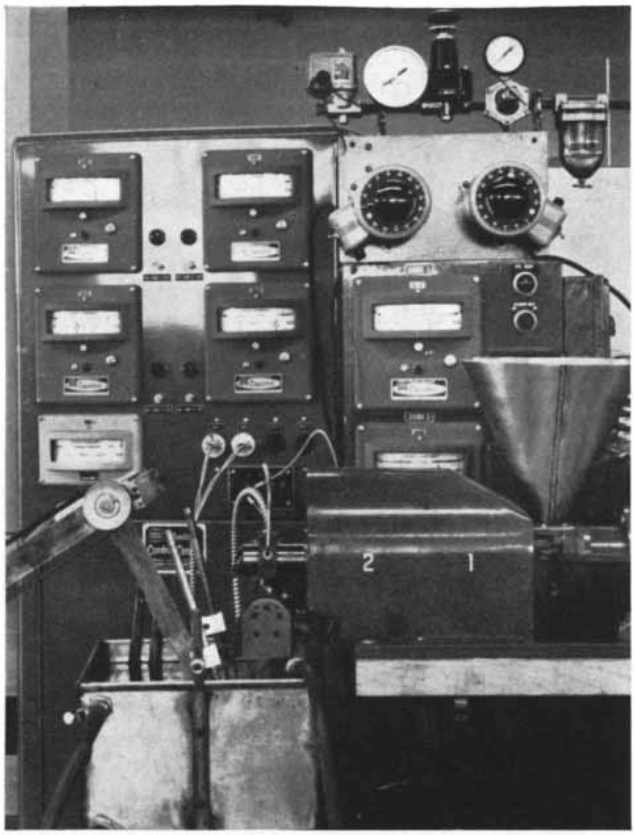
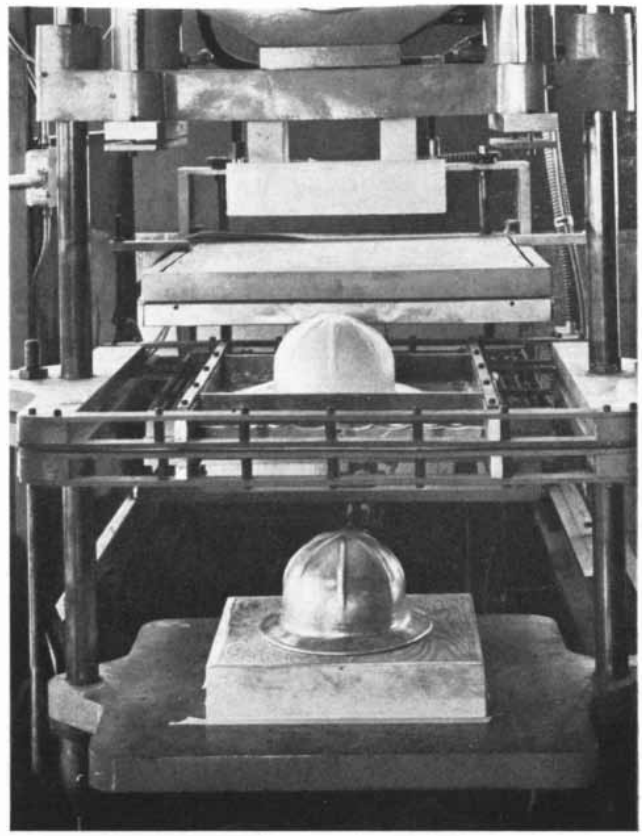
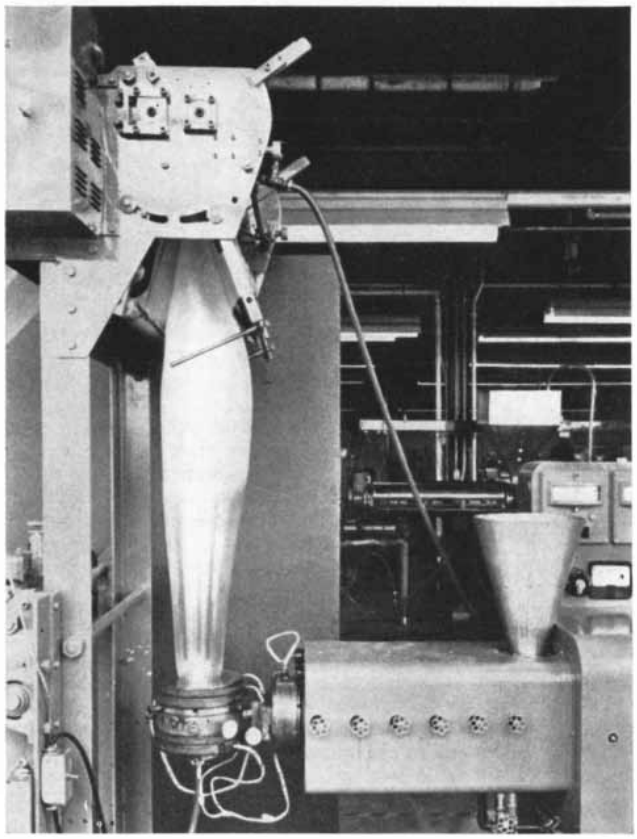
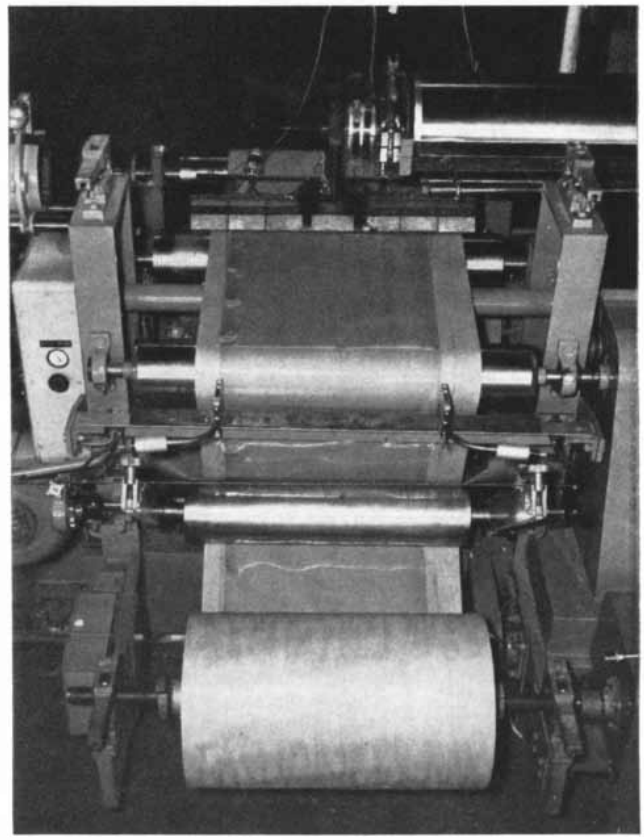








POLYETHYLENE IS FORMED into useful products in a wide variety of ways. The methods shown here were photographed in the laboratories of W. R. Grace & Co. in Clifton, N.J. At upper left polyethylene is extruded in a sheet which may be seen emerging from a water bath at lower left in the photograph. At upper right polyethylene sheet is made into a protective helmet by a vacuum which pulls it down over a metal form. At lower left polyethylene is extruded as a thin film. At lower right it is coated on paper.

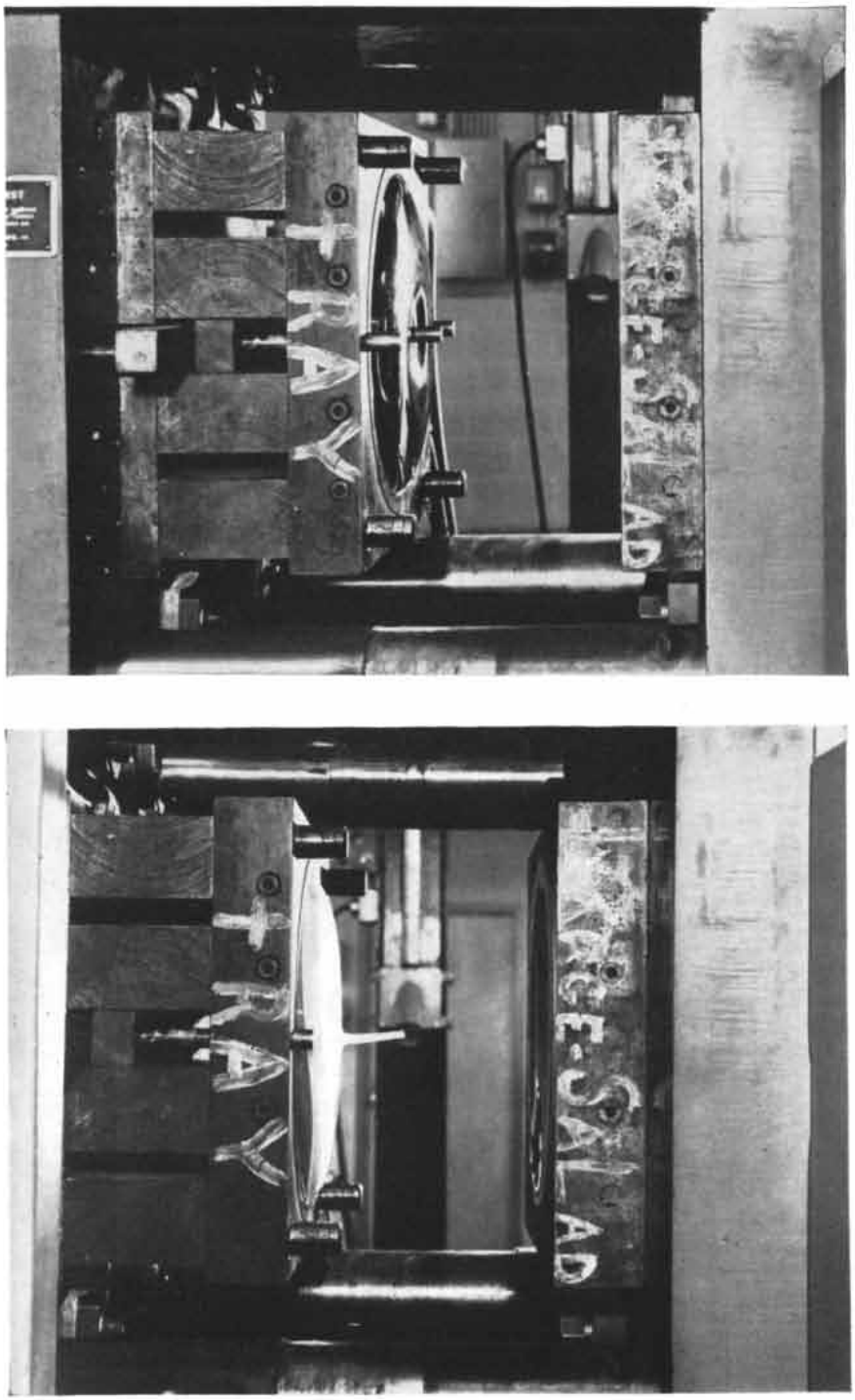
provement of the properties of the material. But it is so promising that within two years or so high-density polyethylene is expected to account for more than a third of the total polyethylene production.

Meanwhile chemists and physicists are operating on the new substance to see what other qualities they can build into it. Its simple, linear molecules offer a tempting material to tinker with. For instance, suppose we cross-linked the chains chemically, as the molecules of rubber are cross-linked when it is vulcanized. The difficulty is that polyethylene lacks chemical groups to form cross-links. But several years ago A. Charlesby, a physicist in the British atomic energy establishment at Harwell, exposed some polyethylene to intense ionizing radiation (about 20 million roentgens) from the nuclear pile and discovered that the irradiation generated cross-links. Apparently it knocks hydrogen atoms off the chains and so frees bonds for cross-linkage. A single cross-link per chain produces a dramatic change in polyethylene. It becomes stronger, all but unmeltable and insoluble in the usual solvents. Although it cannot be fabricated into shaped objects, it has a number of potential uses.

Few manufacturers are likely to invest in an atomic pile or even a less expensive particle accelerator to cross-link polyethylene. However, there is a simpler way. I have found that polyethylene can be cross-linked by ultraviolet rays of certain wavelengths. The rays must be of short wavelength; the longer ultraviolet wavelengths tend to break polyethylene down. For most of our studies at the Polytechnic Institute of Brooklyn we used a 15-watt ultraviolet lamp commonly employed for sterilization. When we send an ultraviolet beam through a batch of polyethylene fortified with certain sensitizers (which apparently break down to free radicals), the molecules become cross-linked in a matter of seconds. The treatment can cross-link both low-density and high-density polyethylene. It cures a bad weakness of high-density polyethylene: namely, a tendency to become brittle after it has been exposed for some time to a very warm environment. This weakness has disqualified polyethylene for use as hot-water piping, but the corrective effect of the ultraviolet radiation, which apparently controls the crystallization of the substance, suggests a possible solution to that problem.

There are other operations we can perform on the polyethylene chains be-

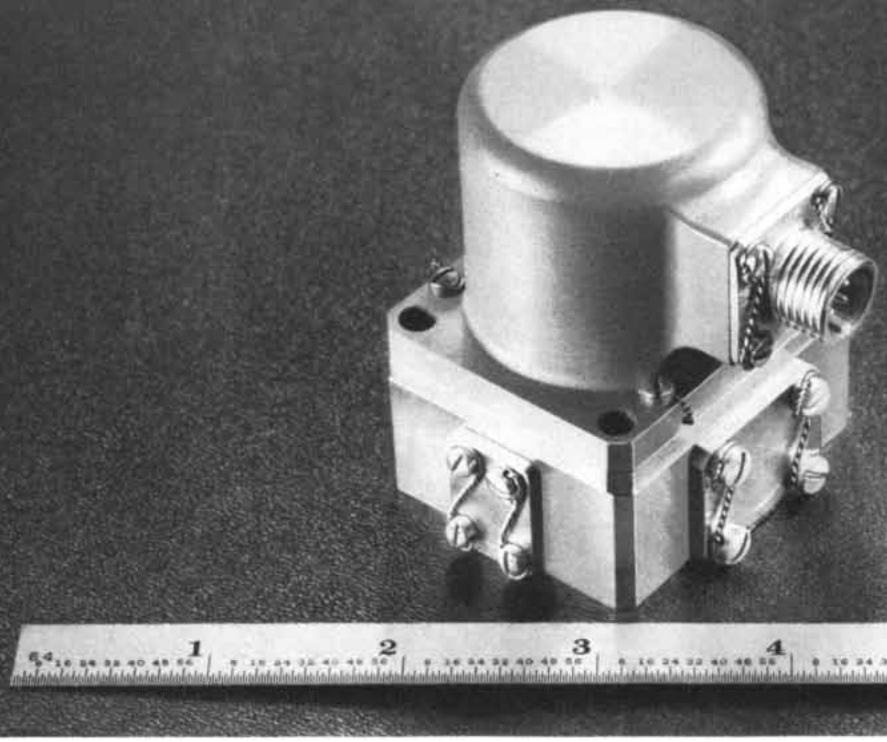
sides cross-linking them. We can graft branches, of our own choosing, onto the chain, and thus modify the properties of the polymer in a chosen way. As several workers in the U. S. and abroad have discovered, ionizing radiation promotes grafting, by producing free radicals which initiate the polymerization of branches on the main chain. In our own laboratory we have used ultraviolet radiation for this purpose. If selected monomers (other than ethylene) are introduced into a batch of polyethylene, the chains grow foreign branches which endow the substance with new properties. For example, we have grafted polystyrene branches onto polyethylene chains and obtained a material which combines properties of both polymers and adds a few new ones. There is an-



INJECTION MOLD makes a salad tray out of polyethylene in the Clifton laboratories of W. R. Grace & Co. At the top the die is open before injection; at the bottom, after injection.

For control system applications...

the AiResearch time dwell electro-hydraulic servo valve



SPECIFICATIONS:

Weight	1.25 lb.
Electrical input	10 milli-amperes
Operating pressure	200 to 4000 psi
Rated flow	0.12 to 5 gpm
Fluid	OS45-1 (or) MIL-O-5606
Oil Temperature	−90°F to 400°F

New design results in high spool control forces with positive switching action

The AiResearch Time Dwell Servo Valve is a two stage switching type electro-hydraulic valve. It converts low level electronic signals into hydraulic energy which actuates mechanisms to steer or control missiles, aircraft, and ground control and similar equipment.

Weighing only 1¼ pounds, this AiResearch valve has the following characteristics:

Spool velocity rather than position is the control parameter.

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Performance is maintained even with contaminated oil.

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In combination with a matched actuator, the Time Dwell Servo Valve gives true $1/s^2$ dynamic performance. This allows the servo systems engineer to achieve system response, resolution and stability previously unattainable.

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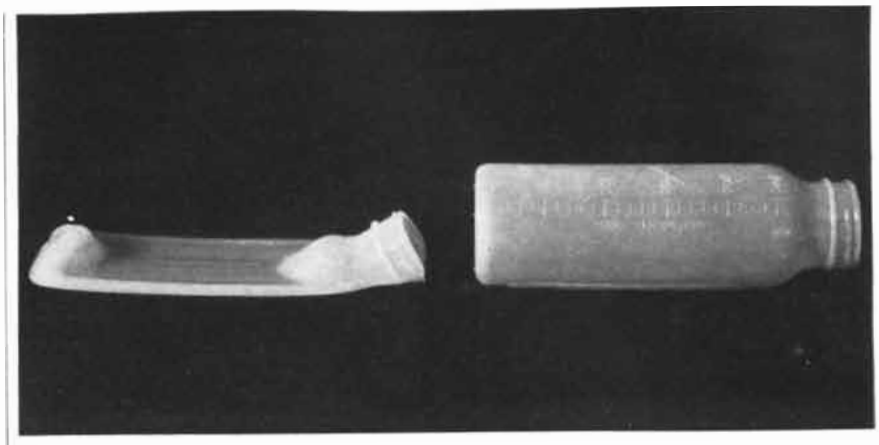
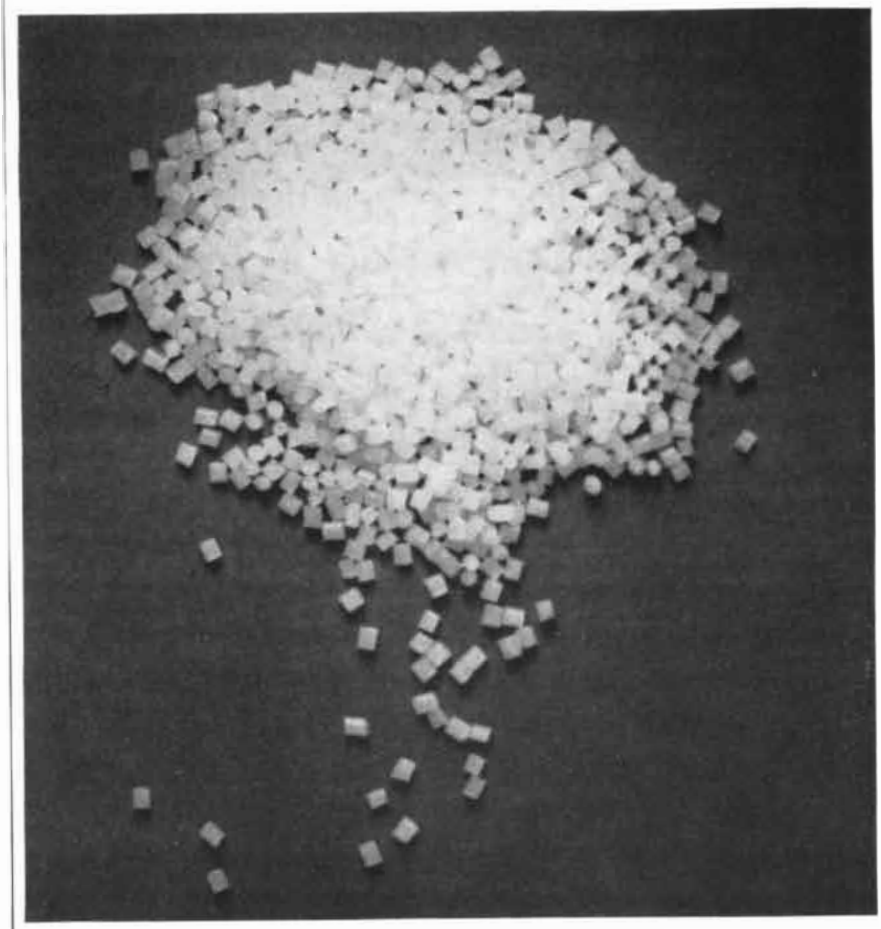


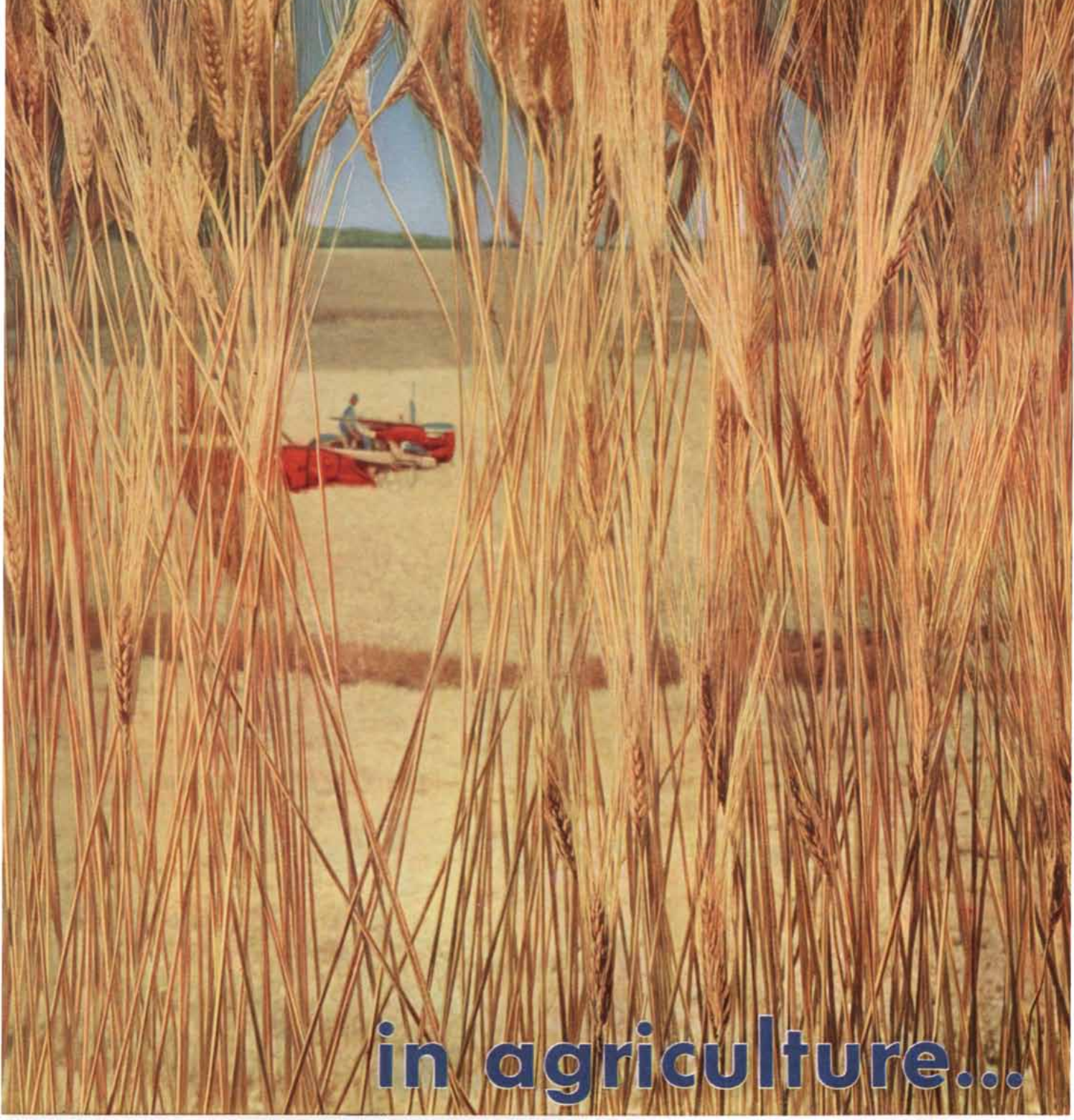
CROSS-LINKED POLYETHYLENE is more resistant to heat than non-cross-linked. These two bottles were heated to 300 degrees F. The one at right is cross-linked; the other is not.

other particularly nice illustration of what can be done by this sort of chemical block-building. The nonwettability of polyethylene is a nuisance when it comes to trying to put a label on a film or wrapper of the substance: it will not take printing ink. But by grafting polyacrylamide, a hydrophilic polymer, onto polyethylene, we have made a polyethylene hybrid whose surface is wettable by water and consequently will take print.

Polyethylene can be regarded as the brightest flower of the high polymers. Among the achievements that entitle our era to be called the age of chemistry, this remarkable man-made substance certainly ranks near the top.



BULK POLYETHYLENE is shipped to fabricators in a variety of forms. It is then converted into other forms by heat. These pellets were made by Phillips Chemical Company.



no substitute can do what copper does!

Heavily-used water supply and drainage lines for barns, outbuildings and homes need the combination of durability, resistance to corrosion and mechanical strength that copper gives. Copper's ability to conduct electricity far better than any other non-precious metal, makes it essential to farm wiring for light and power, electric generators and motors, tractor ignition systems, and copper lightning rod installations. In agriculture, as in so many other fields, copper always gives *something extra* no substitute can match!

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Keeping a fatal rendezvous in 4-D

Any hunter who's fired at a fast-flying duck knows you have to figure *time*—the 4th dimension—if you want the shot to meet the duck in flight . . .

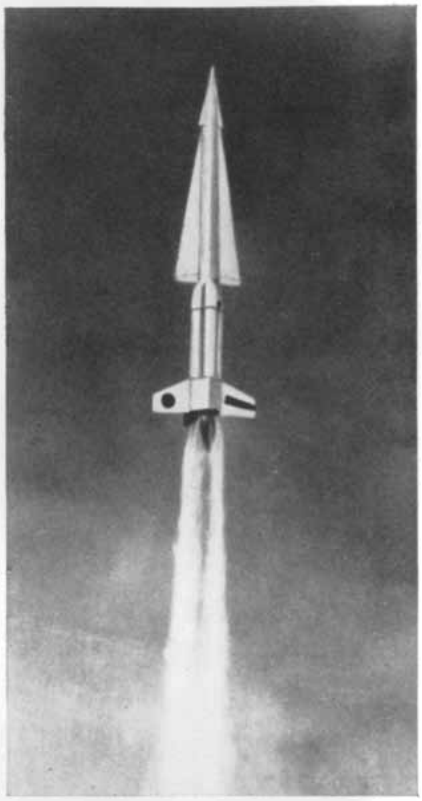
Now substitute an airplane taking full evasive action at 40,000 feet or more, and conventional ways of aiming become obsolete. Yet this problem is *relatively* simple, as was dramatically proved at the first tests of the Nike missile, jointly developed by Bell Telephone laboratories and Douglas.

Even more complex than ground-to-air marksmanship is air-to-air gunnery, where opposing planes top 1000 mph, and fire missiles that move twice that fast. It's an entirely new science, based on principles first expounded by a Douglas scientist, and proved in repeated successful tests—even against unseen targets.

Dramatic moment in aviation history, a Douglas-built Nike-Ajax bores in on a drone bomber.

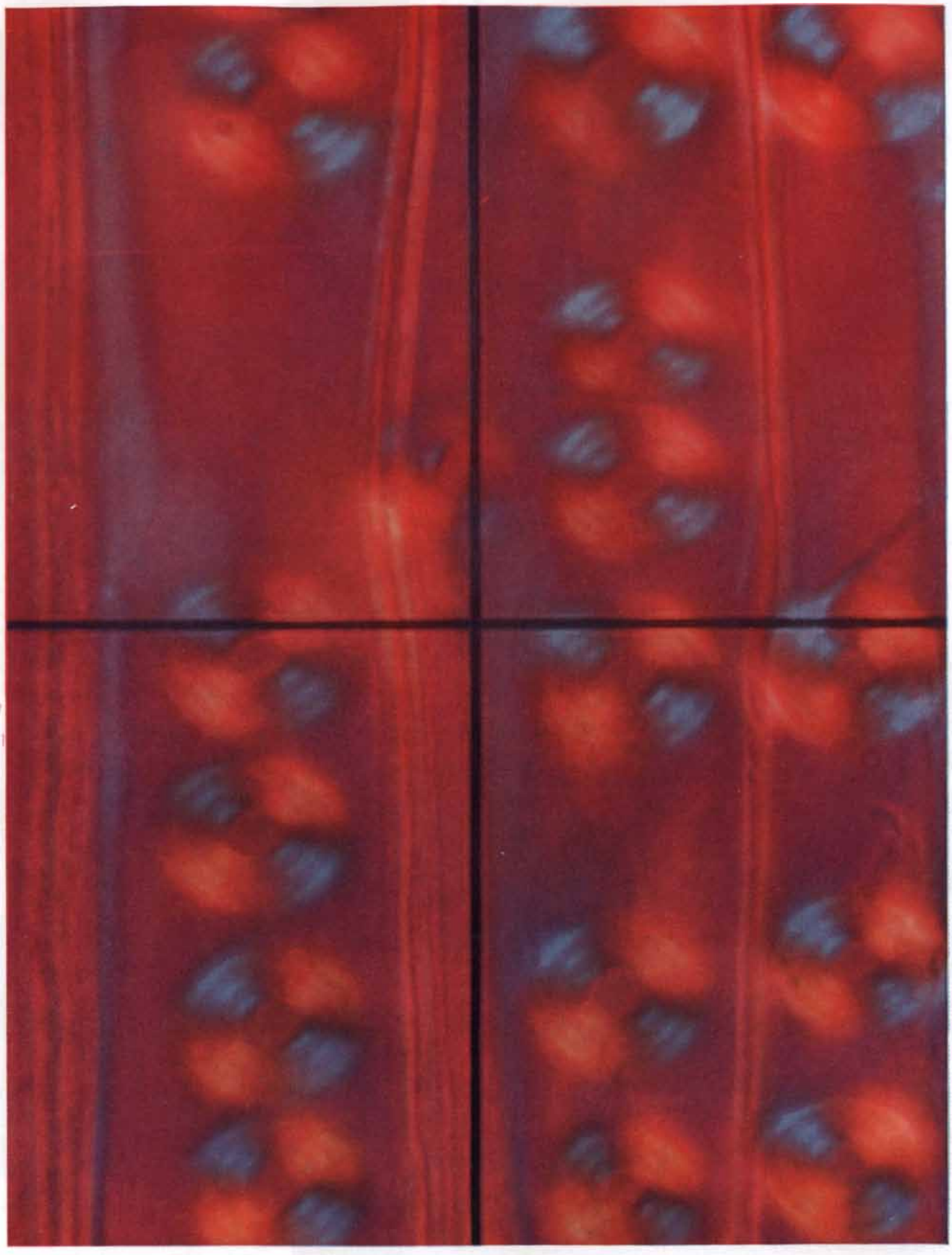
Depend on
DOUGLAS
first in Aviation

A split second later finds the bomber in flames, as Nike-Ajax scores a direct hit.



Here is Nike-Hercules, soon to take over defense of U. S. cities from the earlier Nike-Ajax. Tripling the range of its predecessor, Nike-Hercules can be armed with a nuclear warhead, to knock out entire fleets with a single blast.

Douglas engineers load the rocket pod of an F4D Skyray. Fire control problems at supersonic speed, naturally much greater than encountered at stable ground emplacements, are solved on principles developed by a Douglas engineer. Consistent hits can be scored by planes approaching one another at close to a mile per second, and even when unseen.



CRYSTALLINITY OF CELLULOSE is indicated by this polarized-light photomicrograph of a thin shaving of spruce. The long tubular cells of the wood run from the top of the page to the bottom. The light-red vertical streaks are the walls of the cells. The circular patterns correspond to "pits" in the walls in which the protoplasm of one cell is continuous with that of the next. These patterns arise when the polarized light of the microscope passes through cellulose molecules arranged in crystalline array in the pits.

CELLULOSE

This polymer is made not by man but by plants. Dissolved out of wood or cotton, it is reshaped into rayon and other artificial materials. Such materials still outweigh all those made from synthetic polymers

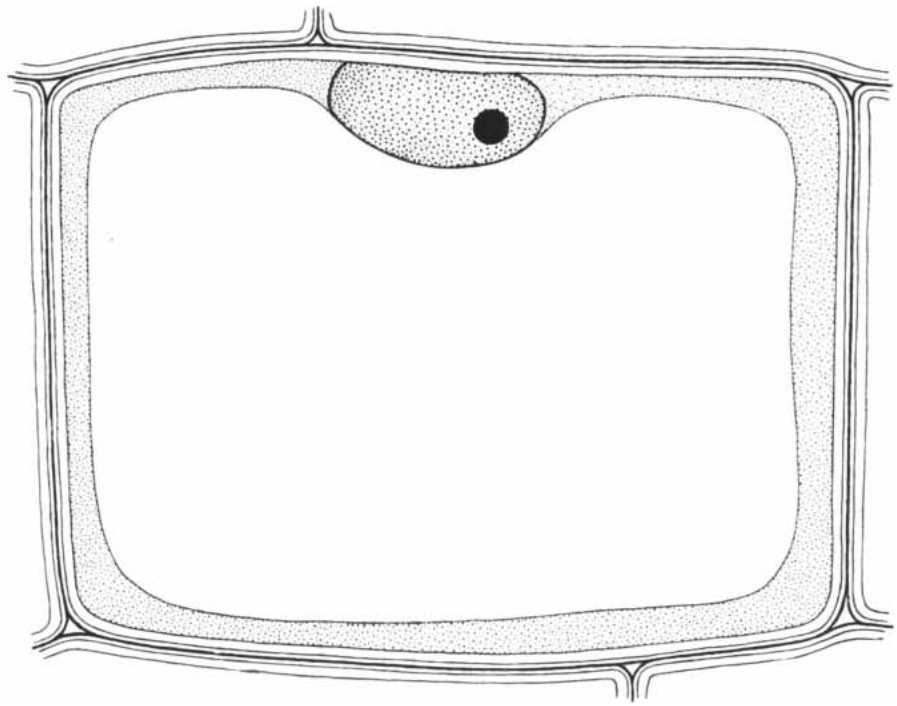
by R. D. Preston

Cellulose, a basic substance of all plants, serves as the structural support of their cell walls, like the steel frame of a building. Empty the cell of its contents, strip away the filling material (masonry) of the walls, and the skeleton remaining is cellulose. This framework of the cell wall is a strong, tough, fibrous material. Its mechanical properties explain the sturdiness of products made of cellulose—for instance, the rigidity and firmness of timbers, the strength and durability of a cotton handkerchief. Cellulose is completely insoluble in water, which accounts for the fact that cotton fabrics can safely be washed. The fibrils composing cellulose are in part rather loosely built; as a consequence other materials, such as dyes, can penetrate into spaces within them. Thus cellulose, an inexhaustible product of the plant world, provides us with a widely useful material of high tensile strength, high bending strength, ability to absorb dyes and so forth.

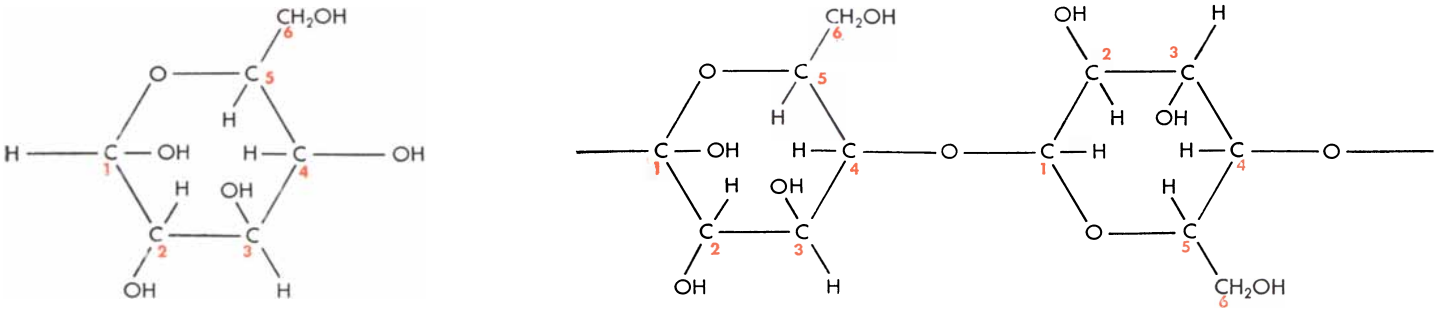
It is not surprising that a substance with such virtues and potentialities should have been an object of intense study for many years. One of the first facts to emerge when chemists began to analyze cellulose was an intriguing paradox: this completely insoluble compound is composed of a building block which is very soluble indeed—namely, the sugar glucose. The paradox is not difficult to explain, however, with the present understanding of organic chemistry. The glucose molecule, comprising a ring of carbon atoms, has hydroxyl groups (OH) attached to five of its six carbons. It is these groups that, by virtue of their strong affinity for water, confer upon the molecule its ready solubility. It follows that in cellulose the hydroxyl groups must be eliminated or blocked in some way. One of these groups in each glucose unit is eliminated in the formation of the cellulose chain: that is, when glucose molecules are joined together, the hydrogen atom is split off from the oxygen of a hydroxyl group and the oxygen atom becomes the link between one glucose molecule and the next [*see diagrams on next two pages*]. The other hydroxyl groups are masked, as we shall see, by the bundling together of cellulose molecules.

A cellulose molecule consists of many thousands of glucose units chained together like a long string of beads. The molecule itself of course is far too fine to be seen, but under an electron microscope we can discern very narrow threads (microfibrils)—evidently bundles of the chain molecules spun out by some spinning agent present in plants. We can calculate that each microfibril probably contains somewhere between 280 and 800 chain molecules.

The microfibrils were first observed in a seaweed called *Valonia*. This alga of the warm seas is a delightful material for study under the microscope, because the plant consists of a single giant cell, sometimes as large as a hen's egg, whose wall is made up of ex-



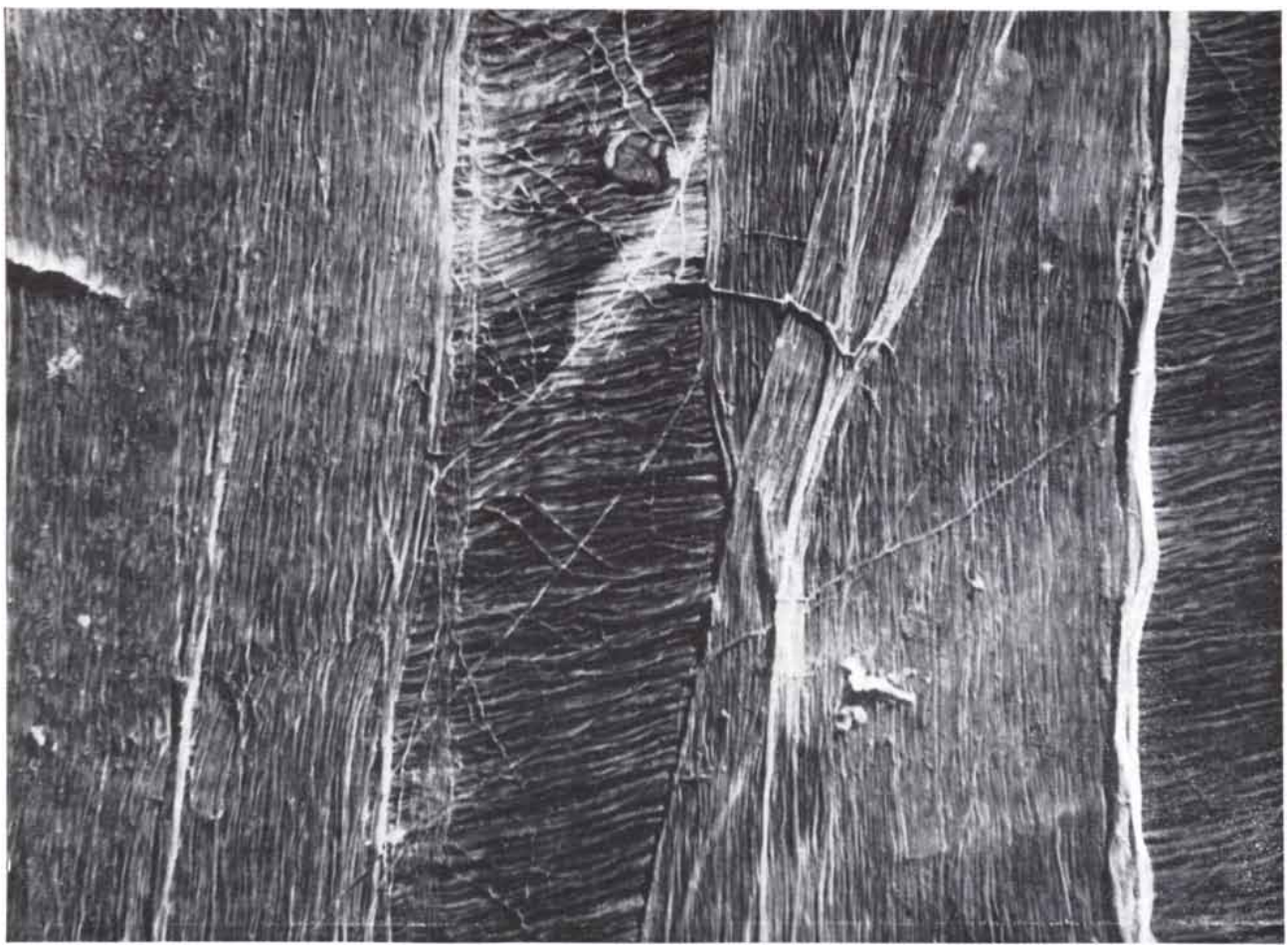
PLANT CELL is shown in cross section. The open area in center is the vacuole, filled with a watery solution. The stippled area around the vacuole is the protoplasm. Around the protoplasm is the cell wall, which consists of cellulose. The oval area at top is the nucleus.



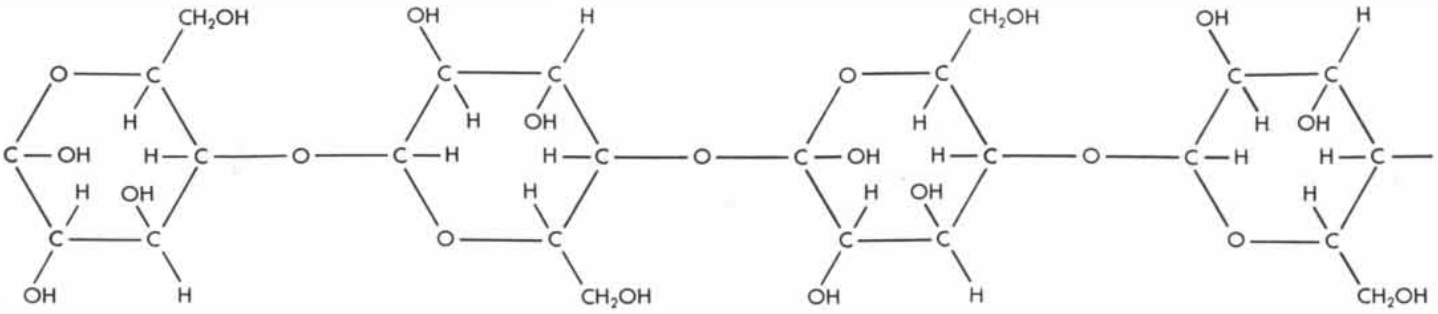
STRUCTURAL FORMULA of a molecule of the simple sugar glucose is given at left. In the molecule of cellulose thousands of these monomers are joined (with the loss of water) in a continuous chain, a short segment of which is given at right. The carbon at-

tremely thin layers. The layers can be stripped apart, and they are thin enough to be penetrated by the electron beam in an electron microscope. It has therefore been possible to obtain some beautiful pictures of the structure of the sheets, plainly showing the microfibrils [*see electron micrograph below*]. Not only are the threads very obvious, but they can be seen to form a crossed pattern: the fibrils in successive layers lie almost at right angles to one another. Nature practiced weaving long before man, but we are still in the dark as to the nature of the "loom" by which the walls of a plant cell achieve their fine and accurate weaving.

The microfibrils of cellulose have themselves been studied intensively by the method of X-ray analysis, and the X-ray diffraction pictures [*see page 160*] show that they too have a regular structure. They are, in fact, crystals. It may seem strange to describe fibers (the fibers of a rayon stocking, for instance) as crystalline, for they certainly do not have the flat, polished faces or sharp edges commonly characteristic of crystals. But the definition of a crystal is that its atoms or molecules form a regular, repetitive



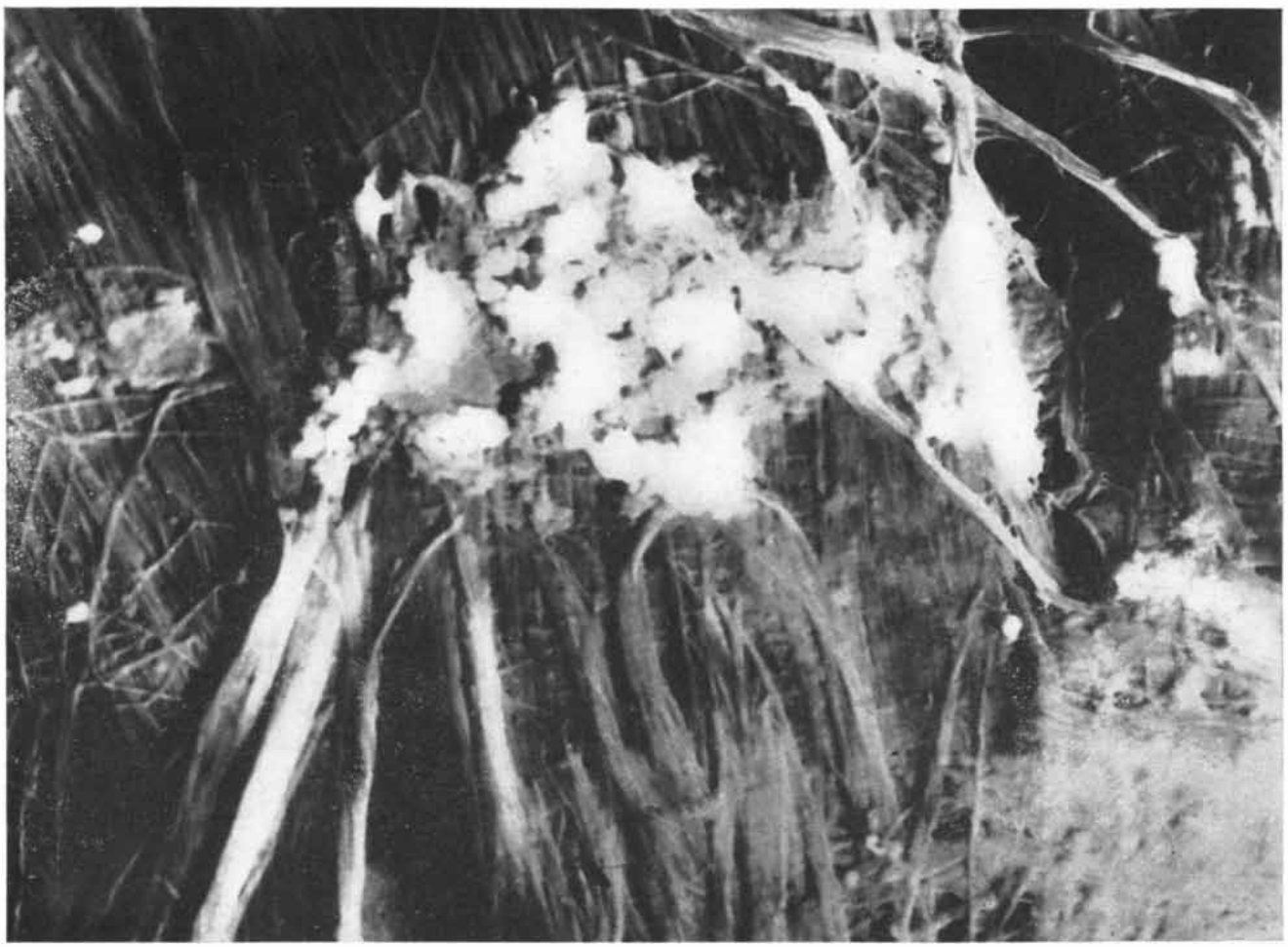
THREADS OF CELLULOSE in the cell wall of the seaweed *Valonia* are enlarged 21,000 diameters in this electron micrograph. These so-called microfibrils, which are from 100 to 200 Angstroms in diameter, lie at right angles to each other in alternate layers.



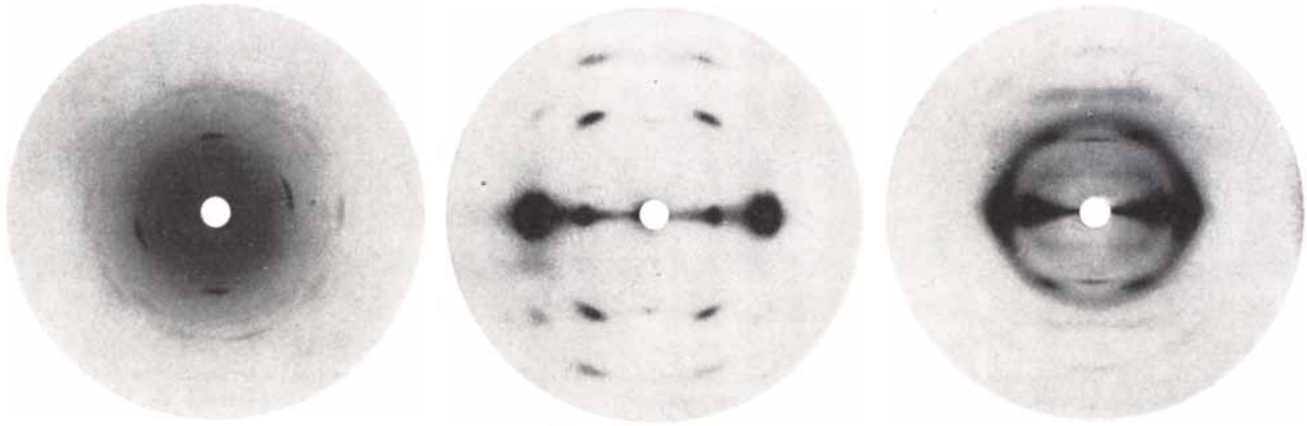
oms of the glucose molecule and the first two units of the cellulose chain are numbered from 1 to 6. In the cellulose chain, carbon atom 1 is joined to carbon atom 4 by an oxygen atom, resulting in a regular alternation in the orientation of the glucose units.

arrangement in space, and the internal arrangement of the molecules in cellulose fulfills this definition—as does that of other natural fibers such as hair. An X-ray diagram of a bundle of cellulose microfibrils demonstrates not only that they have a regular structure but also that the cellulose molecules are long chains lying parallel to one another. It also explains why cellulose is insoluble in water. The molecules, lying side by side, are so close together that their hydroxyl groups are united by hydrogen bonds. This is a very weak type of bond, but there are so many such bonds along the immense length of the cellulose chains that the sum total of the energy binding them together is great enough to prevent their separation (and solution) by water. Furthermore, the force binding the chains together accounts for the fact that cellulose does not melt when heated.

This, then, is a general picture of the molecular architecture of cellulose. Let us now take a look at the arrangement of cellulose in the structure of plant cell walls. A typical example is furnished by a wood, such as pitch pine,

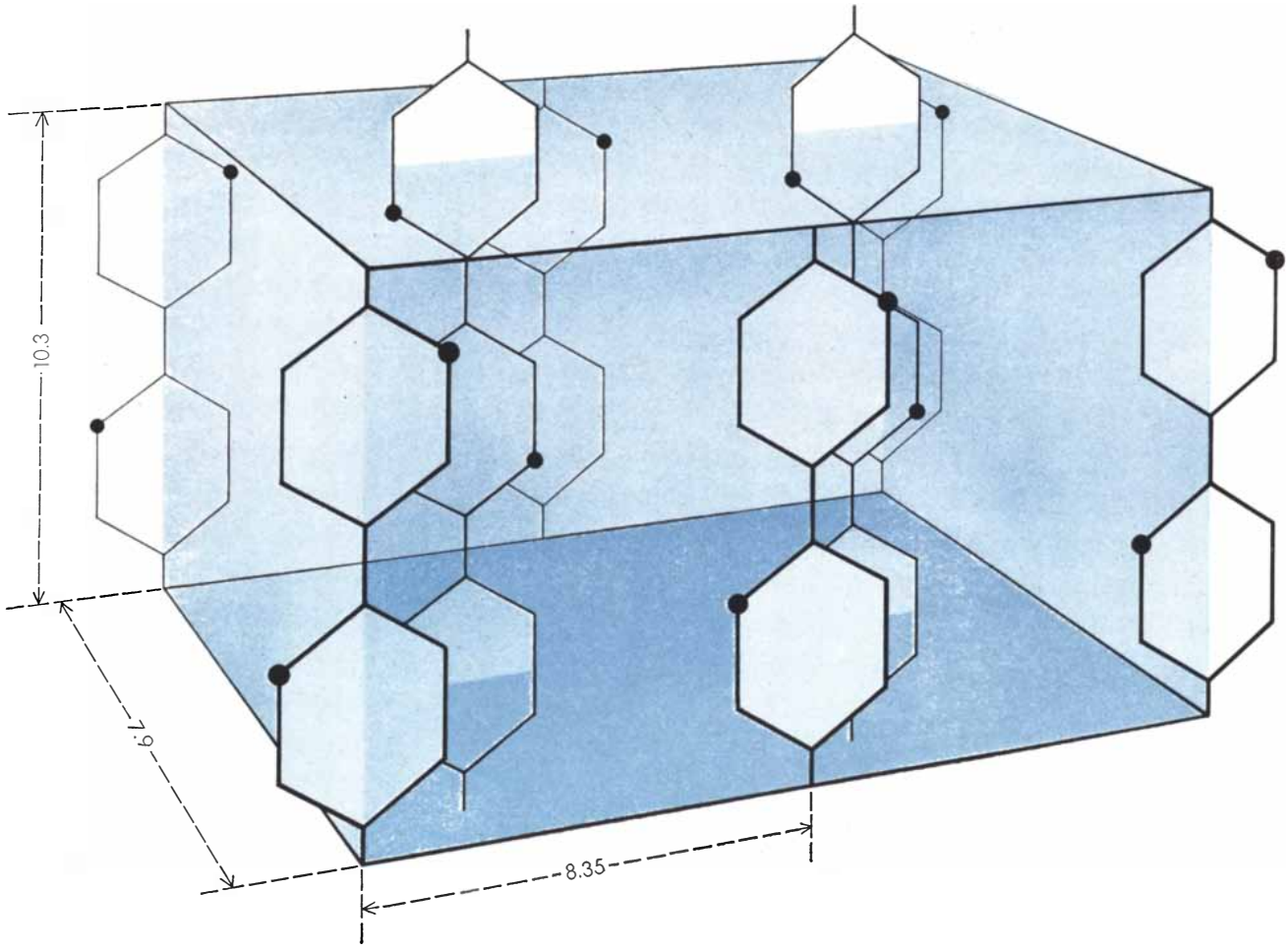


THREADS APPEAR TO GROW out of masses of granular material in this electron micrograph of the *Valonia* cell wall from the inside. The granular material may be the part of the protoplasm in which the cellulose molecules of the microfibrils are synthesized.



X-RAY DIFFRACTION PATTERNS indicate the crystallinity of cellulose in *Valonia* (*left*), wood (*center*) and rayon (*right*). Although the cellulose in all three of these materials is chemically identical, its arrangement in their crystals is somewhat different.

which is made up of long, cylindrical cells. During its period of growth the cell has a very thin, delicate wall. When the cell stops growing, the protoplasm inside it proceeds to thicken the wall by laying down three more internal layers. We can see this structure if we break the wood down into individual cells by immersing some shavings in dilute chromic acid. With a polarizing microscope and an electron microscope we can make out the orientation of the cellulose microfibrils in these layers. In the outermost (original) layer the fibrils tend to run right around the cell, *i.e.*, transversely to its lengthwise direction. In the three inner layers they run at an angle—in other words, they spiral around the cell [*see diagram on page 162*]. The spiral is rather steep in the middle one of the three inner layers and flatter in the

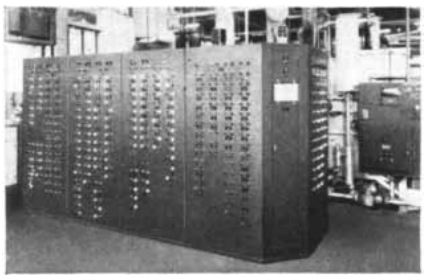


CRYSTAL OF CELLULOSE has this structure. The hexagons correspond to the rings of atoms in the formulas on the preceding two pages. The ball at the corner of each hexagon corresponds to the oxygen atom in the ring. The dimensions are given in Angstroms.

Surface Reports on metal treating

automation at 2200° F

In this age of miracles, high speed production lines with automatic transfer, metal removal, and gaging operations are pretty much taken for granted. Somewhat more novel—but further along than is generally known—is the complete integration of heat treating processes into automated lines. The high temperatures involved present special challenges, the central problem being reliability. Large dollar volumes of product may be in process at one time and interruption of heating cycles can be very costly.



Yet in many plants Surface Combustion has helped to take the furnaces out of the heat treat department and put them "on the line," with improved control of end product quality and high returns on the investment.

Surface mechanized the first batch type furnace a generation ago, and has since developed materials handling techniques, controls, and automatically controlled atmospheres especially adapted to processing requirements at high temperatures.

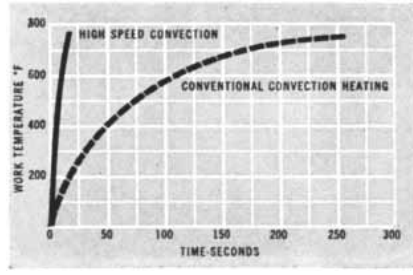
As an example, one automated line for bearing races integrates press forming, machining, annealing, washing, carburizing, and grinding operations. It includes four furnaces through which work moves continuously, protected by controlled atmospheres which insure uniformly high metallurgical specifications. An abundance of technical articles on the subject is available in the Surface files. We invite you to write us for authoritative information on almost any phase of automated heat treating.

new concept–new word

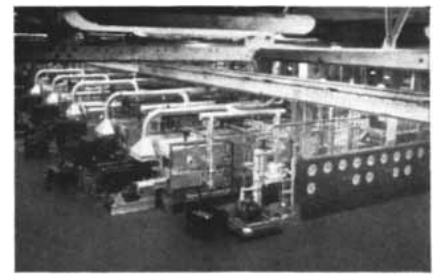
"Super-convection" is the word we coined to describe a new application of a heat transfer technique for heat treating.

Much heat treatment is done simply by raising work temperature in a furnace essentially by soaking or baking. In response to the need for greater speeds, several years ago Surface began experiments in "high thermal-head" heating which elevates air temperatures in the furnaces as high as 2700° F, and conveys parts through the furnace with split second timing. We were able, for instance to stress relieve long steel tubes, moving at 120 feet per minute—and raise their temperature to 650° F in only six seconds.

The latest advance in high speed heat treatment is shown in the chart below. Not only is air raised to very high temperatures: blowers are added to increase the speed of heat transfer to the parts in process, in this case, aluminum billets.



Super-convection is especially desirable in heat treating aluminum and other light metal parts, whose reflectivity makes processing with radiant heat difficult. We invite you to ask for literature or case histories on this important subject.



right atmosphere– for bringing up steel

Modern metallurgy has brightened—not dulled—the magic of carbon in upgrading steel quality. Here for instance are five fully automatic case carburizing furnaces (made by Surface) which provide pin-point control of carbon potential in the atmospheres. Thus a major implement producer is able to pin-point the hardness values and gradients of a great variety of parts—many sizes and many different alloys. The operator presets the desired carbon potential to reduce, maintain, or increase the carbon content of the parts and can program almost any temperature cycle through zone control in the furnaces.

Heat treating equipment for ferrous and non-ferrous metals is just one facet of Surface's many sided organization.

For further information on any phase of heat treating or other Surface services, write Surface Combustion Corporation, 2391 Dorr Street, Toledo 1, Ohio. In Canada: Surface Industrial Furnaces, Ltd., Toronto, Ontario.

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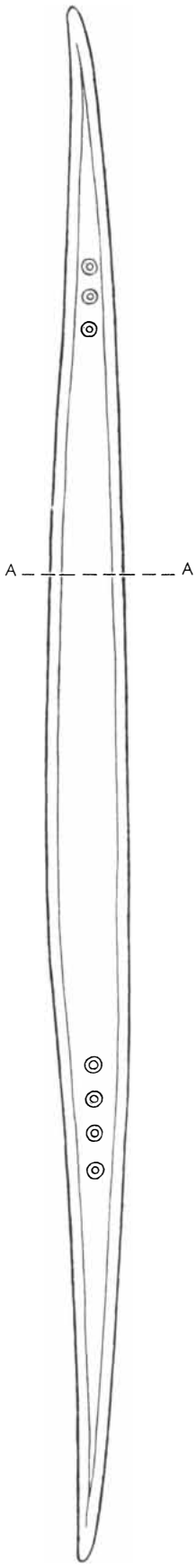
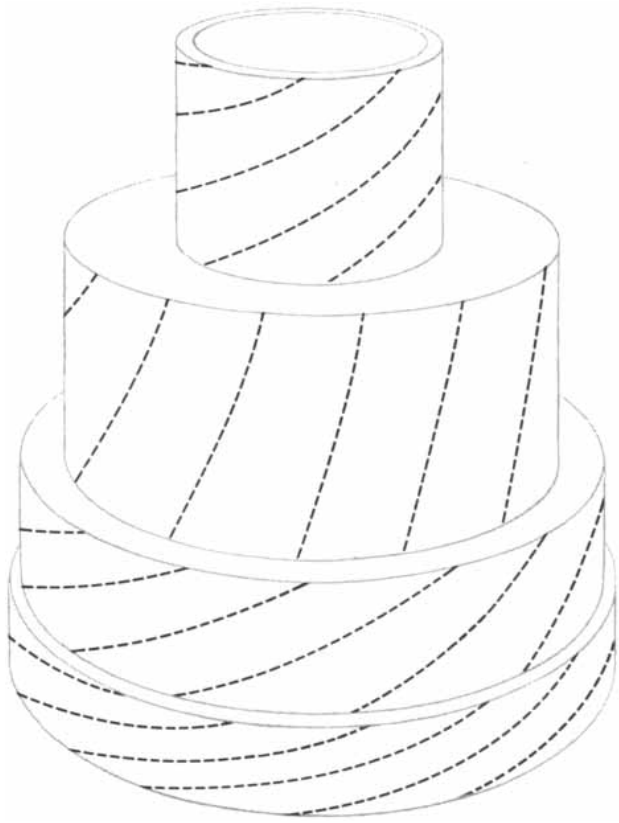


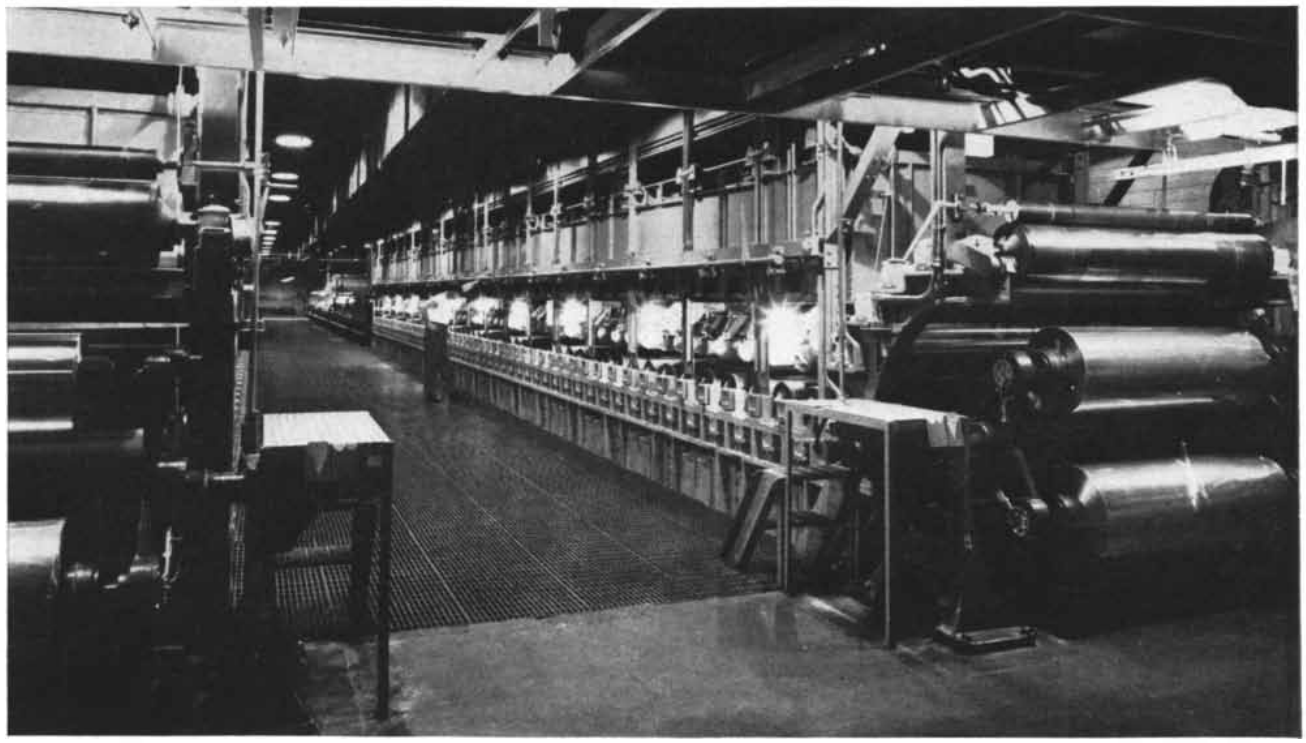
others. It can be seen that this type of framework makes the cells flexible as well as strong and gives to timber many of its remarkable properties. The spirals are normally held together by lignin, the filling in the cell walls that confers hardness on wood. When a timber is short on lignin, it becomes very springy: when apple trees are infected by a virus which causes a breakdown in lignin formation, their branches may be so "rubbery" that they spring back like a fishing rod after they are bent.

This appears to be the basic cell plan of all vegetable fibers—wood, bamboo, jute, hemp, sisal and so on. But there are variations. The cotton cell, for example, has several peculiarities. The cell grows as a hair from a fertilized seed in the flower. For about the first 20 days the thin-walled cell elongates; then it stops growing lengthwise and the wall proceeds to thicken. This goes on for 20 to 40 days; each day the cell lays down a new sheet, or layer, in the wall. Except for the larger number of layers, this follows the same basic plan as the growth of wood cells. But the spiraling microfibrils of cotton develop an odd twist. In



TUBULAR CELL OF A PINE TREE is much shortened in the diagram at left. The small circles are the "pits" described on page 156. At right is an enlarged diagram of the section A-A. The wall of the cell is divided into four layers, in each of which cellulose chains are arranged in parallel helixes (*broken lines*). The pitch of the helix varies with the layer.

CELLULOSE IS PREPARED from wood for the manufacture of fibers, films and other artificial materials by breaking down logs into wood pulp. This is the pulp mill of the Canadian Chemical and Cellulose Company, Ltd., in Prince Rupert, British Columbia.



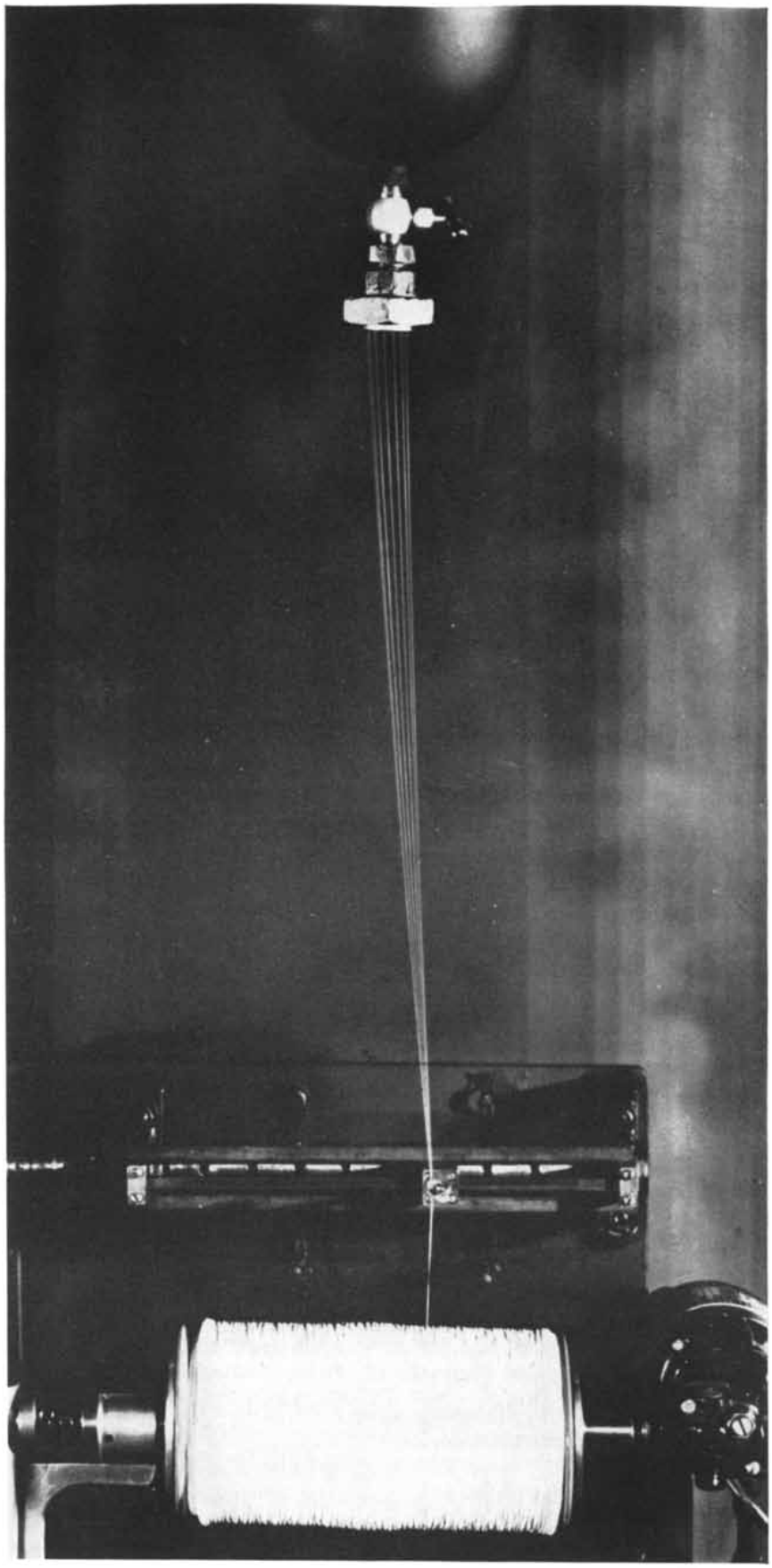
CELLULOSE IS CAST into cellophane in a Richmond, Va., plant of E. I. du Pont de Nemours & Company. Cellulose enters one end of this 200-foot-long casting machine in solution and emerges in rolls of dry, shiny film. The film is now further processed.

the layers where they spiral steeply, they may run in the right-handed direction for a short distance and then suddenly switch over and spiral in the left-handed sense. Indeed the whole structure is much as though the hair were made up of short cells piled on one another (as in fact is the case in some wild cotton plants). Just why the cell develops this structure is not known. In any case, the great length of the cell and its spiral texture make for an easily handled, strong yet flexible fiber with good wearing qualities. Moreover, cotton cells are remarkably rich in cellulose—which constitutes as much as 95 per cent of their walls—so that they furnish an excellent source of this substance.

The water plants known as algae, which have been a subject of intense study in our laboratory over the past few years, generally seem to have a somewhat different form of cellulose from that in the higher plants. But the seaweed Valonia and a few other algae have precisely the same cellulose as wood. Valonia cellulose is, however, more regular in structure; indeed, it is the most highly crystalline and most accurately orientated of any known cellulose. Its cell wall consists of 70 per cent cellulose by weight. This, together with the well-oriented wall structure, obviously results in a wall designed to withstand high tension in all directions. Indeed, the plant needs such a wall, for the large cell, absorbing water by osmosis, has to withstand an internal hydrostatic pressure amounting to many tons of tension per square inch of wall section.

Even bacteria, still lower in the plant kingdom than the single-celled algae, produce cellulose. One of the species capable of doing so is *Acetobacter xylinum*, which grows in vinegar exposed to the air. Oddly enough, however, the cellulose of the bacterium forms outside the bacterial cell itself, apparently from materials synthesized inside the microbe and passed out into the surrounding medium. In a vinegar bottle this mass of cellulose can be seen as a scum on the surface of the liquid. Bacterial cellulose is the same as that of higher plants, but its microfibrils are arranged at random, because they have been produced in a liquid medium instead of on a rigid cell wall. These fibers can be tightly compacted, and hence make a thin, strong, finely porous filter paper.

Cellulose is by no means restricted to the plant kingdom: animals also produce it. It has long been known, for instance, that the envelope (tunic) of the sea squirt is cellulose. Tunicates like the sea



CELLULOSE IS SPUN into rayon in this demonstration apparatus of the Celanese Corporation of America. The vessel at the top contains liquid cellulose acetate. When the liquid emerges through tiny holes in a spinneret at the bottom of the vessel, it hardens into fiber.

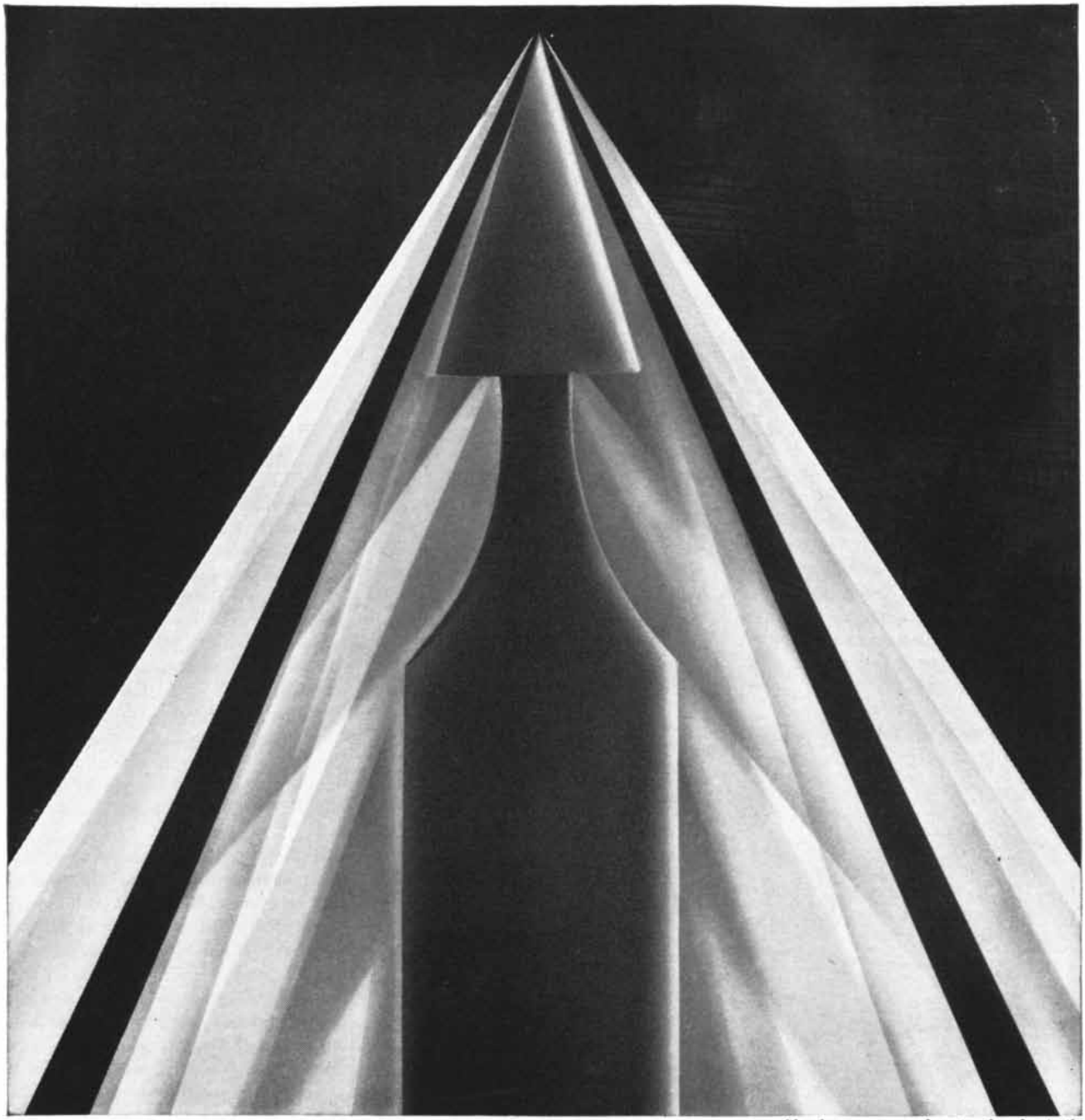
squirt make this "animal cellulose" (which is indistinguishable from plant cellulose) in rather large quantities; apparently many other animals produce small amounts of it. For instance, cellulose has recently been discovered in small quantities in the skin of animals, including man. The significance of its presence there is not yet known.

Now let us look at the uses of cellulose and its derivatives in industry. When treated with caustic soda, cellulose is transformed into a new crystalline form; this "mercerized" product (named after John Mercer, inventor of the process) is porous and shiny and is commonly called artificial silk. A later and now more popular method of converting cellulose to artificial silk involves dissolving the substance with an appropriate solvent and then reprecipitating it. In order to orient the molecules in fiber form, the viscous solution of cellulose is projected into the precipitating bath through a fine nozzle, and the extruded threads are stretched. The physical process is roughly comparable to combing out a mass of cotton wool to draw the threads of the cotton all in the same direction. The filaments can be drawn out to great length to make strong fibers. It is a remarkable fact that many seaweeds contain cellulose in this form or very like it. Nature had discovered mercerized cellulose long before Mercer himself!

Regenerated cellulose of this kind can be transformed into a number of derivatives, each with its own useful properties. In the viscose process, for instance, cellulose is treated with caustic soda and allowed to oxidize for a time in the air; then the material is squeezed and treated with carbon disulfide vapor. The product is spun into fibers to make the well-known viscose rayon. Its chemical composition is the same as that of cellulose except that sulfur has been added to a side chain.

When regenerated cellulose is treated with acetic acid (the acid in vinegar), it becomes cellulose acetate, a compound used for making photographic films, lacquers and many other products. Cellulose treated with nitric acid becomes nitrocellulose; this compound, in various degrees of nitration, can be used for photographic film (now unpopular because it is highly inflammable), for the coating of artificial leather and for guncotton for explosives.

It has thus far been impossible to synthesize cellulose in the laboratory without the intervention of a living plant. Indeed we must confess that we still



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know very little about how plants themselves make this remarkable material. During the past few years, however, some progress has been made toward understanding parts of the process. In the cell wall of the seaweed Valonia we observed granular masses of protoplasm in which the ends of microfibrils were embedded. The writer suggested that the microfibrils were spun out of this material, growing at the ends lying in the protoplasm. Recently a group of investigators in Canada, studying the formation of cellulose by cultures of the vinegar bacterium (*Acetobacter xylinum*), reported confirming evidence that microfibrils do indeed grow in this way; that is, it appears that the long fibers are built up by addition of cellulosic links to their ends, rather than by the aggregation into bundles of long molecular chains already preformed.

The vinegar bacterium has proved a particularly useful tool for studying the synthesis of cellulose. Shlomo Hestrin of the Hebrew University in Israel has demonstrated by tracer experiments with glucose labeled with radioactive carbon that cellulose is in fact formed from glucose, although it appears that under some conditions the glucose molecules are first broken down to smaller fragments and the latter are then assembled into cellulose. In general the synthesis of cellulose requires a continuous supply of oxygen.

Like any other biochemical process, the making of cellulose depends on help from enzymes, the catalysts of living organisms. S. Peat, a chemist at the University of Wales, has discovered that an enzyme called emulsin, extracted from bitter almonds, will cause a concentrated glucose solution to form cellobiose—a well-known compound consisting of two glucose molecules joined by precisely the same kind of linkage that forms the chain of glucose in cellulose. More recently M. Stacey and his collaborators at the University of Birmingham have built up cellobiose to cellotriose (*i.e.*, incorporating a third glucose molecule) by the use of a medium containing certain fungi. It is probable that progress toward the synthesis of cellulose *in vitro* will now be rapid. Indeed, while these lines are being written, Glenn A. Greathouse of the University of Florida has just announced that he has synthesized cellulose completely from glucose with the aid of a cell-free extract from the vinegar bacterium. If this result is solidly confirmed by further work, a great step has been taken toward solving the problem of how the giant molecule of cellulose is made.

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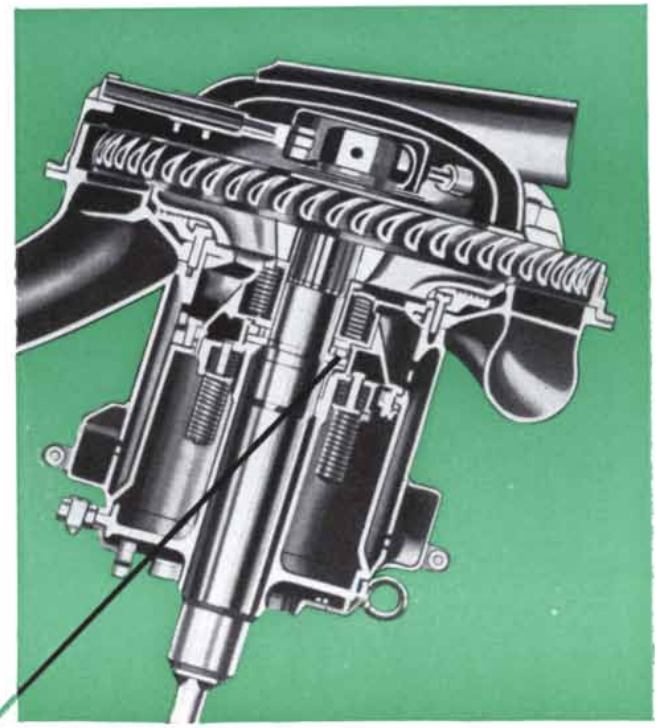
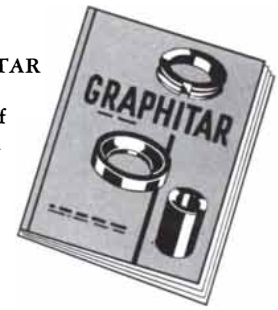


Get the fact-filled GRAPHITAR engineering Bulletin No. 20. Write today for your copy. If you have design questions on problems, our engineering staff will be happy to assist you in any way possible.



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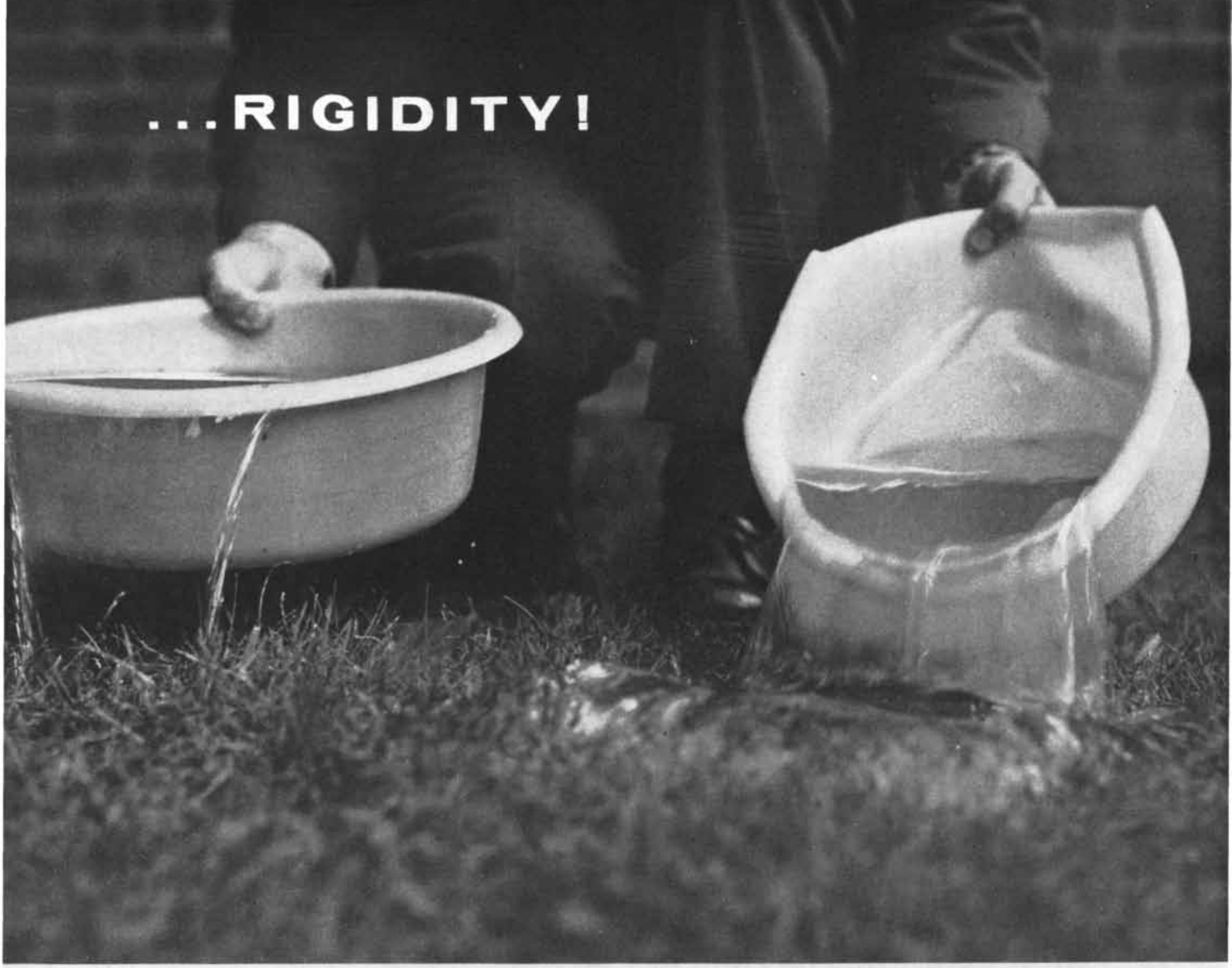

Test dishpans made from the same mold using conventional polyethylene and Fortiflex demonstrate the superior rigidity possessed by Fortiflex. The dishpans were placed on the ground, then filled with equal amounts of water. The tester attempted to lift each with one hand. The Fortiflex molded dishpan had the needed rigidity. The conventional polyethylene dishpan collapsed under the weight.

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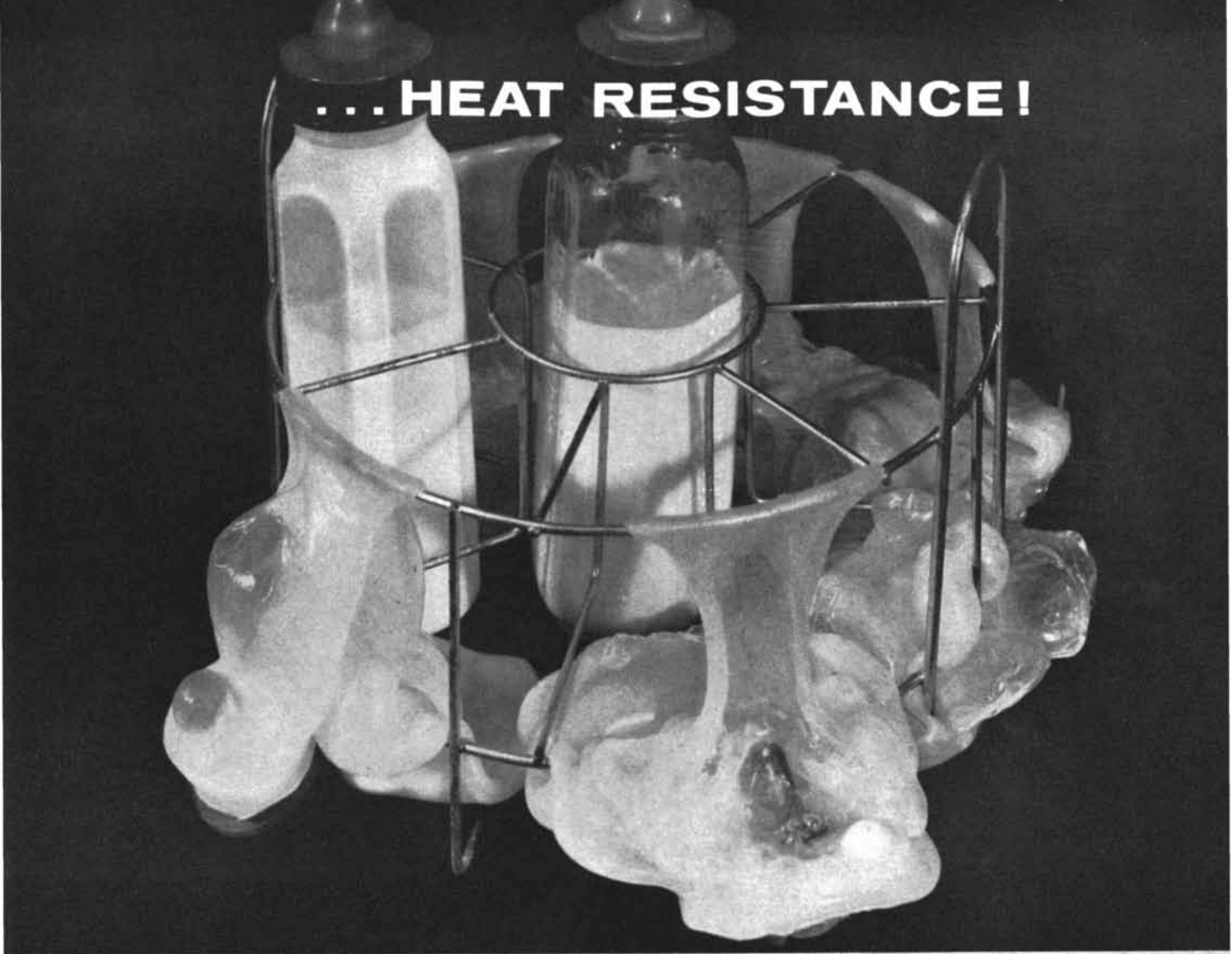

Laboratory test shows the effect of sterilization on standard molded nursing bottles made of conventional polyethylene, Fortiflex and glass. Only the glass bottle and Fortiflex bottle withstood the 15-minute test conducted at 15 psi, 250° F.

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These are the distinguishing characteristics of Celanese Fortiflex—the chief reasons why this new plastic is moving into areas of usefulness never before practical or even possible.

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Complete information can be obtained by writing the Sales Development Department, Plastics Division, Celanese Corporation of America, 290 Ferry Street, Newark 5, N. J. Or, by filling in and returning the coupon below. Celanese® Fortiflex®

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PROTEINS

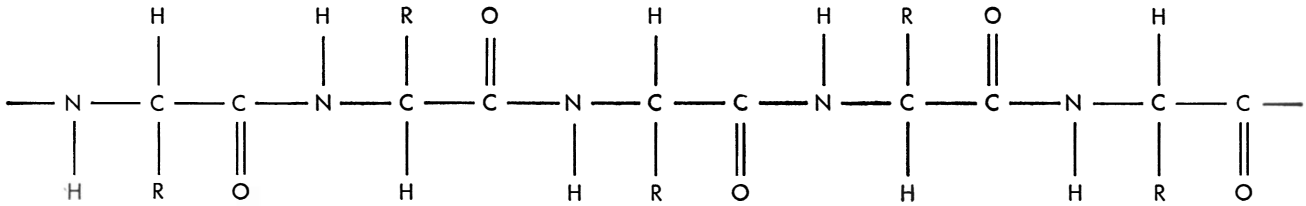
The principal substance of living cells, these giant molecules have identical backbones. Each is adapted to its specific task by a unique combination of side groups, size, folding and shape

by Paul Doty

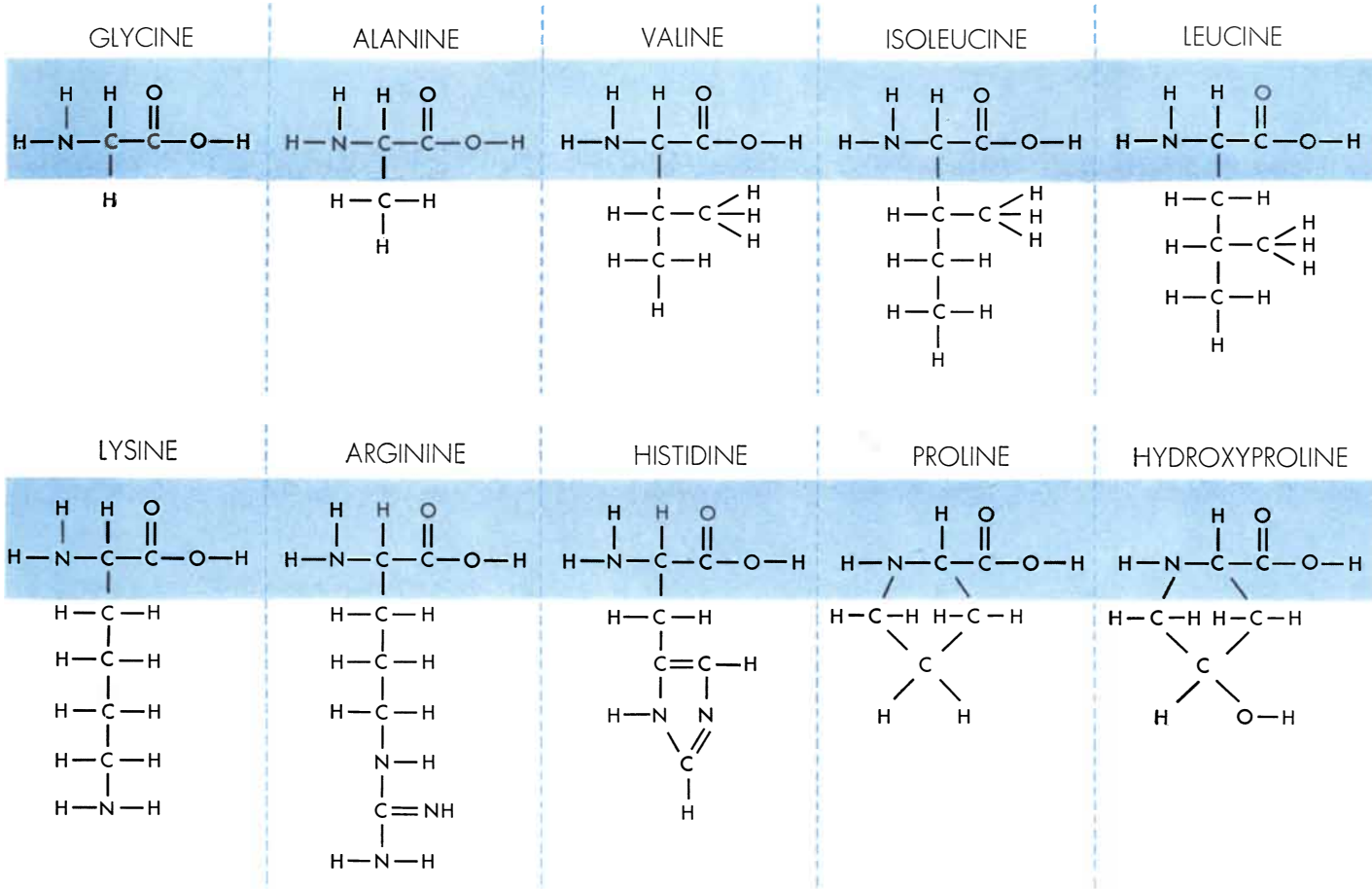
Thousands of different proteins go into the make-up of a living cell. They perform thousands of different acts in the exact sequence that causes the cell to live. How the proteins manage this exquisitely subtle and enormously involved process will defy our understanding for a long time to come. But in recent years we have begun to make a closer acquaintance with proteins themselves. We know they are giant molecules of great size, complexity and diversity. Each appears to be designed with high specificity for its particular task. We are encouraged by all that we are learning to seek the explanation of the function of proteins in a clearer picture of their structure. For much of this new understanding we are indebted to our experience with the considerably simpler giant molecules synthesized by man. High-polymer chemistry is now coming forward with answers to some of the pressing questions of biology.

Proteins, like synthetic high polymers, are chains of repeating units. The units are peptide groups, made up of the monomers called amino acids [*see diagram below*]. There are more than 20 different amino acids. Each has a distinguishing cluster of atoms as a side group [*see next two pages*], but all amino acids have a certain identical group. The linking of these groups forms the repeating peptide units in a "polypeptide" chain. Proteins are polypeptides of elaborate and very specific construction. Each kind of protein has a unique number and sequence of side groups which give it a particular size and chemical identity. Proteins seem to have a further distinction that sets them apart from other high polymers. The long chain of each protein is apparently folded in a unique configuration which it seems to maintain so long as it evidences biological activity.

We do not yet have a complete picture of the structure of any single protein. The entire sequence of amino acids has been worked out for insulin [see "The Insulin Molecule," by E. O. P. Thompson, SCIENTIFIC AMERICAN, May, 1955]; the determination of several more is nearing completion. But to locate each group and each atom in the configuration set up by the folded chain is intrinsically a more difficult task; it has resisted the Herculean labors of a generation of X-ray crystallographers and their collaborators. In the early 1930s W. T. Astbury of the University of Leeds succeeded in demonstrating that two X-ray diffraction patterns, which he called alpha and beta, were consistently associated with certain fibers, and he identified a third with collagen, the protein of skin, tendons and other structural tissues of the body. The beta pattern, found in the fibroin of silk, was soon shown to arise from bundles of nearly straight polypeptide chains held tightly to one another by hydrogen bonds. Nylon and some other synthetic fibers give a similar diffraction pattern. The alpha pattern resisted decoding until 1951, when Linus Pauling and R. B. Corey of the California Institute of Technology advanced the notion, since confirmed by further X-ray diffraction studies, that it is created by the twisting of the chain into a helix. Because it is set up so naturally by the hydrogen bonds available in the backbone of a polypeptide chain [*see top diagram on page 176*], the alpha helix was deduced to be a major structural element in the configuration of most proteins. More recently, in 1954, the Indian X-ray crystallographer G. N. Ramachandran showed that the collagen pattern comes from three polypeptide helixes twisted around one another. The resolution of these master plans was theoretically and esthetically gratifying, especially since the nucleic acids, the substance of genetic chemistry, were concurrently shown to have the structure of a double helix [*see following article*]. For all their apparent general validity, however, the master plans did not give us the complete configuration



POLYPEPTIDE CHAIN is a repeating structure made up of identical peptide groups (CCONHC). The chain is formed by amino acids, each of which contributes an identical group to the backbone plus a distinguishing radical (R) as a side group.



AMINO ACIDS, the 20 commonest of which are shown in this chart, have identical atomic groups (*in colored bands*) which react to form polypeptide chains. They are distinguished by their unique side groups. In forming a chain, the amino group (NH_2) of one

in three dimensions of any single protein.

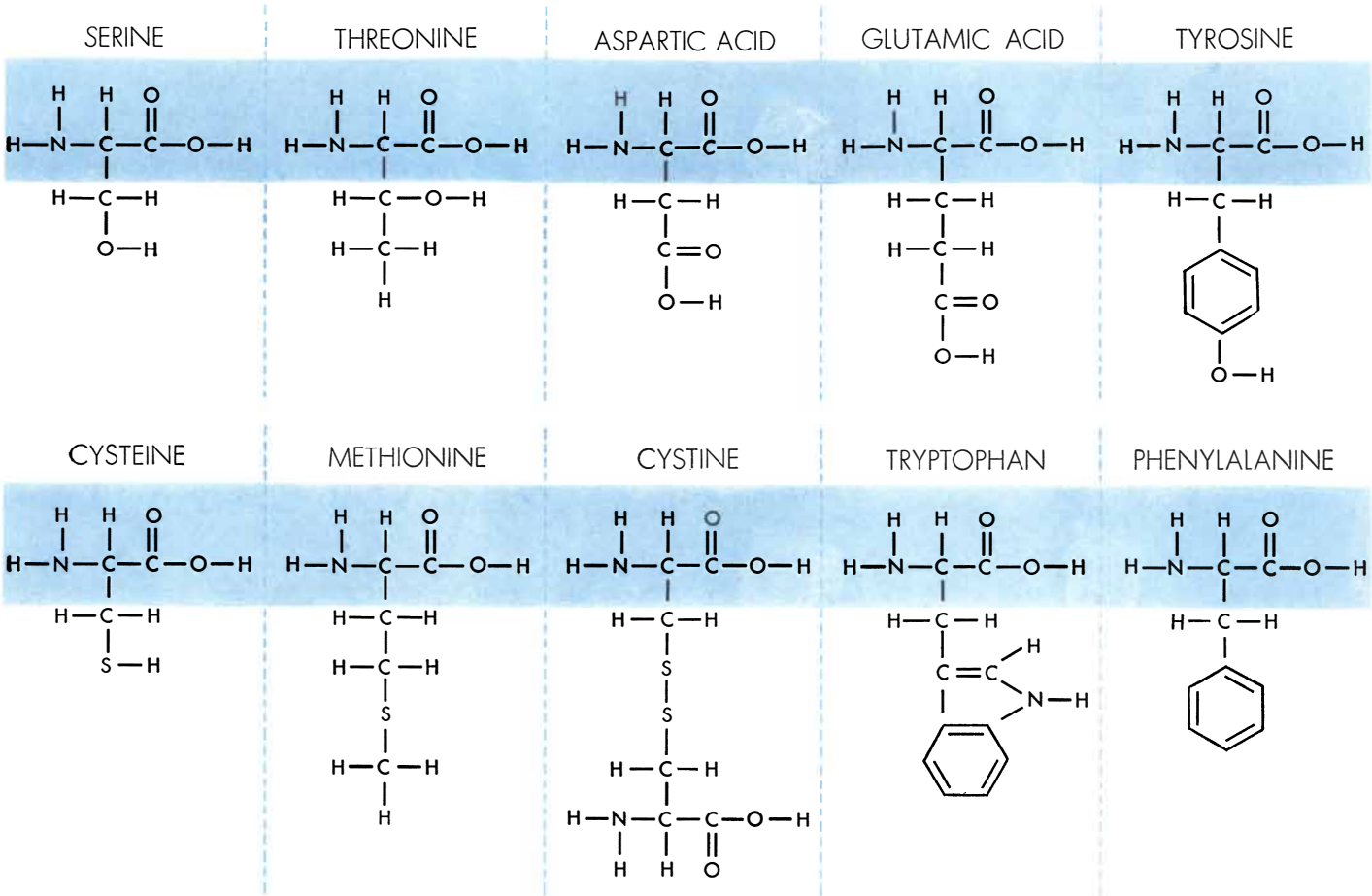
The X-ray diffraction work left a number of other questions up in the air. Since the alpha helix had been observed only in a few fibers, there was no solid experimental evidence for its existence elsewhere. There was even a suspicion that it could occur only in fibers, where it provides an economical way to pack polypeptides together in crystalline structures. Many proteins, especially chemically active ones such as the enzymes and antibodies, are globular, not linear like those involved in fibers and structural tissues. In the watery solutions which are the natural habitat of most proteins, it could be argued, the affinity of water molecules for hydrogen bonds would disrupt the alpha helix and reduce the chain to a random coil. These doubts and suppositions have prompted investigations by our group at Harvard University in collaboration with E. R. Blout of the Children's Cancer Research Foundation in Boston.

In these investigations we have employed synthetic polypeptides as laboratory models for the more complex and sensitive proteins. When Blout and coworkers had learned to polymerize them to sufficient length—100 to 1,000 amino acid units—we proceeded to observe their behavior in solution. For our measurements we employed the techniques described by Peter J. W. Debye [*see page 90*].

Almost at once we made the gratifying discovery that our synthetic polypeptides could keep their helical coils wound up in solutions. Moreover, we found that we could unwind the helix of some polypeptides by adjusting the acidity of our solutions. Finally, to complete the picture, we discovered that we could reverse the process and make the polypeptides wind up again from random coils into helixes.

The transition from the helix to the random coil occurs within a narrow range as the acidity is reduced; the hydrogen bonds, being equivalent, tend to let go all at once. It is not unlike the melting of an ice crystal, which takes place in a narrow temperature range. The reason is the same, for the ice crystal is held together by hydrogen bonds. To complete the analogy, the transition from the helix to the random coil can also be induced by heat. This is a true melting process, for the helix is a one-dimensional crystal which freezes the otherwise flexible chain into a rodlet.

From these experiments we conclude that polypeptides in solution have two natural configurations and make a reversible transition from one to the other, depending upon conditions. Polypeptides in the solid state appear to prefer the alpha helix, though this is subject to the presence of solvents, especially water. When the helix breaks down here, the transition is to the beta configuration, the hydrogen bonds now linking adjacent chains. Recently Blout and Henri Lenormant have found that fibers of polylysine can be made to undergo the



molecule reacts with the hydroxyl group (OH) of another. This reaction splits one of the amino hydrogens off with the hydroxyl group to form a molecule of water. The nitrogen of the first group then forms the peptide bond with the carbon of the second.

alpha-beta transition reversibly by mere alteration of humidity. It is tempting to speculate that a reversible alpha-beta transition may underlie the process of muscle contraction and other types of movement in living things.

Having learned to handle the polypeptides in solution we turned our attention to proteins. Two questions had to be answered first: Could we find the alpha helix in proteins in solution, and could we induce it to make the reversible transition to the random coil and back again? If the answer was yes in each case, then we could go on to a third and more interesting question: Could we show experimentally that biological activity depends upon configuration? On this question, our biologically neutral synthetic polypeptides could give no hint.

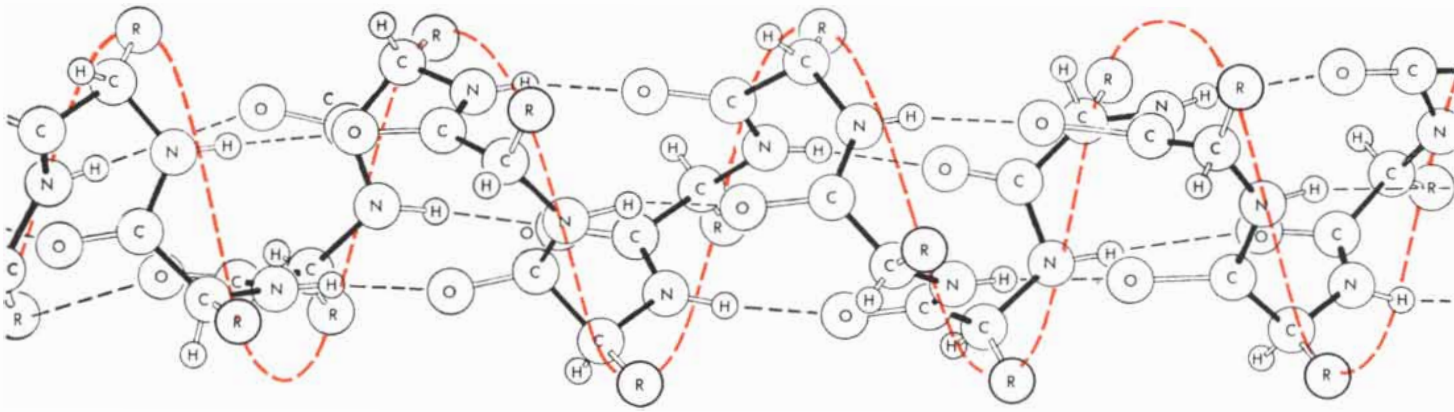
For the detection of the alpha helix in proteins the techniques which had worked so well on polypeptides were impotent. The polypeptides were either all helix or all random coil and the rodlets of the first could easily be distinguished from the globular forms of the second by use of the light-scattering technique. But we did not expect to find that any of the proteins we were going to investigate were 100 per cent helical in configuration. The helix is invariably disrupted by the presence of one of two types of amino acid units. Proline lacks the hydrogen atom that forms the crucial hydrogen bond; the side groups form a distorting linkage to the chain instead. Cystine is really a double unit, and forms more or less distorting cross-links between chains. These units play an important part in the intricate coiling and folding of the polypeptide chains in globular proteins. But even in globular proteins, we thought, some lengths of the chains might prove to be helical. There was nothing, however, in the over-all shape of a globular protein to tell us whether it had more or less helix in its structure or none at all. We had to find a way to look inside the protein.

One possible way to do this was suggested by the fact that intact, biologically active proteins and denatured proteins give different readings when observed for an effect called optical rotation. In general, the molecules that exhibit this effect are asymmetrical in atomic structure. The side groups give rise to such asymmetry in amino acids and polypeptide chains; they may be attached in either a "left-handed" or a "right-handed" manner. Optical rotation provides a way to distinguish one from the other. When a solution of amino acids is interposed in a beam of polarized light, it will rotate the plane of polarization either to the right or to the left [*see diagrams at top of page 178*] Though amino acids may exist in both forms, only left-handed units, thanks to some accident in the chemical phase of evolution, are found in proteins. We used only the left-handed forms, of course, in the synthesis of our polypeptide chains.

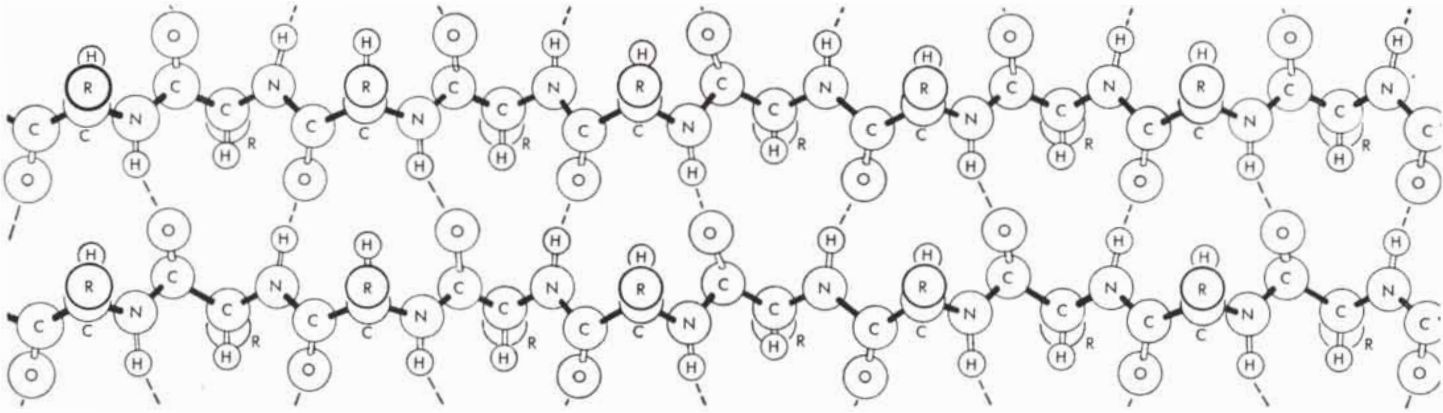
Now what about the change in optical rotation that occurs when a protein

is denatured? We knew that native protein rotates the plane of the light 30 to 60 degrees to the left, denatured protein 100 degrees or more to the left. If there was some helical structure in the protein, we surmised, this shift in rotation might be induced by the disappearance of the helical structure in the denaturation process. There was reason to believe that the helix, which has to be either left-handed or right-handed, would have optical activity. Further, although it appeared possible for the helix to be wound either way, there were grounds for assuming that nature had chosen to make all of its helixes one way or the other. If it had not, the left-handed and right-handed helixes would mutually cancel out their respective optical rotations. The change in the optical rotation of proteins with denaturation would then have some other explanation entirely, and we would have to invent another way to look for helixes.

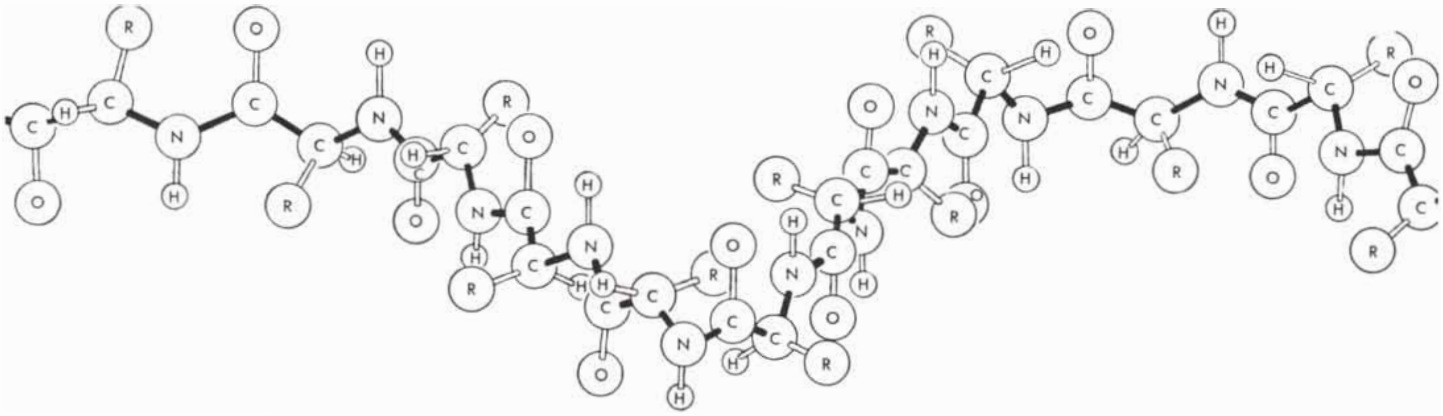
To test our surmise we measured the optical rotation of the synthetic polypeptides. In the random coil state the polypeptides made an excellent fit with the denatured proteins, rotating the light 100 degrees to the left. The rotations in



ALPHA HELIX gives a polypeptide chain a linear structure shown here in three-dimensional perspective. The atoms in the repeating unit (CCONHC) lie in a plane; the change in angle between one unit and the next occurs at the carbon to which the side group



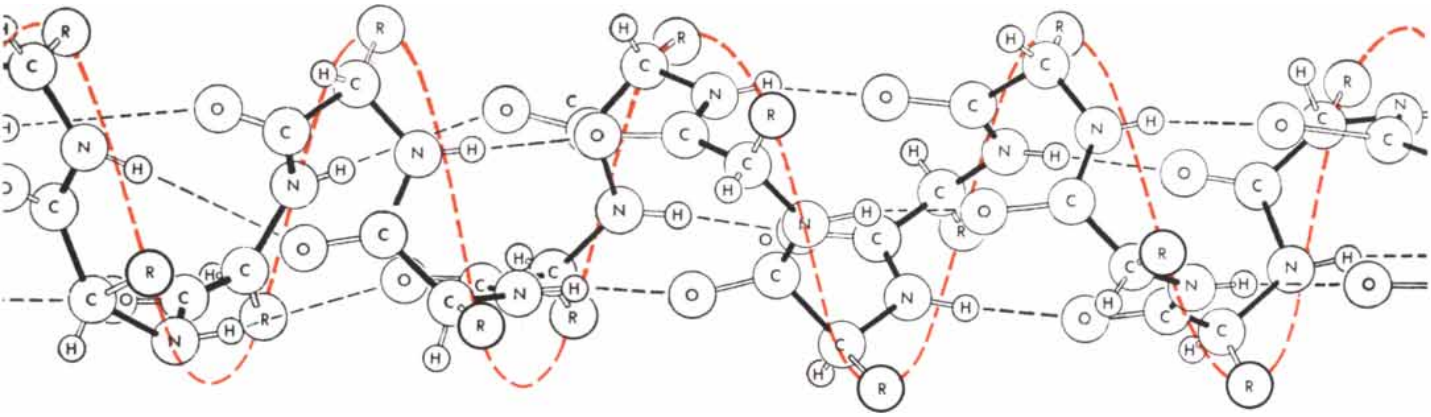
BETA CONFIGURATION ties two or more polypeptide chains to one another in crystalline structures. Here the hydrogen bonds do not contribute to the internal organization of the chain, as in the alpha helix, but link the hydrogen atoms of one chain to the oxygen



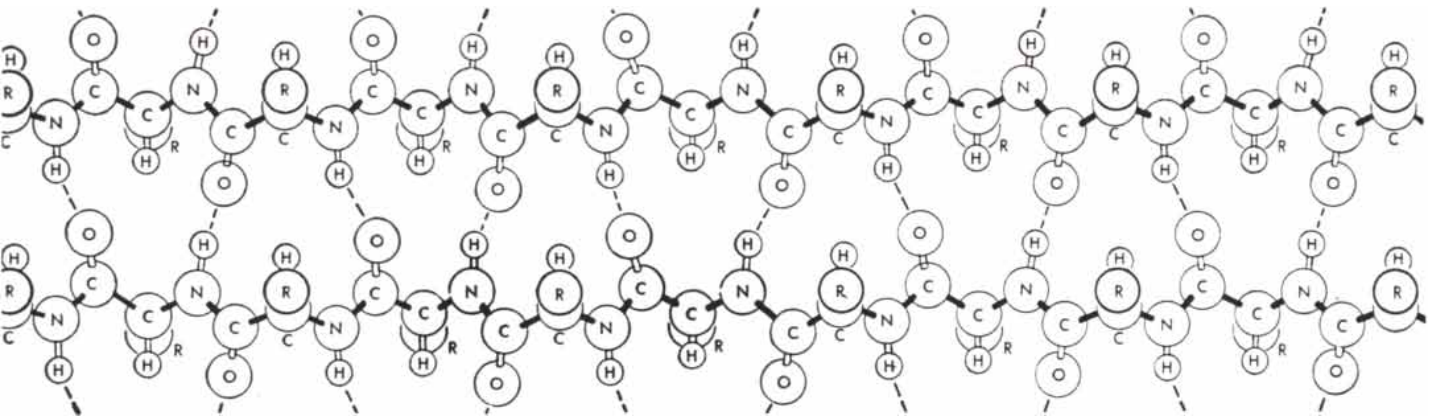
RANDOM CHAIN is the configuration assumed by the polypeptide molecule in solution, when hydrogen bonds are not formed. The flat configuration of the repeating unit remains, but the chain rotates about the carbon atoms to which the side groups are at-

both cases clearly arose from the same cause: the asymmetry of the amino acid units. In the alpha helix configuration the polypeptides showed almost no rotation or none at all. It was evident that the presence of the alpha helix caused a counter-rotation to the right which nearly canceled out the leftward rotation of the amino acid units. The native proteins also had shown evidence of such counter-rotation to the right. The alpha configuration did not completely cancel the leftward rotation of the amino acid units, but this was consistent with the expectation that the protein structures would be helical only in part. The experiment thus strongly indicated the presence of the alpha helix in the structure of globular proteins in solution. It also, incidentally, seemed to settle the question of nature's choice of symmetry in the alpha helix: it must be right-handed.

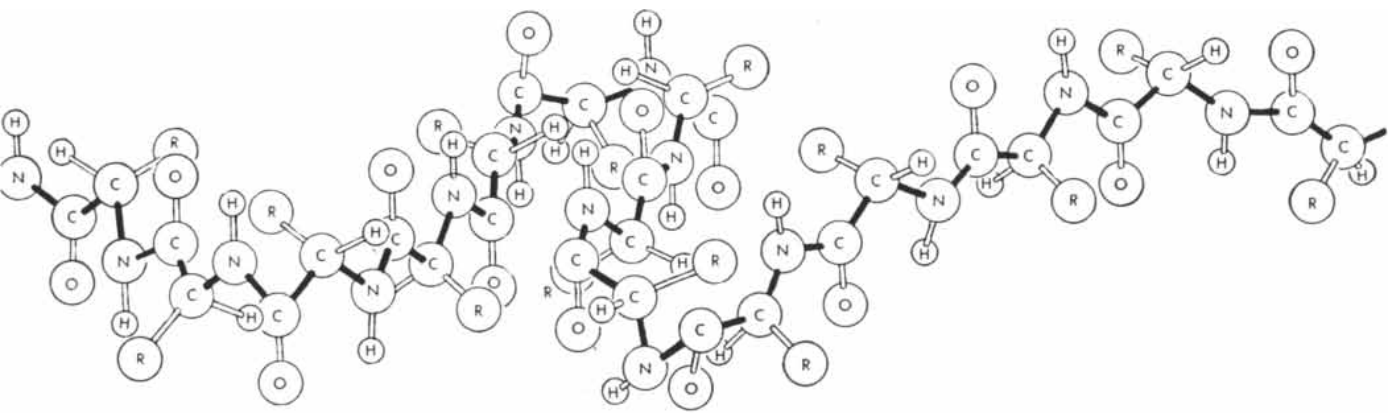
When so much hangs on the findings of one set of experiments, it is well to double check them by observations of another kind. We are indebted to William Moffitt, a theoretical chemist at Harvard, for conceiving of the experiment that provided the necessary confirmation. It is based upon another as-



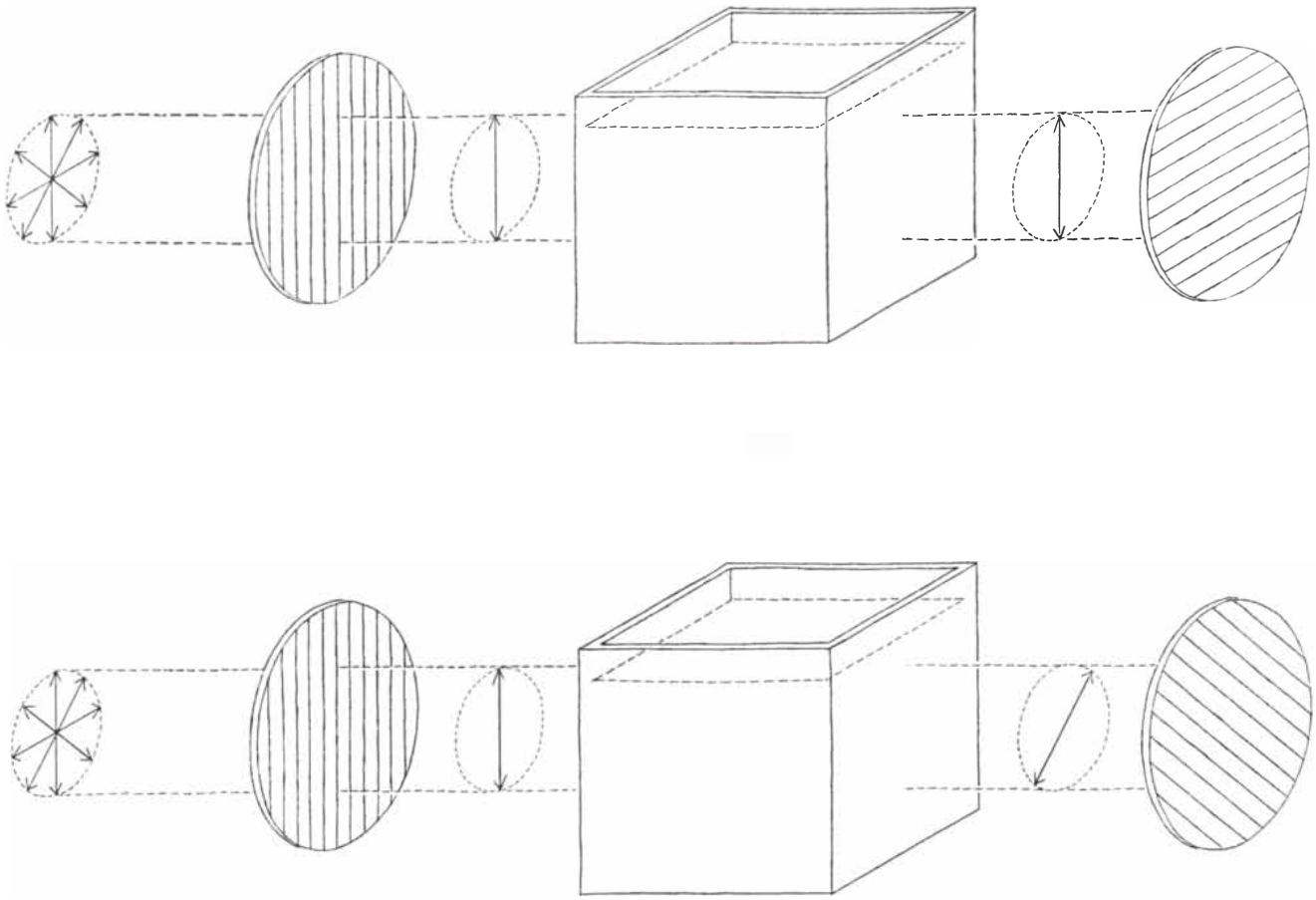
(R) is attached. The helix is held rigid by the hydrogen bond (*broken black lines*) between the hydrogen attached to the nitrogen in one group and the oxygen attached to a carbon three groups along the chain. The colored line traces the turns of the helix.



atoms in the adjoining chain. The beta configuration is found in silk and a few other fibers. It is also thought that polypeptide chains in muscle and other contractile fibers may make reversible transitions from alpha helix to beta configuration when in action.



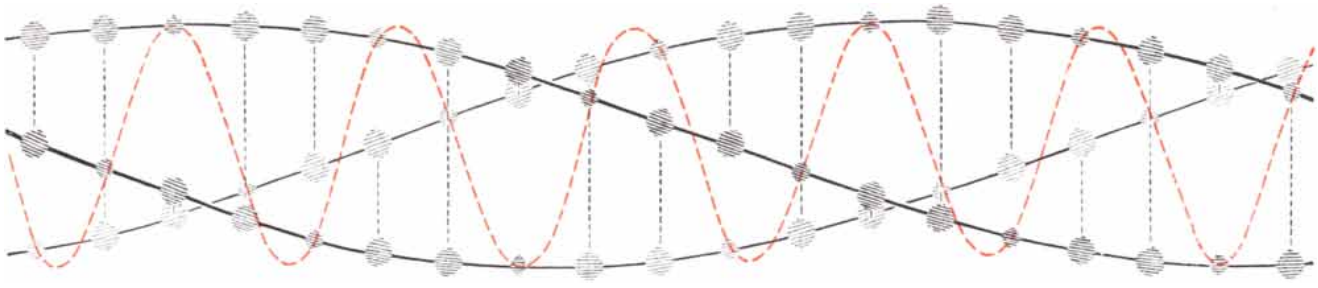
tached. The random chain may be formed from an alpha helix when hydrogen bonds are disrupted in solution. A polypeptide chain may make a reversible transition from alpha helix to random chain, depending upon the acid-base balance of the solution.



OPTICAL ROTATION is induced in a beam of polarized light by molecules having certain types of structural asymmetry. At top a beam of light is polarized in the vertical plane and transmitted unchanged through a neutral solution. At bottom asymmetrical molecules in the solution cause the beam to rotate from the vertical plane. The degree of rotation may be determined by turning the second polarizing filter (*right*) to the point at which it cuts off the beam. The alpha helix in a molecule causes such rotation.

pect of the optical rotation effect. For a given substance, rotation varies with the wavelength of the light; the rotations of most substances vary in the same way. Moffitt predicted that the presence of the alpha helix in a substance would cause its rotation to vary in a different way. His prediction was sustained by observation: randomly coiled polypeptides showed a normal variation while the helical showed abnormal. Denatured and native proteins showed the same contrast. With the two sets of experiments in such good agreement, we could conclude with confidence that the alpha helix has a significant place in the structure of globular proteins. Those amino acid units that are not involved in helical configurations are weakly bonded to each other or to water molecules, probably in a unique but not regular or periodic fashion. Like synthetic high-polymers, proteins are partly crystalline and partly amorphous in structure.

The optical rotation experiments also provided a scale for estimating the helical content of protein. The measurements indicate that, in neutral solutions, the helical structure applies to 15 per cent of the amino acid units in ribonuclease, 50 per cent of the units in serum albumin and 85 per cent in tropomyosin. With the addition of denaturing agents to the solution, the helical content in each case can be reduced to zero. In some proteins the transition is abrupt, as it is in the synthetic polypeptides. On the other hand, by the use of certain solvents we have been able to increase the helical content of some proteins—in the case of ribonuclease from 15 to 70



COLLAGEN MOLECULE is a triple helix. The colored broken line indicates hydrogen bonds between glycine units. The black broken lines indicate hydrogen bonds which link hydroxyproline units and give greater stability to collagens in which they are found.

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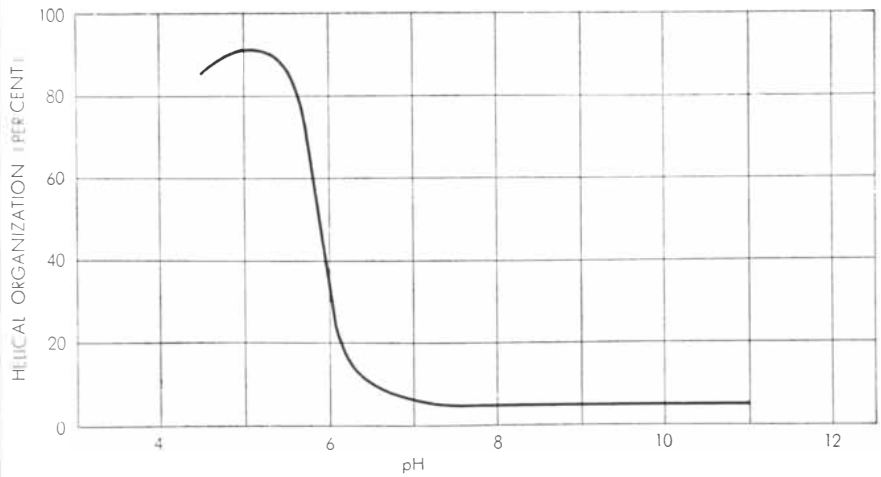
per cent. As in the polypeptides, the transition from helix to random coil is reversible. The percentage of helical structure in proteins is thus clearly a variable. In their natural environment, it appears, the percentage at any given time represents the equilibrium between the inherent stability of the helix and the tendency of water to break it down.

In a number of enzymes we have been able to show that biological activity falls off and increases with helical content. Denaturation is now clearly identified with breakdown of configuration, certainly insofar as it involves the integrity of the alpha helix. This is not surprising. It is known that catalysts in general must have rigid geometrical configurations. The catalytic activity of an enzyme may well require that its structure meet similar specifications. If this is so, the rigidity that the alpha helix imposes on the otherwise flexible polypeptide chain must play a decisive part in establishing the biological activity of an enzyme. It seems also that adjustability of the stiffness of structure in larger or smaller regions of the polypeptide chain may modify the activity of proteins in response to their environment. Among other things, it could account for the versatility of the gamma globulins; without any apparent change in their amino acid make-up, they are able somehow to adapt themselves as antibodies to a succession of different infectious agents.

The next step toward a complete anatomy of the protein molecule is to determine which amino acid units are in the helical and which in the nonhelical regions. Beyond that we shall want to know which units are near one another as the result of folding and cross-linking, and a myriad of other details which will supply the hues and colorings appropriate to a portrait of an entity as intricate as protein. Many such details will undoubtedly be supplied by experiments that relate change in structure to change in function, like those described here.

In the course of our experiments with proteins in solution we have also looked into the triple-strand structure of collagen. That structure had not yet been resolved when we began our work, so we did not know how well it was designed for the function it serves in structural tissues. Collagen makes up one third of the proteins in the body and 5 per cent of its total weight. As can be seen in the electron micrographs that illustrate the article by Francis O. Schmitt [*see page 204*], it occurs as tiny fibers or fibrils with bonds that repeat at intervals of about 700 Angstroms. It had been known for a long time that these fibrils could be dissolved in mild solvents such as acetic acid and then reconstituted, by simple precipitation, into their original form with their bandings restored. This remarkable capacity naturally suggested that the behavior of collagen in solution was a subject worth exploring.

Starting from the groundwork of other investigators, Helga Boedtker and I were able to demonstrate that the collagen molecule is an extremely long and thin rodlet, the most asymmetric molecule yet isolated. A lead pencil of comparable proportions would be a yard long. When a solution of collagen is just slightly warmed, these rodlets are irreversibly broken down. The solution will gel, but the product is gelatin, as is well known to French chefs and commercial producers of gelatin. The reason the dissolution cannot be reversed was made clear when



ALPHA HELIX BREAKDOWN is induced in solutions of some polypeptides when the pH (acidity or alkalinity) reaches a critical value at which hydrogen bonds are disrupted.

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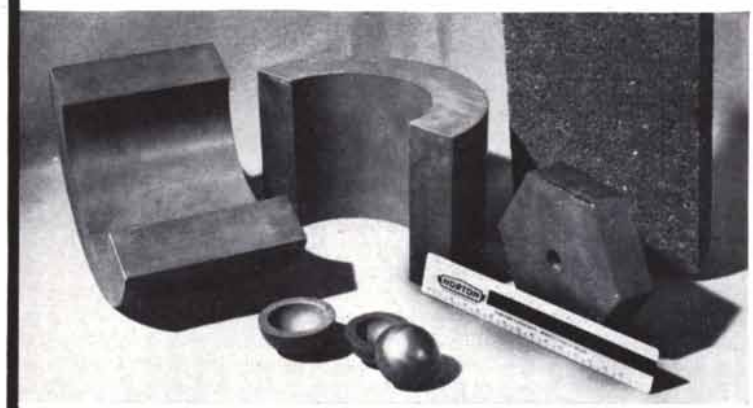

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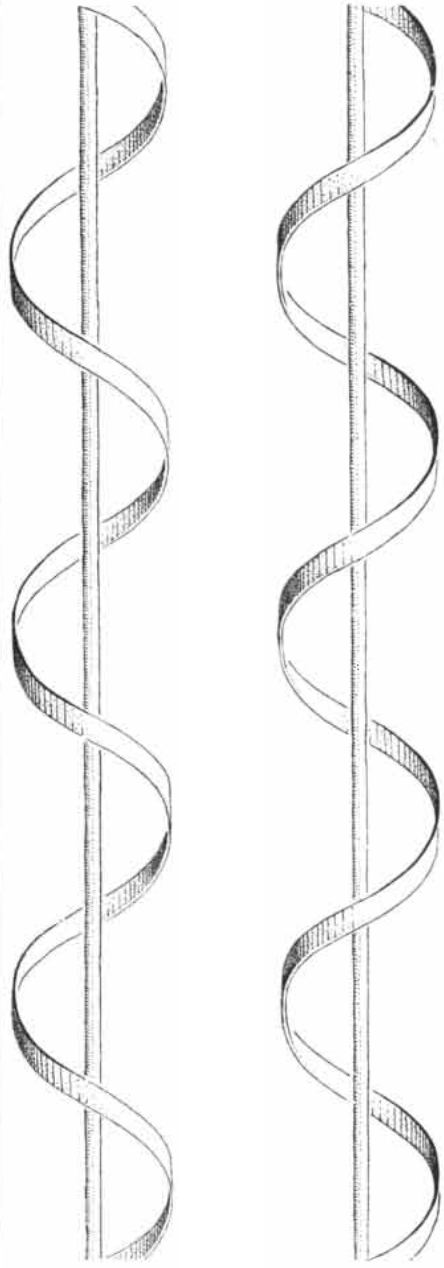
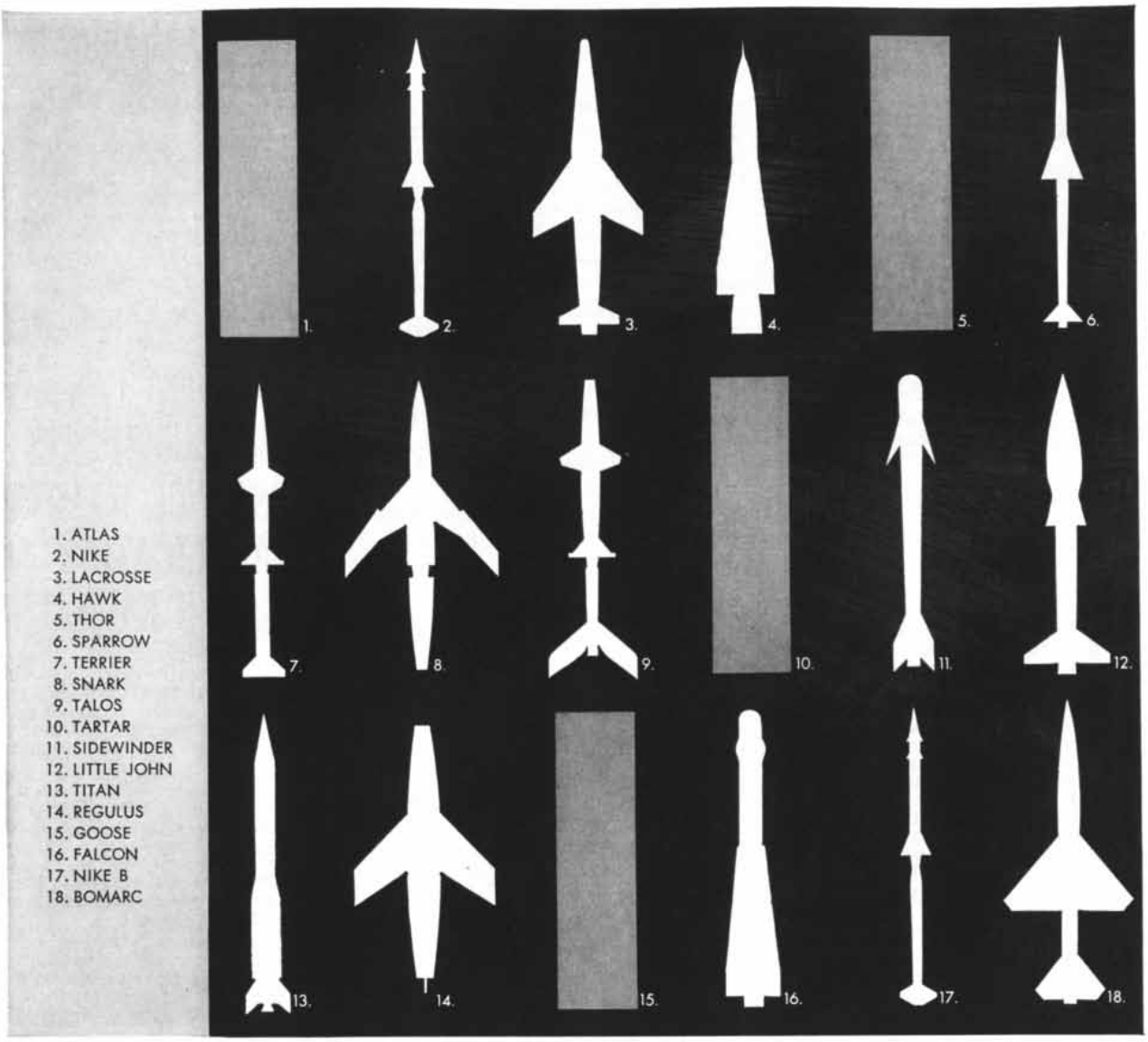


ASYMMETRY of a helix is either left-handed (*left*) or right-handed. Helix in proteins appears to be exclusively right-handed.

we found that the molecules in the warmed-up solution had a weight about one third that of collagen. It appeared that the big molecule of collagen had broken down into three polypeptide chains.

At about the same time Ramachandran proposed the three-strand helix as the collagen structure. Not long afterward F. H. C. Crick and Alexander Rich at the University of Cambridge and Pauline M. Cowan and her collaborators at King's College, London, worked out the structure in detail. It consists of three polypeptide chains, each incorporating three different amino acid units—pro-



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line, hydroxyproline and glycine. The key to the design is the occurrence of glycine, the smallest amino acid unit, at every third position on each chain. This makes it possible for the bulky proline or hydroxyproline groups to fit into the links of the triple strand, two of these nesting in each link with the smaller glycine unit [*see diagram on page 178*].

One question, however, was left open in the original model. Hydroxyproline has surplus hydrogen bonds, which, the model showed, might be employed to reinforce the molecule itself or to tie it more firmly to neighboring molecules in a fibril. Independent evidence seemed to favor the second possibility. Collagen in the skin is irreversibly broken down in a first degree burn, for example, at a temperature of about 145 degrees Fahrenheit. This is about 60 degrees higher than the dissolution temperature of the collagen molecule in solution. The obvious inference was that hydroxyproline lends its additional bonding power to the tissue structure. Moreover, tissues with a high hydroxyproline content withstand higher temperatures than those with lower; the skin of codfish, with a low hydroxyproline content, shrivels up at about 100 degrees. Tomio Nishihara in our laboratory has compared the breakdown temperatures of collagen molecules and tissues from various species and found that the tissue temperature is uniformly about 60 degrees higher. Thus we must conclude that the extra stability conferred by hydroxyproline goes directly to the molecule and not to the fibril.

The structure of collagen demonstrates three levels in the adaptation of polypeptide chains to fit the requirements of function. First there are the chains as found in gelatin, with their three amino acids lined up in just the right sequence. These randomly coiled and quite soluble molecules are transformed into relatively insoluble, girder-like building units when united into sets of three by hydrogen bonds. The subtly fashioned collagen molecules are still too fragile to withstand body temperatures. When arranged side by side, however, they form a crystalline structure which resists comparatively high temperatures and has fiber-like qualities with the vast range of strengths and textures required in the different types of tissues that are made of collagen.

The story of collagen, like that of other proteins, is still far from complete. But it now seems that it will rank among the first proteins whose molecular structure has been clearly discerned and related in detail to the functions it serves.

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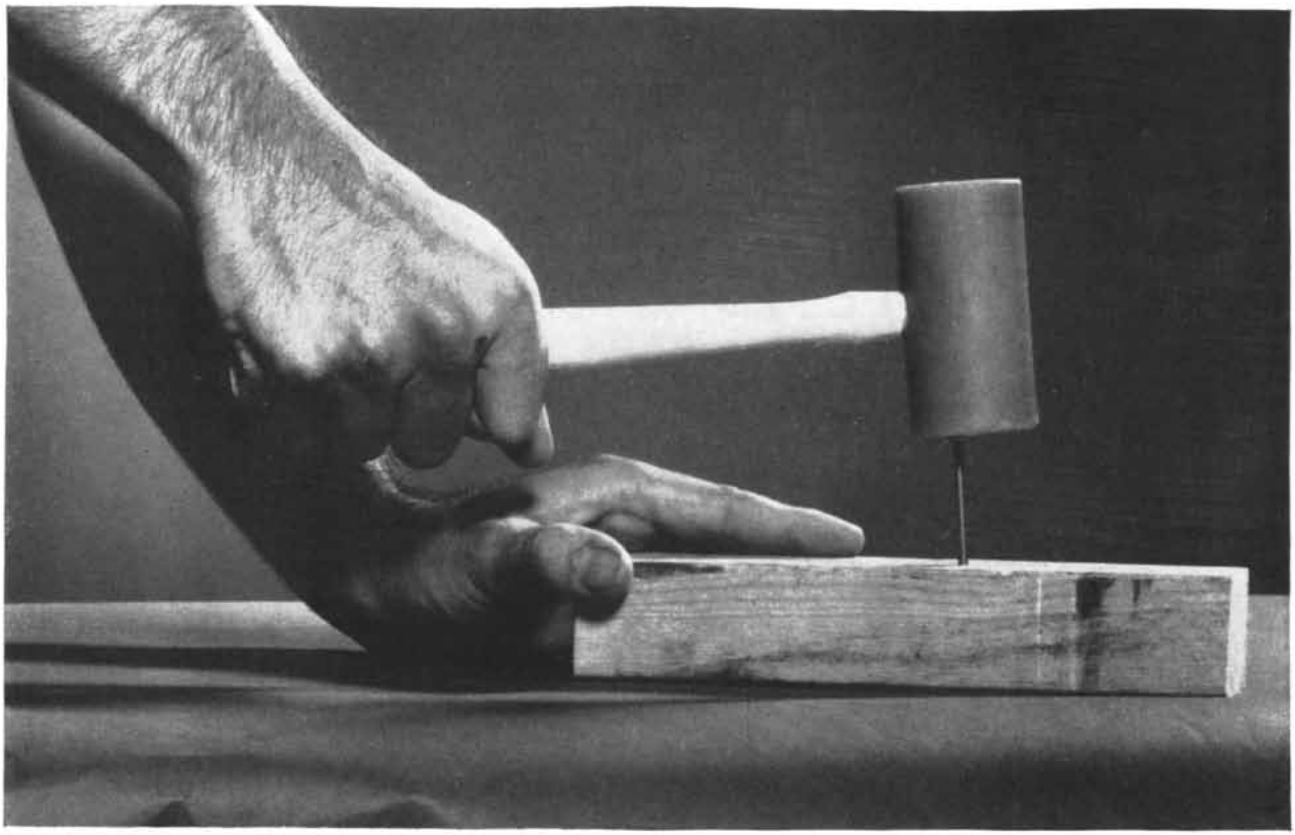

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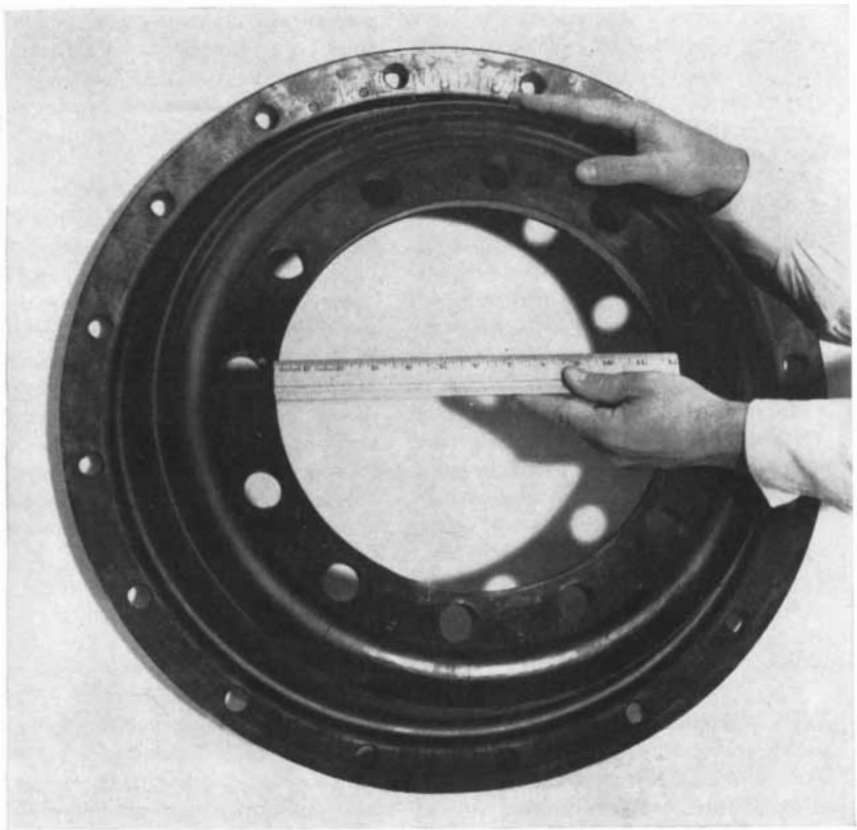

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NUCLEIC ACIDS

These polymers appear to carry the pattern of living matter from one generation to the next. Their basic chain consists of sugars joined by phosphates. Attached to the sugars, in turn, are bases

by F. H. C. Crick

If proteins are the principal stuff of life, the nucleic acids are its blueprints—the molecules on which the Secret of Life, if we may speak of such a thing, is written. The nucleic acids occur in every living cell. It seems, according to our best present information, that they direct the manufacture of proteins and hold the key to the hereditary constitution of all living things. Like the proteins, the nucleic acids are high polymers, but they are polymers with a difference. If we ever achieve a complete understanding of their construction and behavior, we shall probably have the answer to how nature goes about forming each living organism.

In this article I shall give my own view of the meaning of the facts learned about the nucleic acids so far. A great deal of work has been done on these substances, and there is considerable room for disagreement in interpreting the findings. But it is possible to form a general theory which seems to fit most of the known facts and serves as an attractive working hypothesis.

There are two kinds of nucleic acid: DNA, short for deoxyribonucleic acid, and RNA, ribonucleic acid. DNA is always found in the nucleus of the cell, RNA mainly in the cytoplasm outside the nucleus. Chemically they are very similar. Each consists of a long chain of phosphate and sugar molecules with small side groups (called bases) attached to the sugars [*see diagrams on pages 190 and 191*]. In DNA the sugar is deoxyribose; in RNA it is a very slightly different molecule called ribose. The two also differ in one of the four bases attached as side groups. Both contain adenine, guanine and cytosine, but in the case of DNA the fourth base is thymine, whereas in RNA it is uracil.

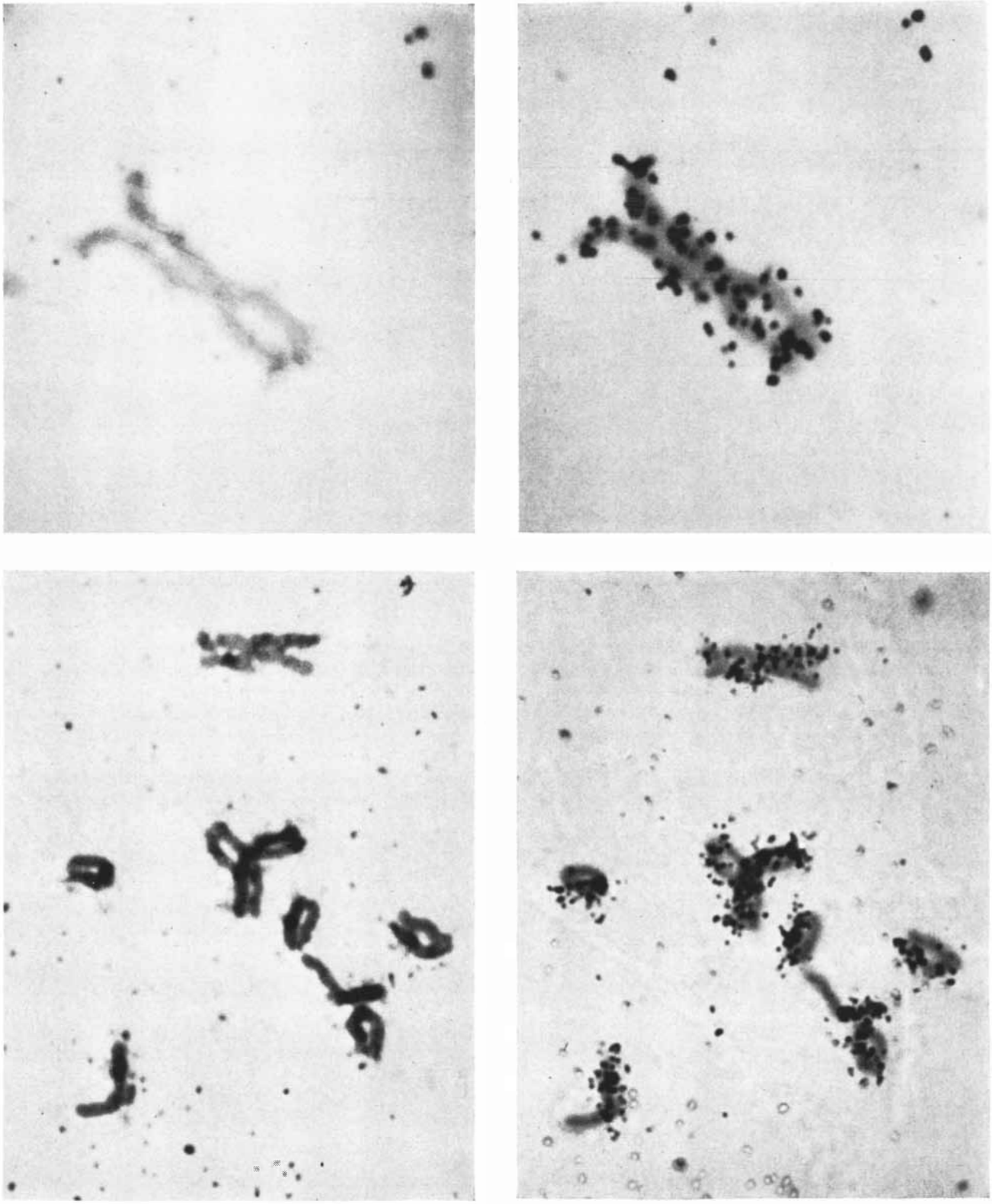
The bases along the backbone of the nucleic acid do not follow a regular order (such as ABCDABCD and so on). We have some reason to believe that the sequence in each case has a particular meaning and determines the function of the molecule, just as the sequence of letters in this sentence conveys my meaning to you as you read. But more about this later.

Electron-microscope pictures show that pieces of DNA are long and rather stiff, like a piece of cord. And by X-ray analysis it has been found that DNA is actually a double molecule, with one chain twined around the other in helical fashion. The bases of one chain fit neatly onto the bases of the other. But in order to fit, a given base on one chain must be opposite a particular one on the other: guanine pairs only with cytosine and adenine only with thymine. Thus the sequence of bases on one chain determines the sequence on the other.

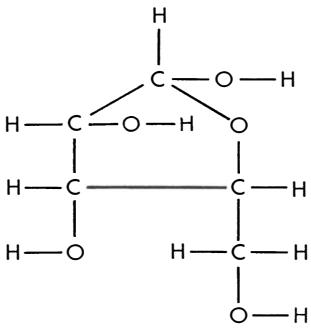
Much less is known about the structure of RNA, but some progress has been made in creating simpler synthetic analogues. One of these polymers has only the base adenine attached to the backbone, and is known as polyadenylic acid—or Poly A to its friends. Under certain circumstances Poly A probably takes the form of two chains wound around each other, with the adenine of one chain fitting onto the adenine of the other. Another synthetic analogue to RNA has been made with uracil as the base—it is known as Poly U. When Poly U and Poly A are put together in a solution, a remarkable combination takes place: the two chains join in an intertwined helical structure like that of DNA. It seems very likely that the structure is held together mainly by hydrogen bonds between the adenines on one chain and the uracils on the other. Alexander Rich and his colleagues at the National Institutes of Health in Bethesda, Md., who deciphered this structure, have found that in the presence of magnesium the mixture of Poly A and Poly U seems to form a three-chain structure, one Poly A chain joining up with two Poly U chains. The details of this new structure are eagerly awaited. Other interesting questions arise. Does Poly G (made with guanine) pair up with Poly C (containing cytosine), as the DNA pairing would lead us to expect? Unfortunately it seems very difficult to produce a good Poly G, so for the present we cannot answer this question.

There are indications that natural RNA consists of two chains, but it gives rather poor X-ray pictures, suggesting an irregular structure. Whether the disorder is inherent in the molecule or is produced during the extraction of RNA from the cell we cannot say, because we have little information to tell us what RNA is like inside living cells. Perhaps in the cell it assumes an orderly and significant configuration only when it is combined with DNA or protein.

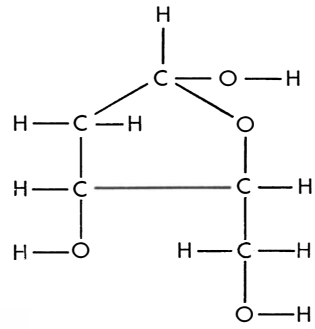
Some progress has recently been made toward synthesizing the nucleic acids with the help of enzymes extracted from living cells. Marianne Grunberg-Manago and Severo Ochoa at New York University discovered an enzyme system in certain bacteria with which they were able to make RNA-like molecules, as well as Poly A and Poly U. Arthur Kornberg and his colleagues at Washington University in St. Louis found a different system, also in bacteria, which produces DNA-like material. The RNA-type polymers were made from diphosphates of the nucleotides corresponding to the four natural bases (adenine, uracil, guanine and cytosine). When all four diphosphates were provided at the same



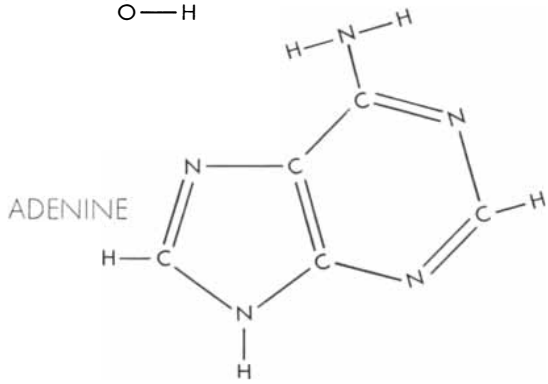
CHROMOSOMES in these photomicrographs are in cells of broad bean seedlings grown in an experiment by J. Herbert Taylor of Columbia University and Philip S. Woods and Walter L. Hughes of Brookhaven National Laboratory. The seedlings were grown in a medium containing thymidine labeled with radioactive hydrogen (tritium). When the cells synthesized new chromosome material, the DNA contained labeled thymine. The photomicrograph at upper left shows a single bean chromosome. The photomicrograph at upper right shows a layer of photographic emulsion above the same chromosome. Each dark spot in the emulsion was made by a particle emitted in the decay of a tritium atom. After the cells had produced one generation of labeled DNA, they were transferred to a medium containing no radioactive thymidine. The photomicrograph at lower left shows several paired chromosomes in a cell two divisions after labeling. The photomicrograph at lower right shows a layer of photographic emulsion above the same paired chromosomes. The spots in this photomicrograph roughly indicate that only one chromosome of each pair is radioactive.



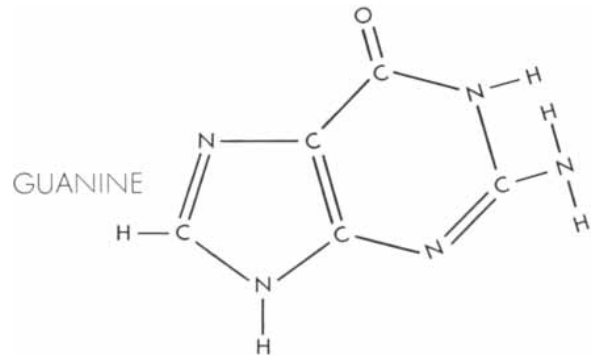
D-RIBOSE



D-2-DEOXYRIBOSE



ADENINE

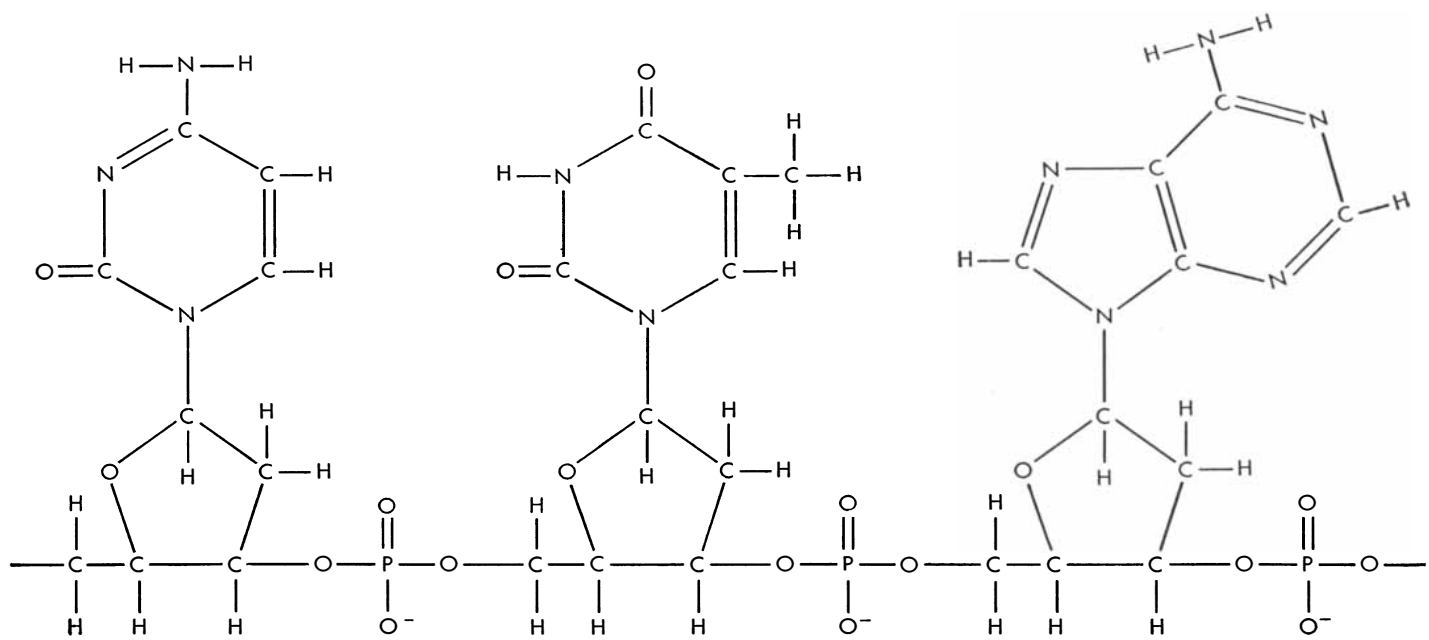


GUANINE

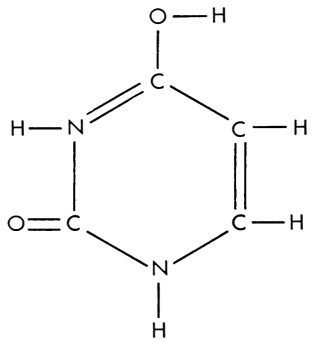
BASES AND SUGARS forming the basic units of nucleic acids are diagrammed. The D-ribose sugar is the basis of ribonucleic acid (RNA) and gives it its name. Deoxyribonucleic acid contains the deoxyribose sugar. Adenine and guanine, which are found in

time, a product called Poly AUGC was formed. This is very similar to natural RNA, but so far has not shown any biological activity. If the sequence of the bases in natural RNA accounts for its biological behavior, this synthetic material may turn out to be "nonsense RNA." But then perhaps some *natural* RNA is nonsense RNA. Who knows? In any event the enzyme system that makes this substance seems to be widely distributed among bacteria, and is presumably there for some purpose.

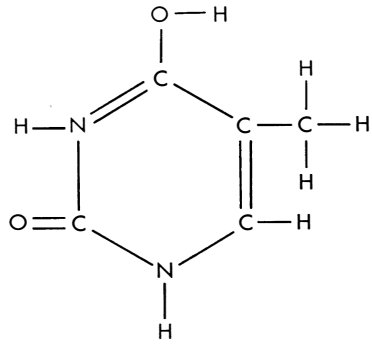
The system that synthesized Kornberg's DNA-type material requires the triphosphate instead of the diphosphate of the nucleotides, and of course deoxyribose rather than ribose. The exact requirements of the system were at first obscure: the brilliant work of Kornberg and his colleagues is a fine example of biochemical order being extracted from confusion. Two conditions appear to be necessary. First, all four nucleotides



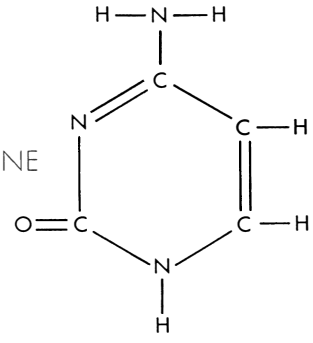
NUCLEIC ACID CHAIN is made up of a backbone of sugar molecules linked by phosphate groups. Each sugar link carries a side chain of a base like those at the top of the page. The chain above has side chains of cytosine, thymine, adenine, thymine, cytosine and



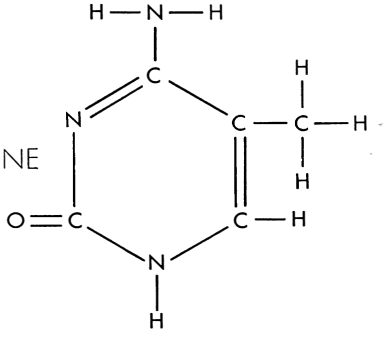
URACIL



THYMINE



CYTOSINE

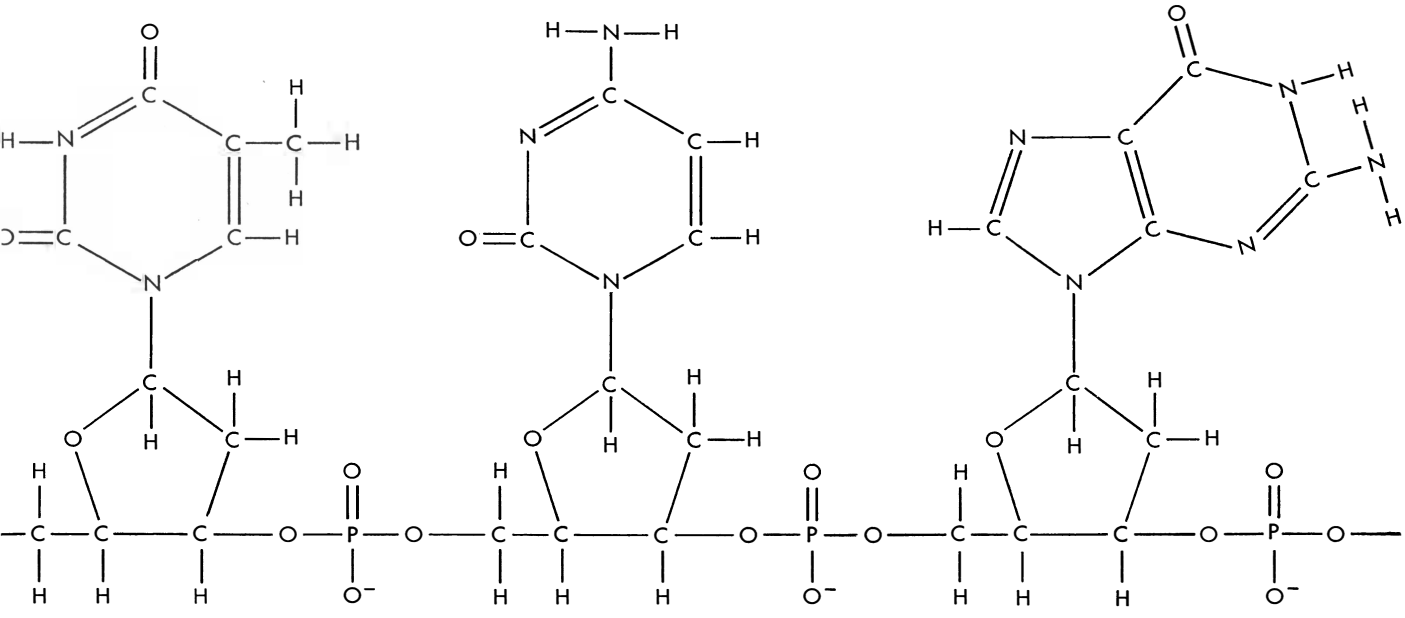


5-METHYL CYTOSINE

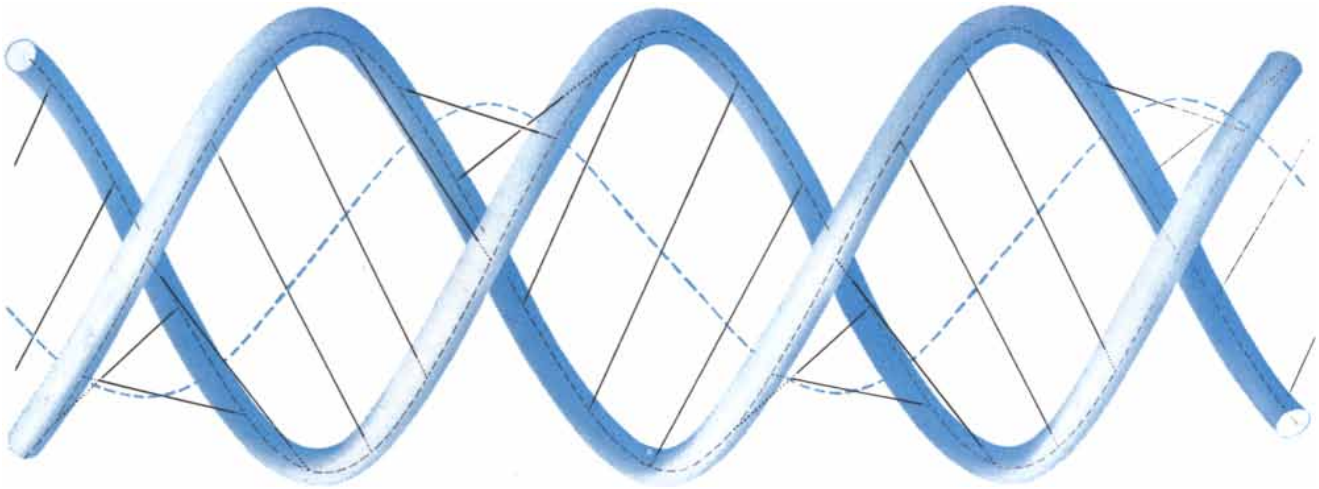
both DNA and RNA, are bases of the purine type. The other bases shown are all pyrimidines. Cytosine is common to both DNA and RNA, but uracil is found only in RNA. In DNA thymine occurs instead of uracil. The 5-methyl cytosine, found in DNA, is less common.

must be present simultaneously: if any one is omitted, little or no synthesis takes place. Secondly, the polymerization will not proceed unless some natural DNA is present as a primer. The experiment has provoked great interest and excitement, because these two conditions suggest the possibility that the synthetic "DNA" is produced by replication of the priming DNA, rather than assembled from the raw materials at random. It has not yet been possible to show that the synthetic DNA is biologically active, but every biochemist arriving in England from the States is eagerly asked if he knows whether Kornberg has done this yet. Perhaps by the time this article is published . . .

There are many reasons to suspect that DNA is either the genetic material of life (what used to be called the genes) or an important part of it. DNA is always associated with chromosomes, and not



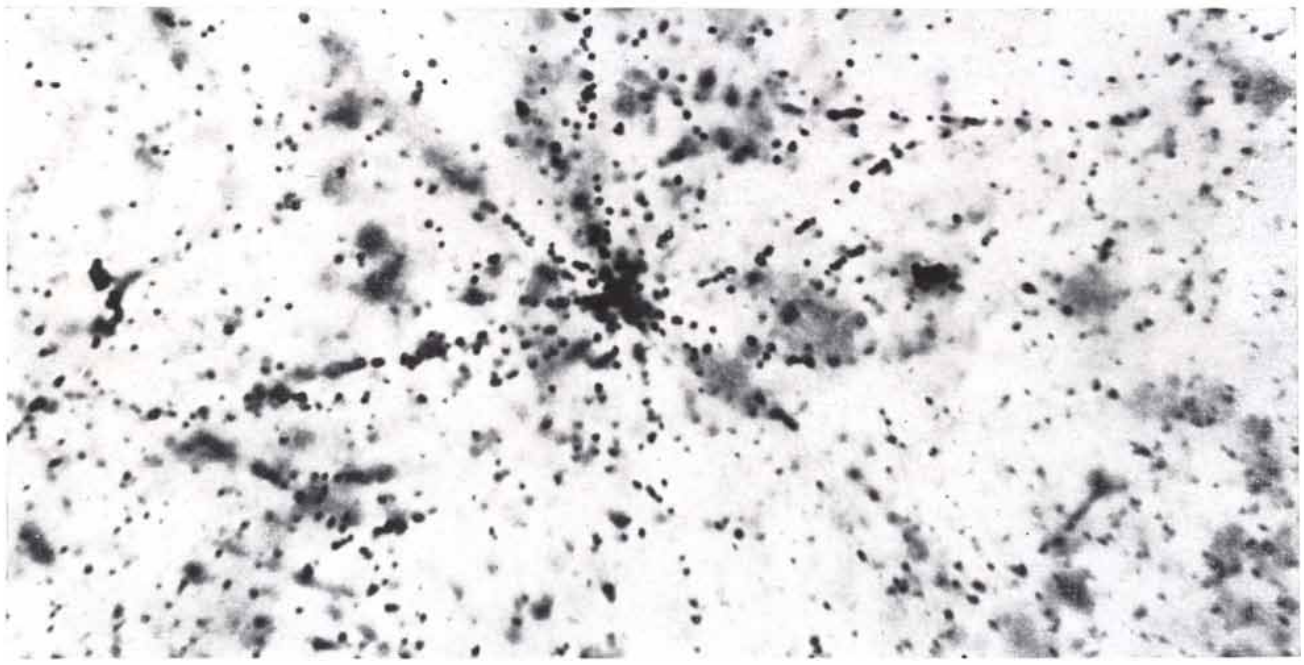
guanine. It represents a fragment of a DNA molecule which consists of thousands of sugar links with side chains in seemingly random order. RNA is similar except that it has ribose as the sugar instead of deoxyribose, and uracil replaces thymine in its side chains.



MODEL OF DNA STRUCTURE is a double helix with slanted cross-links connecting the two chains. The nucleic acid chains which form the helixes are identical but head in opposite directions. The cross-links (*black lines*) consist of complementary pairs of side chains connected by hydrogen bonds. The broken colored line traces the centers of the cross-links and also forms a helix.

with any other part of the cell. Each set of chromosomes appears to have a fixed amount of DNA. There are at least two phenomena which give direct evidence that DNA plays a genetic role. Firstly, it has been found that pure DNA extracted from certain bacteria is capable of transferring some of the properties of this strain to a related strain, and the transformed bacteria pass these properties on to their descendants. Secondly, when a bacterial virus infects a bacterium, it is the virus's DNA (not its protein) that enters the bacterial cell, and much of this DNA turns up in the progeny virus produced in the cell.

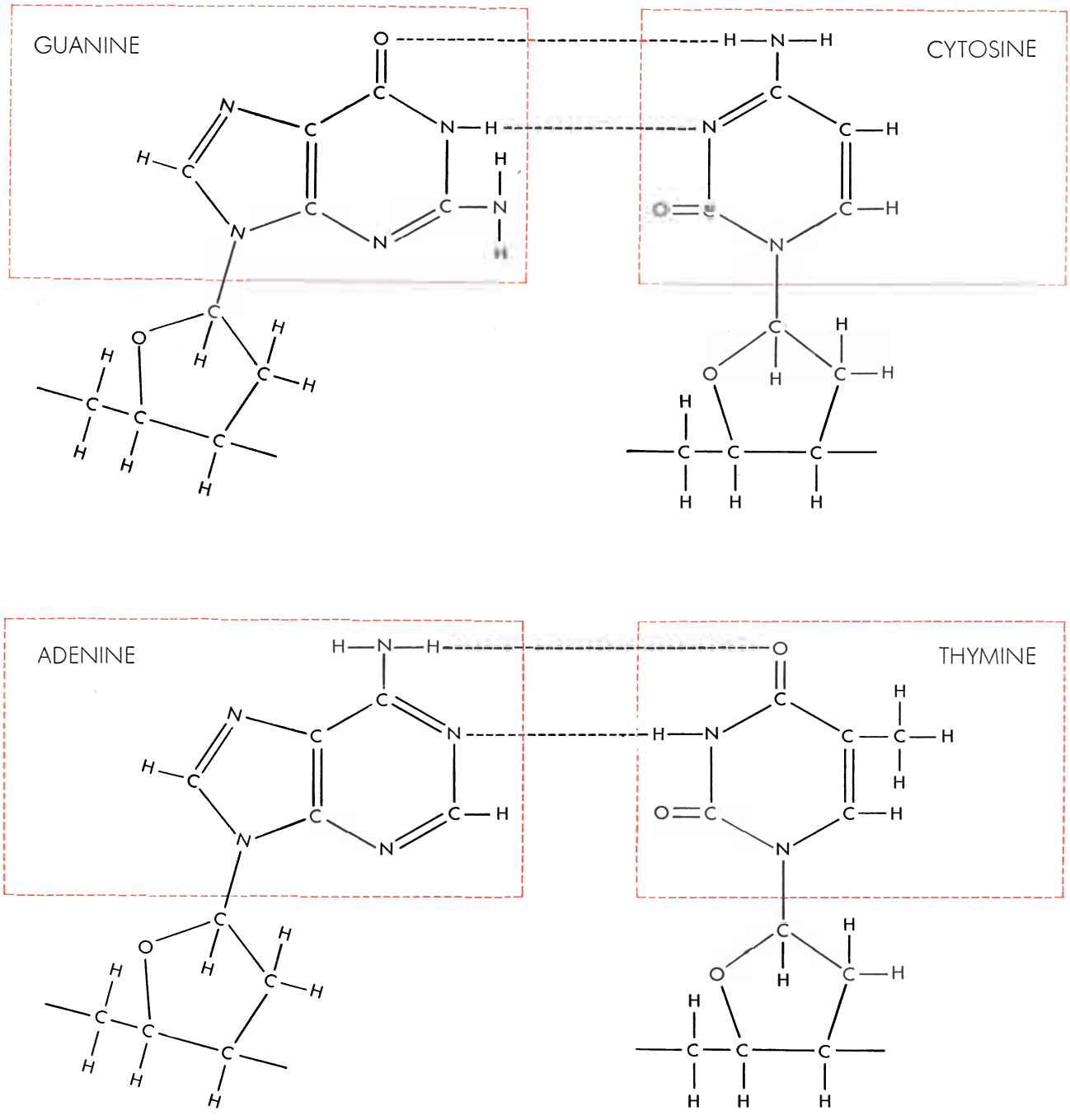
Taking all the evidence together, it is difficult to resist the conclusion that DNA is genetic material. If that is the case, our problem is to learn how DNA reproduces itself. The double-helical structure of DNA suggests a possible answer, which I have discussed in a previous article [see "The Structure of the Hereditary Material," by F. H. C. Crick; SCIENTIFIC AMERICAN, October, 1954]. The basic idea is that the two



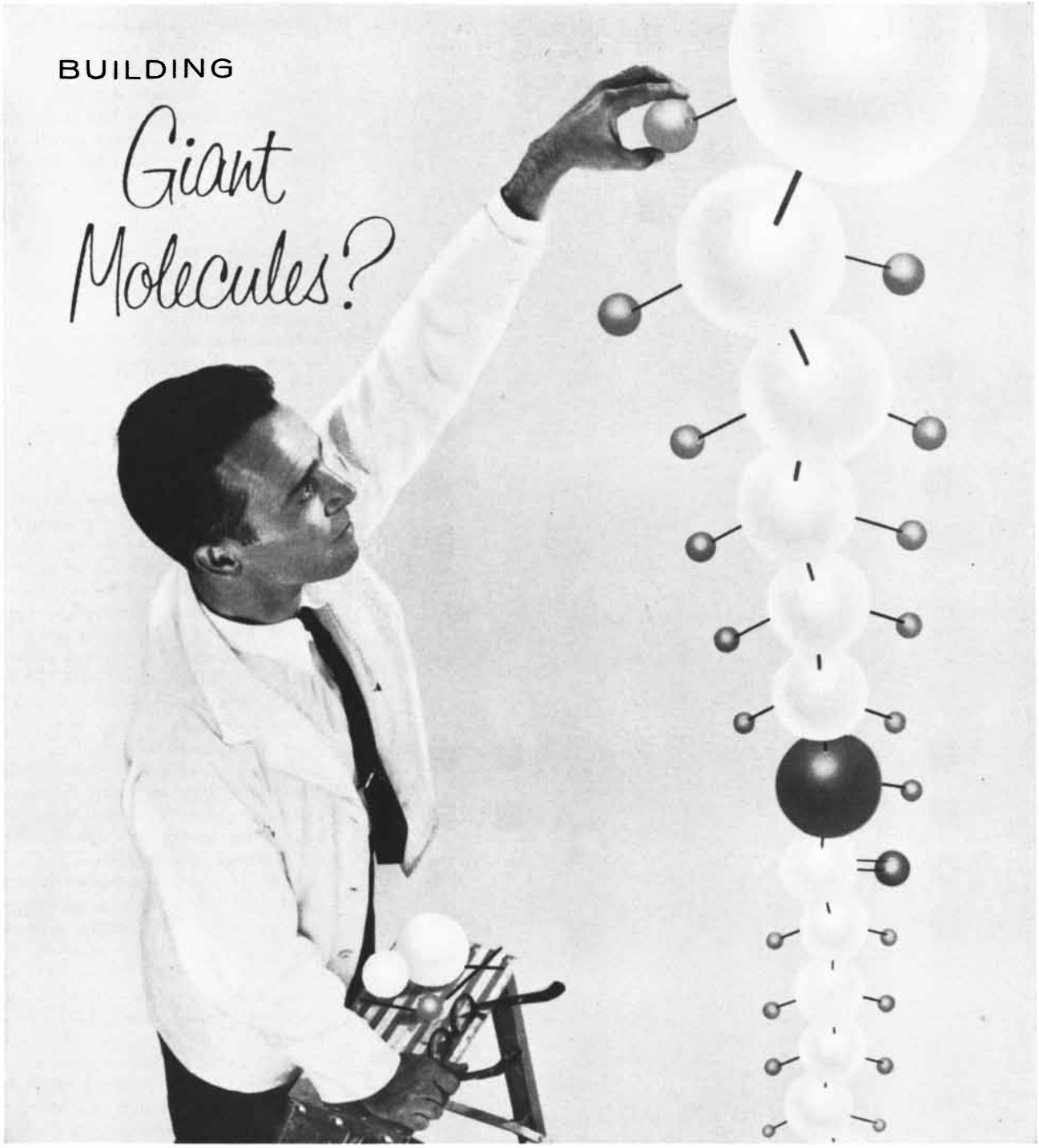
RADIOACTIVITY OF LABELED DNA in a bacterial virus is indicated by this "star" of tracks in a nuclear-emulsion photograph made by Cyrus Levinthal of the Massachusetts Institute of Technology. When bacteria infected with the virus were grown in a medium containing radioactive phosphorus, the viruses used the radioactive material in making new DNA. Then viruses containing radioactive DNA were transferred to a culture of bacteria growing in a nonradioactive medium. When the bacteria were broken open by the virus infection, their contents were mixed with the photographic emulsion. Each track in the developed emulsion is made by a particle emitted in the decay of a phosphorus atom; the number of tracks is proportional to the amount of radioactive phosphorus in the virus. Thus it is possible to trace how the phosphorus in the DNA of first generation of viruses is distributed in later generations.

chains of the DNA, which fit together as a hand fits into a glove, are separated in some way and the hand then acts as a mold for formation of a new glove while the glove acts as a mold for a new hand. Thus we finish up with two gloved hands where we had only one before. In chemical terms we imagine that monomers supplied by the cell align themselves along the mold chain with complementary bases pairing up.

There is experimental evidence which gives some support to this idea. Cyrus Levinthal at the University of Michigan studied the DNA of a bacterial virus (called T2) by a special radioactive tracer method. He discovered that the DNA of the virus is not all in one piece—*i.e.*, it is an aggregation of DNA molecules of different sizes. In each virus there is one "big piece" with a molecular weight of about 42 million, and the rest are considerably smaller. Levinthal concentrated on this big piece and followed it through the reproduction of the virus. He found that after it had been labeled with radioactivity (by growing the virus



BASES OF ADJACENT DNA CHAINS can only be linked when they are paired as indicated in this diagram. The base guanine pairs with cytosine; the base adenine, with thymine. Each pair of bases is linked in two places by hydrogen bonds (*broken lines*).



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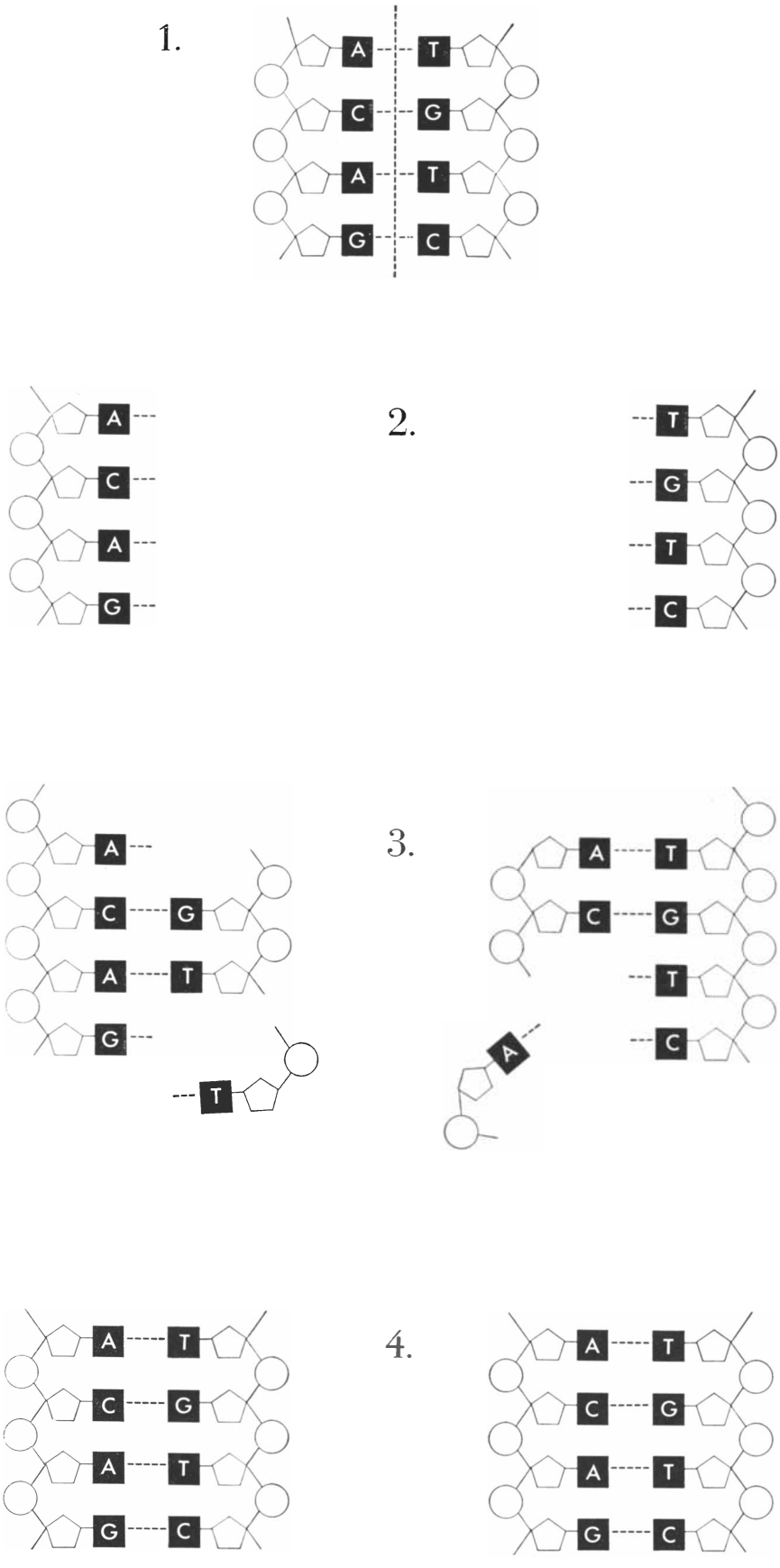


POSSIBLE REPLICATION MECHANISM of DNA is outlined. Two linked chains (1) come apart (2). Monomers then assemble along each chain (3). The result is two pairs of linked chains whose bases (*black squares*) have the same sequence as those of the original pair. The bases are labeled: A, adenine; C, cytosine; T, thymine; and G, guanine.

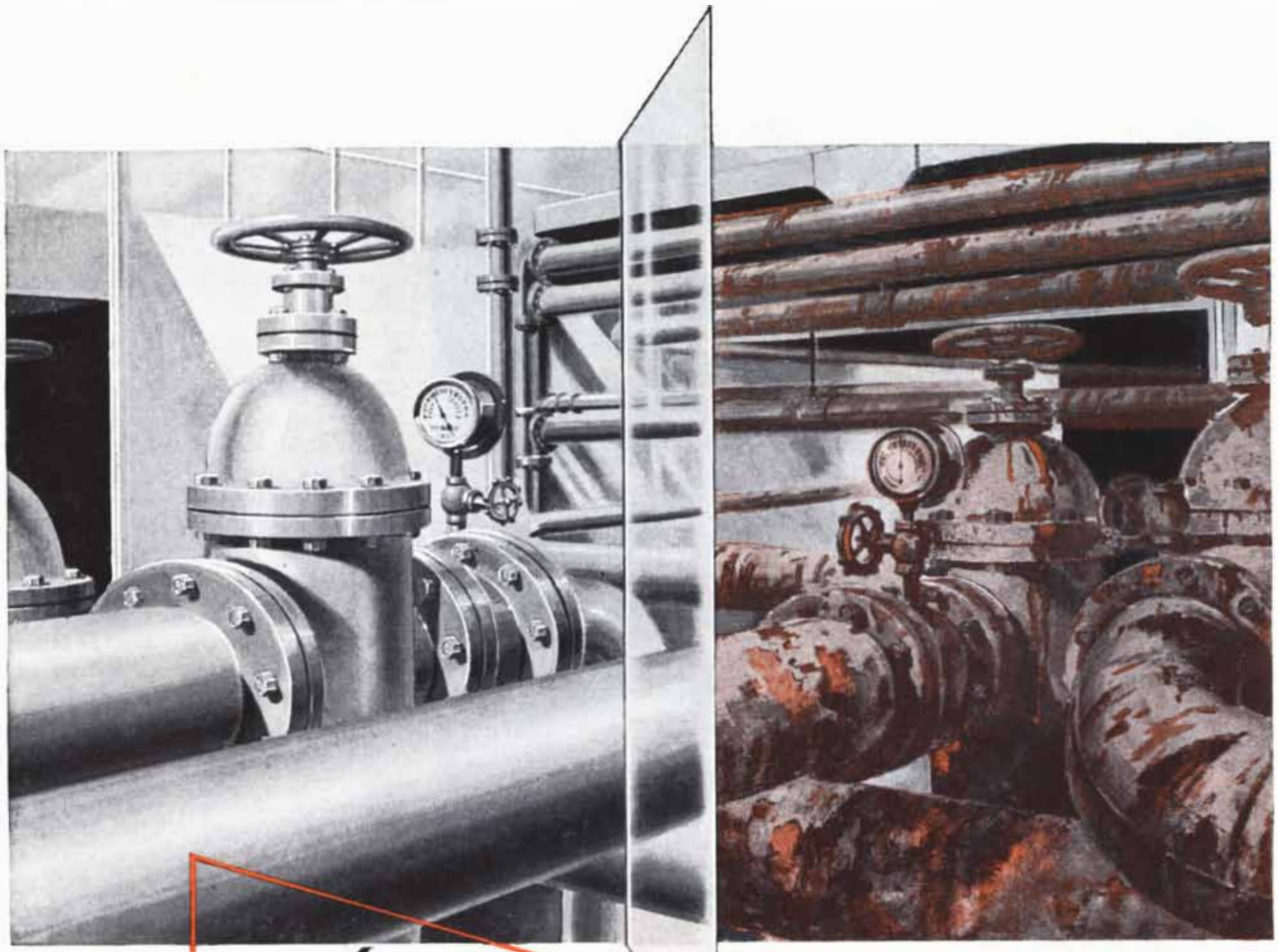
in a medium containing radioactive phosphorus) its radioactivity dropped to one half in the virus progeny produced later in a nonradioactive medium. Presumably this means that the big piece now was composed of two parts—half radioactive DNA from the parent, and half newly synthesized, nonradioactive DNA. When these progeny reproduced themselves in a nonradioactive medium, some of them again had DNA of the same composition—apparently half original and half new.

It is very tempting to construe this as evidence for the hand-glove hypothesis of the replication of DNA: that is to say, to suppose that the radioactivity represents a chain (hand or glove) which acted as the mold and the other half represents the new chain molded on this. We can suppose further that the big piece is the part of the DNA which carries the virus's genes. But these are as yet only assumptions. All we can say is that the experiments do seem to bear out the idea that DNA carries out an internal duplication. However, I should add that certain experimental findings by Gunther S. Stent of the University of California do not easily fit into this picture.

Recently J. Herbert Taylor of Columbia University and his colleagues made a similar experiment with bean seedlings. They grew the seedlings in a medium containing thymidine labeled with radioactive hydrogen (tritium), and thus tagged the thymine of the new DNA synthesized in the bean cells. Then the seedlings were transferred to a nonradioactive medium for further growth. The beauty of bean cells for such an experiment is that their chromosomes are very large, so that under a microscope it is possible to see their various parts and to catch them in the act of dividing [*see photomicrographs on page 189*]. Taylor found that after the second division of the cells one daughter chromosome of a pair tended to be radioactive while the other was not (apart from secondary complications).

This again suggests that the DNA of chromosomes is a two-part structure. However, neither the virus nor the bean-cell experiment really tells us whether the duplicating process operates at the level of the helical chains. Further, we still have the difficult problem of trying to imagine what sort of mechanism the chromosomes can employ to unwind the two DNA chains to free them for replication.

Assuming that DNA does represent the genes, how does it act to determine the make-up of the total organism? Here



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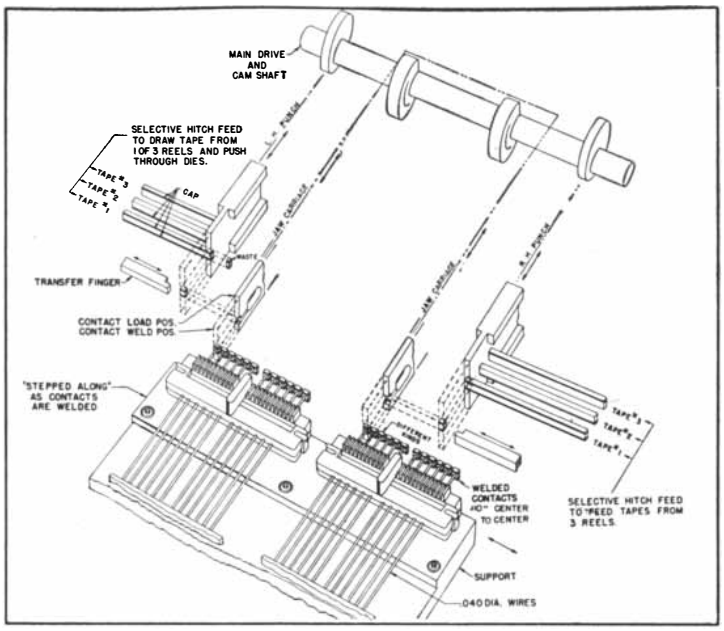
again we have a suggestive general theory but very few facts, although the ones we have are interesting enough. The theory says very simply that the nucleic acids control the making of each organism's characteristic living substances—its proteins. DNA bears the master plans, carrying them on from generation to generation; RNA constitutes the working copies used in the actual synthesis of the proteins. This production is controlled in a rather straightforward way by the sequence of bases in each nucleic acid, which determines in what particular order amino acids will be assembled in the polypeptide chains that make up a protein. The order is all-important, for it governs the character and functions of the protein.

I think it very likely that this hypothesis is correct, at least in broad outline. It makes sense of an enormous body of biochemical facts, and it has the beauty which we associate with simplicity and generality. Moreover it has been a powerful guide in attacking the bewildering complexity of biological systems.

Let us consider first the function of RNA. It is found mainly in combination with protein in particles in the cytoplasm of the cell. These particles are believed to contain the templates on which specific proteins are modeled.

The most convincing evidence that RNA is responsible for the specific construction of proteins has come from recent work on the tobacco mosaic virus, done mainly by Heinz Fraenkel-Conrat and his colleagues at the University of California and by Gerhard Schramm and co-workers at the University of Tübingen in Germany. They have separated the RNA from the proteins of the virus and used the RNA, separately and in combination with different proteins, to generate virus progeny. RNA alone, inoculated into a tobacco plant, has proved capable of reproducing the virus. In this case the progeny multiplying in the infected plant had the protein corresponding to the virus strain from which the RNA was taken, although the plant had never seen this protein before. Equally remarkable is the fact that a "mixed virus," made by combining the RNA of one strain with the protein of another, yields progeny which contain not the new protein but the protein with which the RNA was originally associated. In other words, the infected plant manufactures a protein dictated by the RNA, not a copy of the protein actually given to it. This result illustrates very well a hypothesis which my colleagues and I call the Central Dogma: namely, that

SCHEMATIC OF AUTOMATIC PERCUSSION WELDER USED IN PRODUCTION OF NEW RELAYS FOR BELL TELEPHONE SWITCHING EQUIPMENT.



Long-neglected welding technique adapted to high-speed automatic production line

A highly successful adaptation of percussion welding is being used at Western Electric in the manufacture of the new wire spring relay developed for the Bell Telephone System. The technique is utilized as part of one of the advanced applications of automatic manufacture of telephone equipment.

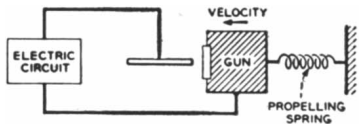
Percussion welding, dating back to the turn of the century, has hitherto been little used in industry. However, engineers at Western Electric, working on the problem of how to produce the relays at high speed and low cost, saw important advantages in the method if it could be applied successfully.

Their problem was to design a machine for automatic multiple welding of bimetallic contact blocks to the ends of an array of small wires extending less than a quarter of an inch from molded phenolic plastic. This array, fixed in the plastic, forms a comb which becomes the stationary contact member of the relay.

In addition to wanting a high-speed automatic machine that would weld parts of unequal size and of differing electrical and heat conductivities Western's engineers sought to develop a welding component that was both flexible and highly precise. For example, this machine should be capable of producing not just one type of comb but a family of combs, varying as to the number and type of contacts required by the code of relays into which each is assembled. Any one of four different contact conditions may be required on one comb.

And because of rigid design requirements, precision was an essential ingredient of this engineering accomplishment. For example, the contact blocks are 0.073″ wide while the wires to which they are welded have a diameter of 0.040″. Moreover, all of the contact surfaces must be located on the same plane within a tolerance of ±0.002″.

The basic process used in the percussion welding machine developed by Western engineers is shown in the diagram below:



It affords these advantages as compared with other welding methods: speed, ease of attaining proper heat balance of mating parts, and accuracy in locating contacts.

As it is applied in the automatic production of relays at Western Electric's Hawthorne (Ill.) Works, percussion welding consists basically of the application of a high potential—900 to 1800 volts—across the gap between the two parts to be welded. One of the parts—a block of 70-30 per cent cupro-nickel with palladium contact surfaces—is gripped by the jaws of a gun which moves at high speed toward the other part—a silicon copper wire—which is held stationary.

Contact blocks are punched from bimetal tapes by tools located adjacent to each of two carriage-mounted jaws. Transfer fingers then thrust the blocks into the jaws. Both carriages are released by drop-off cams and the blocks are propelled toward the wires.

Each jaw carriage is driven by a spring exerting a force of about eight pounds, providing velocity at impact of about thirty inches per second. At a certain point of separation, the airgap breaks down and an arc is initiated. The arc heats the abutting surfaces before they meet, forming a thin layer of molten metal on both surfaces. As the parts come together, the weld is made. Time is allowed for the weld to set before the cam returns the carriage, pulls the jaw off the welded contact and positions for the next cycle.

Each cycle of the cam shaft requires about half a second and 12 cycles are required for welding the twenty-four contacts on two wire combs. Each cycle includes the feeding of the tape, punching a part out of it, transfer of the part to the jaws, positive seating of the contact block in the jaw, advance of the jaws to the drop-off point, release of the jaw carriage, its travel to the wire end, an interval for the metal to freeze, and return of the carriage to the start of the stroke.

The foregoing is not so much a rare instance of the ingenuity of Western Electric engineering as it is typical of our approach. Always, the question confronting us is: what techniques, new or old, can be adapted, modified or invented in order to solve Western's basic problem of finding efficient ways to produce constantly improved designs of Bell telephone equipment. Our success in this area has had a direct bearing upon holding down the costs of Bell telephone service while its quality and dependability have gone up.

once information (meaning here the determination of a sequence of units) has been passed into a protein molecule it cannot get out again, either to form a copy of the molecule or to affect the blueprint of a nucleic acid. The idea is not universally accepted, however. In fact, Sir Macfarlane Burnet, the eminent Australian virologist, persuasively argued another point of view in a very interesting little book which he published recently.

The hemoglobin of a horse's blood is not exactly the same as that of human blood; the insulin molecule, too, differs slightly in horses, pigs, sheep, whales and so on. These well-known facts suggest that genes control the amino acid make-up of specific proteins—but they do not necessarily prove it. The proof has now been provided by my colleague Vernon Ingram, working in the Cavendish Laboratory of the University of Cambridge. He discovered that sickle cell hemoglobin (a defect responsible for a fatal disease) is exactly like normal hemoglobin, as far as he can tell, except for a single alteration: in one place where the normal molecule has a glutamic acid, the diseased hemoglobin has a valine unit. Genetic studies have established that this difference is due to a single gene. It is interesting that a change in one amino acid out of nearly 300 results in the fatal sickle cell condition, but it is even more interesting to see that a gene can control such a small change. Genes not only work powerfully but they can also work delicately.

How do they manage to operate so selectively upon the fine-structure of a protein? The most spectacular information on this point has recently been announced by Seymour Benzer of Purdue University. By very elegant genetic techniques he mapped a single "gene" of a bacterial virus, and he was able to distinguish more than 100 different functional sites arranged in a linear order along the length of the "gene." Assuming that genes are made of DNA, we can perhaps trace a correspondence between his map and the DNA molecule. Benzer calculated that the smallest distance between sites on his genetic map would take in just a few base-pairs along the DNA double chain.

From every point of view biology is getting nearer and nearer to the molecular level. Here in the realm of heredity we now find ourselves dealing with polymers, and reducing the decisive controls of life to a matter of the precise order in which monomers are arranged in a giant molecule.

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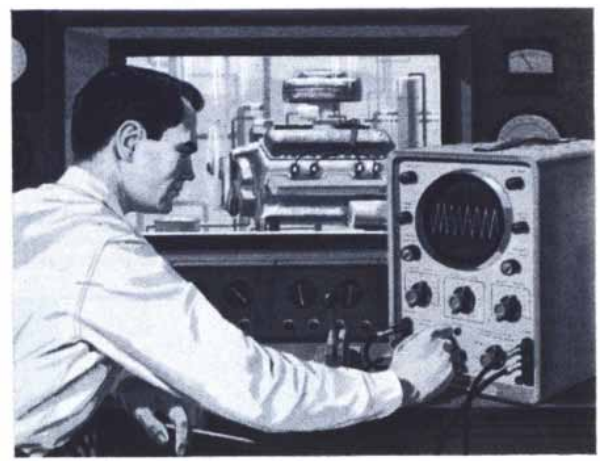

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Life on the Chemical Newsfront

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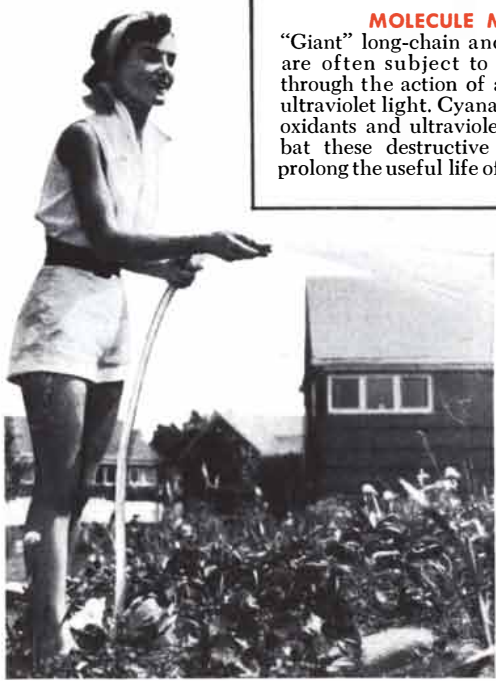

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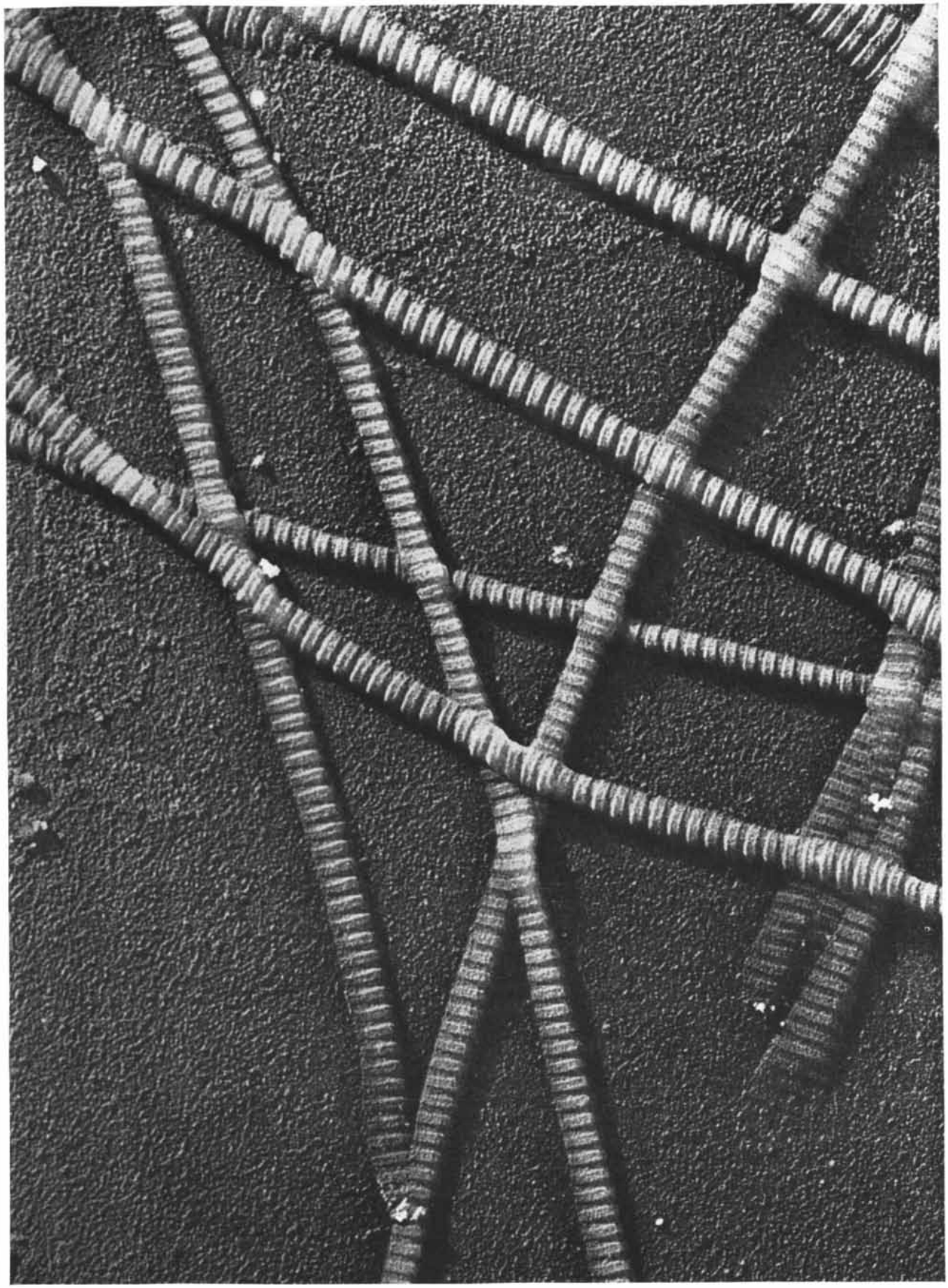


FIBRILS OF COLLAGEN, the principal protein of skin, are enlarged 60,000 diameters in this electron micrograph made by Jerome Gross of the Massachusetts General Hospital. The fibrils have been shadowed with a heavy metal to bring out their banded structure.

Giant Molecules in Cells and Tissues

How are protein and nucleic acid molecules organized in protoplasm? It appears, largely on the basis of evidence supplied by the electron microscope, that these molecules are monomers of higher polymers

by Francis O. Schmitt

The preceding two articles have described the elaborate construction of two kinds of natural high polymers: proteins and nucleic acids. This article will discuss how these giant molecules are organized in the cells and tissues of living organisms. Indeed, proteins and nucleic acids can be considered monomers of larger structures.

As the preceding articles have indicated, the living cell fashions relatively simple monomers into huge molecules. The macromolecules then organize *themselves* into the exquisitely specialized structures of cells and tissues. This spontaneous process apparently depends on specific properties built into the molecules.

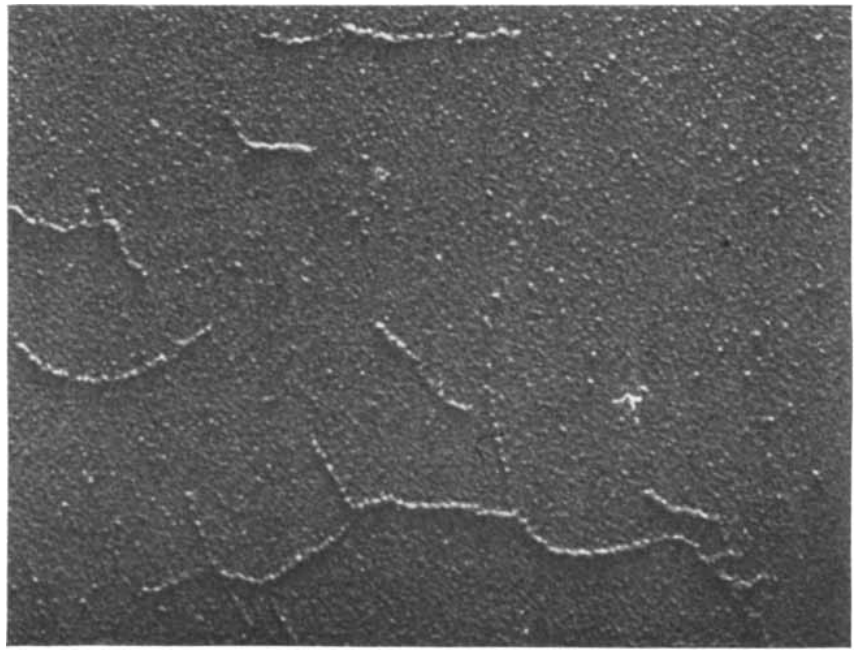
These giant monomers may be polymerized in the cell where they are made, or they may be transported in inactive form to another part of the organism. There they may be activated and polymerized as the occasion demands. For example, the soluble protein fibrinogen is always present in the blood, but it is polymerized into the insoluble fibrin of a blood clot only when bleeding must be stopped.

The function of a natural high polymer is of course reflected in its properties. The protein keratin has great tensile strength; it forms the principal structure of hair, horn and fingernail. The protein collagen serves a similar purpose in skin and tendon. Elastin is a springy protein; it occurs in ligaments and the elastic fibers of connective tissue.

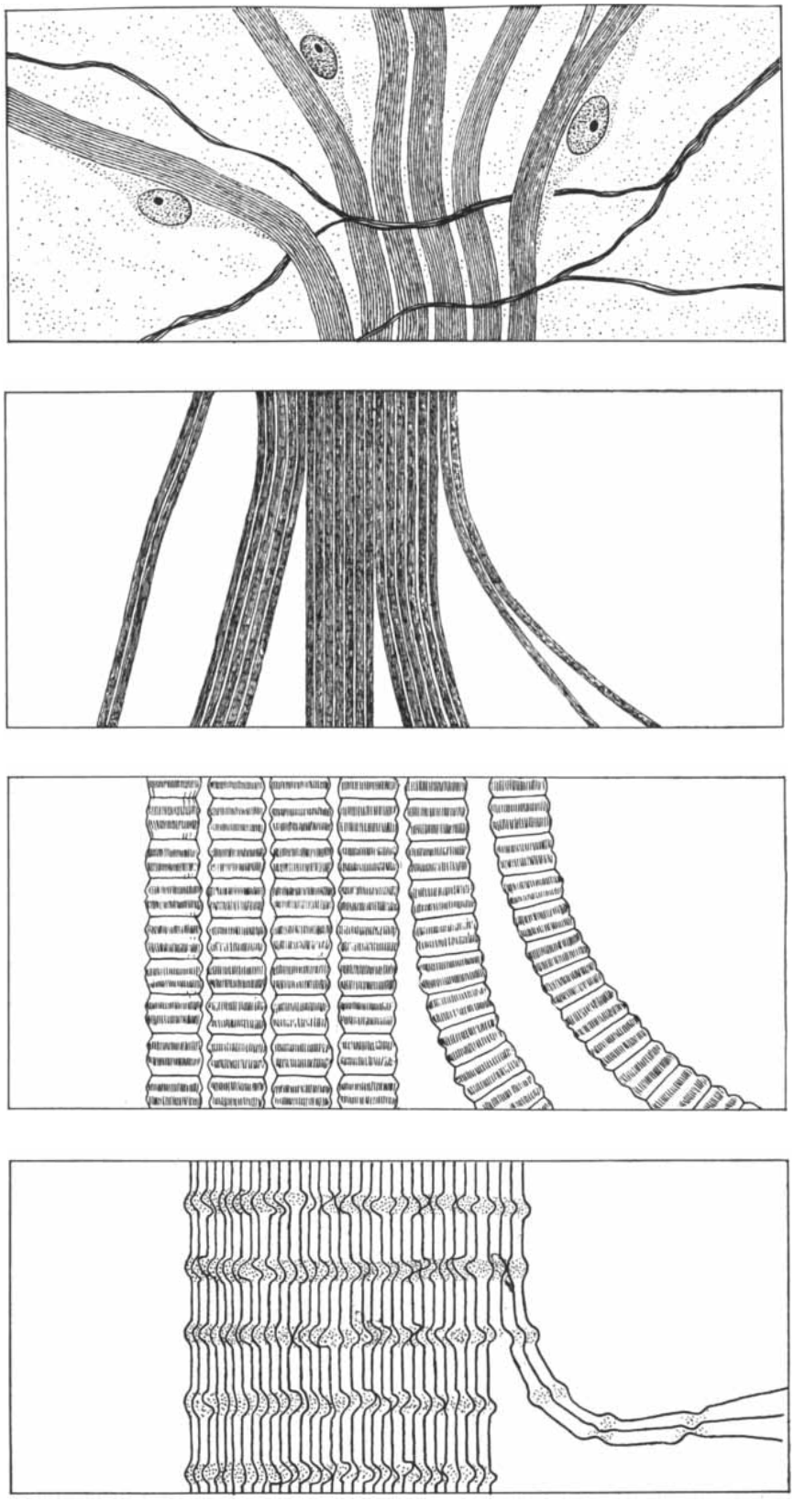
These three types of polymer are more or less passive; others respond actively to changes in their chemical environment. Under the influence of such changes the protein of muscle contracts. Contraction is a property not only of muscle but also of many other biological structures, from the rapidly oscillating tail of the sperm cell to the flowing pseudopods of the amoeba. Indeed, contractility is an essential feature of all living cells, and probably employs a common molecular mechanism.

The threadlike chromosomes of the cell nucleus, made up of protein and nucleic acid, are polymers with another function: the maintenance of the specific linear sequence of the genes. We should also reserve a category for natural high polymers whose purpose is not known. A good example is the fibrous protein of nerve cells. These so-called neurofibrils are very long and less than a millionth of an inch thick. They run through the core of all nerve fibers; in the light microscope they are seen as bundles of coagulated filaments. Their presence in all nerve tissue indicates that they must serve some function, but to date no one has been able to show what it might be. Considerable effort is currently being made to isolate this protein (from the giant nerve fibers of the squid) and to determine its composition and function.

The idea that biological fibers are composed of fibrous molecules is not new. In the 19th century microscopists observed that such fibers tended to fray into finer fibers, and assumed that the hierarchy continued downward in scale. At the same time natural fibers were analyzed with polarized light, and the analysis indicated that their molecules were organized in regular structures. In



MOLECULES OF COLLAGEN, enlarged 100,000 diameters, appear as long, thin threads in this electron micrograph made by Cecil E. Hall of the Massachusetts Institute of Technology.



HIERARCHY OF FIBERS is outlined in these drawings of collagen as seen at four different magnifications. At top are collagen fibers in a bit of connective tissue as they appear under the light microscope. In a light microscope of higher power a single frayed collagen fiber is seen to consist of many fibrils (*second drawing from top*). Enlarged still more with an electron microscope, the same fibrils show cross-bands and other details (*third drawing from top*). X-ray diffraction methods permit even finer analyses revealing that a single fibril is made up of parallel chains of collagen molecules (*fourth drawing*).

the 1920s and 1930s polarization analysis showed that the cellular fibers were very thin. Today we know that they are the molecules themselves; they can actually be visualized in the electron microscope. Used in conjunction with X-ray diffraction and other older methods, this instrument has provided significant information on the molecular organization of structures in living cells.

When a thin section of a muscle cell is observed in the electron microscope, it is resolved into finer fibers called myofibrils, each of which consists of many thin filaments. A striking feature of the fibrils is the striations that occur regularly along their length. These cross-bands are brought out by staining the muscle tissue with compounds of heavy metals, which scatter electrons more than do the lighter elements of which the tissue is composed. Thus the bands are regions that combine well with the stains. When the fibrils are shadowed with metal so that they can be seen in relief, adjacent bands have slightly different thicknesses and hence are more visible.

The band pattern provides a kind of molecular fingerprint by which the protein can be identified in the electron microscope and which provides important clues to how giant molecules are organized into fibers. Let us consider in detail collagen, the protein of skin and tendon. Collagen, which is also present in bone, teeth and loose connective tissue, represents as much as a third of all the protein in an animal. In compact form such as tendon it will resist a pull of as much as 100,000 pounds per square inch, roughly the strength of steel wire. Intensively studied by electron microscopists, X-ray crystallographers and chemists, it is now one of the best-known fibrous proteins.

If we tease a bit of tendon or skin with fine needles, or break it up in a blendor, its fibers are split into fibrils. We can see under the light microscope that the fibrils have a fairly uniform width: usually from 200 to 1,000 Angstrom units (an Angstrom unit is a hundred millionth of a centimeter). The fibrils are composed of still finer strands: protofibrils. These are thought to consist of fibrous molecules strung end to end.

When undried native collagen fibrils are examined in the electron microscope, they show cross-bands which repeat at intervals of about 700 Angstroms. Richard S. Bear of the Massachusetts Institute of Technology has offered the following explanation for this band-

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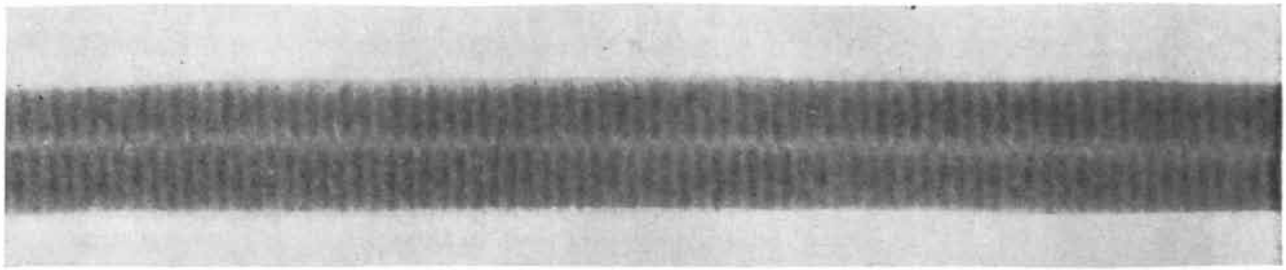
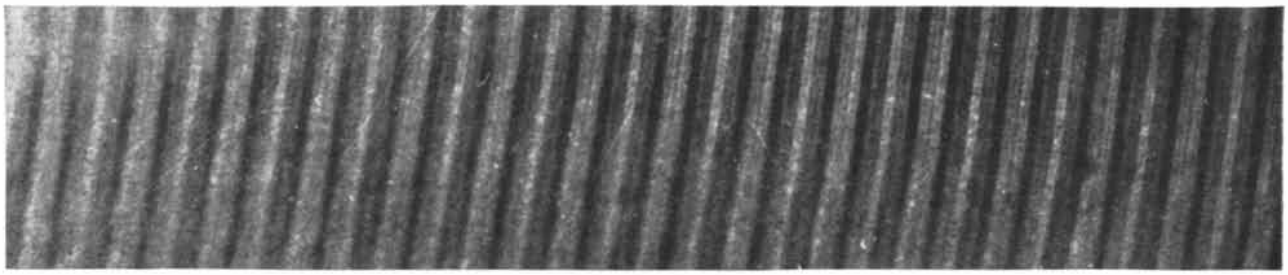
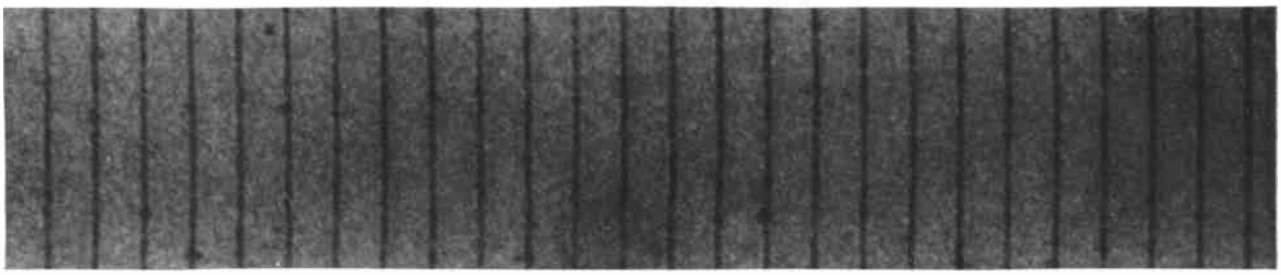


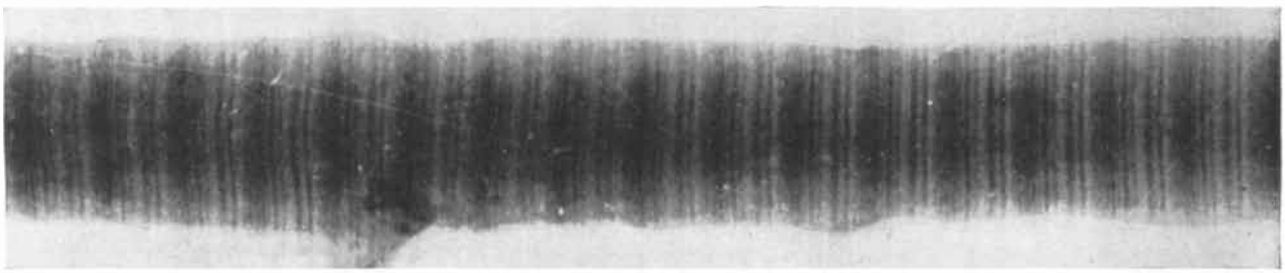
FIBRIL OF PARAMYOSIN, a protein from the muscle of a clam, is enlarged 160,000 diameters in this electron micrograph by Hall. The pattern of bands visible in the fibril repeats every 145 Angstrom units, roughly a 10th the length of the paramyosin molecule.



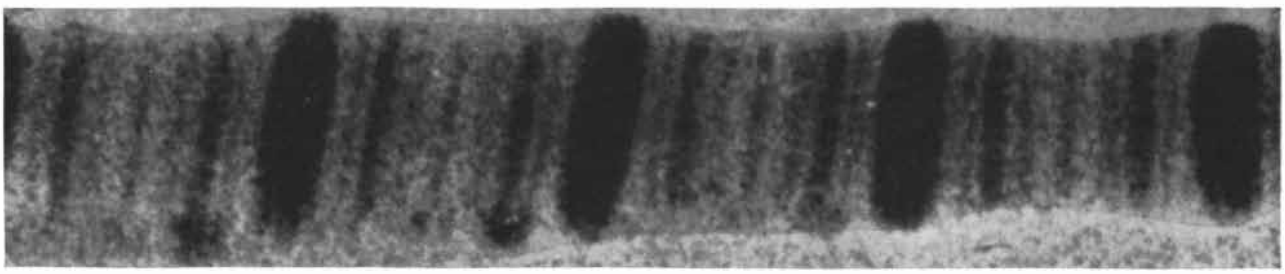
RECONSTITUTED PARAMYOSIN, *i.e.*, paramyosin dissolved in salt solution and then made to reassemble, is enlarged 67,000 diameters in an electron micrograph by J. W. Jacques of M.I.T. Here the band pattern repeates every 1,600 to 1,800 Angstrom units.



LIGHT MEROMYOSIN, derived from the muscle protein myosin, is enlarged 160,000 diameters in an electron micrograph furnished by Andrew G. Szent-Gyorgyi of the Marine Biological Laboratory in Woods Hole, Mass. The pattern repeates every 420 Angstroms.



NATIVE COLLAGEN FIBRIL has a band pattern which repeats at intervals of about 640 Angstroms. Collagen fibrils dissolved in acid and reconstituted in salt solution may also have this pattern. The electron micrograph enlarges the fibril 170,000 diameters.

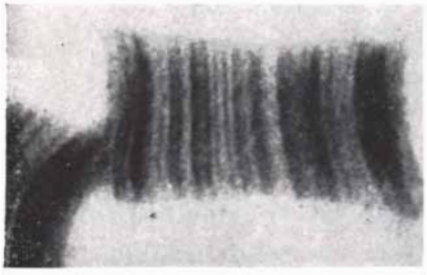


COLLAGEN RECONSTITUTED in a solution containing certain organic substances has a band pattern which repeats at intervals of about 2,800 Angstroms. The electron micrograph at left, made by Gross, shows reconstituted fibrils with "fibrous long-spacing";

ing. The molecular chain of collagen consists of amino acid units in specific sequence. Thus the characteristic side chains of the amino acids also occur in regular sequence. When protofibrils lie side by side, certain side chains, especially the short ones, fit together in regions of relative order. The longer side chains, on the other hand, do not fit well, and give rise to less orderly regions. Bear concluded that the regions of relative disorder correspond to bands (the regions which are slightly thicker and take on more stain); the regions of relative order, to the space between bands (interbands). The banding of collagen would thus reflect the sequence of amino acid units along the molecular chains.

Now when a collagenous tissue, such as the tendon of a rat's tail, is placed in dilute acid, it swells up and eventually dissolves; the resulting solution is as clear as water but relatively viscous. The solution can then be spun in an ultracentrifuge to remove the larger aggregates of collagen. The molecules in the remaining solution were measured by Paul Doty of Harvard University, using the methods of the physical chemist [*see article on page 90*]. He determined that they are 14 Angstroms wide and 2,900 Angstroms long. The molecules were visualized directly by Cecil E. Hall of M.I.T., who found that their dimensions were roughly the same [*see illustration on page 205*].

The dispersed molecules can be reassembled into fibrils by changing the character of the solution. The cross-bands of the artificial fibrils can then be studied in the electron microscope. Depending on the nature of the treatment, the band patterns show considerable variation. First, the bands may be entirely absent. Second, the principal bands may repeat about every 700 Angstroms, as in the native fibril. Third, the bands may repeat in about a third of this distance. Fourth, they may repeat about every 2,800 Angstroms, a distance



the micrograph at right, made by Alan J. Hodge at M.I.T., "segment long-spacing."

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four times that of the normal spacing. This "long spacing" occurs in two forms: "fibrous" and "segment" [*see illustrations on pages 208 and 209*].

Reflecting on these band patterns, Jerome Gross of the Massachusetts General Hospital and John H. Highberger of the United Shoe Machinery Corporation, working in collaboration with the author, deduced that they represent different ways in which the collagen molecules can come together under different conditions. When the molecules are lined up side by side with their ends "in register," their principal bands will repeat about every 2,800 Angstroms. In other words, the distance between the principal bands is about the same as the length of the molecule. If adjacent molecules are in register and pointing in the same direction, the pattern will be of the segment long-spacing type. If adjacent molecules are in register but pointing in opposite directions, the pattern will be fibrous long-spaced. If the adjacent molecules are pointing in the same direction, but are regularly staggered by about a fourth of their length, they will form bands with the native spacing of 700 Angstroms. If the ends of neighboring molecules have no orderly arrangement, no bands at all are formed.

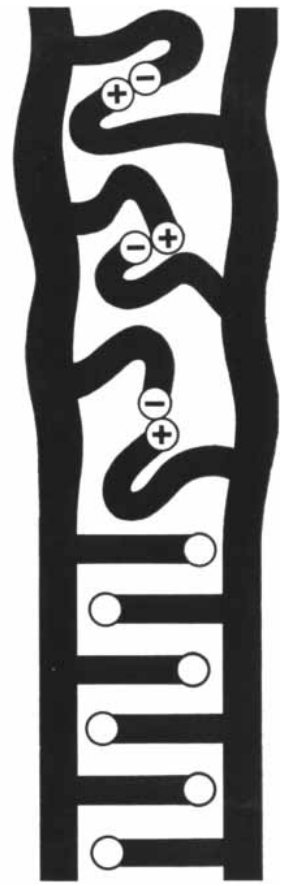
These observations will explain why it seems likely that the organization of protoplasm depends on highly specific properties built into its giant monomers. As Doty indicates in his article on proteins in this issue, the collagen molecule consists of three chains of amino acid units wound in a helix around a common axis. Side chains extending from this molecule interact with similarly placed side chains on adjacent collagen molecules. The molecules will "recognize" each other even if much foreign material is present.

This interaction is significantly influenced by the chemical environment of the molecules. Thus an artificial fibril of collagen with its band pattern repeating every 2,800 Angstroms cannot be made in a solution of pure collagen. A second constituent, such as adenosine triphosphate (ATP), must be added. Presumably the ATP, by combining with certain side chains of the collagen molecule, changes the pattern of the side chains still available for interaction with neighboring molecules.

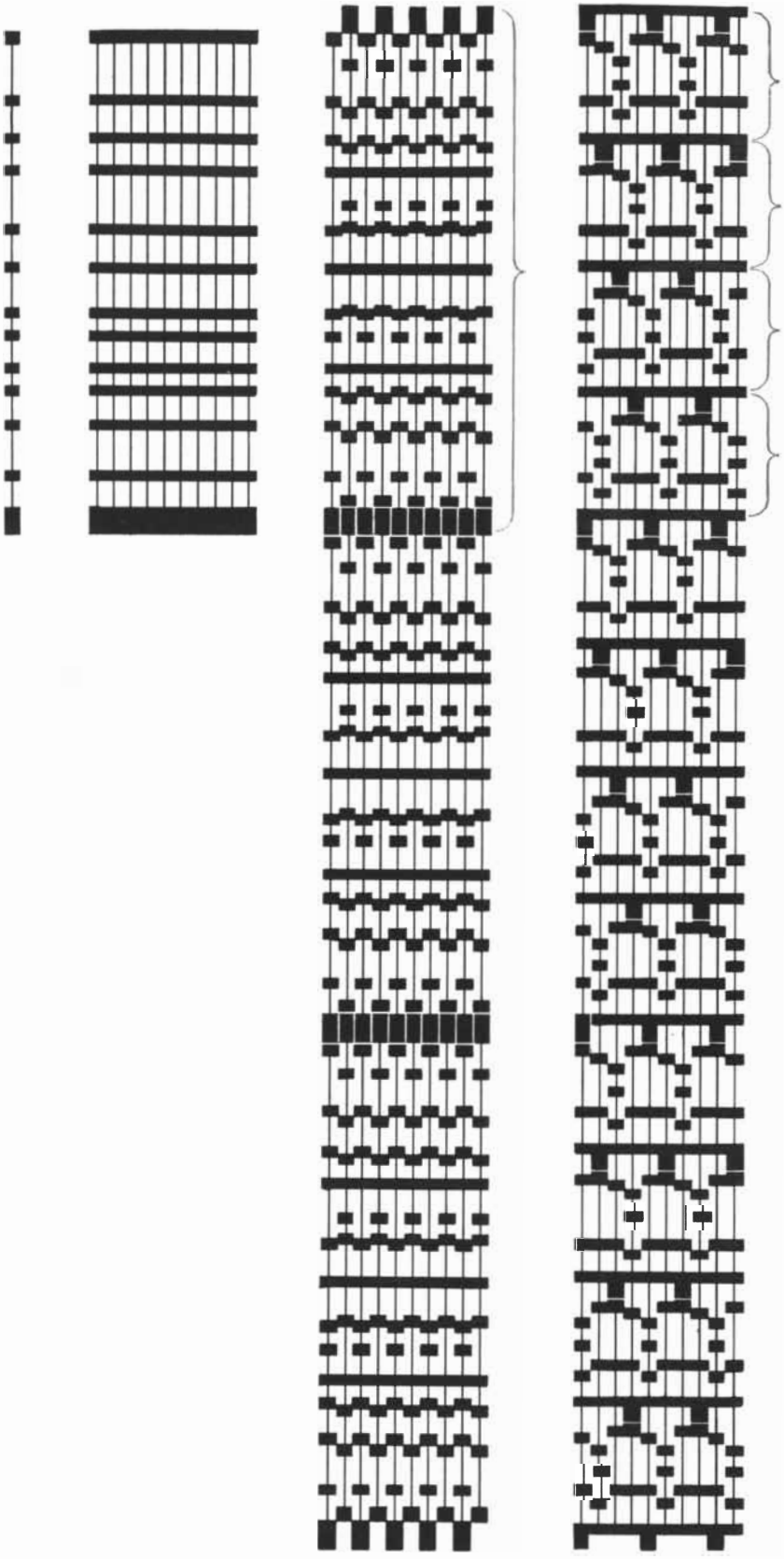
The cross-bands of various kinds of muscle-protein also have been analyzed, though not in such detail as those of collagen. When the muscle that holds shut the shell of a clam is minced in a dilute salt solution, it breaks up into fibrils of the protein paramyosin. In the electron microscope the stained fibrils have a band pattern which repeats about every 145 Angstroms. By means of X-ray diffraction Bear has demonstrated that a unit five times this length also repeats along the fibrils.

Paramyosin fibrils can be dissolved and reconstituted so that the pattern of their bands repeats at the length of the paramyosin molecule. The Australian electron microscopist Alan J. Hodge, working at M.I.T., has shown that this distance is about twice the X-ray period, or about 1,500 Angstroms. It would be interesting to know the connection between the structure of the paramyosin fibril and the long-lasting contraction of the clam's muscle.

A fast muscle of the sort that causes the blink of an eyelid has a rather different construction. The fibrils consist of parallel filaments made up of at least two kinds of protein: actin and myosin. They are segmented into alternating regions, in one of which the filaments are



SIDE CHAINS of collagen molecules lying side by side may be long or short. The long side chains sometimes end in an electrically charged group (+ or —). The short side chains tend to fit together in an orderly manner; the long, to interact in a disorderly manner. These disordered regions correspond to the bands in electron micrographs.



BAND PATTERNS of collagen are explained by means of a schematic collagen molecule (*upper left*) marked at regions where it interacts with other collagen molecules. If adjacent molecules point in the same direction and are in register (*second from left*), their pattern is "segment long-spaced." If adjacent molecules point in opposite directions and are in register (*third from left*), the pattern is "fibrous long-spaced." If they point in the same direction but are regularly staggered (*fourth*), the pattern repeats at a shorter interval.

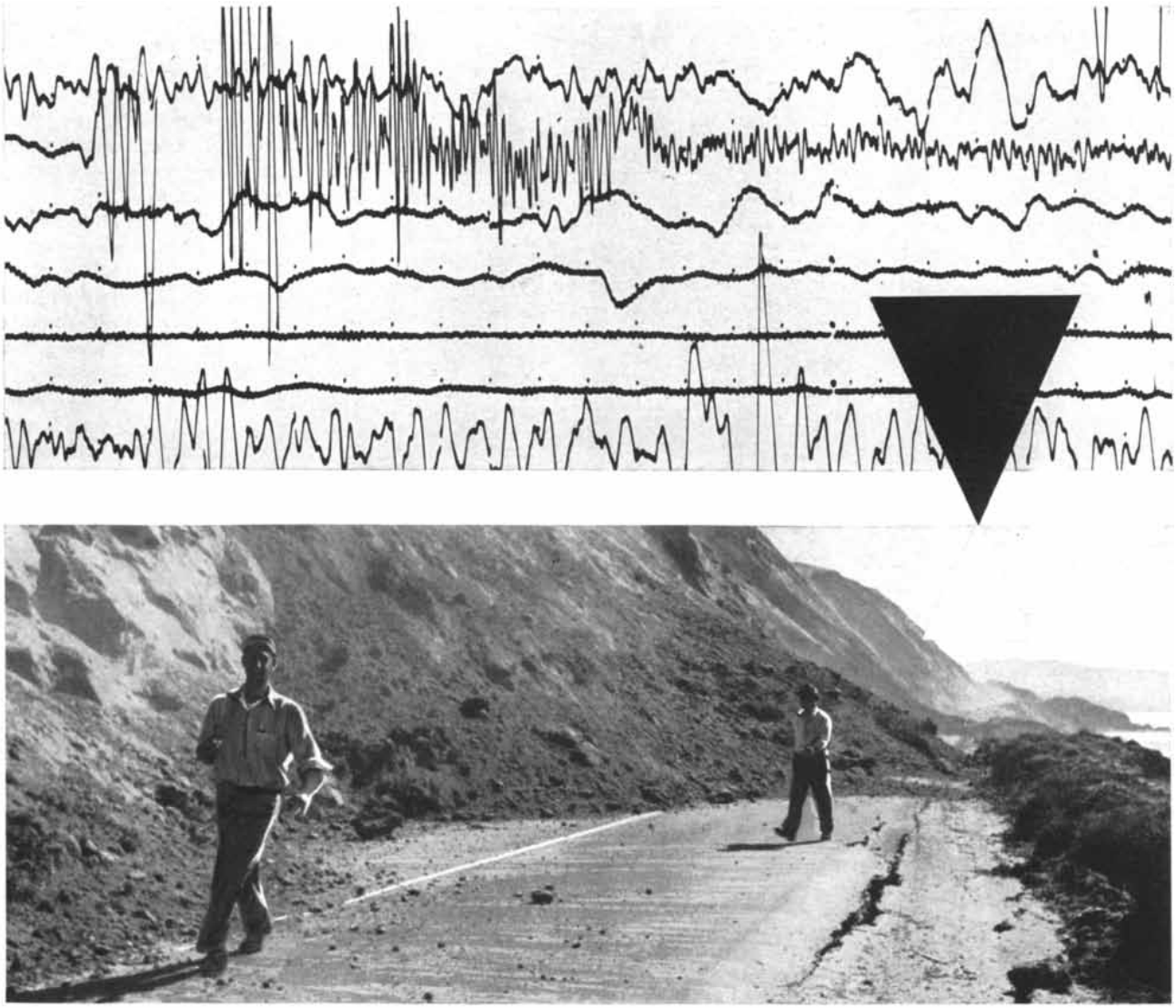
more highly organized than in the other. Throughout both regions a finer band pattern repeats about every 400 Angstroms. The bands of isolated actin fibrils have a similar length, as do those of light meromyosin (a derivative of myosin). How this length is related to the repeating pattern of the fibril and its constituent protein molecules is not yet clear.

In contractile structures other than muscle the filaments may be specialized. The hairlike cilia of microorganisms and higher animals, for example, consist of two fine filaments surrounded by nine thicker filaments or pairs of filaments, the whole encased in a cylindrical sheath. It is not yet known whether such filaments are composed, like those of muscle, of several types of protein.

What makes contractile polymers contract? We can only sketch the process in rough outline. In the case of muscle there must be a protein which forms filaments extending the length of the muscle. This protein transmits tension to the connective-tissue sheath of the muscle and thus to the tendon; it may be actin or a complex of actin and other proteins. In close proximity to these filaments is a second set of filaments, presumably consisting primarily of myosin. The Nobel laureate Albert Szent-Gyorgyi and his school have shown that muscular contraction and relaxation involve a quick change in the relationship between these two proteins. The relationship is influenced by ions of potassium, sodium, calcium and magnesium, and by the energy-rich substance ATP. We must discover what this relationship is if we are to understand what makes fibrous systems contract. According to some workers, contraction occurs when one set of filaments slides past the other. It is believed by others that during contraction a filament of one kind coils in a helix around a filament of the other.

Whatever the mechanism, it seems likely that it is governed by complementary patterns or chemical groups built into both kinds of protein molecule. This complementarity is expressed or suppressed by the presence or absence of substances such as ATP. The function of ATP in turn is regulated by the enzyme adenosine triphosphatase (ATP-ase), which is an integral part of the myosin filament. This enzyme is localized in such a way that it can act on ATP only at one specific moment during the cycle of contraction and relaxation.

Another example of this subtle interaction between specific natural polymers and their chemical environment is the fibrinogen-fibrin system of blood clot-



Trace: courtesy California Institute of Technology. *News photo:* courtesy United Press.

Two ways to look at an earthquake

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Above is a seismic trace made on Du Pont Seismo-Writ photorecording paper. The second line from the top records the San Francisco earthquake of March 22, 1957. It registered a magnitude of 5.3 on the Richter scale.

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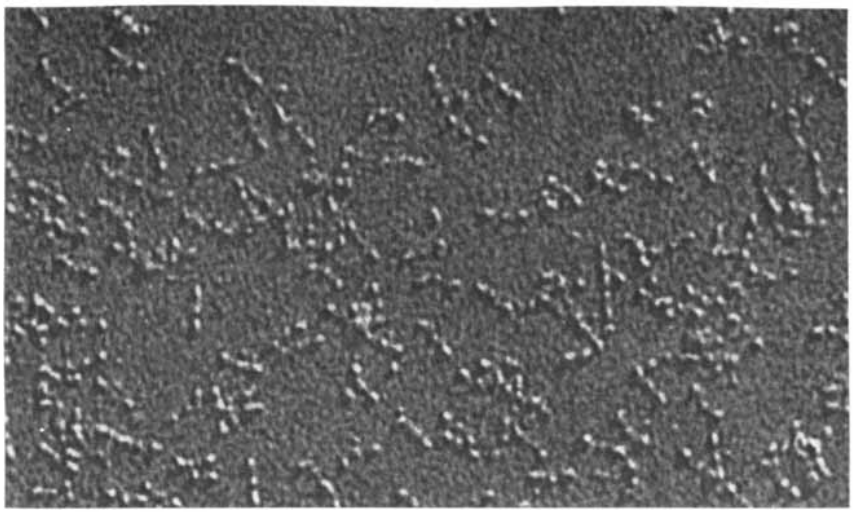
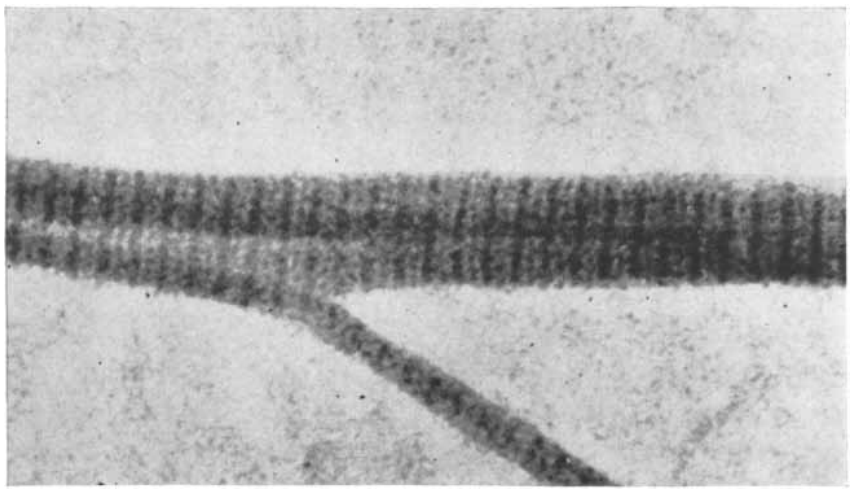
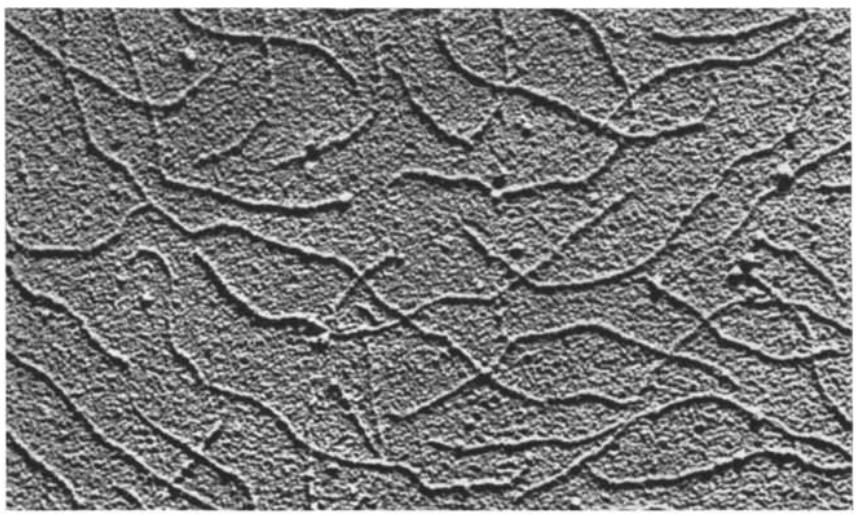


MOLECULES OF FIBRINOGEN are enlarged 130,000 diameters in this electron micrograph by Hall. Each of the molecules consists of three tiny spheres joined by a fine thread.



FIBRIL OF FIBRIN, the insoluble protein made up of fibrinogen, is enlarged 180,000 diameters in this electron micrograph by Hall. Its band pattern repeats every 235 Angstroms.



NERVE FILAMENTS are enlarged 26,000 diameters in this electron micrograph by Myles Maxfield of M.I.T. Filaments of this kind are found in the central core of all nerve fibers.

ting. When measured in solution, fibrinogen molecules are about 40 Angstroms in diameter and 550 Angstroms long. In the electron microscope they are about 400 Angstroms long and consist of three spheres, each 30 to 40 Angstroms in diameter, joined by a delicate thread [*see illustration at left*].

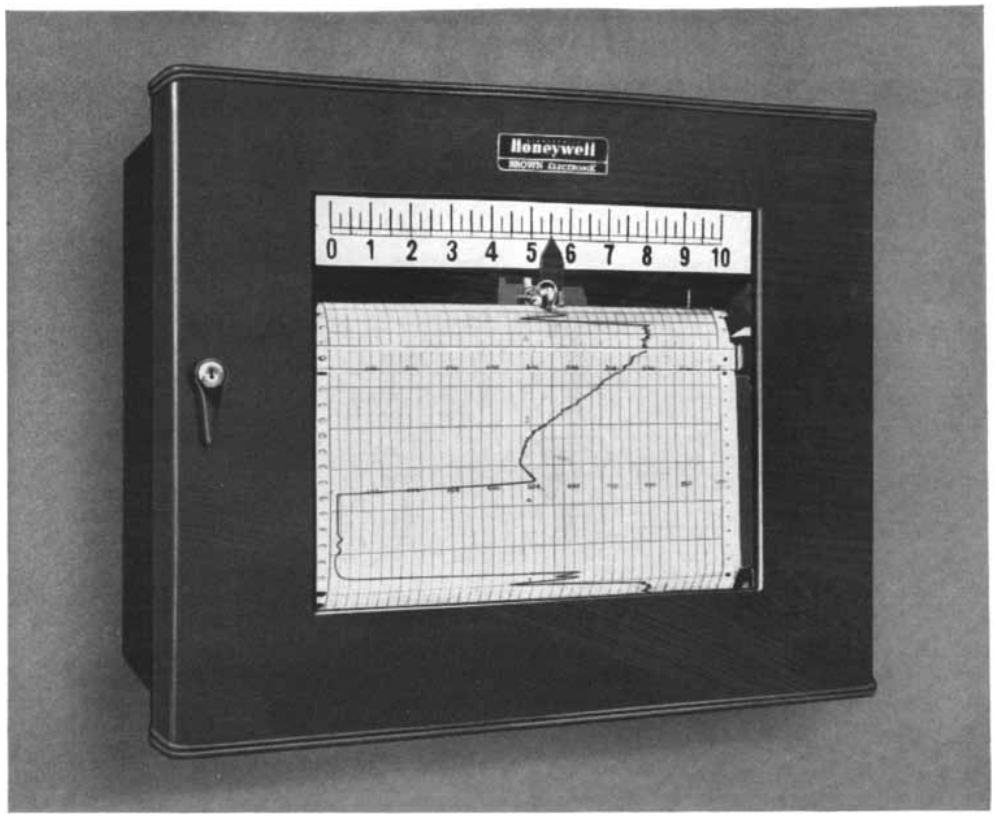
When blood clots, a peptide segment is split out of the fibrinogen molecules. The molecules are thus activated and combine to form a so-called intermediate polymer, the length of which is 4,000 to 5,000 Angstroms. The intermediate polymers, which have been observed in the electron microscope by B. M. Siegel of Cornell University, now come together to form fibrils of the insoluble protein fibrin. These fibrils prevent bleeding by clogging the broken blood vessels. In the electron microscope the fibrils of fibrin have a band pattern which repeats every 235 Angstroms. This distance is not clearly related to the length of the fibrinogen molecule. John D. Ferry of the University of Wisconsin has suggested that the bands may be related to activated fibrinogen molecules which are lined up side by side but staggered.

The mechanism by which soluble fibrinogen is activated and converted into the intermediate polymer is extremely complicated. Like the contraction of muscle, it involves not only the interacting protein molecules but also ions, enzymes and other substances. Some of these facilitate the reaction; others inhibit it. Only by such delicate feed-back mechanisms can the organism maintain high-polymer systems which go into action when they are needed but remain inactive when they are not.

We now come to the most remarkable high-polymer system of all. This is the system that enables the organism to reproduce itself: the nucleic acid and protein of the chromosomes.

The structure of chromosomes has been studied intensively and fruitfully under the light microscope, but reliable information about their molecular organization is scanty. In the electron microscope chromosomes of many kinds appear to have the same basic structure: a relatively dense, smooth-edged filament from 100 to 200 Angstroms wide. On this scale no bands or discontinuities are apparent.

This lack of bands or discontinuities does not mean that the chromosome threads are not made up of long molecules which specifically interact with one another. It is due to the fact that nucleic acid molecules, unlike protein molecules, have no long side chains



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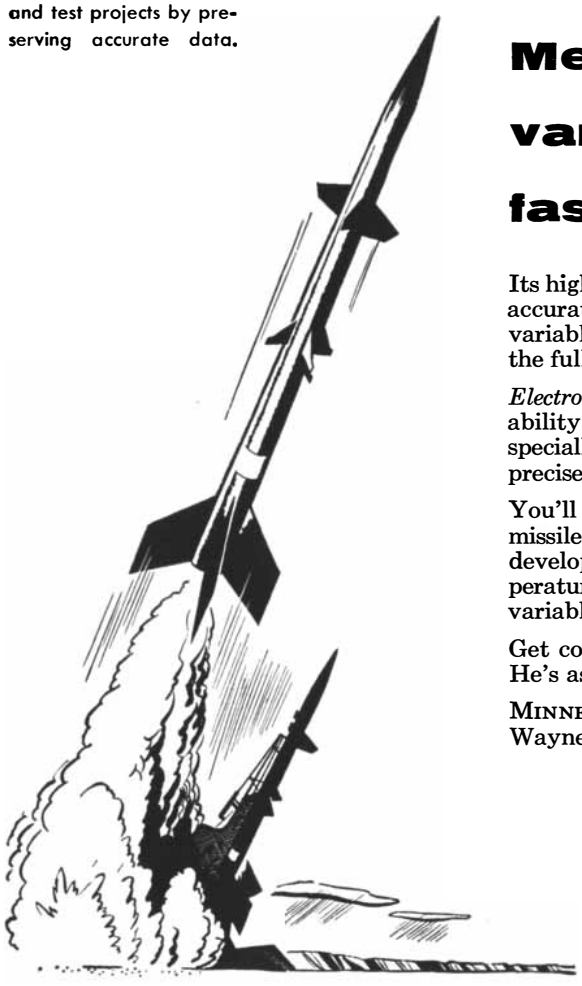

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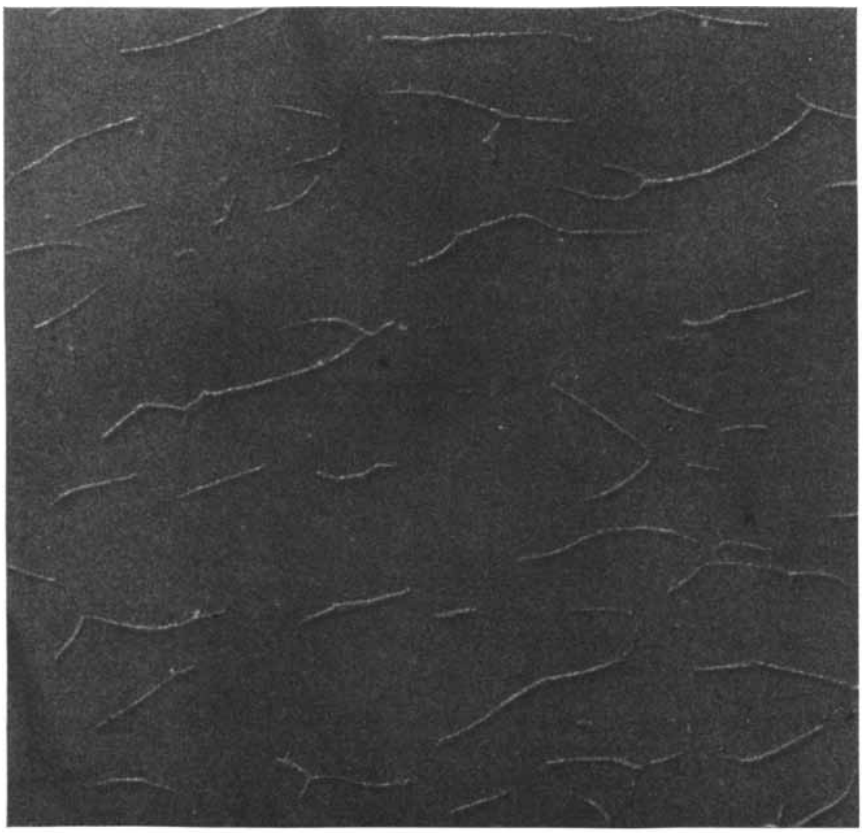
GIANT CHROMOSOMES of the fruit fly *Drosophila* are enlarged 500 diameters in this light-microscope photograph made by Herman W. Lewis of M.I.T. Cross-bands are visible.



MOLECULES OF DNA are enlarged 100,000 diameters in this electron micrograph made by Hall. The material for the micrograph was extracted from the sperm cells of the salmon.

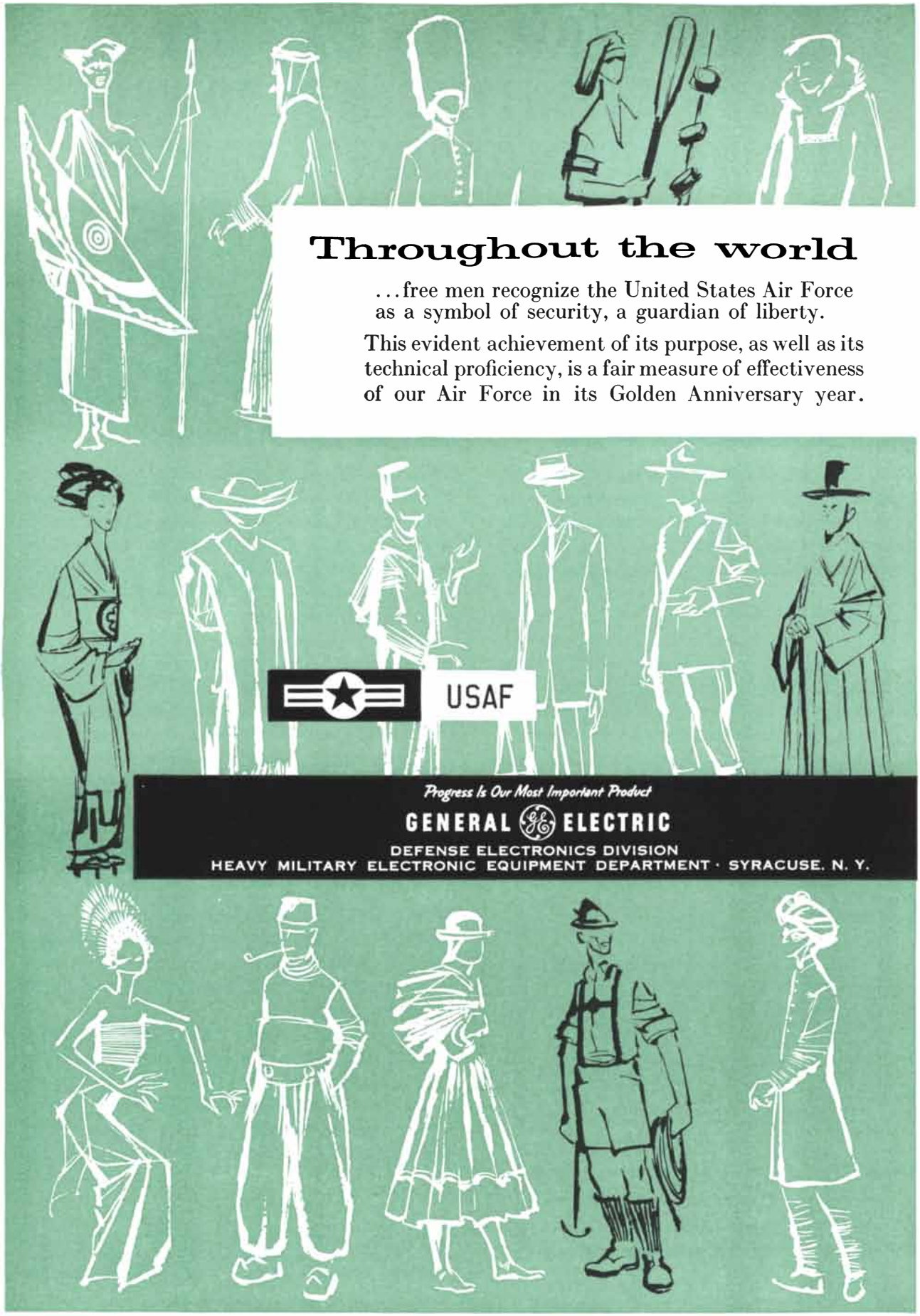
which, by interacting with the side chains of neighboring molecules, can form bands. It is well known, however, that under the light microscope the giant chromosomes in the salivary gland of the fruit fly have pronounced bands. The darker bands represent regions in which the ratio of DNA to protein is high; the lighter bands, regions in which the ratio is low. From this it is obvious that the position of the DNA and protein molecules is precisely determined. What is perhaps more to the point, geneticists have related the hereditary traits of the fruit fly and other insects to specific segments of their chromosomes.

I should like to suggest that the lessons learned from the organization of a protein such as collagen can be applied profitably to the study of the chromosome and the gene. Let us for the moment neglect the internal structure of DNA and its protein partners in the chromosome, and merely make some reasonable deductions from other facts.

First, DNA can be dissolved out of the nucleus of the cell by salt solution. This is a very weak chemical treatment, yet it effectively breaks the bonds that link DNA molecules to protein molecules and to one another. The fact that these bonds can be broken so easily makes it seem rather unlikely that, in its replication and in exerting its biochemical effects, the chromosome is an indivisible unit with all its macromolecules in an unchanging array.

An alternative is that the genetic specificity resides ultimately in the individual giant molecules of the chromosomes and determines the manner in which they interact. Since DNA molecules preserve their chemical pattern from one generation to the next, they must be capable of precise replication. If they can perform such a difficult feat, they may also be capable of highly specific interactions with other kinds of DNA molecules and with protein molecules. Thus they might spontaneously aggregate into the specific patterns characteristic of native chromosomes.

In this picture the chromosome is an aggregation of DNA and protein molecules which is stable in a particular chemical environment in the nucleus of the cell. A change in this immediate environment may alter not only the structural relationship of the molecules but also their biochemical and genetic activity. These possibilities are now being investigated in our laboratory at M.I.T. by applying the techniques used in the study of collagen to DNA, to the protein of chromosomes and to the giant banded chromosomes of fruit flies.



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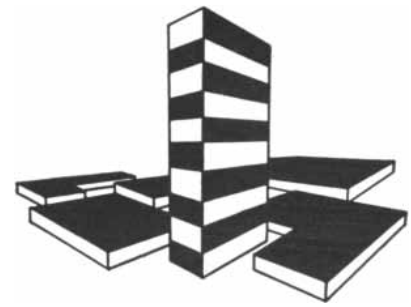

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MATHEMATICAL GAMES

Concerning various card tricks with a mathematical message

by Martin Gardner

Somerset Maugham's short story "Mr. Know-All" contains the following dialogue:

"Do you like card tricks?"

"No, I hate card tricks."

"Well, I'll just show you this one."

After the third trick, the victim finds an excuse to leave the room. His reaction is understandable. Most card magic is a crashing bore, unless it is performed by skillful professionals. There are, however, some "self-working" card tricks that are intensely interesting from a mathematical standpoint.

Consider the following trick. The magician, who is seated at a table directly opposite a spectator, first reverses 20 cards anywhere in the deck. That is, he turns them face up in the pack. The spectator thoroughly shuffles the deck so that these reversed cards are randomly distributed. He then holds the deck underneath the table, where it is out of sight to everyone, and counts off 20 cards from the top. This packet of 20 cards is handed under the table to the magician.

The magician takes the packet but continues to hold it beneath the table so that he cannot see the cards. "Neither you nor I," he says, "knows how many cards are reversed in this group of 20 which you handed me. However, it is likely that the number of such cards is less than the number of reversed cards among the 32 which you are holding. Without looking at my cards I am going to turn a few more face-down cards face up and attempt to bring the number of reversed cards in my packet to exactly the same number as the number of reversed cards in yours."

The magician fumbles with his cards for a moment, pretending that he can distinguish the fronts and backs of the cards by feeling them. Then he brings the packet into view and spreads it on the table. The face-up cards are counted. Their number proves to be identical with the number of face-up cards among the 32 held by the spectator!

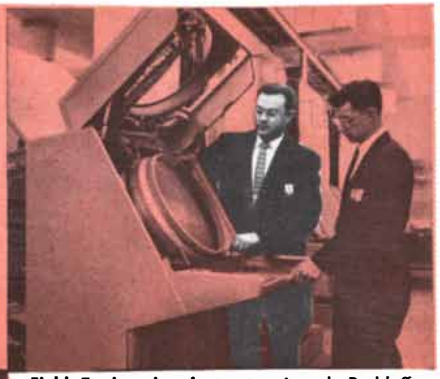
This remarkable trick can best be explained by reference to one of the oldest mathematical brain-teasers. Imagine that you have before you two beakers, one containing a liter of water; the other, a liter of wine. One cubic centimeter of water is transferred to the beaker of wine and the wine and water mixed thoroughly. Then a cubic centimeter of the mixture is transferred back to the water. Is there now more water in the wine than wine in the water? Or *vice versa?*

The answer is that there is just as much wine in the water as water in the wine. The amusing thing about this problem is the extraordinary amount of irrelevant information involved. It is not necessary to know how much liquid there is in each beaker, how much is transferred, or how many transfers are made. It does not matter whether the mixtures are thoroughly stirred or not. It is not even essential that the two vessels hold equal amounts of liquid at the start! The only significant condition is that at the end each beaker must hold exactly as much liquid as it did at the beginning. When this obtains, then obviously if x amount of wine is missing from the wine beaker, the space previously occupied by this wine must now be filled with x amount of water.

If the reader is troubled by this reasoning, he can quickly clarify it with a deck of cards. Place 26 cards face down on the table to represent wine. Beside them put 26 cards face up to represent water. Now you may transfer cards back and forth in any manner you please from any part of one pile to any part of the other, provided you finish with exactly 26 in each pile. You will then find that the number of face-down cards in either pile will match the number of face-up cards in the other pile.

Now try a similar test beginning with 32 face-down cards and 20 face up. Make as many transfers as you wish, ending with 20 cards in the smaller pile. The number of face-up cards in the large pile will of necessity exactly equal the number of face-down cards among the

Associate Engineer Donald A. Patterson demonstrates a problem in pluggable unit layout.



Field Engineering Instructor Joseph Rechloff explains basic display console functions at IBM, Kingston, N. Y.

Associate Engineer Robert M. Blake points out a feature of an advanced magnetic tape circuit development.

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Computer Student Stanley J. Ostrowski studies wave forms in the IBM Computer Engineering School laboratory.

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20. Now turn over the small pile. This automatically turns its face-down cards face up and its face-up cards face down. The number of face-up cards in both groups will therefore be the same.

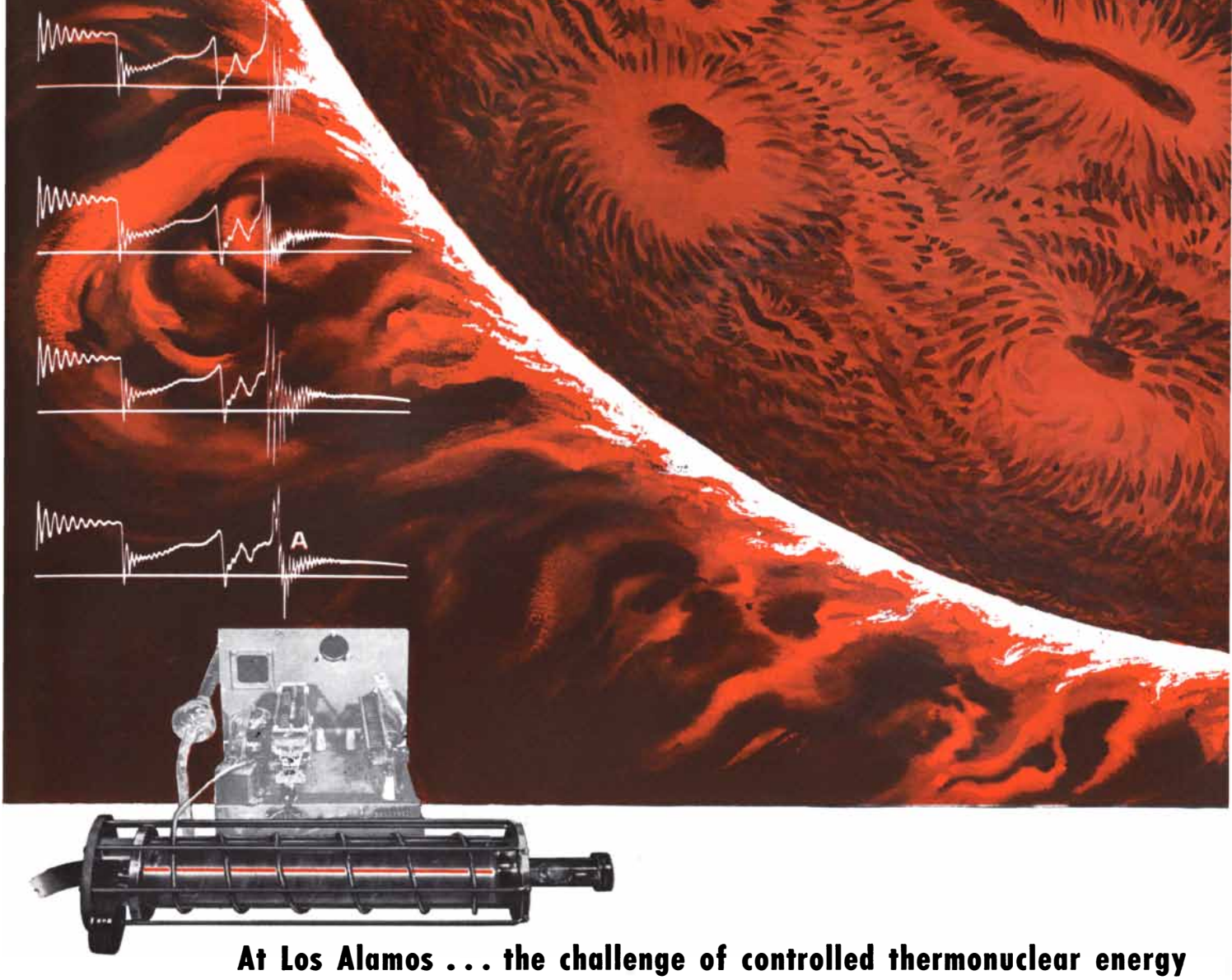
The operation of the trick should now be clear. At the beginning the magician reverses exactly 20 cards. Later, when he takes the packet of 20 cards from the spectator, it will contain a number of face-down cards equal to the number of face-up cards remaining in the deck. He then pretends to reverse some additional cards, but actually all he does is turn the packet over. It will then contain the same number of reversed cards as there are reversed cards in the group of 32 held by the spectator. The trick is particularly puzzling to mathematicians, who are apt to think of all sorts of complicated explanations.

Many card effects known in the conjuring trade as "spellers" are based on elementary mathematical principles. Here is one of the best. With your back to the audience, ask someone to take from one to 12 cards from the deck and hide them in his pocket without telling you the number. You then tell him to look at the card at that number from the top of the remainder of the deck and remember it.

Turn around and ask for the name of any individual, living or dead. For example, someone suggests Marilyn Monroe (the name, by the way, must have more than 12 letters). Taking the deck in your hand, you say to the person who pocketed the cards: "I want you to deal the cards one at a time on the table, spelling the name Marilyn Monroe like this." To demonstrate, deal the cards from the top of the deck to form a face-down pile on the table, taking one card for each letter until you have spelled the name aloud. Pick up the small pile and replace it on the deck.

"Before you do this, however," you continue, "I want you to add to the top of the deck the cards you have in your pocket." Emphasize the fact, which is true, that you have no way of knowing how many cards this will be. Yet in spite of this addition of an unknown number of cards, after the spectator has completed spelling Marilyn Monroe, the next card (that is, the card on top of the deck) will invariably turn out to be his chosen card!

The operation of the trick yields easily to analysis. Let x be the number of cards in the spectator's pocket and also the position of the chosen card from the top of the deck. Let y be the number of letters in the selected name. Your demon-



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stration of how to spell the name automatically reverses the order of y cards, bringing the chosen card to a position from the top that is y minus x. Adding x cards to the deck therefore puts y minus x plus x cards above the selected one. The x's cancel out, leaving exactly y cards to be spelled before the desired card is reached.

A more subtle compensatory principle is involved in the following effect. A spectator is asked to select any three cards and place them face down on the table without letting the magician see them. The remaining cards are shuffled and handed to the magician.

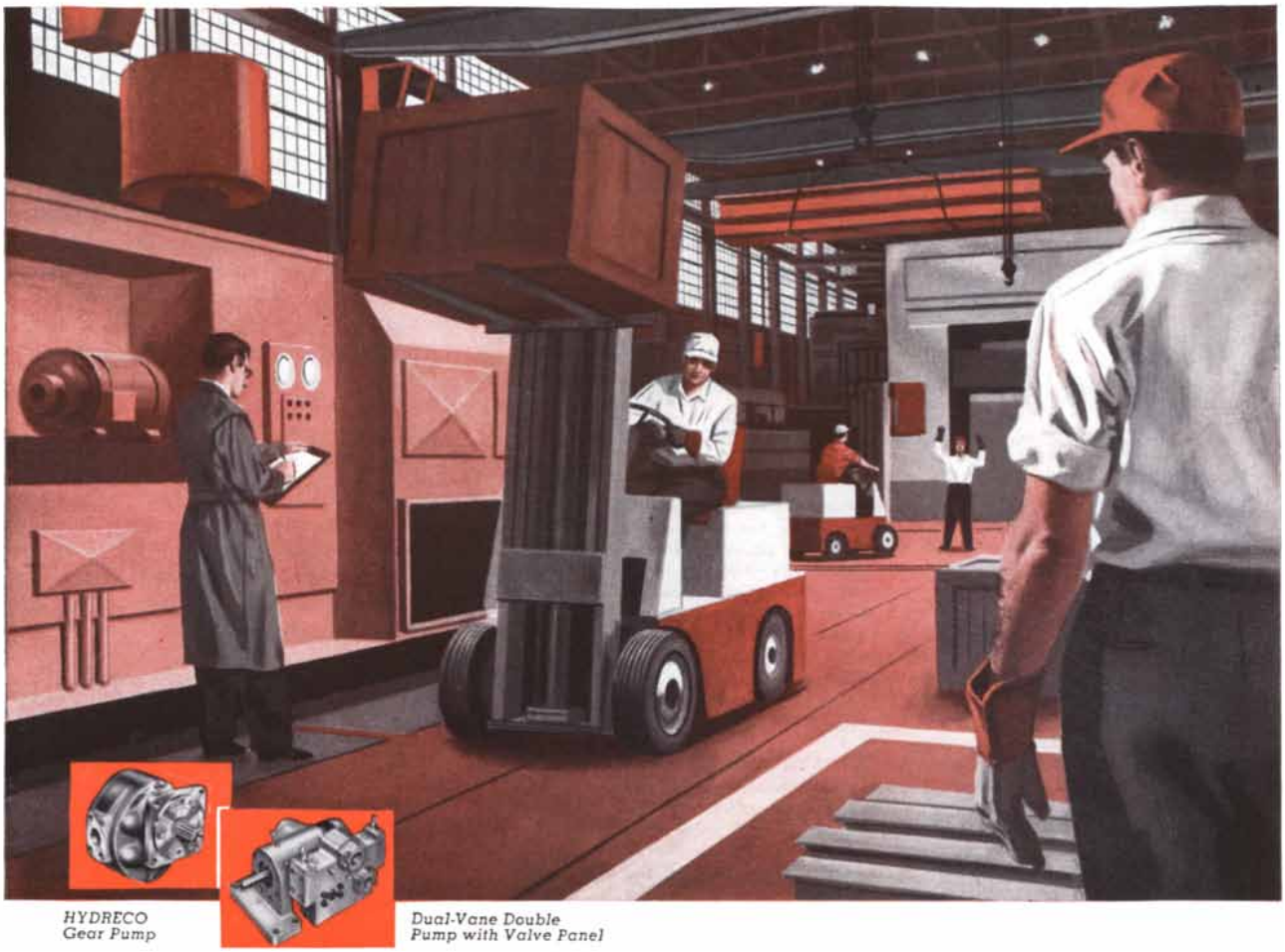
"I will not alter the position of a single card," the magician explains. "All I shall do is remove one card which will match in value and color the card you will select in a moment." He then takes a single card from the pack and places it face down at one side of the table.

The spectator is now asked to take the remaining cards in hand and to turn face up the three cards he previously placed on the table. Let us assume that they are a nine, a queen and an ace. The magician requests that he start dealing cards face down on top of the nine, counting aloud as he does so, beginning the count with 10 and continuing until he reaches 15. In other words, the spectator deals six cards face down on the nine. The same procedure is followed with the other two cards. The queen, which has a value of 12 (jacks are 11, kings 13), will require three cards to bring the count from 12 to 15. The ace (1) will require 14 cards.

The magician now has the spectator total the values of the three original face-up cards, and note the card at that position from the top of the remainder of the deck. In this case the total is 22 (9 plus 12 plus 1), so he looks at the 22nd card. The magician turns over his "prediction card." The two cards match in value and color!

How is it done? When the magician glances through the deck to find a "prediction card," he notes the fourth card from the bottom and then removes another card which matches it in value and color. The rest of the trick works automatically. I leave to the reader the easy task of working out an algebraic proof of why the trick cannot fail.

The ease with which cards can be shuffled makes them peculiarly appropriate for demonstrating a variety of probability theorems, many of which are startling enough to be called tricks. For example, let us imagine that two people



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each hold a shuffled deck of 52 cards. One person counts aloud from 1 to 52; on each count both deal a card face up on the table. What is the probability that at some point during the deal two identical cards will be dealt simultaneously?

Most people would suppose the probability to be low, but actually it is better than 1/2! The probability there will be *no* coincidence is 1 over the transcendental number *e*. (This is not precisely true, but the error is less than 1 over 10 to the 69th power. The reader may consult page 47 in the current edition of W. Rouse Ball's *Mathematical Recreations and Essays* for a method of arriving at this figure.) Since *e* is 2.718 . . ., the probability of a coincidence is roughly 17/27 or almost 2/3. If you can find someone who is willing to bet you even odds that no coincidence will occur, you stand a rather good chance to pick up some extra change.

The answers to the puzzles devised by Sam Loyd, described in this space last month, are as follows:

In the chess problem, for the benefit of chess enthusiasts, White mates in three by taking the pawn with his rook. If black bishop takes rook, White jumps his knight to B3, Black is forced to move his bishop and White mates with pawn to Kt4. If Black had taken the knight instead of the rook, white rook checks on R3, Black interposes bishop, White mates with pawn to Kt4 as before.

After the bullet shatters the white knight, White mates in four by taking the pawn with his pawn. If Black moves bishop to K6, White moves rook to Kt4. Black bishop to Kt4 is followed by white rook to R4 (check). Bishop takes rook and White mates with pawn to Kt4.

After the bullet removes the white pawn at R2, White mates in five with rook to QKt7. Should Black move his bishop to K6, then: (2) R-Kt1, B-Kt4; (3) R-KR1 (check), B-R5; (4) R-R2, PxR; (5) P-Kt4 (mate). Should Black on his first move play B-Kt8, then: (2) R-Kt1, B-R7; (3) R-K1, K-R5; (4) K-Kt6, any move; (5) R-K4 (mate).

If the first bullet had removed White's rook instead of his knight, White mates in six by moving knight to B3. Black's best response is B-K8, which leads to (2) KtxB, K-R5; (3) P-R3, K-R4; (4) Kt-Q3, K-R5; (5) Kt-B4, P-R4; (6) Kt-Kt6 (mate).

The jockeys can be placed on the two donkeys (which miraculously break into a gallop) as shown in the illustration on the next page.

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Lions" paradox, it is meaningless to ask which lion has vanished or which hunter has newly appeared. *All* the lions and hunters vanish when the parts are rearranged—to form a new set of eight lions, each 1/8 smaller than before, and six hunters, each 1/6 larger than before.

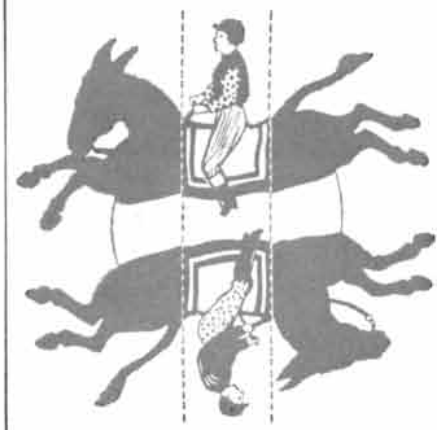
There are many ways to tackle the fighting-fish problem. Here is Loyd's own characteristic account of the solution:

"Three of the little fish paired off with each of three big fish, engaging their attention while the other four little fighters polished off the fourth big one in just three minutes. Then five little fellows tackled one big fish and killed him in 2 minutes 24 seconds, while the other little ones were battling with the other big ones.

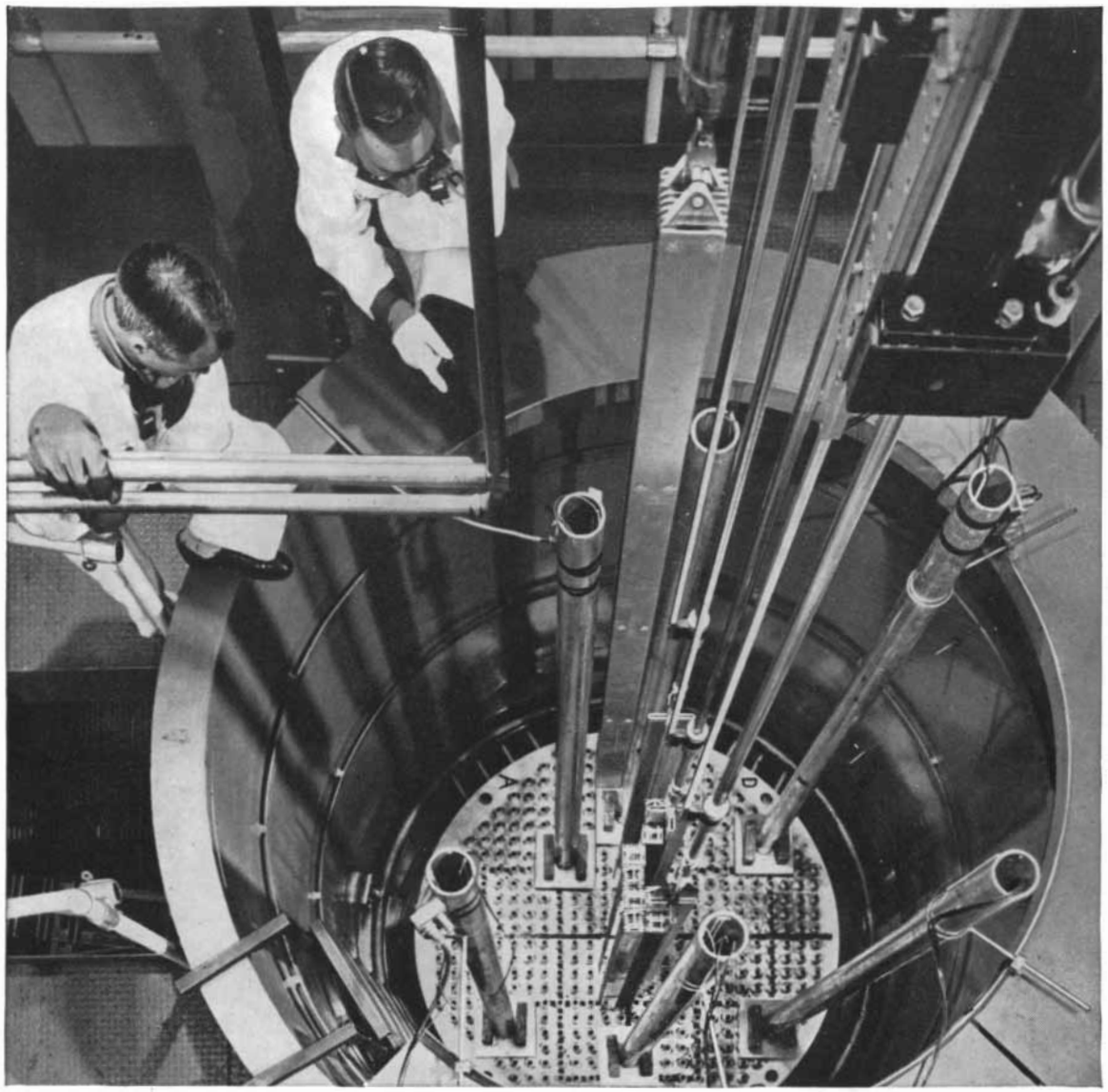
"It is evident that if the remaining two groups had been assisted by one more fighter they would all have finished in the same time, so there is only sufficient resistance left in each of the big ones to call for the attention of a little fish for 2 minutes 24 seconds. Therefore if seven now attack instead of one, they would do it in one seventh of that time, or 20 and 4/7 seconds.

"In dividing the little-fish forces against the remaining two big ones—one would be attacked by seven and the other by six—the last fish at the end of the 20 and 4/7 seconds would still require the punishment which one little one could administer in that time. The whole 13 little fellows, concentrating their attack, would give the fish his quietus in one thirteenth of that time, or 1 and 53/91 seconds.

"Adding up the totals of the time given in the several rounds—3 minutes, 2 minutes 24 seconds, 20 and 4/7 seconds, and 1 and 53/91 seconds, we have 5 minutes 46 and 2/13 seconds as the entire time consumed in the battle."



The puzzle of the donkeys solved



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In this way, the calculations of physicists and engineers can be confirmed or modified; optimum quantity and arrangement of fuel elements and control rods can be determined; the core's ultimate power distribution, safety and stability can be established; and a more accurate forecast of the conversion ratio and reactivity lifetime of the core is made possible.

This privately-financed critical test laboratory is just one example of B&W's investment in facilities, engineering, and research to put nuclear energy to work constructively and economically. The Babcock & Wilcox Company, Atomic Energy Division, 161 East 42nd Street, New York 17, N. Y.

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ATOMIC ENERGY DIVISION

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in the **Machine Tool Industry**

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One of many ways Giddings & Lewis Machine Tool Company has increased profits with the help of Socony Mobil

To Giddings & Lewis, one of the most direct ways to increase net profits is to reduce maintenance costs. That's why this company, a leading builder of quality, high-precision machine tools, relies on a Mobil Program of Correct Lubrication.

In just three years a Mobil "team" of lubrication specialists, working closely with plant personnel, cut lubricant costs per machine 17.9% . . . reduced lubricant application cost 7.6%.

These savings were but a few of the many and varied cost-cuts achieved through Mobil products and Mobil service. They reflect the many hours spent by Socony Mobil field and laboratory personnel in studying machine operations, preparing technical reports, making analyses of products in use.

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Correct Lubrication

A proved program to reduce maintenance costs

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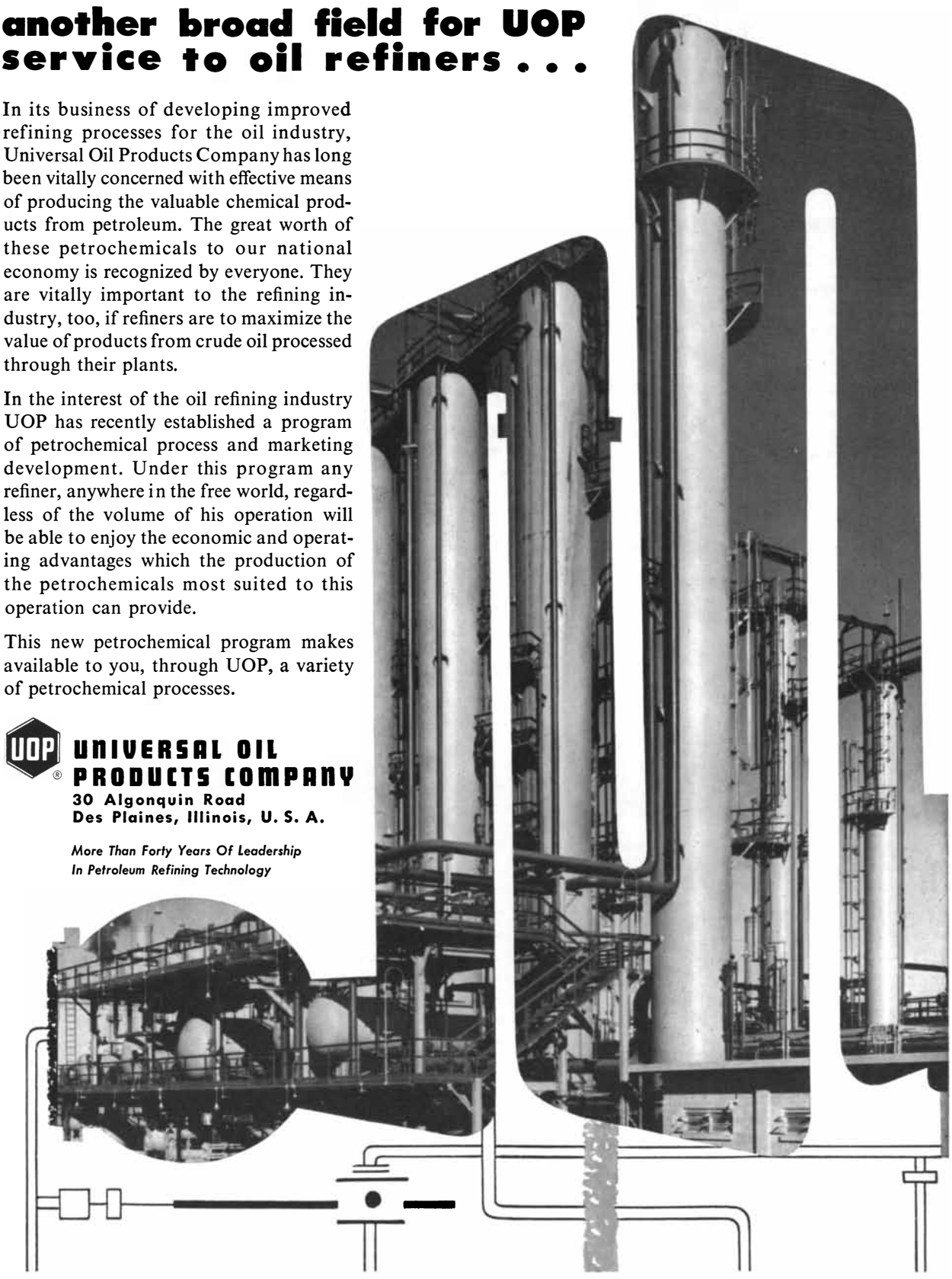

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THE AMATEUR SCIENTIST

How to make an extremely accurate clock based on the vibration of a quartz crystal

The geometry of motion is written in the fundamental concepts of length and time. Events must happen somewhere at some time whether they proceed on the scale of colliding galaxies or the division of cells. If an observer hopes to gather meaningful information about the physical events of the universe, he must therefore begin with a measuring rod and a clock. The better his rod and clock, the more he can learn.

Descriptions of two fine-scaled measuring rods which amateurs can build at home have already appeared in "The Amateur Scientist." One is the "traveling" microscope constructed by Roger Hayward, who illustrates this department. It is capable of measuring lengths over a range of six inches to an accuracy of one part in 60,000 ["The Amateur Scientist," August, 1954]. The other is the interferometer designed by Eric F. Cave, a physicist at the University of Missouri. This instrument can measure distances of less than a wavelength of light ["The Amateur Scientist," November, 1956]. W. W. Withrow, Jr., a radio amateur of Teague, Tex., now describes an extremely accurate clock which can also be built at home. Even if new parts are used in its construction, the clock should cost less than $50.

"Like most amateurs who make a hobby of science, particularly of those branches which have to do with physics," writes Withrow, "I have long wanted a good clock. Ordinary electric clocks do for most purposes and nearly everyone takes it for granted that they keep good time. But do they? The accuracy of electric clocks depends on the care with which the operator at the power station maintains constant frequency on the mains. The Texas town in which I live has an excellent city-owned power plant. But its operators have little reason to maintain frequency as closely as they would if the plant were part of a network of stations which must be synchronized. I found that our clocks sometimes vary as much as a minute from one day to another.

"The principal element in a timing system is the one which, in effect, counts the units of time. This may be entirely mechanical, as in the pendulum clock. It may be electronic, as in the gas-absorption clock [see "Atomic Clocks," by Harold Lyons; SCIENTIFIC AMERICAN, February]. It may be a combination of the two, as in the Marrison, or piezoelectric crystal, clock. In each of the three some resonant element must have a highly constant natural period of vibration which can be coupled to an indicator, usually a clock face, for indicating the passage of time with respect to an arbitrary starting instant such as 0000 Greenwich mean time.

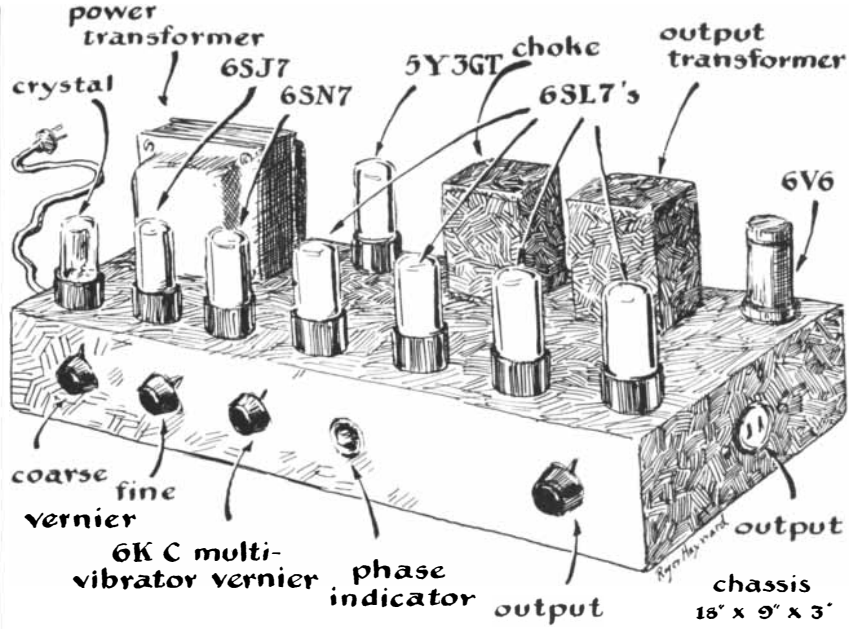
"In casting about for an idea on which to base a clock, I reread an article which appeared in your department for July, 1951. The author, in describing the Hope-Jones Synchronome clock, mentioned that a quartz-crystal oscillator clock may not be beyond the skill of amateurs. When fed with electrical pulses from a vacuum-tube oscillator, a properly cut and mounted quartz crystal vibrates continuously at a rapid and remarkably constant rate. I knew that the National Bureau of Standards uses a crystal clock. But I had dismissed the idea of building a version of it because the Bureau's clock face is driven by a 1,000-cycle motor. Electrical-appliance dealers in my town stock only 60-cycle clocks. Still, I wanted a good clock and could not down the idea of tackling a crystal one, perhaps because electronics has a way of getting tied in with most of my projects whether they are essentially electronic or not.

"I decided to try a simplified version of the Marrison clock, using a quartz crystal cut for 120 kilocycles per second. It seemed likely that a clock could be built around a 120-kilocycle crystal without the complication of such accessories as an oven for maintaining the unit at constant temperature, or a special 1,000-cycle clock motor. The frequency of the crystal could be subdivided to 60 cycles by a highly unstable vacuum-tube circuit called a multivibrator and then amplified as desired for driving the clock mechanism.

"Except for the crystal, the clock was built entirely of standard radio parts plus parts from an old radio plus a spare electric clock. The crystal was made by the Northern Engineering Laboratories of Burlington, Wis. Designated Model T-9D, it is priced at $14, which represents my principal outlay of cash for the clock. The crystal comes mounted in an evacuated bulb with a pronged base that fits a standard vacuum-tube socket. It is driven by a conventional vacuum-tube oscillator [*see circuit diagram on page 236*]. The 120-kilocycle output of the oscillator is boosted by a single-stage resistance-coupled amplifier and reduced to 60 cycles by a series of four multivibrators which respectively operate at 6,000 cycles, 1,200 cycles, 240 cycles and 60 cycles. The output of the last of these multivibrators is fed to a preamplifier, which in turn drives the power amplifier [*see block diagram on page 238*].

"Multivibrators, I learned, are tricky gadgets. It took a long series of experiments to find working values for the resistors and capacitors that finally gave the desired performance. In principle the multivibrator is a two-stage resistance-coupled amplifier in which the output of each tube is coupled to the input of its companion [*see diagram on page 240*]. On the application of power to the unit, a mild pulse of current flows in each of the plate circuits.

"Pulses also appear as a charge on the respective grids. There is a somewhat stronger pulse on one grid than on the other because multivibrator circuits cannot be made perfectly symmetrical. A heavy flow of current promptly builds up in the plate circuit of the tube receiving the stronger pulse. The grid of the companion tube, being coupled to the plate of the conducting tube, is driven strongly negative and soon reaches the point of blocking the flow of electrons from the cathode of the



Electronic generator of precise frequency to drive an electric clock

conducting tube to its plate. The tube is said to have passed the cutoff point. The negative charge on this grid (and on its associated coupling capacitor) then leaks off through a resistor connected between the grid and cathode. The time required for the leaking process depends on the size of the coupling capacitor and the resistor. As the charge leaks away, the potential of the grid rises toward the cutoff point (beyond which the tube can conduct). When this critical point is reached, the tube promptly conducts. The resulting pulse drives the grid of the companion tube (through the coupling capacitor) strongly negative and it in turn cuts off. Thereupon the series of events repeats. The negative charge leaks off the grid and a new cycle is initiated. The seesaw action continues—each tube being cut off and cutting off its companion in return. One grid or the other is always negative and one always positive. Alternately one tube conducts and the other tube does not.

"The frequency at which a multivibrator performs this automatic flip-flop can be increased somewhat without changing the size of the coupling capacitors or grid-leak resistors. If, as either grid approaches the point at which conduction is about to be resumed, a pulse is applied to the grid from an external source, conduction will be initiated early. An external pulse of proper sign (positive) will neutralize the remaining negative charge and push the grid 'over the top.' The multivibrator owes its action as a frequency divider to this effect. Frequency division is accomplished by setting the multivibrator's natural or free-running frequency close to but slightly lower than the desired submultiple of signal frequency and then introducing the signal or controlling frequency to the grid of one of the two multivibrator tubes. The multivibrator then locks in step at the desired submultiple of the signal frequency, because one and only one pulse of the signal can arrive at the critical moment the triggering grid is approaching the cutoff point. Other signal pulses arrive while the grid is either strongly negative or (during alternate half-cycles) when it is charged positively. Thus if a controlling signal of 120 kilocycles is coupled to one grid of a multivibrator which is adjusted for a natural period of slightly less than 6,000 cycles, the first nine cycles of the signal occur while the triggering grid is substantially below the point of conduction. The 10th cycle, however, arrives just in time to push the grid over the top and initiate conduction. During the next 10 signal pulses the triggering grid is positive and the signal has no effect. At the end of this interval the companion tube conducts automatically and drives the triggering grid negative in preparation for the next cycle of events. Thus each 20th pulse of the signal triggers the controlled tube into conduction, and the multivibrator accordingly oscillates at a 20th of the signal frequency.

"The output of one multivibrator can trigger another. Four properly adjusted units can thus reduce the frequency of

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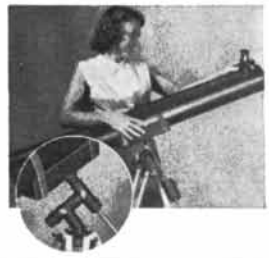

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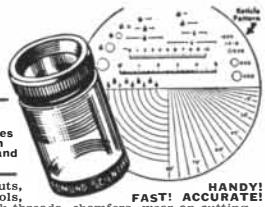

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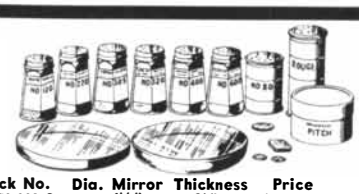

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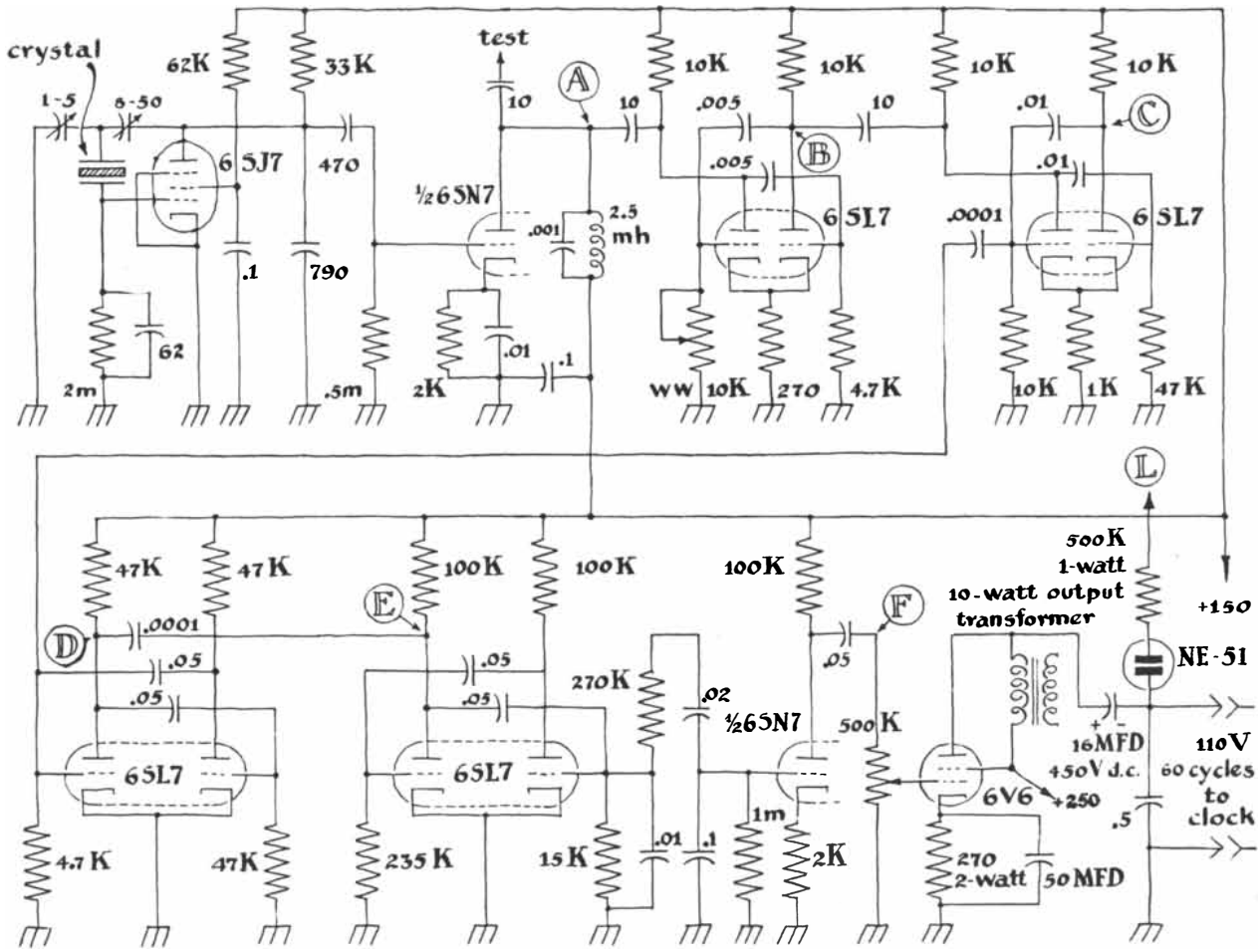
"It must be confessed at this point that the free-running period of multivibrators is influenced by many factors: the voltage of the plate supply, cathode temperature, humidity, atmospheric pressure and even, I have had reason to suspect, the state of one's ulcers. The 6,000-cycle unit is so sensitive to triggering influences that it is apt to lock in step with every disturbance that chances along. It has a revolting way, for example, of deciding to count every 19th pulse or every 21st instead of the desired 20th. This does not mean that multivibrators are too tricky for the beginner. It seems humane, however, to suggest that prospective builders of the clock should lay in an extra supply of aspirin. Fortunately none of the problems are difficult to diagnose. Any amateur with patience enough to make a parabolic mirror will find this project less exacting. One can make major changes in the components at any point, or even start from scratch again without losing anything but time. After all, what fun would one get out of making a piece of gear which behaved well on the first try?

"The layout of the parts on the chassis is not critical. The second tube of the line-up, the 6SN7 twin triode, should be installed with some care. This tube plays a dual role, half of it acting as the preamplifier for 120 kilocycles and the other half as the preamplifier for 60 cycles. Hence it may well be placed next to the oscillator, where it can be fed with short, direct connections. The 60-cycle half can be fed without ill effect by any convenient length of wire. Any method of wiring is satisfactory, provided it does not complicate the task of changing resistors and capacitors in the various multivibrators. The multivibrator circuits must be tailor-made. The values of the resistors and capacitors [*specified in the circuit diagram on this page*] are only approximate. They work in my clock, but may not in someone else's.

"When the chassis has been wired, checked and the tubes installed, it is necessary to set the 150-volt regulator tube under load for a current of 25 milliamperes. One safe method is to place a temporary 100-ohm resistor in series with the ground side of the regulator tube and adjust the variable 20-watt resistor (beginning at about 2,000 ohms) until a voltage of 2.5 is read across the 100-ohm resistor. This method sidesteps the possibility of damaging a milliammeter, should the circuit be accidentally shorted during adjustment. The output control in the grid of the 6V6 power amplifier should be set at minimum while the multivibrator stages are being tamed.

"It is possible to adjust the free-running period of the multivibrator by ear. A headphone (connected through an isolating amplifier) would enable



Circuit diagram of quartz-crystal clock

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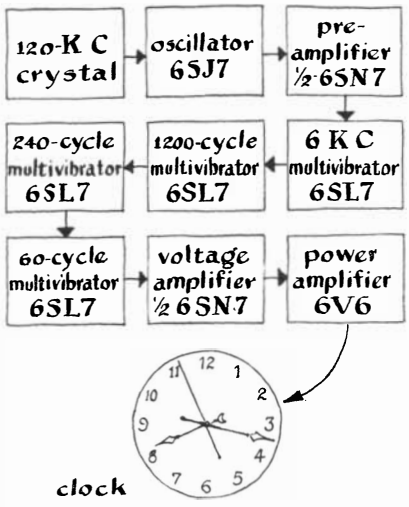

Block diagram of quartz-crystal clock

one to hear the tone and judge the frequency of their respective outputs. But a cathode-ray oscilloscope is by far the best tool for the job. If the amateur does not own an oscilloscope, he may be able to interest a nearby television repairman in the project sufficiently to get the use of one—or even persuade the repairman to try the adjustment.

"The oscilloscope is used to examine the wave forms, and hence the relative frequencies, of two sources of oscillation at a time. Before the tests are begun, one lead of a 1-megohm resistor (of the quarter-watt size) is tightly wrapped to the tip of each of the oscilloscope's two test-probes, one of which causes vertical deflections to be displayed and the other horizontal deflections. The free end of the resistors are thereafter used as probe tips. The tests are based on the pattern presented by the 'scope when its inputs are fed with frequencies related in integral ratio, such as 4 to 1, 20 to 1 and so on. When the frequencies are in exact integral ratio, the resulting pattern is one of the well-known Lissajous figures. If the horizontal swing of the 'scope makes one complete oscillation, for example, while the vertical deflection makes two or more, the pattern may look like a misshapen crown: there are a number of vertical teeth around its upper edge. If the teeth drift a little, the ratio of the two frequencies under observation is nearly but not precisely integral.

"The testing and adjustment procedure may be a bit tedious, but it is not difficult. The probes of the 'scope are applied to a pair of frequency sources, the pattern is observed and the circuit modified as dictated by the pattern. The sources of frequency to be examined are

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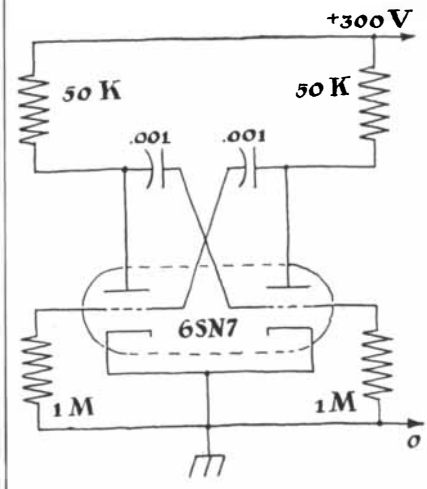
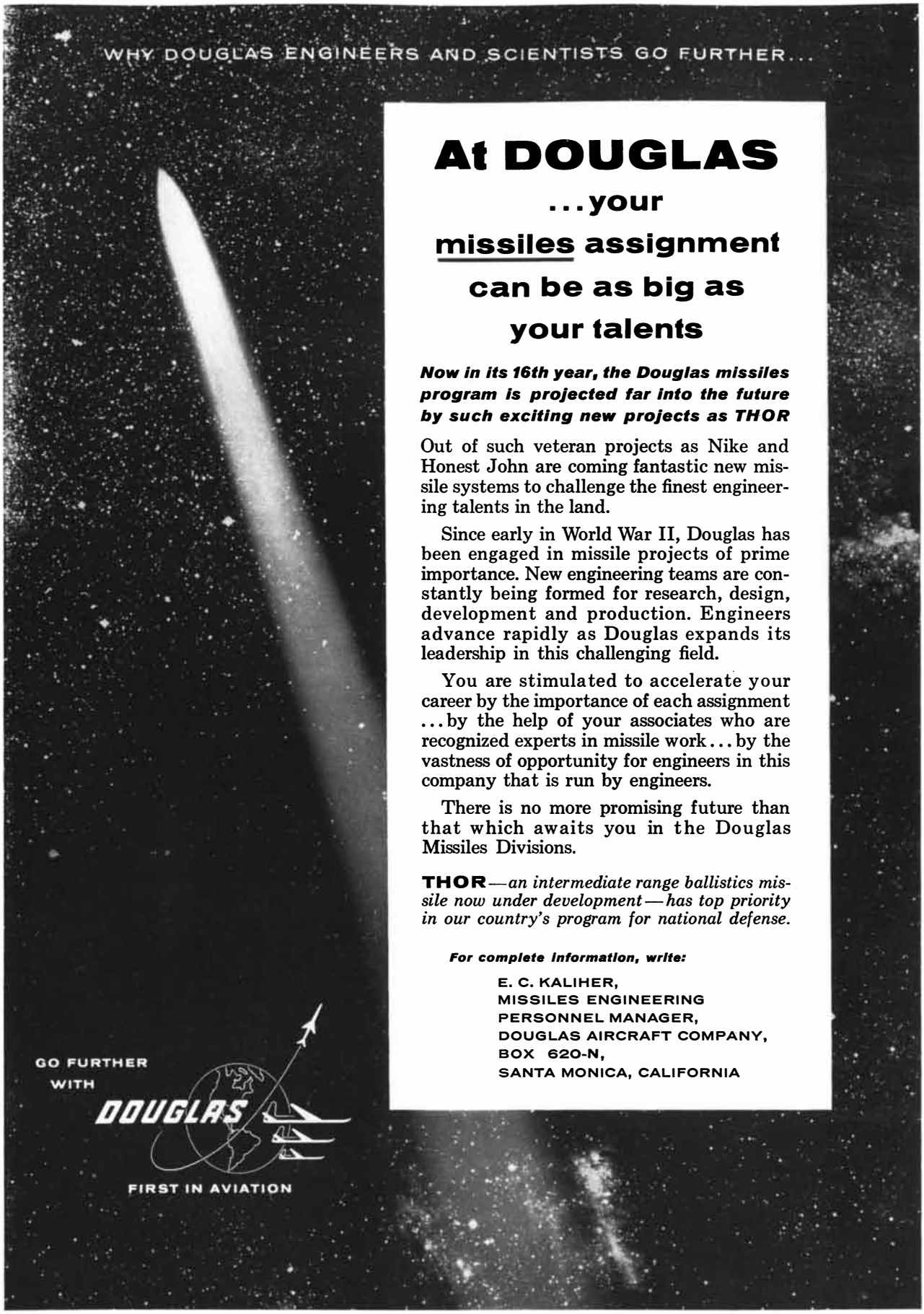
designated by lettered test points [*see circuit diagram on page 236*].

"The testing routine begins with the 6,000-cycle multivibrator. First place the vertical test-probe of the 'scope on point A, the output of the 120-kilocycle oscillator, and the horizontal probe on point B, the output of the 6,000-cycle (we hope) multivibrator. Remove the 6SL7 tube from the succeeding 1,200-cycle multivibrator. Adjust the gain controls of the 'scope for a pattern of convenient size. Now rotate the variable-grid resistor (10 K) of the 6,000-cycle multivibrator to produce a stationary pattern on the 'scope. Several such points will doubtless be found. Select one for examination. Adjust the gain control of the 'scope for full deflection and count the teeth in the pattern. With luck, the count will be 20 [*see drawing on page 242*]. If the count is higher or lower, select another of the stable points and count again. If none of the settings yields the desired count of 20, the value of the 4.7-K resistor in the grid circuit of the second multivibrator tube must be altered. Remove the 4.7-K resistor and substitute a rheostat for it. (One made of a 100-K potentiometer will do.) Now set the 10-K variable grid resistor of the first tube to its midpoint and vary the rheostat. Increased resistance will lower the multivibrator frequency, causing more peaks to appear; decreased resistance will do the opposite. A setting will be found which yields the 20 stationary peaks desired. Measure the value of the rheostat with an ohmmeter, select a corresponding fixed resistor close to this value and substitute it for the rheostat. Replacing the rheostat with the fixed resistor will alter the circuit enough to change the count, but a setting of the variable 10-K resistor should



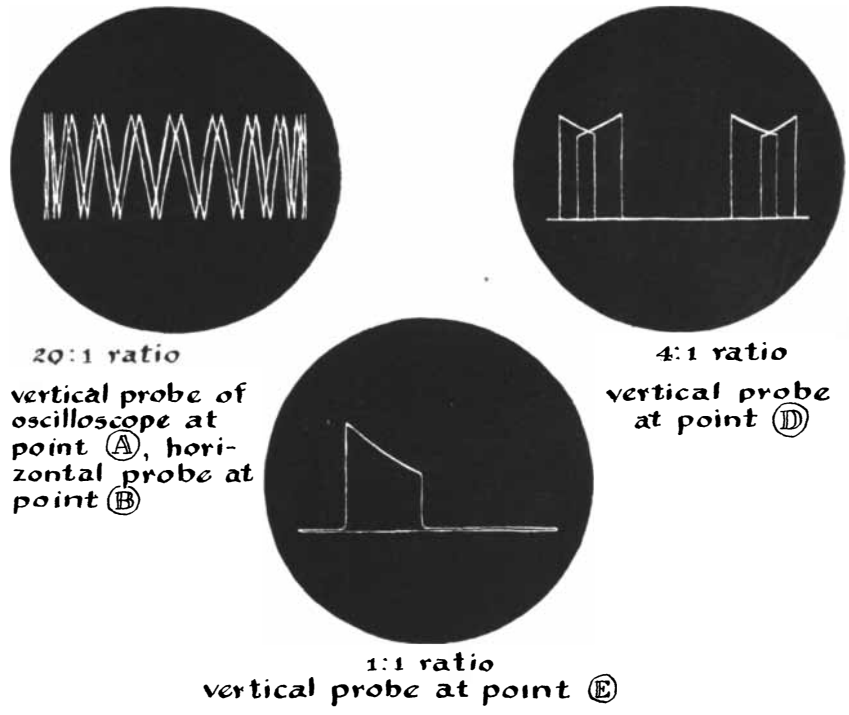
Circuit diagram of a multivibrator



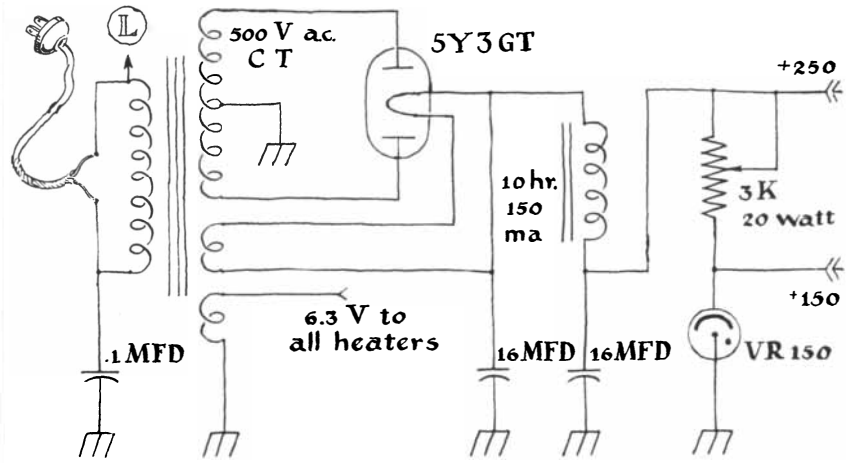
now be found that will restore it to 20.

"Replace the tube previously removed from the 1,200-cycle multivibrator and remove the corresponding tube from the 240-cycle unit. Put the vertical probe on point C and the horizontal one on the ungrounded side of the heater circuit at any convenient point. This feeds the horizontal sweep of the 'scope with the frequency of the power line. If the second multivibrator is oscillating at the desired 1,200 cycles, the 'scope pattern will again show 20 teeth. A slow rotation of the pattern will doubtless be observed, indicating that the power-line frequency is not a precise multiple of the crystal frequency—not quite the 60 cycles customarily advertised. If, in contrast, the pattern shows a pronounced vertical deflection and moves rapidly, substitute the rheostat (just removed from the 6,000-cycle multivibrator) for the 10-K resistor in the grid circuit of the first tube of the 1,200-cycle multivibrator. Again verify the frequency of the 6,000-cycle unit. Now vary the rheostat to produce the 20-tooth pattern, with perhaps the slow rotation mentioned (the vertical probe of the 'scope being on point C and the horizontal one on the ungrounded heater circuit). Measure the value of the rheostat setting which yields a count of 20 and replace the rheostat with a fixed resistor of this value. Again verify the operation of all units of the assembly to this point. The adjustment procedure is similar for the remaining units. In each case, while a unit is being adjusted, the first tube of the following unit must be removed from its socket. The horizontal probe of the 'scope remains on the ungrounded side of the heater circuit while the 1,200-, 240- and 60-cycle units are adjusted. The vertical probe is placed at point D (the output of the 240-cycle unit) and the 47-K grid resistor adjusted until the pattern shows *four* peaks. Similarly, with the vertical probe at point E (the output of the 60-cycle unit), alter the 15-K grid resistor (of the second tube) for a pattern displaying a *single* peak. Finally, place the vertical probe on point F (the output of the 60-cycle preamplifier). The pattern should now take the form of a smoothly rotating ellipse which slowly changes into a straight line at one extreme and opens into a circle at the other.

"All may not go smoothly. When the tube of the 1,200-cycle unit is replaced following the adjustment of the 6,000-cycle unit, for example, the 6,000-cycle unit may tend to lock into a higher or lower multiple of the crystal frequency (because of the shunting effect of the 1,200-cycle tube). A simple adjustment of the 10-K variable resistor may cure the difficulty. At the other extreme, it may be necessary to repeat the whole procedure and find still another value for the original 4.7-K resistor. If so, your luck will improve on the second try because the 1,200-cycle multivibrator will now tend strongly to lock in at its de-



Lissajous figures of multivibrators as displayed on the face of a cathode-ray oscilloscope



Circuit diagram of power supply for quartz-crystal clock

signed frequency. The desired goal has been brought much closer by virtue of previous adjustments.

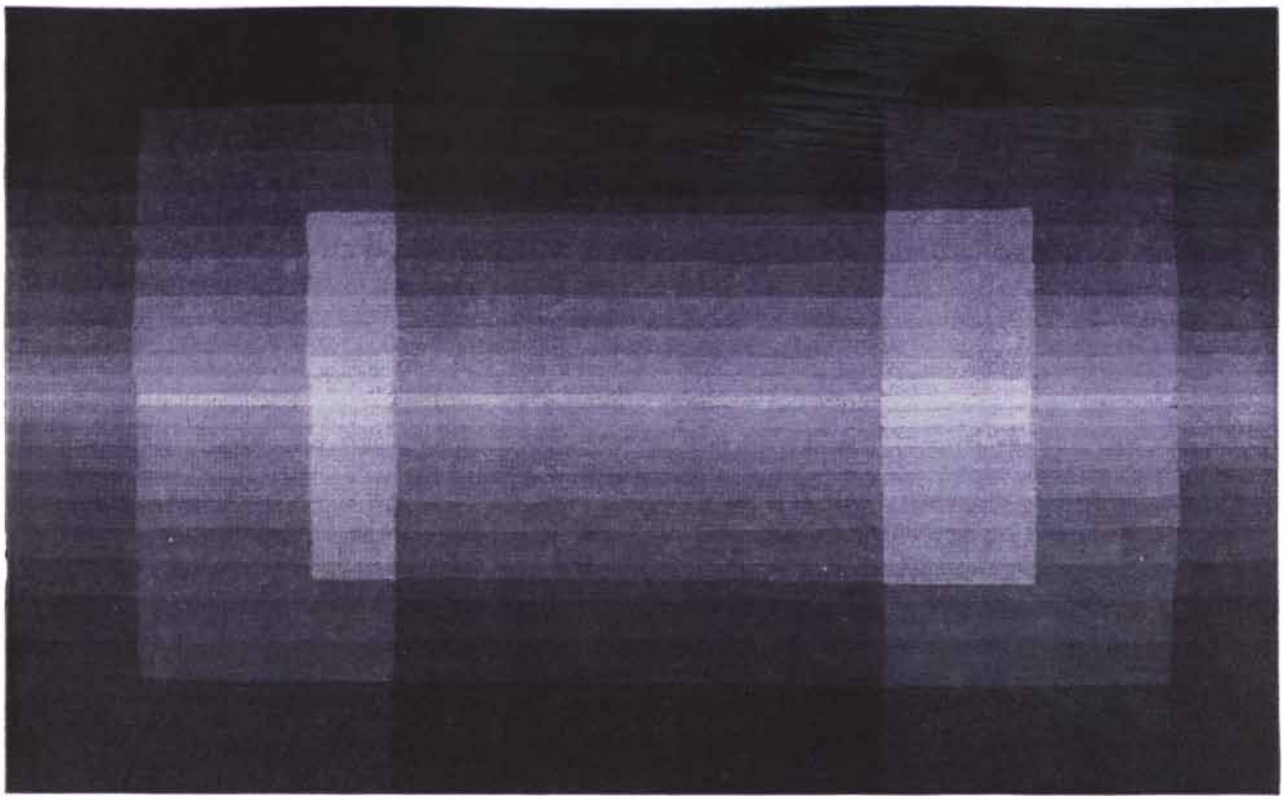
"A permanent indicator of over-all operation, although a rough one, is provided by a small neon-lamp circuit [*see diagram on page 242*]. Test-point L of the indicator is connected directly to one side of the 110-volt power line [*also see point L in diagram on page 236*]. Normally, as the line frequency drifts in and out of synchronization with the 60-cycle frequency derived from the crystal, the lamp pulsates gradually from dark to bright and back again in step with the difference frequency of the two. If the multivibrators are not synchronized, the lamp will pulse rapidly.

"A 60-cycle, 110-volt electric clock drawing not more than three watts is now connected to the output of the power amplifier. As the gain control of the power amplifier is advanced to produce an output of 110 volts, the motor should start running.

"One final pair of adjustments puts the clock in business. It must be regulated (the crystal frequency adjusted as closely as possible to 120 kilocycles) and the hands set for correct time in the local time zone. The control device to regulate the rate at which the clock runs is based on the fact that a piezoelectric crystal can be forced to vibrate faster or slower than its natural period (within narrow limits) by altering the amount of electrical 'push' imparted to the crystal during each vibration by the associated vacuum-tube oscillator—just as the pendulum of a mechanical clock can be made to beat slightly faster or slower than its natural period by altering the amount of energy imparted to or subtracted from the pendulum by the escapement mechanism. Driving energy for the crystal, in the form of periodic pulses, is taken from the oscillator tube through a variable capacitor which covers a range of 8 to 50 micromicrofarads. This capacitor may be thought of as a rough regulating adjustment. A second variable capacitor (1 to 5 micromicrofarads) is connected between the 'hot' side of the crystal and the ground. It shunts a portion of the energy from the tube to the ground, the amount depending upon the setting of the capacitor. This is the 'fine' adjustment.

"The primary reference frequency in this country is the time signals broadcast by radio station WWV of the National Bureau of Standards. These signals appear on carrier frequencies of 2.5 megacycles, 5 megacycles, 10 megacycles and so on in multiples of 5 megacycles up to 25 megacycles. The signals can be picked up almost anywhere on a short-wave radio. They are accurate to better than one part in 100 million. All WWV carrier frequencies are modulated periodically by time announcements in voice and by a series of pulses or 'ticks' which persist for .005 second and commence each second.

"Tune in WWV and listen to the seconds tick. Then, by any convenient means, arrange your clock so it will also make audible second clicks. My clock is of the drum-counter type, in which a ratchet coupled to the drum mechanism is moved by a motor-actuated pawl. The movement of the drum begins on the minute and the pawl clicks precisely three seconds later. The clock is set roughly by WWV's voice announcement and regulated by comparing the click of the pawl with the fourth tick (after the minute) of WWV. This is the tick marking the end of the third second. It is possible to judge the interval between the tick of WWV and that of my clock within about a tenth of a second, de-



"STUDY FOR ECLIPSE," a preliminary development by the creative team of Simpson-Middleman, artists whose work is a penetrating expression of the forces and phenomena of the natural sciences. This painting is one of the steps—ground structure—in which the ultimate action will take place. Courtesy of John Heller Gallery, Inc.

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pending on how far my clock is running ahead of, or behind, WWV. Note the difference when the new clock is put into operation. At the end of an hour the difference will doubtless have increased or decreased. Rotate the fine adjustment a few degrees and note the setting. Another hour should show the effect of the adjustment. Mark the dial of the regulator control with an arrow to indicate the direction in which the knob must be turned for 'fast' and 'slow.' If the rate requires major adjustment, use the rough control. From this point the task is merely one of narrowing the margin of error. When finally set, the clock should remain within a 10th of a second of WWV for weeks on end.

"Some amateurs may live in areas where WWV cannot be heard. It is possible for them to set and regulate the clock with fair accuracy if they can pick up a radio station which broadcasts on a frequency which has a submultiple of 120 kilocycles, such as 600 cycles, 720, 840, 960, 1,080 and so on. The plate circuit of the preamplifier provides access to the crystal frequency through a 10-micromicrofarad capacitor at the point marked 'test' [*see circuit diagram on page 236*]. This frequency is compared with that of the broadcasting station by connecting a wire between the test point and the external antenna post of the radio receiver, tuning in the station and listening for the beat or difference frequency of the clock and station. If the receiving set has an internal-loop antenna instead of an external antenna, drape a foot or two of wire (connected to the test point of the clock) over the loop antenna of the set. Adjust the volume of the set so the beat can be heard clearly. The sound will doubtless resemble an undulating or pulsating swish. The rate of the pulsation is equal to the difference frequency between the clock and a submultiple of the carrier frequency. Adjust the regulating controls of the clock for zero beat. The clock will then be as accurate as the frequency of the broadcasting station—which is pretty good.

"The adjustment procedures have been outlined in some detail because, as those who undertake the construction of this clock will discover, it is no 'cookbook' project. Multivibrators are such fickle critters that each clock must be regarded as an original project in its own right. But the instrument is worth whatever time and patience it costs. Once operating, the 60-cycle output can be further amplified if desired and wired to distant locations for driving all sorts of apparatus, including telescopes, seismograph pens and so on."

Above: Members of the Santa Cruz Test Base discuss site development problems. Left to right: J. W. Strain, Propulsion Systems Engineer; A. L. Hubbard, Manager of the Santa Cruz Test Base; Doyle F. Mattson, Instrumentation and Electronics Engineer; and T. J. Blecher, Ordnance Development and Test Section Engineer.

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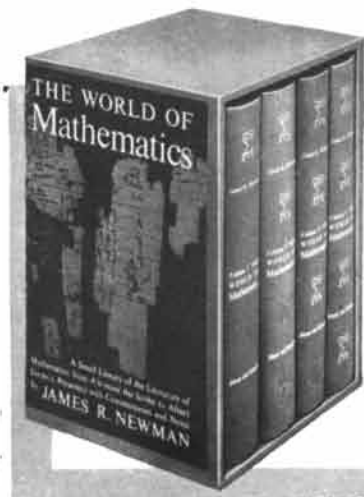

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The work of an influential but little-known philosopher of science: Ludwig Wittgenstein

by Gilbert Ryle

PHILOSOPHICAL REMARKS ON THE FOUNDATIONS OF MATHEMATICS, by Ludwig Wittgenstein. The Macmillan Company ($5.75).

The late Ludwig Wittgenstein was a deep and influential philosopher of science, yet outside the circle of professional philosophers little is known of the man and his work. This book is the second collection of his papers to be published since his death. The editors of SCIENTIFIC AMERICAN have asked me to take this occasion, not to review the book, which in any case is too specialized for the general reader, but briefly to describe who Wittgenstein was and what he did.

First for the man.

He was born in 1889 in Austria and died in 1951 in England. He was of Jewish origin, though he was brought up a Roman Catholic. He, with the rest of his family, was intensely musical. His father was a wealthy steel magnate. He himself was trained as an engineer, and was engaged in aerodynamical researches in England when in 1911 and 1912 he became perplexed about the logical and philosophical foundations of mathematics. Advised, apparently, by the German mathematician Gottlob Frege, he went to Cambridge to study under the author of *Principles of Mathematics,* Bertrand Russell.

During the First World War he served in the Austrian army, and ended up a prisoner-of-war in Italy. His rucksack contained the manuscript of the only book of his that was published during his lifetime, the *Tractatus logico-philosophicus.* This was published in 1922, with the German text faced by an unreliable English translation. It contains an introduction by Russell, but Wittgenstein disapproved of this. A revision of the translation should appear fairly soon. Wittgenstein became professor at Cambridge in 1939, succeeding G. E. Moore, and he resigned in 1947.

He was a spellbinding and somewhat terrifying person. He had unnervingly piercing eyes. He never used hackneyed expressions—not that he strove after originality of diction, but he just could not think in clichés. To his own regret, he could not help dominating his associates. He remorselessly excommunicated persons of whom he disapproved.

He loathed being connected with academic philosophers, and he avoided academic chores. After 1929 he attended no conferences; he did no reviewing for journals; only once did he attend a philosophical meeting in Oxford; he was inaccessible to visiting philosophers; he read few, if any, of the philosophical books and articles that came out during his last 25 years.

He was like Socrates in rigidly separating the philosopher from the sophist; unlike Socrates in shunning the market place; like Socrates in striving to convert his pupils; unlike Socrates in feeling the need to conserve his genius by insulation. He was hermit, ascetic, guru and *Führer.*

What of the philosopher?

He had no formal training in philosophy. His ferments came from his own insides. I do not know just what shape his initial perplexities about mathematics took. Anyhow he consulted Frege and Russell, and studied their logico-mathematical writings; the central problems of his *Tractatus,* though not the same as theirs, were clearly reactions to their doctrines.

Frege and Russell tried to show that all pure mathematics derives from the completely general truths of formal logic, *i.e.,* that these truths stand to arithmetical truths as Euclid's axioms to his theorems. But what was the point of trying to demonstrate this continuity between logic and arithmetic? Surely the truths of mathematics are as well established as anyone could demand, so what is gained, except for tidiness, by underpinning them with an ulterior foundation?

At that time reflective mathematicians were in trouble. Their science seemed all limbs and no body. The very vigor of these branches was generating cross-purposes between them. The notion of number itself seemed to take as many shapes as there were branches of the science of number. Mathematics felt like a caravanserai, not a house.

Its external relations with other sciences also were precarious. John Stuart Mill had likened the truths of mathematics to those of the natural sciences: they are generalizations from experience, susceptible of overthrow by unexpected exceptions. It would be much more surprising to find an exception to $7 + 5 = 12$ than to find a black swan, but only much more. Which is absurd. For another thing, many thinkers, when asked, "Of what entities is mathematics the science?", were giving a psychological answer. The physical world contains countless sorts of things, but it does not contain numbers. There are nine planets, and the earth has one moon. But you cannot see 9 or 1. So, if numbers are not physical things, what else is there for them to be, save ideas in our minds or thoughts or something of the sort? But then arithmetic ought to make allowances for the differences between what goes on in lunatic and in sane minds; in visualizers' and in nonvisualizers' minds, and so on. Which is absurd.

Because mathematics needed, internally, coordination between its members and, externally, autonomy from the inductive sciences, especially psychology, its affiliation to logic felt like a rescue operation. Mathematics could be saved from internal discord and from external pressures by becoming part of the unchallengeable science of logic.

But what sort of science is this? What sort of truths are the truths of logic? What sorts of information does logic give us about what sorts of entities? That is, I think, the central problem of Wittgenstein's *Tractatus logico-philosophicus.*

The truths and falsehoods of the natural sciences are truths and falsehoods about what exists and happens in

the world. Their truth or falsehood depends upon what is the case with things in the world. But the truths of logic give us no information about the world. "Either it is raining or it is not raining" exemplifies a logical truism, but it tells us nothing about the weather. It is true whatever the weather. "Socrates is mortal" gives us important information or misinformation about Socrates, but "*If* all men are mortal and Socrates is a man, *then* he is mortal" gives us an applied logical truth, which is true whether or not he is mortal.

The truths of the natural sciences are factual truths, while those of logic are purely formal. Their truth is neutral between the world as it is and as it might have been. This formal nature of logical truths shows itself in another way. The truism "Either it is raining or it is not" remains true if for "raining" we substitute "snowing," "freezing" or anything you please. For any proposition whatsoever, either it or its negative is true. The force of "either . . . , or not . . ." is indifferent to the material fillings of the clauses that it links, so long as the clauses are the same. Hence truths of logic can be expressed most cleanly if we algebraize away all material elements like "Socrates," "mortal," and "it is raining." This leaves, for example, "For any p, either p or not-p."

Thus logic is unconcerned with the actual truth or falsity of the factual statements which can be draped on its skeletons. Nonetheless logic is essentially concerned with the truth-or-falsity of these statements, since it has to work out how the truth or falsity of one *would* follow, if another *were* true or *were* false. That Jack went up the hill would have to be true *if* Jack and Jill went up the hill; and from the falsity of "Jack went up the hill" would follow the falsity of "Jack and Jill went up the hill."

Well then, why should we not answer the original problem by saying that the subject matter of logic consists of truths-or-falsehoods, and that it has to discover in them their formal properties which secure that one would be true if another were true? But then what sorts of entities are truths-or-falsehoods, and what sorts of properties are these formal properties?

When I say "It is raining," my words convey something to you. You understand them even though you do not know that it is raining. They make sense, even if it is not raining. So the actual state of the weather is one thing; the truth-or-falsehood that it is raining is something else. In getting the meaning of my words, you are getting not what the state of the weather is, but what-it-is-being-represented-as-being. But what enables expressions to represent things as they are, or as they are not? What enables a complex of symbols to *mean* something *vis à vis* some actual matter of fact? Consider a simple map representing, truly or falsely, the relative positions and distances of three towns: A, B and C. The dot "A" is one inch higher on the page than the dot "B," and this is two inches higher than the dot "C." This map might tell you that the town A is north of B, which is north of C, and that B is 20 miles from C and 10 from A. How does it do this? By an understood code by which lettered dots stand for towns, the top of the page for north and an inch for 10 miles. It is the way in which the dots are situated on the page that says how the towns are related to one another on the ground. In this case the map, if true, is in certain respects photographically like the corresponding stretch of ground. But with a different code the same dots might represent or misrepresent the heights of three peaks, or the degrees below boiling point of three saucepans. Representation can, but need not, be photographic. The notes played by the musician are not *like* the black marks on his score, yet the arrangement of the latter, by a complex code, may faithfully represent the arrangement of the former.

The "codes" which enable different arrangements of words to represent different states of affairs are enormously complicated, and they vary among different tongues. In English, if you wish to say that Brutus killed Caesar you must put "Brutus" before the verb and "Caesar" after it. Not so in Latin, which achieves the same result by different word terminations. But without applying some syntactical rule or other you cannot say anything, not even anything false. Symbol-structures can represent and misrepresent the structures of actual states of affairs because, though the representing structure is not usually *like* the represented structure, they are still structurally analogous to one another. A sentence has a meaning if its syntax *could* be the structural analogue of an actual state of affairs, even though, when false, it actually has no such factual counterpart. Caesar did not kill Brutus, but "Caesar killed Brutus" makes sense, since there is, so to speak, room in reality, though unfilled room, for this uncommitted murder.

Not all complexes of words or dots or gestures convey truths or falsehoods. An unorganized jumble of words or dots makes no sense. Even a sequence of

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words with an orthodox grammar can make nonsense. Lewis Carroll concocted many such sentences; for example, "The Cheshire cat vanished leaving only her grin behind her." Sometimes serious thinkers inadvertently construct senseless sentences. Early geometricians seriously held that Euclidean points are round. A truth-or-falsehood, then, is an organized complex of symbols representing, by analogy of structure, a counterpart actual-or-possible state of affairs. It is, for example, a sentence "in its projective relation to the world." To find out whether it is actually true or actually false we have to match it against its should-be counterpart state of affairs in the world.

Already we can see how Wittgenstein's account of what it is to make sense, that is, to be true-or-false, led to the famous principle of verifiability, by which the logical positivists ostracized as nonsensical the pronouncements of metaphysicians, theologians and moralists. Observation and experiment are our ways of matching the propositions of, say, astronomy against the stellar facts. Where observation and experiment are excluded, our pretended truths-or-falsehoods have no anchorage in facts and so say nothing. They are nothing but disguised gibberish.

What of the truths of logic, the status of which it had been Wittgenstein's main task to fix? Are these also disguised gibberish? Or are they salved by being classed with the most general truths of natural science? Wittgenstein steers between this Scylla and this Charybdis.

An everyday "either-or" statement, like "Either Jack climbed the hill or Jill did," leaves it open which climbed the hill; but it still rules out something that might have been the case, namely, the climbing of the hill by neither of them. But if we ask of an "either-or" truism of logic, like " 'Either Jack climbed the hill or he did not'; what is ruled out by *this* assertion?", we see that the only thing ruled out is Jack's neither climbing nor not climbing the hill. And this is not something which might have been but just happens not to be the case. An ordinary factual assertion gives the "yes" or the "no" answer to a question; it invites us to select the one and to forswear the other. But a truth of logic gives us nothing forswearable to forswear, and so nothing selectable to select. It is factually empty, or "tautological."

It does not, however, follow that the truths of logic are of no use simply because they are uninformative. They serve to show up, by contrast with their own absolute hospitality, the ways in which ordinary statements convey, by their relative shut-doored-ness, positive information or misinformation.

The truths of logic, then, are not nonsensical, though they are empty of information or misinformation. Their business is to *show* us, by evaporation of content, how our ordinary thoughts and assertions are organized.

I pass over Wittgenstein's accounts of the connections and differences between logic and mathematics and between logic and mechanics, important though these are for showing up, by contrast, the positive nature of logic. But I must not pass over his account of the relations between logic and philosophy. For, as his title *Tractatus logico-philosophicus* hints, his book was secondarily concerned to fix the status of philosophy. What sorts of things can philosophers tell us—philosophers as distinct from logicians and from scientists? Are the truths of philosophy factual or formal truths?

Earlier philosophers, if they tried at all to place philosophy, had tended to treat it either as psychology or as non-empirical cosmology. But Russell and others realized that philosophy was neither a natural science nor yet a supernatural science. Russell had emphasized the close connection between logic and philosophy by treating all seriously philosophical questions as problems for "logical analysis," as if logic supplied the lines of latitude and longitude, while philosophy had to fill in the geographical detail.

In partly the same way Wittgenstein, having separated off all philosophical from any scientific questions, describes the positive function of philosophy as "elucidatory." Its function is to disclose that logical architecture of our ordinary and scientific thoughts which our vernaculars conceal but which the designed symbolism of logic would expose. But now there breaks out a seemingly disastrous difference between logic and philosophy. The formulae of logic, though they tell us nothing, still show us, so to speak, at their limit the positive force of the "ors," "ands," "alls" and so forth on which our ordinary truths and falsehoods are built. But philosophical pronouncements are in a worse state, since their elucidatory mission is to *tell* us what sort of sense or nonsense belongs to the propositions of the sciences and of daily life; and this is not the sort of thing that can conceivably be told. The meanings, that is, the truths or falsehoods that we express, cannot then be lifted out of their expressions. We can

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talk sense, but we cannot talk sense about the sense that we talk.

Consider again my map in which the situations of three dots on the page told you, truly or falsely, the situations of three towns. Now I ask you to draw another map which is to tell me not about things on the ground, but about the information or misinformation conveyed by the first map. It is to tell me whether the first map is accurate or inaccurate, and especially it is to tell me the cartographical code by which the three original dots represent the compass bearings and distances of the towns. You will promptly protest that you cannot make a map of what another map says or of how it says it. What an ordinary map alleges about the earth's surface is not another bit of that surface and so a second map could not map it. The significance-conditions which an ordinary map exemplifies are not *stated* by these or any other maps.

Similarly, we normally know when a sentence expresses a truth-or-falsehood, and when it is nonsensical. We read the composition of an actual-or-possible state of affairs out of the composition of the sentence. But we are debarred from *stating* this correlation. Attempts to state it would be attempts to stand outside the significance-conditions of statements. They would therefore break these conditions, and so be nonsense.

Philosophical elucidation advances only over the ruins of its attempted articulations. The sort of clarity that we seek we achieve in becoming conscious of what makes us stammer. Critics quickly pointed out that Wittgenstein managed to say many important and understandable things. So perhaps the language of maps has limitations from which the language of words is exempt; and perhaps the notion of sense is wider than the notion of truth-or-falsehood to empirical fact.

Wittgenstein left many manuscripts which are now in process of being published. The first book to be so published was his *Philosophical Investigations*. This has the German text faced by a quite good English translation.

Philosophical Investigations differs from the *Tractatus* in presentation, subject and direction. The *Tractatus* consists of a chain of sentences or short paragraphs, prefaced by numerical and decimal index-numbers signaling both the train of the argument and the relative weights in it of the successive items. Each sentence seems to be the product of an almost Chinese process of pruning and recasting. Many of them mystify, but the reader cannot get them out of

his head. In many stretches the *Tractatus* presupposes familiarity with mathematical logic. The *Philosophical Investigations* is more like a conversation. It is a dialogue between the author and his own refractory self, and it presupposes no technical sophistication. It is split up into relatively long paragraph-sections, the continuities between which are often hard to see. Indeed, they are not always there. Unfortunately the book contains no aids to the reader in the shape of table of contents, index or cross references.

Notoriously the *Philosophical Investigations* throws overboard some of the cardinal positions of the *Tractatus*. Some people assume that this exempts them from trying to understand the *Tractatus*. This is a mistake, since a philosopher jettisons what he has taught himself to do without, and we need just the same teaching.

Moreover, a great deal of the *Tractatus* survives, both in the later Wittgenstein and in us too. It comes natural to us now—as it did not 30 years ago—to differentiate logic from science much as Wittgenstein did; it comes natural to us not to class philosophers as scientists or *a fortiori* as super-scientists; it comes natural to us to think of both logic and philosophy as concerned not with any ordinary or extraordinary kinds of *things*, but with the meanings of the expressions of our thoughts and knowledge; and it is beginning to come natural to us, when we reflect about sense *v.* nonsense, to take as the units of sense what is conveyed by full sentences, and not what is meant by isolated words, that is, with what is *said*, and not with what is, for example, *named*.

How does the later differ from the earlier Wittgenstein? First, his central problem is different. He is no longer exercised about the status of logic. It is philosophy now that is pestering him for justice. Next he had in the *Tractatus* been scanning the notions of sense and nonsense through the perforated screen of logic. Through its apertures he could see only elementary atoms of truth and falsehood being combined into molecular truths and falsehoods by the operations of "and," "or" and "not." The only discernible differences between sayables were in their degrees and patterns of compositeness. All their other differences had been algebraized away. But now he forsakes this screen. He examines those differences between sayables which will not reduce to degrees of compositeness. Where he had examined the algebraized skeletons of statements in which only the logical con-

stants were left functioning, now he watches the functioning of the live expressions with which we say real things. One thing that he quickly remarks is this. Not all sayables are truths or falsehoods. The logician attends only to assertable premises and conclusions. But not all saying is asserting. There is questioning, advising, entreating, ordering, reassuring, rebuking, joking, warning, commiserating, promising, deploring, praising, parodying. We talk a lot to infants and dogs, but we do not make statements to them.

In the *Tractatus* we were told, in effect, that only those sentences made positive sense which could be the premises or conclusions of a bit of natural science. In the *Philosophical Investigations* the door is opened to anything that anyone might say. We are home, again, in the country of real discourse.

The central notion of sense or meaning has correspondingly thawed. In the *Tractatus* truths-or-falsehoods seemed to be icicles of printer's ink; and their coordination with states of affairs in the real world resembled the congruence between the structures of two crystals. But sentences are normally things said, not written, by one person to another. So now Wittgenstein constantly discusses such questions as "How do children, in real life, actually learn to understand this or that expression?" and "How would we teach a savage to count, or tell the time?". Talking sense and following the sense talked by others are things that we have learned how to do; so the notion of sense comes out of the fog if we constantly ask just what we must have learned, and just how we must have learned it in order to be able to communicate. Most of Part I of the *Philosophical Investigations* is concerned with questions about sense, understanding, grasping, mastering, interpreting, etc.

One device that Wittgenstein constantly uses is that of exploring imaginary situations in which people have to think up and teach ways of communicating. A builder, for example, wants his inarticulate assistant to pass him bricks and slabs. How would he teach him to distinguish between the orders "Brick" and "Slab"? How would he teach him to bring *two* or *five* bricks, that is, to understand number-words? Wittgenstein calls these imaginary lingo-creations "language-games." This is unfortunate because many readers think he implies that talking is a sort of *playing*. In fact the central idea behind the label "language-game" is the notion of *rules*. Learning to communicate is like

learning to play chess or tennis in this respect, that in both we have to master written or unwritten rules—and there are many different, but interlocking, sorts of rules to be learned in both. The chess player has had to learn what moves are allowed, what moves in what situations would be tactical mistakes, and even what moves in what situations would be unsporting. A crude generalization of Wittgenstein's new account of sense or meaning is that the meaning of an expression is the rules for the employment of that expression; that is, the rules licensing or banning its coemployment with other expressions, those governing its effective employment in normal and abnormal communication-situations, and so on. The dynamic notion of rules to be mastered has replaced the notion of an imposed structural congruence.

With his new notion of meaning, Wittgenstein is in a position to say new things about the philosopher's task of meaning-elucidation. But in the main he avoids trying to give any general account of what sort of task this is, or why and when it needs to be done, though there are passages in which he does enigmatically give such an account. Rather, especially in Part II of *Philosophical Investigations*, he tries to demonstrate in examples what philosophical quandaries are like, how to get out of them and what sideslips of thought get us into them. He is trying to teach us methods of operation, rather than give us the answer to a question in an examination.

I do not think that anybody could read the *Philosophical Investigations* without feeling that its author had his finger on the pulse of the activity of philosophizing. We can doubt whether his hinted diagnosis will do; not that he has located, by touch, that peculiar and important intellectual commotion—philosophical puzzlement.

Short Reviews

THE RAILROAD STATION: AN ARCHITECTURAL HISTORY, by Carroll L. V. Meeks. Yale University Press ($7.50). The railroad station is a comparative newcomer to the history of architecture, but it has had an eventful career. Modern railroads came into existence in two places almost at once: in England and the U. S., a little before 1830. The first British station was built on Crown Street in Liverpool to serve the Liverpool and Manchester Railroad. In 1830 the small, polygonal Mount Clare Station ("hardly more than a box office") was erected in Baltimore. It is

still preserved. These unpretentious depots were the ancestors of the colossal terminals of today. Carroll Meeks, who is associate professor of architecture at Yale University, has written an engrossing book about the evolution of these wonderful structures. The advent of the iron horse raised many questions for station designers. Should arrival and departure be handled on one side of the tracks or should there be two platforms with arrival and departure handled on opposite sides? Was a single building at the end of the tracks—the so-called head type—the most convenient arrangement? Were baggage and freight to be handled in the same building as passengers? What comforts and amenities were to be provided for elegant travelers; for the prosperous but less lordly; for the *hoi polloi*? How could the train shed itself be designed so as to avoid fires, to reduce noise, to provide illumination, to prevent the waiting customers from being suffocated by smoke? A little boy, "brought up in the Calvinist way," got off a train at the first New Haven station soon after it was opened. "Finding himself engulfed in smoke and darkness, he clutched his father's hand and asked, 'Is this Hell?' 'No, my son,' his father replied, 'New Haven.' " The new problems prompted many ingenious experiments; some of the earliest stations "bore in them the patterns for the great terminals of the future." Warfare sprang up between architects and engineers. The architect's main concern was apt to be with style and ornament; the engineer's, with function. But there were audacious engineers who strived for more and more daring spans in the train sheds, who combined new materials and new methods of fabrication in forms which were no less poetic and dramatic than those conceived by the architects. As the traffic increased and the railroads became more prosperous, the stations became larger and the "picturesque eclecticism" of Victorian architecture found a wide variety of expression. The conservative tendency was reflected in semicircular arches; the progressive, in towers. The towers, stumpy at first, soon soared and had spires. Large terminal hotels were built, and vast vaulted iron sheds. These were called "room-streets" because the glass of the vault allowed so much light to flood the interior "that the old distinction between a ceilinged room and an unroofed street was dissolved." During the middle or sophisticated phase of station development, between 1860 and 1890, advances in railroad technology—bridges, tunnels, Pullman cars, diners, air brakes, rails with

a T-shaped cross section (as opposed to the murderous strap-iron rails), higher speeds, coal-burning locomotives—were matched by lavishness in the station. At Newcastle-on-Tyne the architect John Dobson erected a grand structure with pavilions, towers, arcades and a 600-foot-long stone façade interrupted by a colossal *porte-cochère*. The Gare de l'Est in Paris, designed by François Alexandre Duquesney, had a head building containing a great concourse or vestibule through which passengers could move back and forth at will from one platform to another without interfering with train operation and without crossing any tracks. This was a major step forward, and the station was rightly acclaimed the finest in the world. King's Cross in London was a majestic affair with two 105-foot-wide sheds and arched steel ribs. The sheds of the Gare St. Lazare were so beautiful that they became the subject of numerous paintings by Monet. Zurich had a fine *Bahnhof*, as did Munich and Leipzig and Berlin. Other striking monuments rose in Turin, Rome, Genoa, Naples, Budapest. Towers began to give way to domes. As they did so the fashion in men's hats swung from stovepipes to bowlers. At first U. S. stations were not so grand as their European counterparts, but as the century drew to a close we began to catch up. New York's first Grand Central was only the beginning. The Pennsylvania Railroad built huge sheds—in Jersey City, New York, Philadelphia and Pittsburgh—that were 250 to 300 feet wide and 600 feet long. This megalomania passed from the sheds to the buildings. The present Grand Central Station in New York, for all its leviathan dimensions, is one of the outstandingly successful stations of history. Its immense concourse, multiple levels and ramps were brilliantly designed to handle trains and passengers efficiently. The nearby Pennsylvania Station is even taller but perhaps not quite as opulent. Megalomania came to an end about the time of the First World War. A 20th-century style has evolved which has already passed through several phases characterized by "functionalism," the elimination of "eclectic ornament" and the free use of glass. Lately the severities of rectangle and prism have been alleviated, and the dome and other curved forms have reappeared. Descriptions of buildings and architectural criticism do not usually make easy reading; even in this well-written book there are sections in which the author is carried away by his own words. Nevertheless it is a rich and extraordinarily interesting account of the buildings

themselves and of one aspect of the interaction of culture and technology. The book itself is well-tailored; the many illustrations are a joy.

A HISTORY OF ENGLISH CRIMINAL LAW AND ITS ADMINISTRATION FROM 1750, by Leon Radzinowicz. The Macmillan Company ($45). No brief review can fairly describe this magnificent survey. It deals with the evolution of the English criminal law from 1750: the movement for reform from 1750-1833, the clash between private initiative and public interest in the enforcement of the law, crosscurrents in the movement for the reform of the police. ("As far as I can see," observed a somewhat ironical Frenchman, referring to English ways of maintaining public order, "the glory of having no police appears to be easier to acquire than the glory of finding a good one.") Dr. Radzinowicz, a fellow of Trinity College and director of the department of criminal science at the University of Cambridge, has performed a heroic research. He has produced a study of the first importance not only in the annals of legal history but also of sociology. This work, it may be assumed, is still in progress, but the volumes which have already appeared brilliantly illuminate the problems and struggles of a great democratic society striving to establish order while preserving liberty, to achieve justice under law, to cultivate what might well be considered the best of the arts—"the husbandry of the human creature."

THE FUTURE OF ARID LANDS, edited by Gilbert F. White. American Association for the Advancement of Science ($6.75). In this symposium, based on the International Arid Lands Meetings held in New Mexico in 1955, scientists from 17 countries have contributed their views on the state of "man's struggle to make productive and stable use of the world's arid lands." In one section are discussed the variability and predictability of water supply; in another, the improved use of present resources; in a third, the prospects for additional water sources. E. G. Bowen's paper on induced precipitation discusses the interesting hypothesis that the arrival of dust in the upper atmosphere and its descent to the ground might turn out to be one of the most important factors controlling rain formation. Evidently there is need for further study of meteoric dust: it has already been noticed that prominent meteor showers precede by almost exactly 30 days the world peaks in rainfall. In the final sec-

tion of the book, on the adaptation of plants and animals to arid conditions, Knut Schmidt-Nielsen reports on his researches on the remarkable physiology of the camel. This legendary creature can withstand an exceptional degree of dehydration of the body: 40 per cent, as against a top limit of 15 to 20 per cent in man and other mammals. It is quite capable of going through the entire winter without water; in fact, if a drink is offered, the camel often refuses. The camel does not store water in his hump, for while the fat in the hump would yield more than its weight in water, the oxygen required to effect this conversion involves ventilation of the lungs and a consequent loss of water in the expired air greater than the gain from oxidation of the fat. One of the factors contributing to the camel's extraordinary water economy is its woolly coat, by means of which water is retained and, as an old Arab saying goes, the desert heat is excluded. Another factor is that while man maintains a temperature of 37 degrees centigrade regardless of the heat (at a high cost in evaporated water), the camel's temperature apparatus permits a variation from 34 degrees C. in the morning to 40.7 degrees in the afternoon. Thus the camel stores heat during the day and dissipates it in the cooler night without undue loss of water. A camel can drink 100 quarts of water in 10 minutes, but it never drinks more than it needs. It maintains its appetite in spite of dehydration, and it can eat almost anything.

THE OPEN SEA, ITS NATURAL HISTORY: THE WORLD OF PLANKTON, by Alister C. Hardy. Houghton Mifflin Company ($6.50). The name "plankton," from a Greek word meaning "that which is made to wander or drift," embraces both animals and plants which float and drift with the flow of tides and ocean currents. The great tureen of the sea holds a planktonic soup of plant life —a fine aquatic floating dust of "living microscopic specks"—and untold billions of tiny animals with limited locomotor ability. Minute shrimplike creatures of many different kinds, mostly ranging from the size of a pinhead to that of a grain of rice, predominate. (The number of copepods—*i.e.*, oar-footed crustaceans—alone is greater than that of all other multicellular animals put together.) There are also jellyfish; small, wormlike creatures; miniature snails with flapping fins to keep them afloat; and hosts of other little organisms with incredible shapes, fantastic internal structures and gorgeous or delicate col-

oring. Alister C. Hardy, the distinguished British marine biologist, has written this survey of the plankton as the first instalment of a two-volume natural history of the sea. The work is pure delight, unquestionably the best popular book on the subject. It is clearly written; it abounds in the kind of fascinating detail which the working scientist alone can provide; it is illustrated with 300 accurate line-drawings and maps, 142 lovely watercolor sketches made by Hardy aboard R.R.S. *Discovery II*, and 67 superb electronic-flash photographs revealing many plant and animal structures never before seen. Hardy describes the movement of the waters, the seasons in the sea, the baffling puzzle of the up-and-down migrations of planktonic animals (toward the surface of the sea at night and away from it in the daytime). Among the planktonic crustacea, as one learns from Hardy, there are species in which the male passes its sperm into a homemade "bottle" which is then attached to an opening on the first abdominal segment of the female. The genus *Oikopleura* has developed a remarkable method of feeding. It fashions for itself a transparent gelatinous house which has openings covered by a network of threads. They act as a grid to prevent all but the smallest particles from entering. Inside the house are two conical nets of finer threads which lead to the mouth of the animal. By the undulations of its tail Oikopleura swims about inside its house and draws in a constant stream of sea water. As the water circulates, minute flagellates and protozoa are strained by the nets and disappear into Oikopleura's mouth. Oikopleura, a prudent creature, has a little doorway at the side of its house, an exit in time of crisis so that the owner can swim away and make a new home. There are hundreds of such diversions in these pages.

VISTAS IN ASTRONOMY, VOL. II, edited by Arthur Beer. Pergamon Press ($44). The imposing tribute paid to F. J. M. Stratton on the occasion of his 70th birthday and retirement from the chair of astrophysics at the University of Cambridge is now complete. Nothing less is offered in this set, the first weighty volume of which was reviewed last year in these pages, than a panorama of contemporary astronomy and its allied sciences. Men in the forefront of these disciplines have prepared reports on their instruments, methods, discoveries, theories. Harold Urey contributes to this volume an article on the origin and significance of the moon's surface; Gerard

P. Kuiper discusses the origin of satellites; Sir Edward Appleton writes on the ionosphere; Dirk Brouwer, on minor planets; P. M. S. Blackett, on cosmic rays and the sun; Robert Stoneley, on the thickness of the continents; Miroslav Plavec, on meteor streams; John Jackson, on the distances of the stars; Sydney Chapman, on the morphology of geomagnetic storms; Thomas Gold, on cosmology; George Gamow, on the theory of the expanding universe; Henry Norris Russell, on eclipsing variables in the Clouds of Magellan; Sir Harold Spencer Jones, on changes in the earth's rotation; S. F. Singer, on research in the upper atmosphere with rockets; H. C. van de Hulst, on the zodiacal light; R. van der Riet Woolley, on monochromatic magnitudes; Tcheng Mao-Lin and M. Block, on observational results on variable stars with composite spectra; Wilhelm Becker, on the Milky Way; H. Kienle, on stellar temperatures; E. R. Mustel, on the mechanism of ejection of matter from novae; Harlow Shapley, on galactic and extragalactic studies at the Harvard College Observatory. These are only a small sample of the whole, consisting of some 100 articles in Volume II alone, totaling 1,770 pages and illustrated by hundreds of photographs and diagrams. A major event in the literature of astronomy.

RÉAUMUR'S MEMOIRS ON STEEL AND IRON, translated by Anneliese Grünhaldt Sisco. The University of Chicago Press ($6). In his introduction to this admirable edition of a scientific classic, Cyril Stanley Smith points out that Réaumur's name is today widely known only in connection with a thermometric scale and a station on the Paris *métro.* The fact is he made many solid contributions to science, though none was spectacular. Well-connected and financially independent from birth, Réaumur lived a quiet bachelor's life dedicated to the physical sciences, natural history and the improvement of several branches of technology. He firmly believed that knowledge should be shared, and in his recording and publication of craftsmen's techniques he anticipated the noble program of the Encyclopedists a generation later. In his youth he became a full-fledged member of the Académie des Sciences, and almost until the day of his death in 1757, aged 74, he devoted himself assiduously to research in geology, physics, metallurgy, entomology, marine biology and other branches of knowledge. In suburban Paris he had his own laboratory, staffed with assistants and illustrators. He accumulated vast collec-

tions of minerals, insects and other specimens. He established a private aviary and "menagerie." In the autumn he would journey to his estate in the Vendée, and there in the secluded village, where his simple manor house still stands, "old men tell stories of the seigneur who had a taste for sorcery, who chased insects and who observed the stars." But a dilettante he was not, despite the breadth of his interests. As a biographer said of him, he was an encyclopedic spirit outside the Encyclopedist movement. He wrote some 75 papers which were published in the *Mémoires* of the Academy, and left behind 138 portfolios of unpublished notes and papers. His history of insects fills six quarto volumes. He prepared, as part of an Academy series, three volumes of description of existing arts and crafts. His close observation of the way in which wasps build their nests from vegetable fibers led him to proposals "which eventually gave rise to the wood-pulp paper industry." Réaumur's concern with iron and steel, which is reflected in the present treatise, began about 1716. His study was prompted largely from a "sense of duty to the state"; steel was important to France, yet most of it had to be imported. A number of useful books recording metallurgical practice were published prior to Réaumur's, but practice, as Smith says, was far ahead of theory. The beginnings of modern science had not yet made themselves felt in writings on metals. Réaumur was the first to attempt to combine a systematic study of the properties of materials with the art of metallurgy; thus he may properly be considered one of the first applied scientists—as we use the term. The treatise, for all its serious shortcomings, was much more than a cookbook. It dealt quantitatively with such matters as the amount of air a blast furnace actually uses; the difference between the amount of heat (which depended on the amount of fuel burned) and its intensity or temperature; the conduction of heat by refractory materials and metals; the most efficient arrangement for combustion. One of the curious gaps in Réaumur's thinking lay between his realization of the importance of air in combustion and his total failure to recognize that combustion is a chemical union of air with fuel. The memoirs discuss measurement of the hardness of metals; describe the first materials-testing machine for measuring the deflection of a bar of heat-treated steel before fracture; depict, as well as could be done at the time, the microstructure of steel and the nature of frac-

tures; and correctly appraise the relation between wrought iron, steel and cast iron. Miss Sisco's translation is clear and smooth; Smith's introduction and notes are invaluable; the plates are very handsomely reproduced. The entire volume is a credit to the University of Chicago Press, which for its several fine translations and reprints of hard-to-get scientific works deserves the gratitude of the entire scholarly community.

PHILOSOPHY OF SCIENCE, by Gustav Bergmann. The University of Wisconsin Press ($4.75). PHILOSOPHY OF SCIENCE, by Philipp G. Frank. Prentice-Hall, Inc. ($8). These studies complement each other. Bergmann, a member of the Vienna Circle and now professor of philosophy and psychology at the State University of Iowa, had planned to write a book on the philosophy of psychology. But as he got under way he began to realize the ambitiousness of his project and so, for the present at least, he has settled for a smaller volume which represents the introductory chapter of the intended survey. His emphasis is on the logical analysis of language; on the elucidation of such concepts as deduction, existence and number; on the philosophical bases of the contrasting disciplines of physics and psychology. In view of his philosophical leanings it is not surprising that his primary goal is to erect the framework of a language in which everything that makes sense, from acorns to quantum mechanics to problems in ideas, can be fully and sensibly stated. Bergmann is an irritating writer. He is mannered, sometimes chummy, and often makes flat statements about things which are far from flat. But irritating means provocative as well as exasperating, and this keen book will undeniably jog and stimulate students of philosophy. The strength of Philipp Frank's book is its lucid presentation of the philosophical underpinning of physical theories. His account of the foundations of classical mechanics, of the Newtonian system and of relativistic physics is flowing and understandable. He gets into the corners and makes everything bright and coherent. But he is less successful in his general assessment of different philosophies and in his discussion of cause and probability. The separate themes no longer stand out distinctly; everything is baked together as in a clam pie. Nevertheless this is a superior work from which the reader can derive much that is refreshing and informative; and one can admire Frank's insistence on the point that scientific theories of "high generality" cannot be

simply judged within the sciences themselves—as to whether they conform to experience, facilitate prediction and the like—but must meet the test of social good. The function of the philosophy of science, in his view, is not only to establish criteria of "simplicity," "elegance" and "truth" (*i.e.*, agreement with observation) but also to promote a coherent system in which science will contribute to the understanding of human behavior and to human welfare.

Notes

THE PHYSIOLOGY OF FISHES, VOL. I: METABOLISM, edited by Margaret E. Brown. Academic Press Inc. ($12). The first of two volumes containing reviews of the present state of knowledge of fish physiology. The papers cover respiration, the cardiovascular and digestive systems, endocrine organs, reproduction, growth studies, biochemical composition of fish.

THE CLIMATE NEAR THE GROUND, by Rudolf Geiger. Harvard University Press ($6). The second edition of this standard work on microclimatology has been thoroughly revised and brought up to date.

A GUIDE TO THE LITERATURE OF CHEMISTRY, by E. J. Crane, Austin M. Patterson and Eleanor B. Marr. John Wiley & Sons, Inc. ($9.50). The second edition of a comprehensive literature-finder for chemists. It contains information on books, periodicals, patents, government publications, trade literature, indexes, libraries and other sources.

THE PRINCIPLES OF MECHANICS, by Heinrich Hertz. Translated by D. E. Jones and J. T. Walley. Dover Publications, Inc. ($3.50). This classic work of physical thought, to which Hertz devoted the last three years of his life, presents the principles of mechanics "in a new form," which is to say that a much greater emphasis than in any earlier writings on the subject is placed on deducing theories from a set of clearly defined axioms of motion. The Dover reprint of the 1899 translation includes a new introductory essay by Robert S. Cohen and a preface written shortly after Hertz's death by his teacher, the great Hermann von Helmholtz.

AERODYNAMIC COMPONENTS OF AIRCRAFT AT HIGH SPEEDS, edited by A. F. Donovan and H. R. Lawrence. Princeton University Press ($17.50). Volume VII in the comprehensive series "High-

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Dr. Peter J. W. Debye, professor emeritus of chemistry at Cornell University, and Dr. Lloyd P. Smith, President, Avco Research and Advanced Development Division, discuss the Avco research program prior to Dr. Debye's recent colloquium at the Division's Lawrence, Massachusetts, headquarters.

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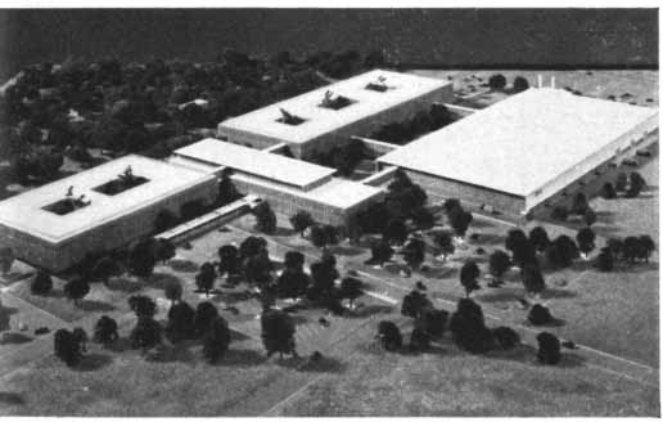

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ALGEBRAIC GEOMETRY AND TOPOLOGY, edited by R. H. Fox, D. C. Spencer and A. W. Tucker. Princeton University Press ($7.50). The 25 papers composing this volume were contributed to celebrate the 70th birthday of Professor S. Lefschetz, for many years on the faculty of Princeton University and a leading investigator in the field of algebraic geometry.

LUDWIG SCHLÄFLI, 1814-1895, COLLECTED MATHEMATICAL WORKS. Birkhäuser Verlag (172 francs). Schläfli was a distinguished 19th-century Swiss mathematician who contributed to algebra, geometry, topology and analysis. During his lifetime his work was not as fully appreciated as it deserved, although the famous British mathematician Arthur Cayley so much admired some of his papers that he translated them into English to introduce them to a wider audience. Schläfli's complete works are now presented in German in this elegant, handsomely printed edition, which includes his celebrated paper on the theory of n-dimensional spaces.

MODERN MATHEMATICS FOR THE ENGINEER, edited by Edwin F. Beckenbach. McGraw-Hill Book Company, Inc. ($7.50). This volume in the University of California Engineering Extension Series presents a survey by 19 mathematicians of the applications of advanced mathematics, from equilibrium analyses to methods of steep descent to problems of technology. The book affords an uncommonly broad view of the many-sidedness and adaptability of mathematics in the treatment of physical questions.

AUDUBON WESTERN BIRD GUIDE, by Richard H. Pough. Doubleday & Company, Inc. ($4.95). Some 200 land, water and game birds of western North America are described in text and drawings, color and black-and-white.

A PICTORIAL HISTORY OF THE AMERICAN INDIAN, by Oliver La Farge. Crown Publishers ($7.50). A distinguished writer and scholar presents an illustrated survey of the North American Indian from the time the white man first landed on the continent up to the present time.

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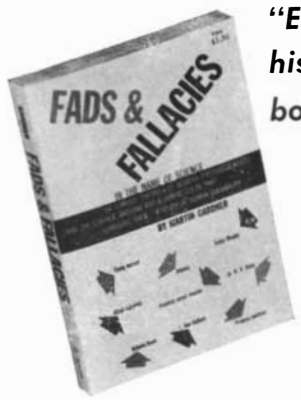

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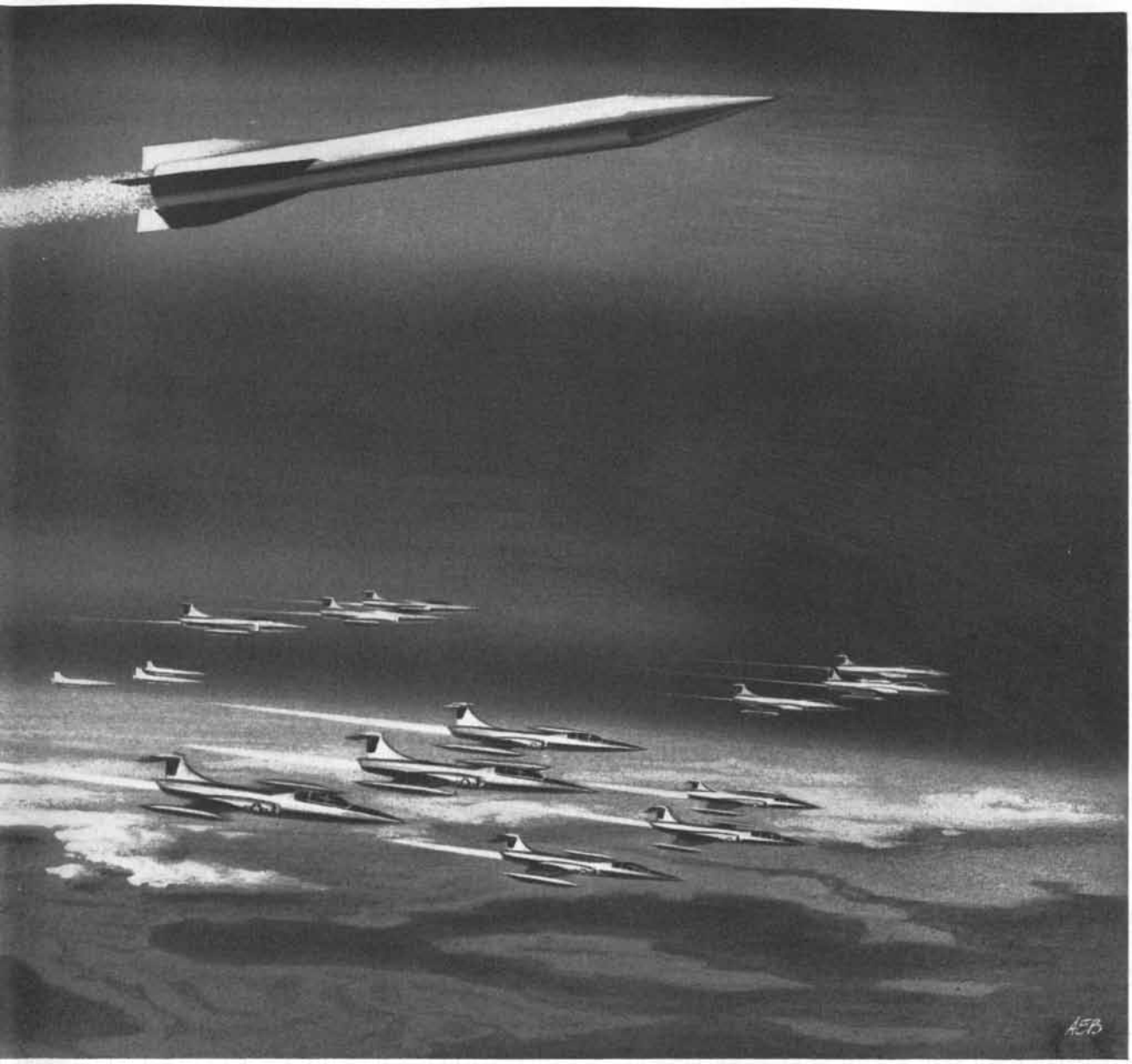

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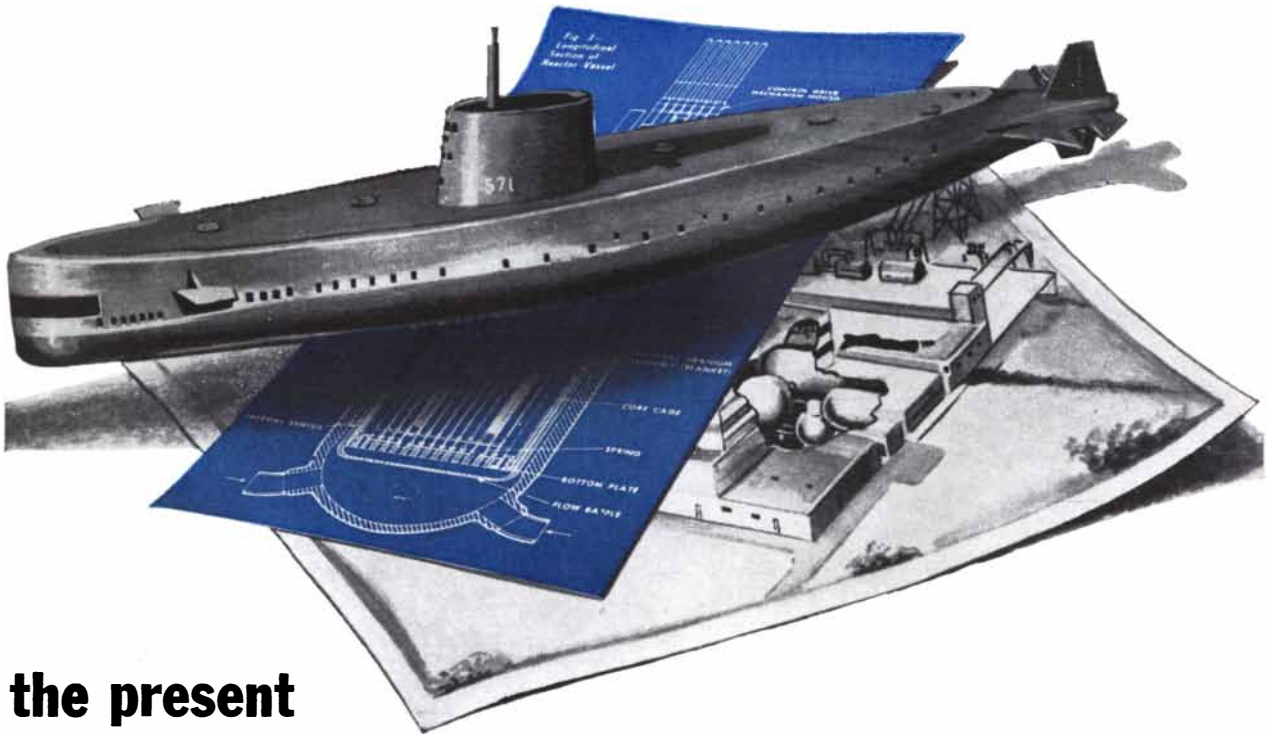

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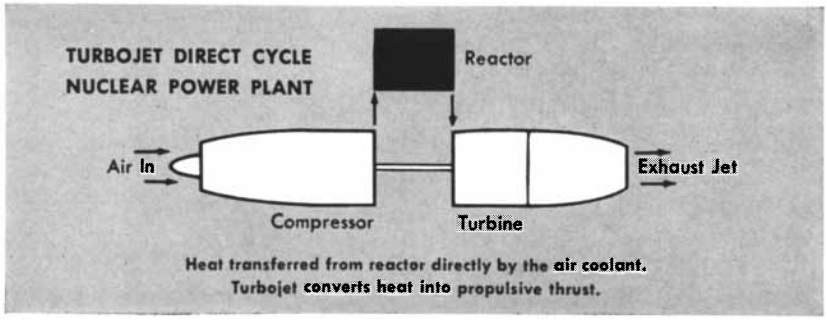

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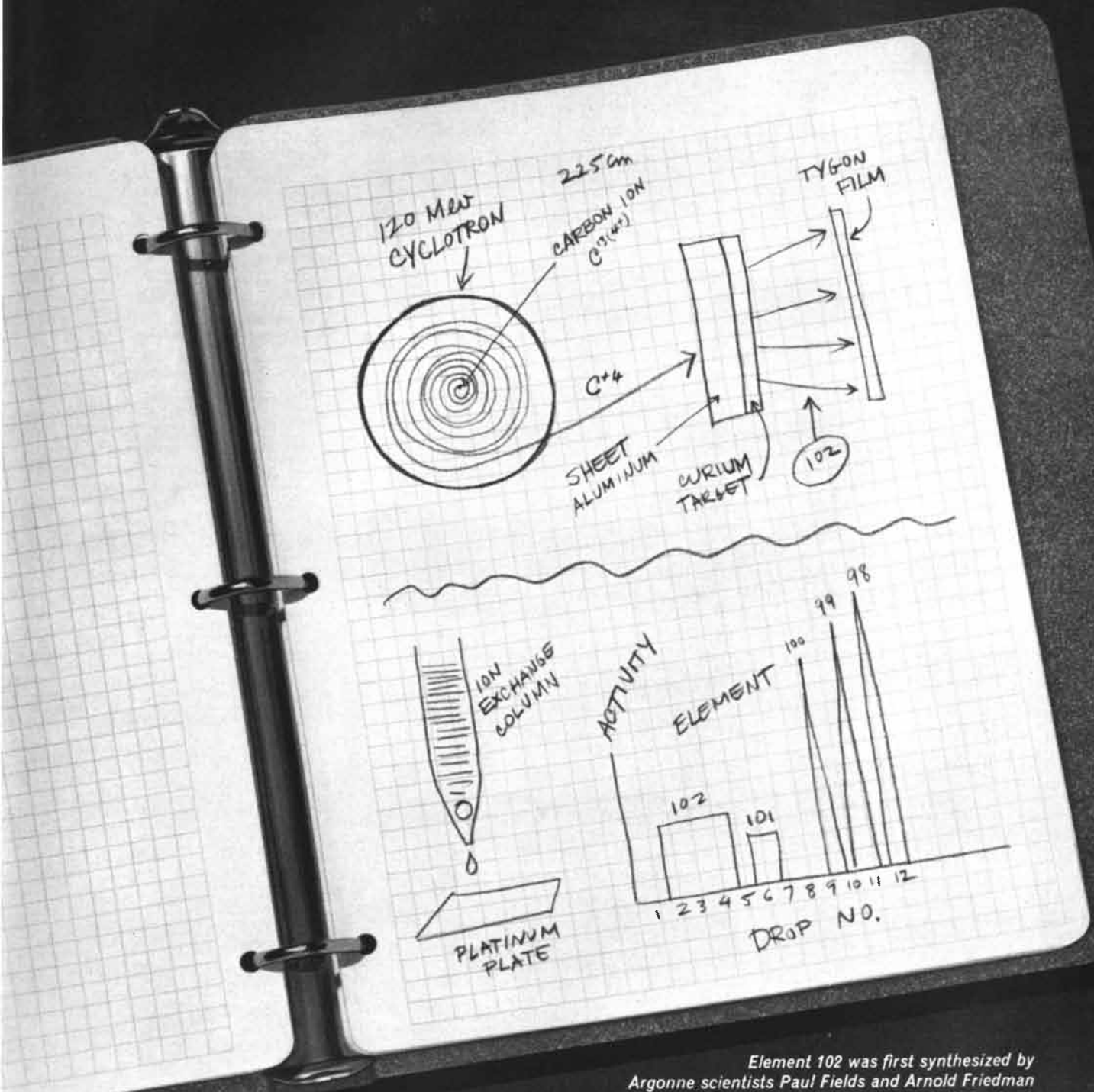

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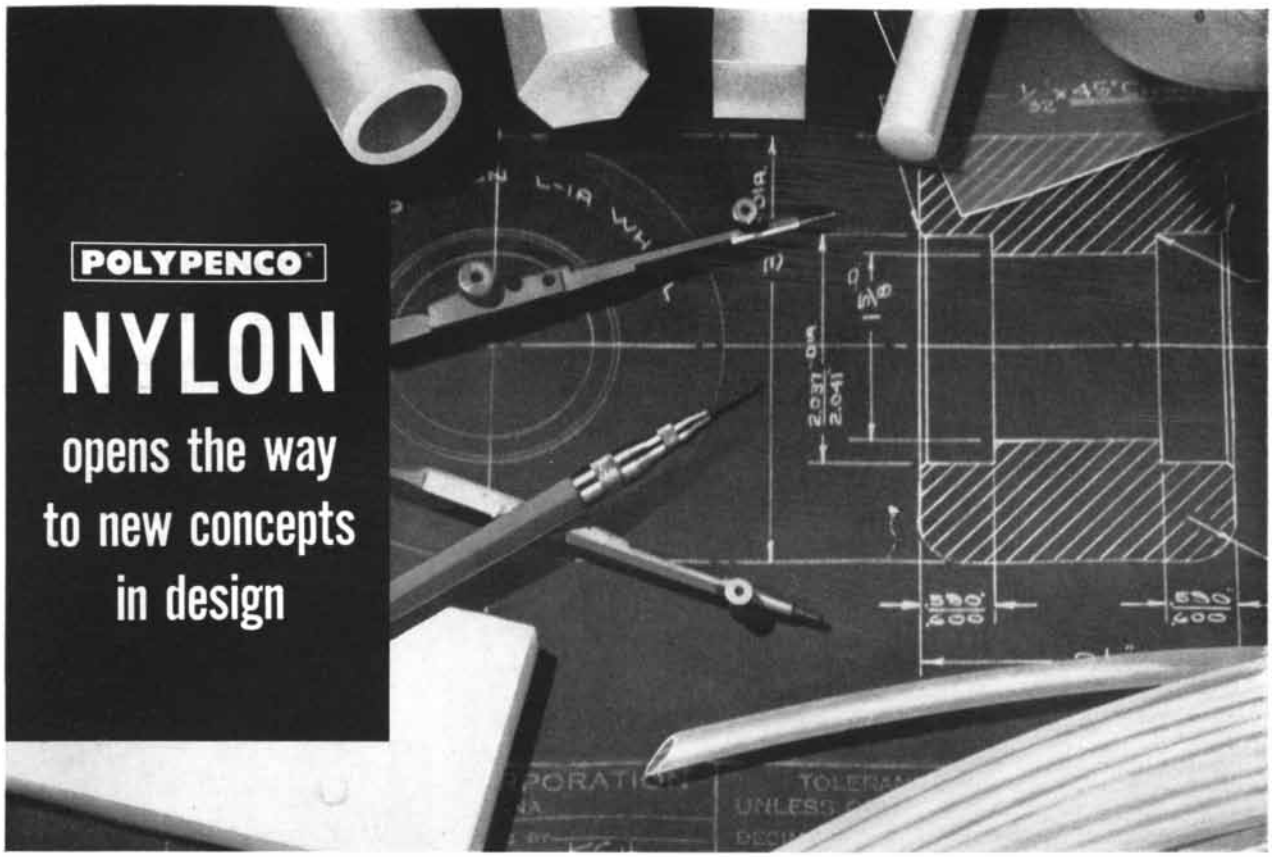

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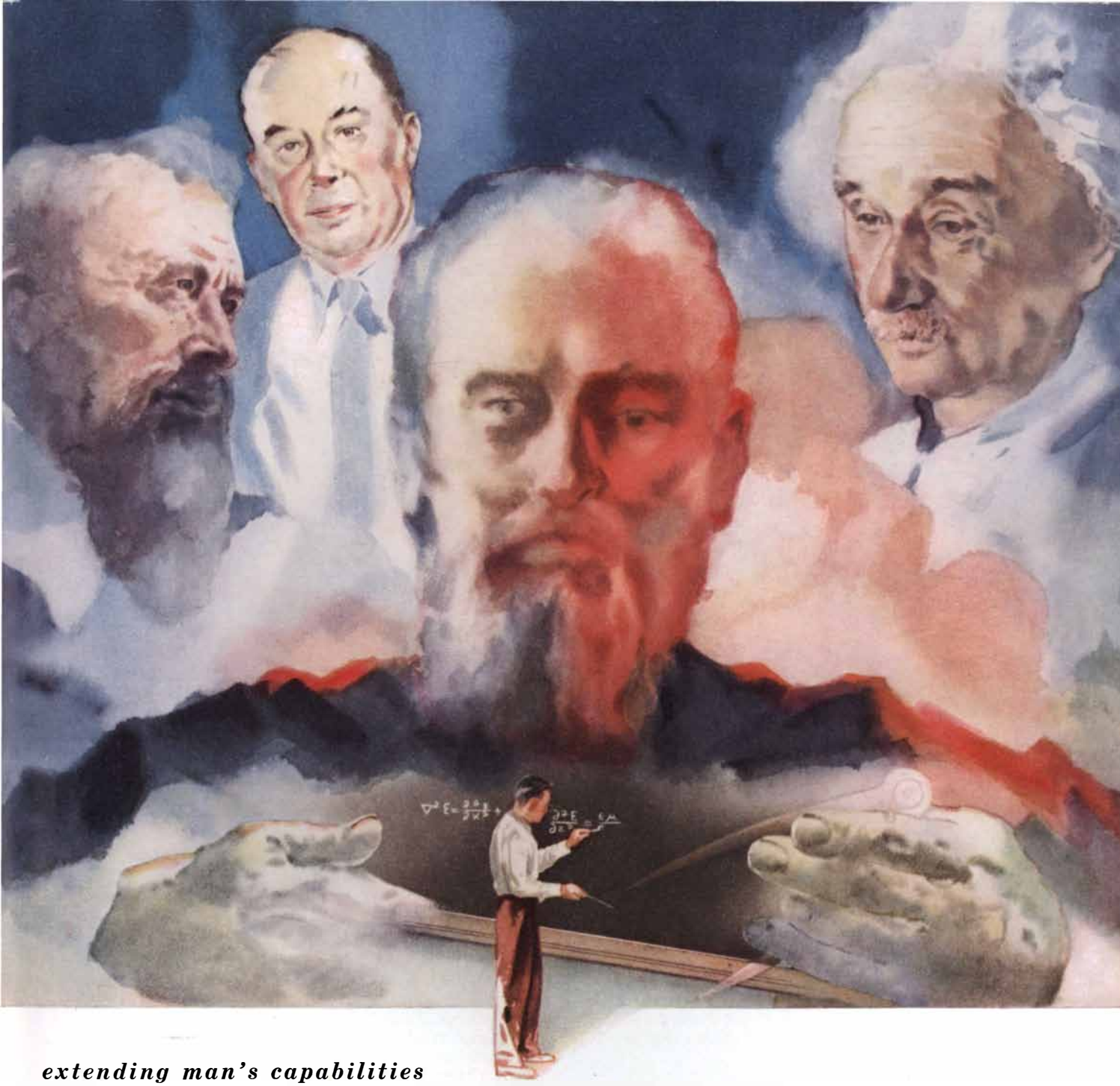

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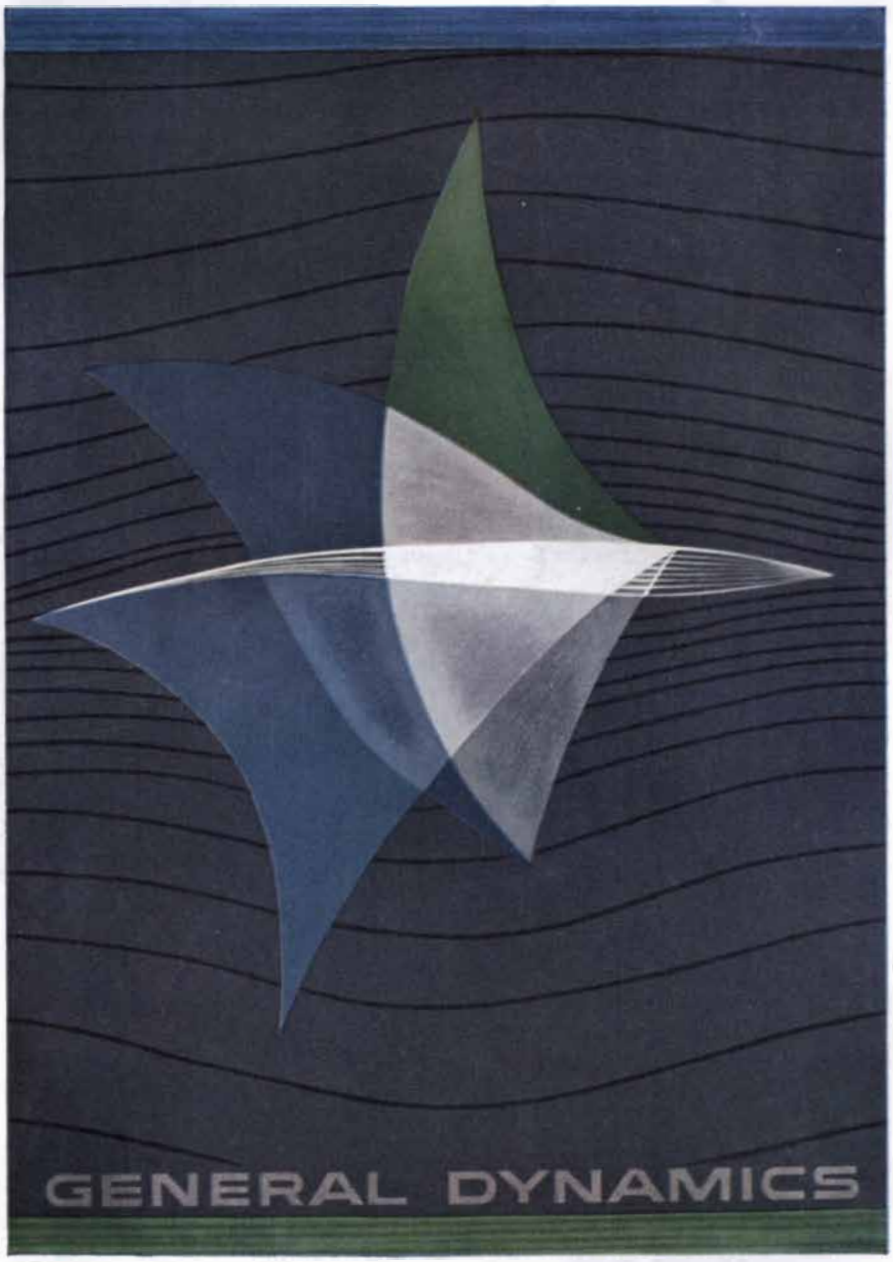

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